taking up Stewardship

28th SAIIE ANNUAL CONFERENCE

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A society is defined not only by what it creates but by what it refuses to destroy. John Sawhill

We take care of the future best by taking care of the present now.
Jon Kabat-Ziinn

At the beginning of 2017 members of the Southern African Institute for Industrial Engineering (SAIIE) were challenged by means of a call for papers to "take a broader perspective, to not only seriously start taking an active interest and responsibility for our public sector, but more than that, to take up stewardship".

They were asked:

"... what is the potential role of Industrial Engineers within the National Development Plan (NDP) and the Strategic Infrastructure Programs (SIPs)?"

Within a few months 181 persons responded to this call for papers.Of these, 169 authors indicated their intention to prepare a full paper by submitting to the *Full Peer-Reviewed Paper* track. The rest submitted to the *Abstract and Presentation only* track.

In the former track 131 of the 169 abstracts were provisionally approved on the basis of quality and the potential to address the question above. A few weeks later a total of 93 full papers were submitted. Thesewere blind reviewed by at least two peers. A total of 60 full papers successfully passed this double-blind peer review process, of which 43 appear in these proceedings. The remaining 13 paperswere diverted to a special edition of the *Southern African Journal for Industrial Engineering*(SAJIE).

All review comments and editorial decisions taken during the process have been recorded andcan be traced by means of the online conference management system used for thisconference. In an effort to avoid any possible conflict of interest, the reviewers were usuallynot from the same institution as the author to whose papers they were allocated. When thereviewers recommended minor improvements, the final checks were performed by only one ofthe two reviewers and the programme director. When major improvements were required,both reviewers were involved in a second (and in some cases, a third) review round.

All papers published in these proceedings passed this double peer-reviewed process.

This conference has culminated in three outputs:

1. The **conference proceedings** (this document) is an electronic document that will bedistributed on USB Flash drives to all delegates. It contains the full-length papers thatwere submitted, reviewed and approved, excludingthose diverted to the special edition of SAJIE. The proceedings are also available onlineto ensure that it remains accessible and indexed by scholarly search engines.
2. An abstract of each conference presentation is printed in the **conference programmeand abstract book**. This includes papers printed in these proceedings, those divertedto the special edition of SAJIE, as well as all the other non-peer-reviewed submissions(presentations, workshops and keynote speakers).
3. Thirteen papers from this conference will be published in a **special edition of SAJIE**.

We trust that you will enjoy interacting with the authors of the papers that appear in theseproceedings and be inspired to take up stewardship as Industrial Engineering community

Prof Liezl van Dyk
School of Industrial Engineering
North-West University
Editor 2017

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SOLVING STOCHASTIC MULTI-OBJECTIVE OPTIMISATION PROBLEMS WITH SIMULATION

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ABSTRACT

Simulation-optimisation (SO) is an umbrella term for techniques used to optimise complex stochastic simulation problems. Many multi-objective optimisation problems in real life often fall within this category of problems. Various SO techniques attempt to deal with such problems and a number of these techniques are incorporated in commercial simulation software packages today. In this paper, one such software product is considered. The software usefulness as well as limitations are demonstrated in the SO context by considering two practical problems solved with the software. A solution architecture is subsequently proposed to improve on the software limitations based on knowledge in the literature.

OPSOMMING

Simulasie-optimering (SO) is ŉ oorkoepelende term vir tegnieke wat gebruik word om komplekse stogastiese simulasieprobleme mee te optimeer. Baie multi-doelwit optimeringsprobleme val in hierdie probleemkategorie. Verskeie SO tegnieke poog om hierdie probleme te hanteer en heelwat daarvan word deesdae in kommersiële simulasieprogrammatuur integreer. Een van hierdie produkte word in hierdie studie bestudeer. Die bruikbaarheid van die programmatuur sowel as die beperkings daarvan word in die SO konteks illustreer deur twee praktiese probleme daarmee te ontleed. ŉ Oplossing-argitektuur word vervolgens voorgestel om van die beperkings van die programmatuur te oorkom deur gebruik te maak van bestaande kennis uit die literatuur.

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1. INTRODUCTION

Many problems that industrial engineers must solve often require that multiple objectives be simultaneously optimised while searching for the best solutions. These problems come in many forms across various industries and with varying levels of complexity.

Consider the following simple example [1]: A company may want to improve (maximise) the performance of a product while trying to minimise cost at the same time. Here, it is easy to see that there is more than one objective (in this case two) to the problem and that they are in conflict as high performance often comes at a cost. Problems like these are often referred to as *multi-objective optimisation* (MOO) problems. The conflicting objectives in an MOO problem make it difficult to isolate a single best solution. This is simply because a solution (*i.e.* a decision or set of decisions) that optimises one or some objectives may not necessarily optimise the rest of them, in fact, in many cases it makes them worse off [1]. The solution to an MOO problem, therefore, is rather a number of solutions that "score" differently on the different objectives and have the characteristic of being the best possible options in the sense that no other solution besides them provides better results to the problem. In other words, they belong to the *dominant* set of solutions among all the existing candidate solutions. In the literature, this set of solutions is known as the *Pareto optimal* (PO) set. Consequently, the goal in solving an MOO problem is to find such solutions.

Optimisation problems, MOO or otherwise, are often complicated further with the reality of uncertainties (or randomness) and the need for solutions that can be found in practical computational times. Techniques capable of finding "good enough" solutions in reasonable time (such as metaheuristics) are, thus, often preferred to those that may find the ultimate best solutions but take too long in the process. We are interested in such techniques.

Moreover, consider again our simple example above. It might be that performance is dependent on the reliability of a component in the product that varies randomly. As the problem is being solved, this "noise" must be taken into account to ensure that the solution to the problem is valid. However, when there is noise in a problem, it may not be easy to model it analytically, let alone find its optimal solution. In such cases, it is strongly recommended that stochastic simulation be used [2]. This opens up an entire field for techniques that are most appropriate for dealing with such problems known in literature as *simulation-optimisation* (SO).

Various SO techniques are incorporated in many commercial simulation software packages today. In this paper, we specifically look at one such software, namely Tecnomatix, and the way in which it enables SO and deals with MOO by considering two problems.

This paper is part of an on-going research that aims at strengthening Tecnomatix current SO capabilities, particularly with regards to MOO problems. Therefore, we only present in this paper the architecture of the proposed solution to the study. Tecnomatix has been proven to be a powerful tool at the disposal of an industrial engineer when conducting complex simulation studies. Our goal in this paper is to demonstrate that though a powerful tool, Tecnomatix could still be improved.

The paper is organised as follows: after this introductory section, the second and third sections discuss MOO an SO, respectively. The fourth section discusses two problems solved with Tecnomatix and the fifth section presents the solution architecture. The sixth and last section concludes this work.

2. MULTI-OBJECTIVE OPTIMISATION

In general, a multi-objective optimisation (MOO) problem is formulated as follows, without loss of generality:

$$\text{Minimise } \mathbf{f}(\mathbf{x}) = [f_1(\mathbf{x}),\ f_2(\mathbf{x}), \dots, f_k(\mathbf{x})\ ]^T \qquad \textbf{(2.1)}$$

Subject to

$$g_j(\mathbf{x}) \leq 0, j = 1,2, \dots, o; \qquad \textbf{(2.2)}$$

$$h_i(\mathbf{x}) = 0, i = 1,2, \dots, p; \qquad \textbf{(2.3)}$$

where k is the number of conflicting objective functions, o is the number of inequality constraints, and p is the number of equality constraints. $\mathbf{x} \in X$ is a vector of decision variables and X is the *feasible decision space* formally defined as $\{\mathbf{x}|g_j(\mathbf{x}) \leq 0, j = 1,2, \dots, o; \text{and } h_i(\mathbf{x}) = 0, i = 1,2, \dots, p\}$. Similarly, $\mathbf{f}(\mathbf{x}) \in Y$ is a vector of objective functions and Y is the *feasible objective space* formally defined as $\{\mathbf{f}(\mathbf{x})|\ \mathbf{x} \in X\}$. For each element in X, there exists an equivalent element in Y [3].

Throughout this paper, we will also use the term *system design* or *design* to refer to the decision vector $\mathbf{x}$.

Though we write $\text{Minimise } \mathbf{f}(\mathbf{x})$ in **(2.1)**, not all components of $\mathbf{f}(\mathbf{x})$ follow, necessarily, the same optimisation direction as we saw with our simple example in Section 1 *i.e. Max*. Performance and *Min*. Cost. Nonetheless, it is possible through the *duality principle* [3], to use one optimisation direction for all the objectives. Thus, according to this principle, if we desired to solve our simple example through minimisation, we would have to solve the following problem: Min. – Performance and Min. Cost.

Because of the conflicting objective functions, MOO problems have many optimal solutions [3] called *Pareto-optimal* (PO) solutions (see Section 1). The following definitions from [4] formally describe the Pareto optimality concept:

Definition 2.1: Given two vectors of objective functions $\mathbf{u} = (u_1,\ u_2, \dots, u_k)^T$ and $\mathbf{v} = (v_1,\ v_2, \dots, v_k)^T \in Y$, we say that $\mathbf{u} \leq \mathbf{v}$ if $u_i \leq v_i$ for $i = 1,2, \dots, k$, and that $\mathbf{u} < \mathbf{v}$ if $\mathbf{u} \leq \mathbf{v}$ and $\mathbf{u} \neq \mathbf{v}$.

Definition 2.2: Given two vectors $\mathbf{u}, \mathbf{v} \in Y$, we say that $\mathbf{u}$ dominates $\mathbf{v}$ (denoted by $\mathbf{u} \prec \mathbf{v}$) if $\mathbf{u} < \mathbf{v}$.

Definition 2.3: We say that a solution $\mathbf{x}^* \in X$ is Pareto optimum if there does not exist another $\mathbf{x} \in X$ such that $\mathbf{f}(\mathbf{x}) \prec \mathbf{f}(\mathbf{x}^*)$.

Definition 2.4: The Pareto optimal set P^* is defined by: $P^* = \{\mathbf{x} \in X|\ \mathbf{x} = \mathbf{x}^*\}$.

The vectors in P^* are said to be *non-dominated*.

We thus wish, when solving an MOO problem, to obtain for **(2.1)** the PO set P^* by identifying in X all the system designs $\mathbf{x}^*$ that satisfy the constraints **(2.2)** and **(2.3)**, if any. The reality in practice, however, is that we only approximate P^* as in many cases it is hard to know with certainty whether the actual set was obtained.

Although we desire to approximate P^* in our research, in some cases this may not be necessary. The *Scalarisation* and *Constraint* methods are examples of alternative ways of solving MOO problems where only a few or simply one solution in P^* is of interest. The interested reader is referred to [5], where a comprehensive survey on different approaches for solving MOO problems is presented. We will show in Section 4, however, that approximating P^* is often ideal. We call it the *Pareto approach*.

In the next section, we discuss the impact that uncertainties have on optimisation problems and how such problems are solved.

3. SIMULATION OPTIMISATION

The term *simulation-optimisation* (SO) is an umbrella term for techniques used to optimise stochastic simulation problems [6] or simply SO problems.

Due to the presence of noise in SO problems, solving these problems consists of seeking, through a number of n simulation replications, an estimate of the best solutions. This will be discussed shortly when we look into multi-objective SO problems.

In their work, Fu *et al.* [7] distinguished between two kinds of approaches for solving SO problems: one where a constraint set (possibly unbounded and uncountable) is provided, over which an algorithm seeks improved solutions; and another where a fixed set of alternatives is provided a priori and the so-called *ranking and selection* (R&S) procedures are used to determine the best system design. According to Fu *et al.* [7], the focus in the first approach is on the searching mechanism, whereas in the second approach, statistical considerations are paramount.

In a similar way, Yoon and Bekker [8] have also distinguished between SO problems based on their solution space size which, in the words of the authors, determines the fundamental approaches needed to solve them. They have categorised, on one hand, SO problems with a relatively small solution space (*small-scale SO problems*) for which R&S procedures are sufficient for finding the best solutions and, on the other hand, large solution space problems (*large-scale SO problems*) for which intelligent search mechanisms, with or without the partnership of R&S procedures, are needed for seeking the best solutions.

We shall look into small-scale and large-scale SO problems in more details. First, we discuss SO problems with multiple objectives.

3.1 Multi-objective simulation optimisation

Multi-objective simulation optimisation (MOSO) problems are MOO problems subject to noise or SO problems with more than one objective. They are often formulated as, without loss of generality,

$$\text{Minimise } (E[f_1(\mathbf{x},\xi)], E[f_2(\mathbf{x},\xi)], \ldots, E[f_k(\mathbf{x},\xi)])^T$$

$$\text{Subject to } \mathbf{x} \in X;$$

where the expression $f_i(\mathbf{x},\xi)$, $i = 1, \ldots, k$ represents varying values that objective i can take on when system design $\mathbf{x}$ is selected in the presence of random element ξ, which is responsible for the noise in the system. $E[f_i(\mathbf{x},\xi)]$ is the expected value of objective i. Because it is difficult to obtain the true value of $E[f_i(\mathbf{x},\xi)]$ due to ξ, we rather seek for an estimate that can be obtained with some confidence when a number of n simulation replications (or observations) are made.

Consider the notation $f_{ij}(\mathbf{x},\xi)$ where $j = 1, \ldots, n$ represent the j^{th} observations made for objective i, then

$$E[f_i(\mathbf{x},\xi)] = \left(\frac{1}{n}\right)\sum_{j=1}^{n} f_{ij}(\mathbf{x},\xi),$$

is an estimate value for objective i.

3.2 Small-scale SO problems

Small-scale SO problems were defined and it was said that these problems can be solved with R&S procedures.

R&S procedures are statistical methods developed to select the best system design or a subset that contains the best system design from a set of n competing alternatives [9]. Efficient R&S procedures also aim, in the process, to minimise the total number of simulation replications required while preserving a desired confidence level. Two important R&S procedures dominate the literature: The *Indifference-Zone* (IZ) methods and *the Optimal Computing Budget Allocation* (OCBA) methods.

The main idea behind the IZ methods is to guarantee, with a probability of at least P, that the system design ultimately selected is the best [10]. Kim and Nelson [11] provide a comprehensive survey on recent advances on the topic and they discuss, in detail, a number of IZ methods. In [8], which is another survey, a procedure by Chen and Lee [12] is presented where the Pareto approach is integrated in an IZ method for multi-objective problems.

OCBA methods, on the other hand, have been developed to address the efficiency issue related to the many simulation replications that are often utilised during R&S procedures. The idea here is to maximise the probability of correct selection (PCS) by intelligently controlling the number of simulation replications based on the mean and variance information in the face of limited computing budget [13]. OCBA has also been successfully adapted for multi-objective problems. Lee and Goldsman [14], for example, incorporated the concept of Pareto optimality in OCBA and used the method to find non-dominated system designs.

3.3 Large-scale SO problems

It was said earlier in this section that the focus in solving large-scale SO problems was on the search mechanisms used to explore the vast solution spaces [7]. It was also said in Section 1 that techniques capable of finding good enough solutions in reasonable computational time were favoured in practice. In effect, many large-scale SO problems may be expensive to run in terms of time, money or resources [6]. The use of effective techniques or search mechanisms in solving these problems is therefore key.

Though the literature has a number of techniques for solving large-scale SO problems [6], [8], metaheuristics seem to be preferred in practice [6], [15]. For details of rationales on this, we refer the reader to [15], where the author contrasts between the focus of researchers in the SO field and the techniques being adopted in practice.

Nevertheless, metaheuristic algorithms such as the genetic algorithm (GA), the simulated annealing (SA) algorithm [16], [17], [18], the tabu search (TS) algorithm [16], [17], [19], [20] and the cross-entropy method (CEM) [21], [22], [23] have been proven to be effective search mechanisms for many large-scale deterministic problems, including those with multi-objectives. This, logically, makes them good candidates for large-scale SO problems as well. In fact, many simulation software packages use these algorithms to enable SO. The survey by Amaran *et al.* [6] lists a comprehensive number of commercial simulation software packages available today and the algorithms they use to enable SO. Among these software products is Tecnomatix Plant Simulation.

Tecnomatix has been proven to be a powerful tool for conducting simulation studies for relatively small-scale SO problems due to its flexibility and statistical features for output analysis. Moreover, the software also has *some* SO capabilities for large-scale problems. In the following section, we demonstrate current SO capabilities of the software and their limitations.

4. SOLVING SO PROBLEMS WITH A COMMERCIAL SOFTWARE

In this section we show the current SO capabilities (and limitations) of Tecnomatix by briefly discussing two problems that have been solved by the authors using the software, namely, the mechanised car park (MCP) problem and the buffer allocation problem (BAP).

As it was mentioned in Section 1, Tecnomatix has been proven to be a powerful tool for conducting complex simulation studies. In the first problem that will be discussed, one of the goals was to demonstrate that such a problem could be, indeed, solved with Tecnomatix as the problem had been solved before using a different software package [24]. The goal was successfully achieved and the solution to the problem deemed valid.

4.1 The mechanised car park problem

A mechanised car park (MCP) is an automated parking system that provides parking services whereby the only act of request to a client is to park and lock the car at an entrance parking lot on ground level. The car is then taken and stored by the main dynamic mechanisms of the system: a hoist and a vehicle transfer car (VTC). When the client returns, the system retrieves and delivers back the car to its owner using the same mechanism.

The system structure can be described as a parking garage consisting of “shelves” with closely packed cages (parking bays) where cars are stored. It is a multi-level structure that consists of m horizontal levels and three vertical layers, namely, the front, the back and the middle layer. The back layer is populated with parking bays (PBs). The front layer is similar to the back layer with the only exception that some of its PBs are lost in order to provide for n number of hoist shafts. The middle layer serves as a canal for VTCs and connects the front and back layers. Figure 1 illustrates the concept. The n PDs are park-drive areas where the cars are dropped to and retrieved from the MCP by clients whereas the n queue lanes are the different entrances to the MCP where clients wait should the PDs be occupied.

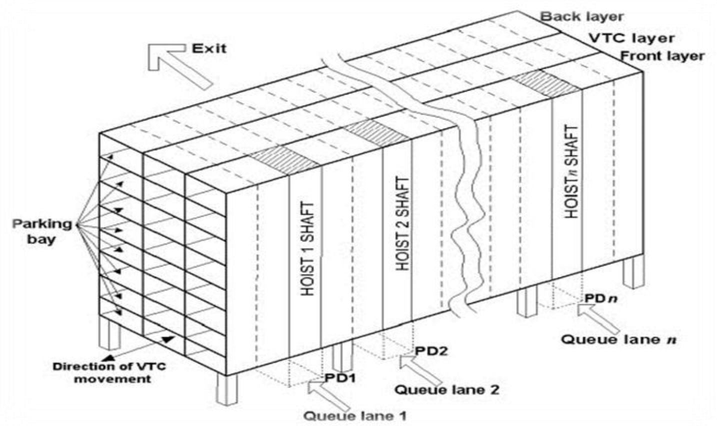

Figure 1: Schematic drawing of a mechanised car park [24]

The MCP problem, thus, consists of finding efficient ways of operating the system such that the system outputs (the MCP problem objective functions) are optimised. This is achieved by effectively utilising the system resources (*i.e.* hoists and VTCs) through a set of operational policies. The goal is to maximise the system throughput (T_R) *i.e.* the total number of cars stored in the MCP over a period of time, and minimise the system waiting time (W_T) *i.e.* the average time a client spends in a queue before being serviced. The MCP problem is complex. Its main challenge lies in the fact that the same resources must handle both storage and retrieval tasks. Moreover, the system is subject to the noise, ξ, caused by clients' random arrivals and returns to the MCP.

The system designs $\mathbf{x}$ in this problem are, therefore, the different set of policies to be generated by the analyst. $\mathbf{x}$ in this case is a decision vector such that $\mathbf{x} = (x_1, x_2, x_3)$ where x_1 is the parking bay allocation (PBA) or storage policy, x_2 is the entrance lane assignment (ELA) policy and x_3 is the priority choice between arrival and departure service (PAD) policy. These policies are identified to be the main factors capable of influencing the system outputs (*i.e.* $T_R(\mathbf{x}, \xi)$ and $W_T(\mathbf{x}, \xi)$). Since only a relatively small number of system designs can be generated, the MCP problem can be considered as a small-scale SO problem.

It is important to mention here that although this problem has two objective functions, it is not a multi-objective problem because the two objectives are not in conflict. In effect, maximising $T_R(\mathbf{x}, \xi)$ equates to minimising $W_T(\mathbf{x}, \xi)$ and vice versa.

4.1.1 Solving a small-scale SO problem with Tecnomatix

It is possible to do R&S with Tecnomatix using one of the software statistical tools for output analysis *i.e.* analysis of variance (ANOVA). The software itself does not, directly, provide for an R&S procedure such as those mentioned in Section 3. However, a simple procedure can be devised using Tecnomatix ANOVA. We briefly describe the procedure below.

Once all system designs are identified, an initial number of replications n (*e.g.* 10) is used to run the simulation model with a confidence level of 95% (the default value in Tecnomatix). Tecnomatix then outputs results for all system designs (*i.e.* the estimated objective function values) with their respective confidence intervals (CI). If the analyst is satisfied with the largest CI half-width (h) observed, then the ANOVA results (which are automatically provided by the software) are used to select the best system design. If, on the other hand, the analyst is not happy with h, then he/she reduces it to a desired value h^*. With this, a new number of replications n^* can be calculated using the formula by Law and Kelton [2]:

$$n^* = n\left[\frac{h}{h^*}\right]^2. \qquad \textbf{(4.1)}$$

The simulation model is then run again and the ANOVA results are used to determine the best solution.

ANOVA (as done by Tecnomatix) does a pairwise comparison between all system designs of interest. The analysis is based on the hypothesis that all n or n^* observations made on any two system designs being compared are equal. A probability (*p*) is then calculated to indicate evidence against this hypothesis. If *p* is equal or smaller than a certain threshold value (often 5%) then this is considered strong evidence against the hypothesis and the two system designs being compared are said to have a statistically significant difference. Otherwise, they are said to be, statistically-wise, identical. With this information, the analyst can then select the best solution with confidence. In cases where more than one objective function is being considered, separate ANOVA are made for each. The result of ANOVA in Tecnomatix is presented in a table containing all *p*-values, from which the analyst must make a selection based on the observed *p*-values.

4.1.2 Specifics of the MCP problem solved

In the MCP problem that was solved with Tecnomatix, the number of levels was $m = 11$ and the number of hoist shafts was $n = 6$.

10 PBA, 3 ELA and 1 PAD (first come first served) policies were generated, amounting to an overall of 30 system designs that were evaluated for efficiency. We will not discuss the nature of all the policies in detail here but it was found that PBA policies, in general, had much more influence on the system outputs than ELA policies. We briefly discuss the approach that was used to generate PBA policies.

It was discovered that the MCP could be viewed as a matrix (Figure 2) with each cell representing a PB. Thus, various ways of searching this matrix for available PBs could be created with Tecnomatix, taking into account the limited number of resources (*i.e.* hoists and VTCs).

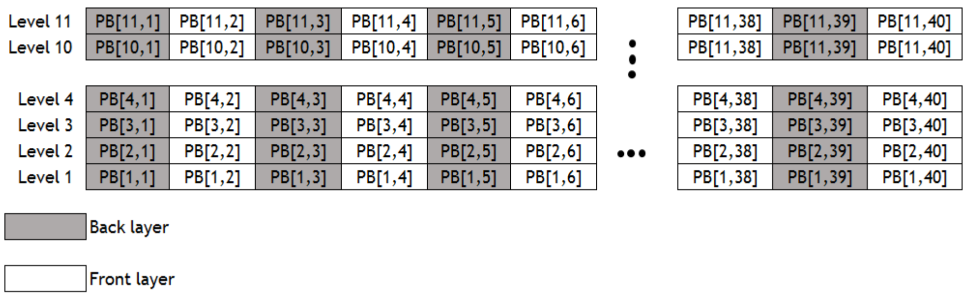

Figure 2: Schematic view of the MCP as a matrix

Thus, 10 search patterns were created to look for unoccupied PBs in the matrix (PBA1-PBA10). These were combined with three ELA policies (ELA1-ELA3) to generate a total of 30 system designs. All system designs used a first-come-first served approach with regards to the PAD policy.

4.1.3 Results and limitations

We present here an extract of the actual results that were obtained for the problem and we discuss the limitations of the software.

Table 1: Top nine results for the MCP problem

System design	PBA Policy	ELA Policy	T_R	W_T (min)
1	3	1	5775	4:58
2	3	2	5766	5:02
3	3	3	5751	5:08
4	5	1	5171	8:17
5	5	3	5168	8:20
6	5	2	5153	8:25
7	9	3	4812	8:42
8	9	1	4804	8:42
9	9	2	4795	8:46

Table 2: T_R ANOVA results

System design	2	3	4	5	6	7	8	9
1	0.089	0	0	0	0	0	0	0
2		0.008	0	0	0	0	0	0
3			0	0	0	0	0	0
4				0.534	0.003	0	0	0
5					0.015	0	0	0
6						0	0	0
7							0.241	0.013
8								0.198

Table 1 presents the top nine results that were obtained. It can be seen that some of these results are very close to one another. This is, in effect, where R&S procedures draw their importance as these numbers are mere estimates. The closer their true values, the higher the chances that the observed better one is not the actual better one [25]. For example, though system design 1 appears to be numerically the best, we learn from Table 2 that actually, the difference between system designs 1 and 2 is not statistically significant. Thus, we can either choose to go for a higher n (*i.e.* a lower h), or, because we already selected our desired h^* in this case, be indifferent in our choice between the two designs (with regards to T_R). Note that a similar table to Table 2 also exists for W_T and may give the analyst more information about designs 1 and 2. We choose to leave it out in this article due to space limitations.

A major drawback in our R&S procedure is that n^* replications are allocated to all system designs. Although this guarantees that all designs have h values that are within the desired h^*, the approach is not efficient as it can be computationally expensive. There are more efficient techniques in the literature such as OCBA and IZ (see Section 3) that have the ability to intelligently allocate simulation replications among system designs while still maintaining the desired confidence level.

One can see the importance of R&S from this problem. Though the results obtained with Tecnomatix were more than decent, using a more efficient R&S procedure would better the process in terms of simulation execution time.

In the next subsection, we discuss another problem. The problem demonstrates Tecnomatix capabilities but also limitations in handling large-scale SO problems, especially those with multi-objectives.

4.2 The buffer allocation problem

Production systems are often organised with machines connected in series and separated by buffers. This arrangement is often called a flow line or a production line [26]. The buffer allocation problem (BAP) is a well-known problem in the design of production lines.

The basic setting of the BAP is the following [27], [28]. Consider a production line consisting of m machines in series, numbered $1, 2, \dots, m$. Jobs are processed by all machines in sequential order. The processing time at machine i has, generally, a fixed distribution with rate $\mu_i, i = 1, 2, \dots, m$. The machines are assumed to be unreliable with exponential life- and repair times. Specifically, machine i has failure rate β_i and repair rate r_i $, i = 1, 2, \dots, m$. All life, repair and processing times are assumed to be independent of each other.

The machines are separated by $m - 1$ storage areas or niches in which jobs *i.e. work-in-progress* (WIP) can be stored (Figure 3). The total number of storage spaces, or *buffer spaces*, is unknown and must be minimised and the required number of buffer spaces can be determined by estimating the WIP.

When a machine breaks down, this can have consequences for other machines upstream or downstream in the production line. In other words, an upstream machine can become blocked when its successor has failed, while a downstream machine can eventually become starved if its predecessor has failed.

The objective functions in this case are the throughput rate $T_R(\mathbf{x})$ (to be maximised) and WIP (to be minimised), denoted by $W_P(\mathbf{x})$. The values of the objective functions are estimated by means of simulation models of the BAPs as the system is subject to the noise, ξ, caused by the different uncertainties (distribution rates) mentioned above. Also, because these objectives are conflicting, the problem is a multi-objective simulation-optimisation (MOSO) problem and can be formulated as follows:

$$\text{Minimise } (E[-T_R(\mathbf{x}, \xi)], E[W_P(\mathbf{x}, \xi)])^T$$

$$\text{subject to } \mathbf{x} \in \mathbb{N}.$$

$\mathbf{x} = (x_1, \dots, x_{m-1})$ is the decision vector, where x_i is the number of buffer spaces at niche i. Because x_i is a discrete number and there is potentially an infinite number of alternatives for $\mathbf{x}$, this BAP is a combinatorial optimisation problem and thus has a large solution space.

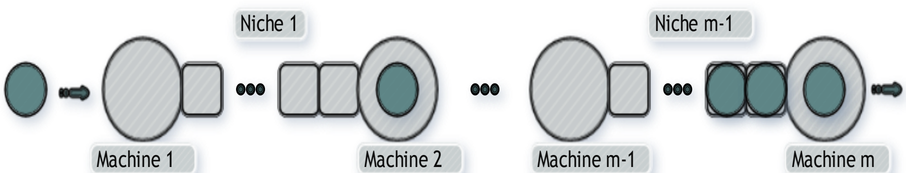

Figure 3: A typical series of m machines with m-1 niches

4.2.1 Solving a large-scale SO problem with Tecnomatix

Tecnomatix uses a built-in optimisation suite that enables SO. The suite uses a genetic algorithm (GA) metaheuristic for the task. Though there are many variants of the GA in the literature, their core principles are similar. We briefly explain how GAs work from [29].

GAs are inspired by the biological principle of evolution with the survival of the fittest being a fundamental property. In nature, weak and unfit species within their environment are faced with extinction by natural selection while stronger ones have greater chances of surviving by passing their genes to future generations via reproduction. GAs base their search mechanism on these principles.

In the GA terminology, $\mathbf{x} \in \mathbb{N}$ is called a chromosome [29]. Chromosomes are made of units called genes. In many variants of the GA, genes are binary digits and chromosomes correspond to unique $\mathbf{x}$ values in $\mathbb{N}$. Thus, the actual values of $\mathbf{x}$ are encoded in binary form during the search process and decoded again to evaluate the fitness of the results found (*e.g.* $T_R(\mathbf{x}, \xi)$). GAs operate iteratively with a collection of chromosomes, called *population*. In every iteration, fitter chromosomes exchange their genes with one another to form new chromosomes that are carried in the following iteration. In this way, future populations have progressively fitter chromosomes as the search progresses. When the search is carried out for long enough, convergence usually occurs, meaning that one chromosome has achieved a level of fitness that can hardly be improved. An iteration in GA terms is also referred to as a *generation*.

When making use of the optimisation suite, the analyst must specify the desired number of generations as well as the size of a population. Also, the analyst specifies the objective functions of interest, the optimisation direction, the solution space to be searched and the desired number of observations n^* to be applied to each chromosome that must be evaluated.

For multi-objective problems, Tecnomatix does not use the Pareto approach. Instead, MOO problems are treated as single-objective problems by using the weighting sum approach (a scalarisation method) (see [5]). The solution found by the optimisation suite is therefore a single solution.

4.2.2 Specifics of the BAP solved

In the BAP that was solved with Tecnomatix, the number of machines was $m = 5$. All repair and life times were assumed to be exponentially distributed whereas processing time distributions were both exponential and constant depending on the machines.

The input parameters in the optimisation suite were as follows. The optimisation direction was chosen to be *maximisation* and the objective functions were, consequently, entered as $T_R(\mathbf{x}, \xi)$ and $-W_P(\mathbf{x}, \xi)$. Both objectives were given weights indicating that they were equally important to us. The number of generations was chosen to be 20 while the population size was 10. To create the solution space, x_i was constrained such that $1 \leq x_i \leq 20$ and n^* was chosen to be 30.

4.2.3 Results and limitations

The single solution obtained was $\mathbf{x} = (20, 13, 12, 5)$ with $T_R = 208.04$ and $W_P = 50$.

To test how good the result was, the model was run further with more constrained solution spaces while using the same weights. The results obtained are summarised in Table 3.

Table 3: GA solutions for more constrained solution spaces

Solution space	Solution obtained	T_R	W_P
$1 \leq x_i \leq 15$	$\mathbf{x} = (14, 14, 9, 3)$	206.78	40
$1 \leq x_i \leq 10$	$\mathbf{x} = (10, 10, 5, 1)$	203.30	26
$1 \leq x_i \leq 8$	$\mathbf{x} = (8, 8, 3, 1)$	199.48	20
$1 \leq x_i \leq 5$	$\mathbf{x} = (5, 5, 4, 1)$	193.15	15

Comparing the first solution obtained to those in Table 3, one can easily see that increases in buffer spaces do not improve the throughput by much. For practical purposes, there is no doubt that it would be ideal for a decision-maker to know about these other solutions as they are also not dominated by the first solution obtained, especially if buffer space is expensive.

Moreover, because in our original run the solution space was the largest, it is possible that at some point during the search mechanism, the algorithm evaluated solutions in Table 3. However, it decided to output the solution with the highest T_R as the ultimate best; which is good in theory (assuming that the solution is Pareto optimal) but not ideal in practice. This is why the Pareto approach is important. Assuming again that the first solution obtained was Pareto optimal, using an algorithm with a Pareto approach would have output all the solutions in Table 3 as well.

It has been proven that the weighting approach can approximate Pareto solutions. However, it can only do so effectively for convex problems [30]. The weighting approach does not, in fact, work correctly for non-convex problems. This may be an issue when dealing with problems for which it may not be easy to check for convexity such as SO problems [30].

Furthermore, it can also be seen that there are no statistical considerations (R&S) involved when dealing with large-scale SO problems in Tecnomatix. This is another drawback. In [7], Fu *et al.* state that statistics must come into play (when solving large-scale SO problems) if any convergence results are to be rigorously established for search algorithms.

Having pointed out these limitations, we present in the next section a solution architecture.

5. SOLUTION ARCHITECTURE

We desire to develop a solution that addresses Tecnomatix limitations as illustrated in the previous section. Specifically, we desire to develop an optimisation suite for Tecnomatix that uses a number of metaheuristic algorithms that deal with MOSO problems more effectively; that is, metaheuristics that use the Pareto approach. A number of such algorithms were mentioned in Section 3 with references that prove their capability. Such algorithms are believed to be potential solutions.

Though we discussed R&S procedures in the context of small-scale SO problems, our focus is in including R&S in the search mechanism for large-scale SO problems with multi-objectives. The procedures mentioned in Section 3 are also believed to be potential solutions.

Figures 4 and 5 illustrate Tecnomatix search mechanisms for large-scale MOSO problems currently and how we believe it could be improved, respectively.

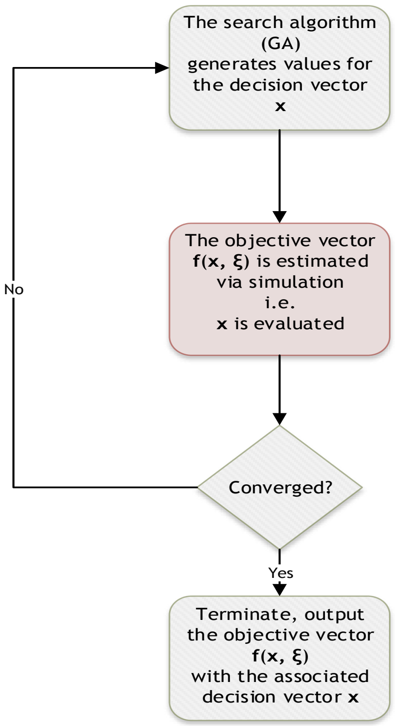

Figure 4: Current SO process.

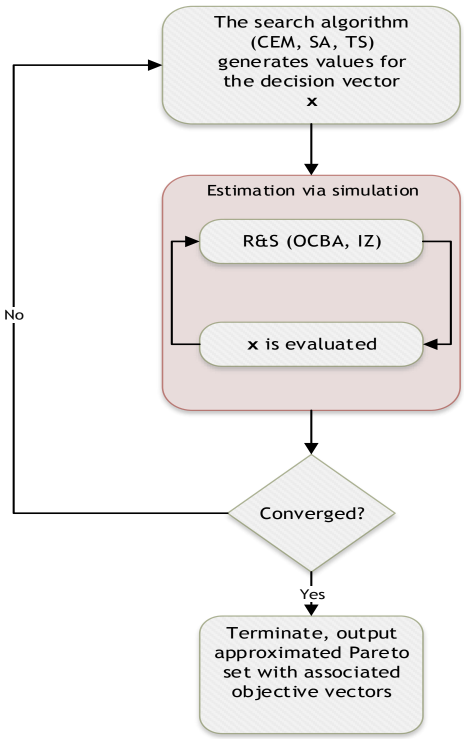

Figure 5: Improved SO process.

6. CONCLUSION

In this paper, the authors reported on an on-going research that aims at strengthening the SO capabilities of a simulation software package, Tecnomatix. The software usefulness was demonstrated by discussing two problems that have been solved with the software. This, also, helped shed the light on areas where the software needed improvement. A number of proven, efficient and effective, methods were explored from the literature and considered as candidate solutions to Tecnomatix current limitations and a solution architecture was presented. Though the focus of the solution is on large-scale SO problems, future research in this area could look at the integration of more efficient R&S procedures for, specifically, small-scale SO problems.

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AN INVESTIGATION INTO THE PROSPECTS OF EXISTING TECHNOLOGIES TO ADDRESS THE CHALLENGES FACED BY PHARMACOVIGILANCE SYSTEMS

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ABSTRACT

Pharmacovigilance (PV) is defined as the science and activities relating to drug safety surveillance, i.e. the detection, assessment, understanding and prevention of adverse effects or any other drug-related problem. Even though substantial progress has been made over the past several decades to improve the effectiveness and efficiency of PV systems, literature suggests that the vast majority of PV systems are still burdened by similar challenges. Typical challenges often relate to aspects considered to have the ability to facilitate improved PV, i.e. engaging the public, building collaborations and partnerships, incorporating informatics into PV systems, adopting a global (standardised) approach, and assessing the impact of efforts. Furthermore, researchers argue that these challenges are not new and have been, and still is, pivotal research objectives within PV studies.

Advances in science and technology over the past couple of decades have seen technologies being developed, and subsequently successfully employed, to address similar challenges in other industries. The impact of these technologies are described in literature, proving their success. This paper argues the case for such technologies within PV systems, proposing a research agenda for identifying technologies that hold the potential to address the challenges faced by PV systems.

OPSOMMING

Pharmacovigilance (PV) word gedefinieer as die wetenskap en aktiwiteite wat verband hou met farmaseutiese dwelm veiligheid toesig, dit wil sê, die opsporing, assessering, verstaan en voorkoming van ongunstige gevolge of enige ander dwelm-verwante probleem. Ten spyte van die aansienlike vordering oor die afgelope paar jaar om die effektiwiteit en doeltreffendheid van PV sisteme te verbeter, stel literatuur steeds voor dat 'n groot deel van PV sisteme steeds belas word met soortgelyke uitdagings. Tipiese uitdagings hou dikwels verband met aspekte met die vermoë om verbeterde PV te fasiliteer, dit wil sê, die innemendheid van die publiek, die verbetering van samewerking en vennootskappe, die inkorporëring van informatika in PV sisteme, die aanneming van 'n globale (gestandaardiseerde) benadering, en die assessering van die impak van pogings. Verder argumenteer navorsers dat hierdie uitdagings nie nuut is nie en was, en is steeds, deurslaggewende navorsingsdoelwitte in PV studies.

Vorderings in wetenskap en tegnologie oor die afgelope paar jaar het leiding gegee tot ontwikkelings in tegnologie wat gevolglik suksesvol onderneem is, wat soortgelyke uitdagings in ander nywerhede aanspreek. Die impak van hierdie tegnologieë word beskryf in literatuur wat dien as bewys van die sukses behaal deur hierdie tegnologieë. Hierdie navorsingsverslag beweer die toepassing van hierdie tegnologieë en stel 'n navorsingsagenda voor vir die identifikasie van sulke tegnologie wat die potensiaal het om die uitdagings in PV aan te spreek.

1. INTRODUCTION: BACKGROUND

The Thalidomide disaster of the 1960s ([1]; [2]) has been described as the largest man-made medical disaster in history [3], that led to nearly 10 000 babies worldwide being born with extremity defects [4]. Speculation followed on the true nature of these defects and whom is to be held responsible [5]. To this day survivors of the tragedy are compensated by both government and the original manufacturers of the drug, however, they still live with the consequences [3]. Various researchers (including Wang et al. [4]; De Abajo [6]; and Klausen & Parle [7]) concur that this disaster made the need for drug safety monitoring and surveillance to prevent a tragedy of similar stature occurring in the future apparent.

Subsequently, pharmacovigilance (PV) was introduced to the healthcare environment in the late 1960's [5]. At this time, the World Health Organisation (WHO) unveiled the WHO Programme for International Drug Monitoring, an organisation consisting of multiple international partners aimed at international monitoring and surveillance of new and existing drugs [8]. PV enjoys much attention in this programme, now co-ordinated by the Uppsala Monitoring Centre (UMC) [8].

THE PHARMACOVIGILANCE SYSTEM

The WHO defines PV as the "*science and activities relating to the detection, assessment, understanding and prevention of adverse effects or any other possible drug-related problems*" [8]. Regularly associated with PV are adverse drug reactions (ADRs) or adverse drug events (ADEs) which describe the unintentional and unpredicted reactions to, or side-effects of new or existing drugs [9]. When such unpredicted reactions or side effects occur, the ideal is that it is reported to the appropriate authorities. Depending on the degree of severity of the reaction, the report is either terminated at the national level or sent on to the UMC [10].

Referring to the nature of PV, the WHO describe it as being based on surveillance [11]. It is therefore reasonable to expect that, at least at an abstract systems level, the PV challenge landscape will share some characteristics with other surveillance based industries. More specifically, it is reasonable to expect that at least some of the challenges faced in the PV landscape will be similar to those faced in other surveillance based industries.

The common ground that exist between the PV challenge landscape and other industries are clear in the resource management (in particular human resource management) use case described by Rabiul et al. [12]. A study is conducted in a software based model known as high-involvement human resource management [12], which is implemented in a variety of organisations, delivering good results in terms of increased organisational process efficiency and reduced human resource expenses.

The use case illustrates the relationship that exist between PV and other industries, both requiring resource management in general and human resource management in particular. It is clear that there are existing technological developments that can have a beneficial impact on PV. Prior to the investigation of such developments, the PV system and the PV challenge landscape are described, providing an understanding of the current condition of PV. This allows for the research to pinpoint exactly where in the PV landscape improvements are necessary.

2. THE PV SYSTEM

PV is described from a systems perspective by the organisation Strengthening Pharmaceutical Systems [10], who categorise the PV system into people, functions, structures, and expected outcome and impact. This systems view of PV is briefly described in this section.

Within the PV system, people are categorised as either reporters or evaluators [10]. Reporters are those who report ADRs (or suspected ADRs) to the relevant authorities, known as the evaluators. Evaluators largely consist of various healthcare professionals whom have the ability to do the necessary analysis to identify and categorise ADRs from the data that is reported. Forming part of the processes are the functions associated with PV, from ADR reporting to analysis and implementation of solutions. Critical to the effective and efficient operation of these processes are the structures and bodies involved including PV organisations, medical infrastructures and networks, regulatory bodies, product manufacturers, and the media [10]. These structures, as well as the people involved, are essential in providing the necessary resources and managing the overall PV system.

A PV system consist of several sequential stages. Figure 1 provides and overview of the six stages [10].

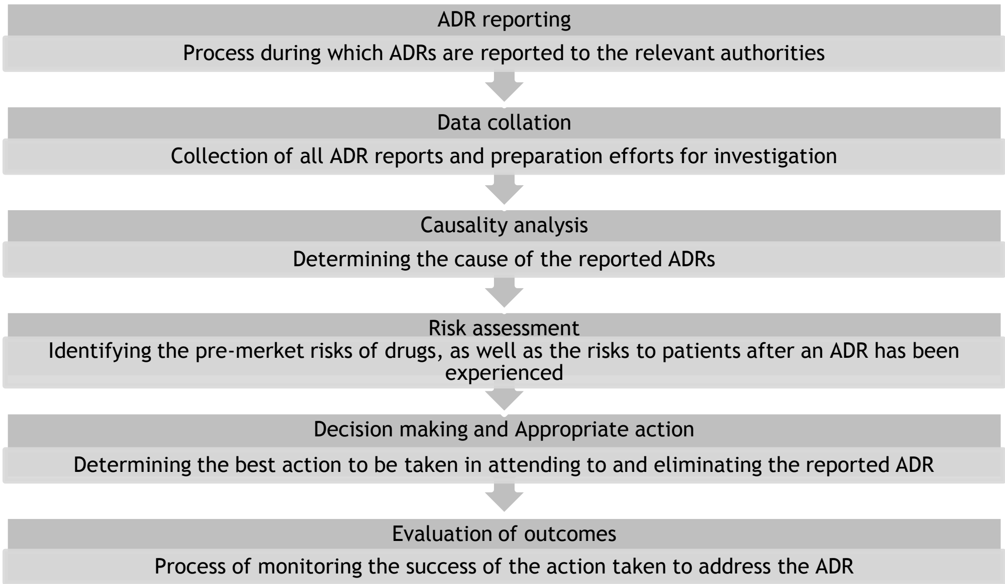

Figure 1: The stages of a PV system.

As one would expect, the increasing scope of PV systems has increased the complexity and number of challenges faced within the PV landscape ([13] and [14]), giving rise to challenges such as the under-reporting of ADRs, ineffective culture, lack of transparency, and the lack of sufficient resources. Pan [14] also states that increased pressure is put on new technological developments that are intended to counter the challenges in the PV landscape. The WHO describes how the inter-relatedness of the various stages in a PV system cause challenges that exist within the PV landscape to have a system-wide impact [8]. The under-reporting of ADRs is an example of a prominent PV challenge that has a system-wide impact. PV systems are initiated by ADR reports, serving as the line of communication between PV authorities and the people experiencing certain ADRs [15]. Due to the integrated global nature of PV monitoring (as managed by the UMC), the impact of a challenge such as under-reporting of ADRs can also stretch beyond a specific PV system to the global PV monitoring level.

3. OVERVIEW OF THE PV CHALLENGE LANDSCAPE

Each stage of a PV system is associated with a specific set of challenges and Pan [14] states that the PV challenge landscape is vast. It is therefore advantageous to this research that these challenges be identified, enabling associations to be made between the challenges and the various stages of a PV system where they are likely to have an impact.

Due to the large landscape of PV challenges, a systematic review was conducted in order to ensure that a significant portion of existing research conducted in the challenge landscape is considered in this research. Three academic databases were used, namely: Scopus, Google Scholar and PubMed. The Scopus database was used for the primary systematic search protocol while the PubMed and Google Scholar databases were used for snowballing and other informal search methods. In total, 2301 relevant documents are available based on specific search terms (these search terms are detailed in Appendix A). These search terms were based on the suggestions made by the articles found on the databases. Also, suggestions made by grey literature were used as search terms. To reduce the number of articles to a more manageable quantity, only the articles published during the year 2000 and onwards were included in the search. Then, the abstracts were consulted to determine the applicability of the article to the research. An important inclusion criteria was that the abstract had to contain words associated with PV, such as “pharmacovigilance”, “drug safety monitoring”, or “drug safety surveillance”. The documents were filtered to 64 documents of which the majority are referenced in the proceeding section.

Shown in Figure 2, the most prevalent PV challenges were organised into a network, illustrating the inter-related nature of the PV challenge landscape. This was done by interpreting the suggestions made by literature, taking into account both the severity and prevalence of the challenge. The PV challenge landscape have been organised into two categories, namely partnerships and ADR reporting, both overarched by culture:

- Culture can be regarded as an overarching element of the PV challenge landscape, underpinning the other challenges in PV. The suggestion that the improvement of PV culture will contribute to the improvement of the entire PV system is regularly made by literature ([16]; and [17]).
- Partners are regarded as essential to a system such as PV, responsible for providing essential resources. The public is a key partner in PV, as they can be utilised across the PV spectrum, especially during ADR reporting ([8]; and [11]).
- ADR reporting is widely regarded as one of the most important stages of a PV system [18], as it serves as the starting point for the PV system providing the data on which the system relies to identify ADRs.

Each of the challenges presented in Figure 2 are briefly described in the following section, providing a succinct overview of the PV challenge landscape.

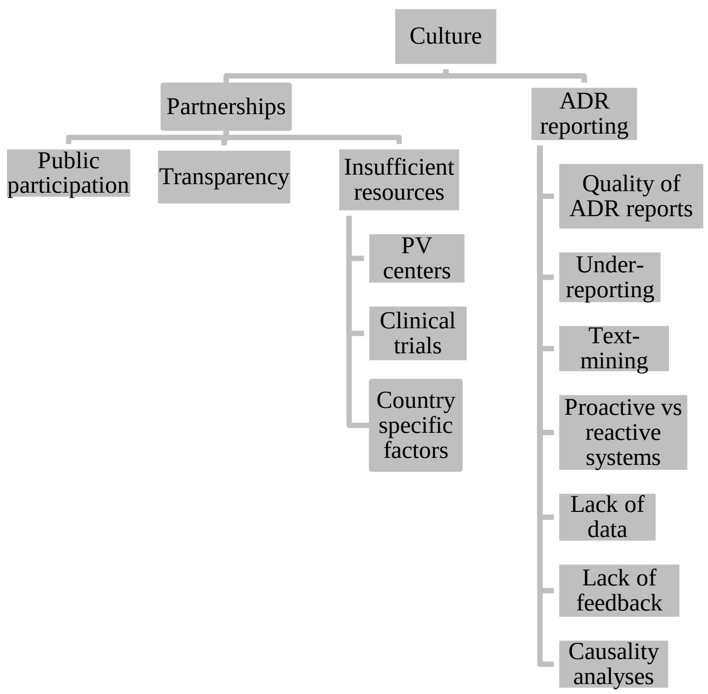

Figure 2: The PV challenge landscape network.

3.1 Culture

PV is based on the culture of safety, where PV professionals provide the foundation upon which the principles of this culture is built [16]. Literature, however, argues that there is a need to improve the culture in modern PV systems [17]. It is believed that the improvement of PV culture will give lead to the improvement of the other challenges in PV, as illustrated in Figure 2. It is often discussed that the improvement of PV culture requires participation across all disciplines in order to become a reality.

The culture of PV is closely related to both Inman's – and the KAP models of under-reporting [17], discussed in Section 3.3.2. To achieve this culture, the challenges presented by these models should be investigated. This is also the opinion of Rodrigues & Khan [17], who refer to the need to develop a safety culture, associated with the reporting of ADRs, amongst surgeons and surgical wards. The establishment of a culture of safety amongst healthcare professionals across the globe is time-sensitive [19], emphasising the need for the timely establishment of such a culture.

3.2. Partnerships

PV is a collaborative endeavour [14]. Sustained collaboration and commitment are vital to attend to future challenges of PV ([8]; and [11]). However, ineffective partnership is a threat to PV [11]. Operating in a resource constrained environment, partners in PV must sometimes provide expertise, training, political support, scientific infrastructure, and a capacity to accomplish comprehensive monitoring and investigations of the safety of medicines [14]. Failure in providing such resources, ineffective partnerships can lead to failed PV initiatives. In order to maintain a certain inventory of these resources, it is vital that PV organisations form lasting relationships with its partners. Management for Science [20] emphasises the importance of relationships between partners and how failed relationships often lead to failures.

3.2.1. Public participation

The scope of PV is large [17], as it monitors a wide range of new and existing drugs in several countries, therefore requiring the participation of numerous stakeholders. Consumers and patients are described as key stakeholders [21], having the ability to contribute through an integrated and efficient reporting system. These direct reporting systems enables PV professionals to detect ADRs much earlier, as well as remove the healthcare professional as filter to reporting ADRs.

However, patients and consumers have been losing faith in the pharmaceutical industry. A survey of the US public, conducted in 2006, illustrated this loss in trust with approximately 42% of public participants indicating that they are sceptical of the pharmaceutical industry [16]. Similarly, a study conducted in 2007 on similar participants also indicated that the public had indeed lost confidence in the pharmaceutical industry [16]. Surveys such as these serve as proof that the PV industry must shift its focus in maintaining collaboration with the consumer and patient.

3.2.2. Transparency

In close association with the culture found in PV, the lack of transparency amongst the stakeholders in PV may lead to failed PV initiatives [19]. It is essential that key stakeholders, especially those with the relevant experience in PV, share information with their peers. This will enable participants in PV to learn of new ways in solving the problems they might be experiencing. Increasing the visibility of information in PV is critical [19], as it will support an improved drug safety culture.

3.2.3. Insufficient resources

It is well-known that PV operate within a resource constrained environment [2]. Especially in developing countries where other challenges such as drought and war are of high priority, PV organisations struggle to implement new PV systems [2]. In these countries the available resources are rather invested elsewhere, leaving little for the requirements of PV.

The resources required by PV systems are unique in specific countries e.g. a country might have the necessary expertise and manpower to assist a PV system but lack the governmental funding, whereas another country might have the necessary budget but lack the required manpower [14]. Countries experiencing this phenomena include Sub-Saharan African countries [2], India [22], and certain South-East Asian countries [23]. Common resources required by PV systems include monetary assistance, hardware and software infrastructure, expertise and training curricula amongst healthcare professionals, and common PV knowledge amongst both healthcare professionals and consumers ([2]; and [14]). PV systems are dependent on the combination of these resources and are not able to function properly without it [2]. Heinrich [24] make reference to effective resource management, a crucial element to the successful operation of a PV system.

Lack of PV centres

Serving as the base of operation for PV monitoring efforts, PV centres are important elements of the PV industry. Zhang et al. [25] describes the PV centre network: the UMC is the international database, taking ownership of millions of ADR reports received from numerous countries each year [22]. Serving as filter to such ADR reports are national PV centres, supported by provincial centres, usually located in provincial hospitals and other medical institutions. Lastly, municipal centres serve as the first line of defence i.e. initially receiving and processing ADR reports before sending it to PV centres further up the PV centre network hierarchy. Zhang et al. [25] provides a description of the Chinese PV centre network, consisting of one national PV centre, 34 provincial centres and 400 municipal centres, all reporting to the UMC.

The challenge faced, especially in developing countries, is the gaps found within this PV centre network. The Sub-Saharan Africa case where there are many countries with no or few municipal – and provincial centres is discussed by Isah et al. [2]. Olsson et al. [26] and Isah et al. [2] are of the opinion that this deficit is due to the lack of resources such as tangible infrastructure, human resources, training and capacity building, governance, sustainable methodologies, and innovations within a number of areas in the Sub-Saharan Africa context. With no intermediate body to receive and filter initial ADR reports, it is difficult for healthcare professionals and consumers, in countries with no municipal – or provincial PV centre, to report ADRs to the appropriate authorities [25].

Clinical trials

Clinical trials are conducted premarket and are used to determine the effect that a drug will have on consumers, as well as to identify certain ADRs that cannot be predicted in laboratory conditions [27]. Similarly, Dubey & Handu [28] state that clinical trials are important to know the drug's effect on humans as it cannot be directly extrapolated from preclinical animal studies. Although the results detained from clinical trials are beneficial to the PV industry, clinical trials are burdened by some limitations ([27]; [29]; [28]; and [30]).

Though clinical trials undoubtedly play a vital role in drug safety, they can sometimes deliver limited results [30]. For example, due to the limited number of patients participating, it is generally not possible to identify ADRs that occur only rarely [27] and such ADRs will therefore only be identified and investigated after a drug has been marketed to the public. Another example of the limitation to clinical trials, is a possible lack of correspondence in characteristics (e.g. age and sex) between the populations in which a drug is tested and those where it will be developed post-market [28]. This limits the extrapolation of results obtained from clinical trials to the population at large [30].

Country specific factors

Country specific factors refer to challenges faced by PV organisations outside the traditional resource architecture and are described by Edwards [13] and Härmark & Van Grootheest [30]. Closely related to the effect of the public on PV, the social factors of an area must be considered which includes the culture, religion, age groups, and sex groups of a specific region. It is often a burden to clearly identify these factors, since it requires manpower and funding that are not always available.

Situational factors which refer to border regulations, policies for implementation, governmental budget constraints, conflict in countries, and environmental issues such as severe drought must also be considered. Often governments refuse to authorise and support the implementation of new PV systems since its priorities are elsewhere [8], delaying the implementation of PV systems. Similar to the social factors, the required resources needed to identify these factors are not always available, proving to contribute to the failed deployment of PV initiatives.

3.3. ADR reporting

ADR reporting is widely regarded as the starting point of a PV system. An ADR report is present across the entire PV system, serving as source of information to the relevant authorities conducting the investigations into the ADR query. Furthermore, many ADR reporting techniques exist in practice including spontaneous reporting, targeted reporting, cohort event monitoring, and electronic health record mining [18].

3.3.1. Quality of ADR reports

The quality of medical data, in a PV context, is of utmost importance [31]. Without ADR reports, PV systems cannot function and literature regularly emphasise the need for advancements to be made with regards to the quality of such reports [32].

Spontaneous reporting is a widely used method in PV [18], dependent on both healthcare professionals and the consumer. However, Bandekar et al. [33] describes a looming threat to spontaneous reporting: the poor quality of the reports. These quality issues, regularly found in reports by non-healthcare professionals, include issues with credibility, uniqueness, frequency, and salience of the data contained in the report [32]. Such issues can be motivated by the lack of necessary PV knowledge amongst consumers.

However, poor quality reports are not restricted to those generated by consumers, but is also generated by healthcare professionals. Such poor quality is evident in a study by Bandekar et al. [33], where ADR reports from ten different countries were collected, with the objective of determining the quality of the reports. It was found that several reports lacked critical information (e.g. pregnancy status, age, sex, and allergic status), regardless of the fact that many of these reports were generated by healthcare professionals. Sub-Saharan African countries were rated particularly poorly, achieving below 50% with regards to the quality standard baseline.

The poor quality of ADR reports can be traced back to the culture of PV [33]. The establishment of a culture where more emphasis is put on the quality of ADR reports, as described by Edwards et al. [19], may therefore contribute to the improvement of ADR reports.

3.3.2. ADR under-reporting

Under-reporting of ADRs occur when healthcare workers (HCWs) (general practitioners, nurses, surgeons, pharmacists etc.) fail to efficiently report new and existing ADRs. Two prominent models that explain the causes of under-reporting are widely cited in literature namely Inman's model of the seven deadly sins of under-reporting and the KAP (knowledge, attitude, and practice) model of under-reporting. Taken together, these two models provide a comprehensive overview of the causes of under-reporting of ADRs. The KAP model is said to be the leading cause, in association with Inman's model, of under-reporting of ADRs [34].

Inman's seven deadly sins of under-reporting

In the 1990s Dr William Inman conducted research on PV with specific reference to the causes of under-reporting [15]. This study, known as Inman's seven deadly sins of under-reporting, is widely cited in literature ([15]; [35]; [36]; and [17]). More recent studies ([15]; and [17]) have confirmed the findings, specifically highlighting the ignorance, insecurity and indifference aspects of the model.

The so-called sins of Inman's model are:

- Fear: Of litigation,
- Indifference: About contributing to the general advancement of knowledge,
- Ambition: To collect and publish a personal case series,
- Guilt: At having caused and adverse effect,
- Complacency: The mistaken belief that only safe drugs are licensed,
- Ignorance: Of the need for reporting, and
- Diffidence: About reporting a mere suspicion.

Many of these so-called sins such as indifference, ambition, complacency, and diffidence strongly relate to the culture in PV and research in eliminating these sins is believed to improve the overall culture within PV.

KAP model

The first aspect of the KAP model is knowledge, closely related to education according to Herdeiro et al. [34]. The shortcomings of PV in the undergraduate and postgraduate syllabus of medical students is regularly referred to in literature ([37]; [38]; [39]; [40]; and [41]). These shortcomings are also not unique to specific countries. Studies in Nigeria [38], Malaysia [40], Portugal [34], Turkey [1], India [42], and China [43] all discuss the need for medical students' curriculum to either include or improve PV education.

The aforementioned country specific studies also highlight the lack of sufficient knowledge on the correct PV practices in practicing healthcare professionals. Toklu & Uysal [1] discuss the need for improved PV knowledge amongst community pharmacists in Turkey, Passier et al. [44] the need for improved PV knowledge amongst general practitioners in Netherlands, and Herdeiro et al. [34] the need for improved PV knowledge amongst pharmacists in Portugal. It is clear that thorough knowledge of PV is a challenge, hurdling several PV initiatives to be completely successful in many countries.

Secondly, the KAP model refers to the general attitude of healthcare professionals towards PV. This element of the KAP model is closely related to the indifference and ignorance aspects of Inman's model and also strongly relates to the culture aspects of the PV challenge landscape. Some examples of the role of attitude in under-reporting are given in a recent study by Shamim et al. [45] who seek to build an understanding of the general attitude of physicians, pharmacists, and nurses towards PV in Pakistan. It was found that a large portion of these healthcare professionals are indifferent towards PV, with only 14.3% being aware that there was an ADR reporting organisation in Pakistan. Similarly, a study within a Spanish context also discuss the poor attitude of healthcare professionals towards PV [15]. The indifference found in the Spanish context is associated with the lack of interest of healthcare professionals to register for ADR reporting and a lack of time for the many activities in the clinical routine.

Lastly, the lack of sufficient practice in PV is also a challenge faced in the PV industry. Closely associated with training, Varallo et al. [15] is of the opinion that the lack of sufficient practice has recently surfaced and is nowadays referred to as the eight sin of Inman's model. The lack of practice in PV is regularly referred to in literature, including Aronson [46] discussing the need for increased, real-world PV practice amongst British healthcare professionals, and Beckmann et al. [47] who similarly emphasises this need in a general context.

3.3.3. Text-mining

Text mining is defined as the computational process of extracting meaningful information from large amounts of unstructured text [48]. In a PV context, meaningful information is regarded as information that can support ADR detection and assessment [49]. Contrary to popular belief, a major challenge faced in text mining, as described by Harpaz et al. [48], is not necessarily the extraction of useful information from severely unstructured text, but rather realising the value text mining holds for the PV industry [48]. Extraction is a challenge [49], but advancements in software have simplified information extraction efforts [48].

The use of text-mining on social media is regularly discussed in literature ([48]; [49]; and [50]). The challenge of some PV organisations not realising the value of text mining, as described by Harpaz et al. [48], is evident in the late adoption rate of social media. Nikfarjam et al. [50] is of opinion that this unwillingness to use social media for ADR reporting is due to the informal nature of social media i.e. consumers make use of informal words and phrases to report a suspected ADR, therefore PV organisations are sceptical of the quality of information that can be gathered from social media. Harpaz et al. [48] and Yang et al. [49] argue that technological developments are only contributing to an increased adoption rate of text-mining to a limited extent.

3.3.4. Proactive versus reactive systems

Regulatory enforcement and increased accountability demands for the protection and welfare of patients, forces the PV industry to be more proactive in its efforts [51]. These regulations govern proactive PV systems that must include comprehensive risk management plans and signal detection and analysis throughout a clinical product's lifecycle [51]. Proactive PV is not only able to respond to ADRs prior to the marketing stage of drugs, but also decreases the probability of a known ADR to be experienced during such a large scale deployment [17].

Certain modern PV systems are outdated [52]. Spontaneous reporting, as described by Hill [18], is the first ADR reporting system implemented in PV. Such reports are of reactive nature, depending on healthcare professionals and consumers to report ADRs after a drug has been marketed and the ADR experienced. Spontaneous reports are still widely used, increasing the pressure on PV systems in which these operate to make a transition towards proactive operation [17].

Existing PV systems struggle with the reactive to proactive conversion process ([51]; and [52]). It is simpler to design a proactive PV system from scratch than to convert an existing PV system to a proactive mode of operation. Resistance to change is a major cause of this struggling transformation since it is well known that people often prefer an existing system rather than having to learn the functions of a new system [18].

3.3.5. Lack of data

PV relies on good information i.e. information of proper quality [14]. It is argued that the lack of the physical data as well as the quality of such data burdens PV systems [53], limiting the possibility of investigations. Pan [14] also discuss the limitation to current PV data. This argument is supported by case studies conducted by Rachlis et al. [53] and Weber-Schoendorfer & Schaefer [54] that made the phenomenon of insufficient data apparent. This phenomenon is closely related to under-reporting and the quality of ADR reports.

3.3.6. Lack of reporter feedback

A challenge faced by the PV industry, regularly overlooked by researches, is the lack of feedback given to ADR reporters ([55]; [56]; [57]; [58]; and [59]). A study of Saudi Arabia's PV system indicated that participants of the existing ADR reporting network see no point in reporting ADRs if they cannot get feedback and support from the country's PV authorities [55].

A similar study completed in the UK, Netherlands, and Australia found that ADR reporters, especially patients, want personal feedback to put them to ease that their voices and opinions are heard by the relevant PV authorities [56].

This need for personal feedback as a sociological component of PV is described by Rios et al. [57] as a routinely overlooked component of the PV system. The lack of adequate feedback is also evident further up the PV authority hierarchy, where gaps in the PV centre network are regularly found.

3.3.7. Causality analysis

Establishing causality in PV is a difficult and time consuming process, requiring resources such as manpower, expertise, and funding that is often scarce and hard to come by [13]. Avorn & Schneeweiss [60] make reference to this issue, stating that it is a common challenge experienced in various locations. Even though a large body of ADR data exists [60], the volume is often too much for causality initiatives. Similar to the case described earlier, undertaking such a volume of data require resources that are not always available. This lack of resources and the difficulty in identifying linkages between ADRs and its source are hindering causality analyses from being conducted in a timely fashion.

4. RELATIONSHIP BETWEEN THE PV SYSTEM AND THE CHALLENGE LANDSCAPE

As discussed in Section 2, literature suggests that relationships exist between the stages of a PV system and the challenge landscape. Table 1 depicts the proposed relationships between the challenges (as organised in Figure 2) and the stages of a PV system (as shown in Figure 1).
Table 1 illustrates where exactly in the PV system the challenge landscape has an impact. From the table it is evident that challenges such as partnerships, culture, and transparency are prominent and the dominant positioning of these three challenges in the typology of the challenge landscape presented in Figure 2 is thus supported. Cognisant of the vast number of challenges that exist in the PV landscape, Table 1 can be useful in assisting to direct future research efforts by enabling researchers to prioritise those challenges that have the most far-reaching impact on the PV system. Thus encouraging more in-depth research in specific challenges that are likely to have a system-wide positive impact.

Table 1: Relationship between a PV system and the challenge landscape.

Stages of a PV system / Challenge landscape	ADR reporting	Data collation	Causality analysis	Risk assessment	Decision-making	Appropriate action	Evaluation of outcomes
Culture	X	X	X	X	X	X	X
Partnerships	X	X	X	X	X	X	X
Public participation	X					X	X
Transparency	X	X	X	X	X	X	X
Insufficient resources	X	X	X	X	X	X	X
Lack of PV centres		X			X	X	X
Clinical trials		X	X	X			
Country specific factors	X	X	X	X	X	X	X
Quality of ADR reports		X	X	X			
ADR under-reporting	X						
Text-mining		X	X	X			
Proactive vs reactive systems	X					X	
Lack of data		X	X	X			
Lack of reporter feedback					X		
Causality analysis			X	X			

5. PROSPECTS OF TECHNOLOGICAL DEVELOPMENTS FROM OTHER INDUSTRIES

As discussed in the introductory chapter, it is believed that PV shares common characteristics with other surveillance based industries. The ever increasing environment of technological developments (such as tangible hardware, software, business processes, frameworks, and models) in various industries that have a similarity to PV, is believed to hold the potential to address aspects of the PV challenge landscape.

Limited research has been conducted with regards to the prospects of existing technological developments to address the challenges faced by PV systems, therefore, this section is limited to a brief overview of the existing technological developments. Subsequently, a succinct overview of three technological developments, believed to have a possible impact on the PV challenge landscape, is provided.

5.2. Improving PV transparency with *Workmate*

As discussed in Section 3.2.2, transparency, especially between key stakeholders, is a challenge faced in PV. Literature often claim that transparency in PV is essential as it allows for healthcare workers to share experiences with certain ADRs and support one another in attending to such ADRs.

A software program, *Workmate,* a human resource management system developed by *HRCloud,* an organisation developing software models for human resource management purposes [61], can be used for the general improvement of transparency in PV. It enables users, in this case PV stakeholders, to share experiences and recognise peers' work and achievements. This software has the capacity to improve transparency in PV, as well as contribute to the improvement of PV culture.

5.3. Understanding the attitudes, perceptions and behaviours of stakeholders in PV with the Health Belief Model

The health belief model is a popular theory used in health education and health promotion, first developed in the 1950s as a way to explain why medical screening programs offered by the US Public Health Service were not successful [62]. The model consists of various elements, with the ultimate goal of identifying the attitudes, perceptions and behaviours of participants towards certain health services. It has been applied in various contexts, especially in nutritional studies [63].

This model can also be applied in the PV industry, enabling researchers to understand the phenomenon of the ADR under-reporting. Directly associated with Inman's model and the KAP model discussed in Section 3.3.2, the attitudes of both healthcare workers and the public can be determined. This allows for research to determine the appropriate actions to be taken to address the findings of the health belief model.

5.4. Partnership Success Model

Literature make reference to various business partnership models that have the capacity to aid the establishment of partner relationships. One of these models, the partnership success model, can be used to contribute to improved partnership management in PV. This model states that in order to achieve success in partnerships, certain attributes must be established. These attributes are the key characteristics of partnerships such as commitment and trust, communication behaviours such as information sharing and participation from all parties, and finally effective conflict resolution techniques [18].

5.5. Conclusion: Potential of technology to contribute to PV

It is evident that there are existing technological developments that can be used to address the PV challenge landscape. Further investigation of other technological developments such as algorithms developed for big data analysis, existing resource management systems, sociological studies to understand the country specific factors, and transition models for changing reactive reporting systems into proactive systems, is therefore motivated as there is reason to believe that these may have the capacity to address aspects of the PV challenge landscape.

6. CONCLUSION AND FURTHER RESEARCH

The association made between a PV system and the PV challenge landscape is discussed in this paper. A succinct overview of the PV challenge landscape is provided, where it is made clear that PV culture is in need of improvement. This can be done by addressing the challenges sprouting from PV culture. The associations made between the PV system and the PV challenge landscape illustrates the challenges that are most prevalent, making it clear that research in these challenges is necessary.

A succinct overview of the prospects of existing technological developments in addressing the PV challenge landscape is provided. This shows that there are technological developments, used outside the PV context, which can be applied to the PV challenge landscape.

For further research, subject matter experts and literature will be essential in prioritising the PV challenge landscape, allowing for more in-depth research to be conducted in the most prevalent challenges in PV, which will allow for a comprehensive understanding of these challenges. Subsequently, research into the prospects of technological developments in industries that experience similar challenges than that of PV can continue.

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APPENDIX A: STRUCTURED LITERATURE SEARCH PROTOCOL

As described in Section 3, a structure search protocol was followed to identify literature for inclusion in the review of the PV challenge landscape. In total, 33 searches were conducted, the protocol used for each search is detailed in Table 2. The "W/" operator indicated in the table is used in Scopus to denote that terms must appear within the specified number of words from one another.

Table 2: Structured literature review search protocol.

Search ID	Search terms
1	pharmacovigilance AND challenge*
2	adverse AND drug AND reaction AND area* W/3 improvement*
3	adverse AND drug AND reaction AND area* W/1 improvement*
4	adverse W/0 drug W/0 event OR reaction* AND area* W/1 improvement*
5	limitation* AND clinical AND trials AND pharmacovigilance
6	limitation* W/1 clinical AND trials AND pharmacovigilance
7	pharmacovigilance AND culture
8	pharmacovigilance AND culture AND challenge
9	pharmacovigilance AND feedback
10	pharmacovigilance AND feedback AND challenge*
11	pharmacovigilance AND feedback AND limitation*
12	adverse AND drug AND reaction AND report* AND feedback
13	pharmacovigilance AND minimal W/0 data
14	adverse AND drug AND reaction AND report* AND minimal W/0 data
15	adverse AND drug AND reaction AND report* AND lack W/0 of W/0 data
16	pharmacovigilance AND education
17	pharmacovigilance AND education AND limitation
18	pharmacovigilance AND expertise
19	adverse AND drug AND reaction AND expertise
20	adverse AND drug AND reaction AND expertise AND challenge
21	adverse AND drug AND reaction AND training AND challenge
22	adverse AND drug AND reaction AND training AND limit*
23	adverse AND drug AND reaction AND partner*
24	adverse AND drug AND reaction AND partner* AND challenge
25	pharmacovigilance AND proactive
26	pharmacovigilance AND proactive W/0 system
27	pharmacovigilance AND public AND participation*
28	adverse AND drug AND reaction AND public AND participation*
29	adverse AND drug AND reaction AND consumer* AND challenge
30	adverse AND drug AND reaction AND report* AND poor W/0 quality
31	adverse AND drug AND reaction AND report* AND text-mining
32	adverse AND drug AND reaction AND report* AND under-reporting
33	pharmacovigilance AND under-reporting AND challenge

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FOCUSED IMPROVEMENT FOR REDUCTION OF CROWNER LOSSES FOR A PACKAGING LINE

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ABSTRACT

The beverage industry is characterised by players who continuously strive to improve their processes in order to enhance competitiveness on the global market place. Waste reduction has become imperative for industries to remain afloat in the modern manufacturing world. This paper outlines the reduction of crowner losses on a packaging line at a case study company. The procedure commenced with gathering the data for average monthly crowner loss, followed by a root-cause analysis through use of fishbone diagram for fallen bottles stoppages from the bottle crowner. Possible solutions for process improvements were then identified and Deming's PDCA cycle was implemented for focused improvement for the packaging line. Two-Sample t-Test, assuming unequal variances were used to compare the before- and-after scenarios and the results revealed that there was a significant improvement from the previous scenario to the later situation.

1. INTRODUCTION

The current global manufacturing arena is characterised by increasing demand for customized, cost-competitive, quality products that aimed to fulfil continuously changing customer tastes. The beverage industry also thrives for continued customer delight, through commitment to quality and continually improving its processes to augment high operating costs and enhance competiveness. The beverage industry is highly competitive and the industry players should reduce operational costs, continuously increase their efficiency by producing more products with fewer resources in order to remain competitive in industry [1]. Production waste during beer packaging is problematic since it increases the production costs and efficient use of the available production hours is critical for fulfilling the demand from the market while keeping operating costs as low as possible. It is against this background that it becomes imperative to establish the root causes of waste during beer packaging and then put in place the right cost-effective measures to eliminate the loss. By deploying a focused improvement approach, this paper focuses on the reduction of crowner losses from a packaging line. Focused improvement is a process of identifying the problems within a system and then modifying the system to recognise cost effective, time saving and least disruptive solutions for system optimisation [2].

2. LITERATURE REVIEW

The beverage industry is one of the world's largest industrial sectors with food production, preservation and distribution consuming a substantial amount of energy that result in resource depletion and emissions of pollutants [3]. Beverage packaging can maintain or increase the quality and safety of food, retard product deterioration, and extend shelf-life. The packaging industry has been focusing on the development of solutions to provide maximum food security while maintaining the nutritional value at competitive prices. As a result, food packaging products have evolved from simple preservation containers to include aspects such as convenience, point of purchase, marketing issues, material reduction, safety, and environmental-friendly materials [4].

A liquid beverage bottling plant can comprise a beverage filling machine with several beverage filling positions, and each beverage filling device would supply the liquid beverage filling material to a specific beverage filling position. The filling devices are designed to inject a predetermined volume of liquid beverage filling material into the bottle to a predetermined level of liquid beverage filling material and will terminate the filling process when the liquid material has reached the predetermined level in the bottle. Conveyer systems may be placed to transport bottles between stations [5].

As shown in Figure 1, a typical beverage packaging line for returnable glass bottles would generally include movement of pallets with crates for empty glass bottles, bottle and pallet cleaning, bottle filling and crowning, labelling, and packing [6].

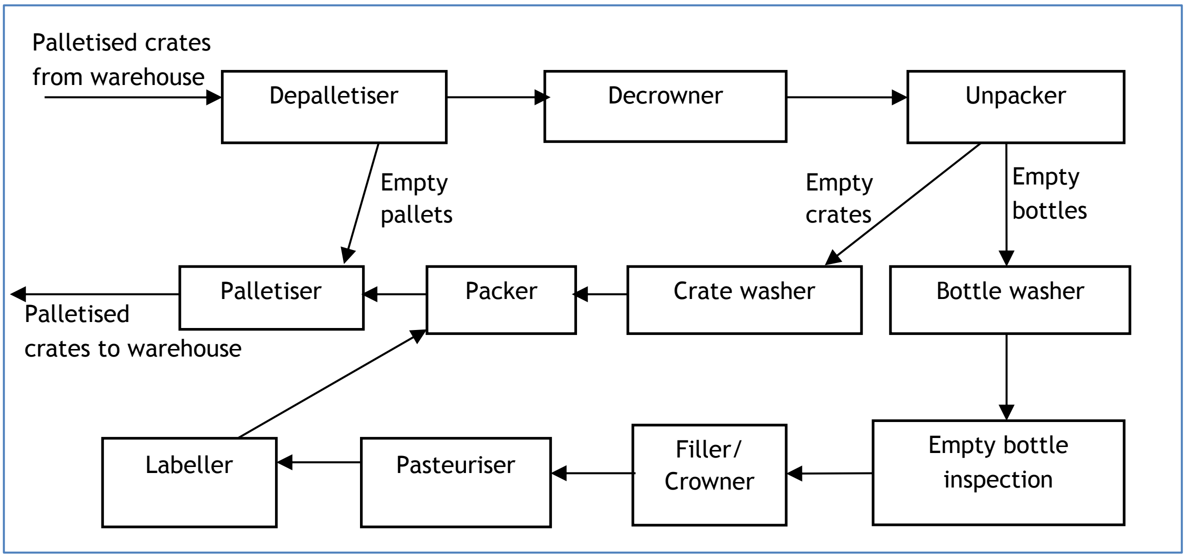

Figure 1: Flow diagram for beer packaging operations

The packaging process commences at the filler where the beer comes from the brewing process. Pallets with crates for empty glass bottles are brought from a warehouse after which the depalletiser removes the crates and places them on a conveyor belt, leading to the decrowner where crowns are removed from the empty bottles. The crates would then move to the unpacker where the empty bottles are removed from the crates which go the crate washer and subsequently wait for the bottles at the packer. The empty bottles are taken by a conveyor to the bottle washer. After which they are inspected for cleanliness before being taken to filler. The bottles are filled with beer, crowned and then transported to the pasteuriser, where there beer is pasteurized to increase its shelf life. After pasteurisation, the bottles continue to the labeller, then to the packer where they are placed into the washed crates, before being palletized and transported to the finished goods warehouse [6].

Filling machines are generally designed around a carousel of valves, thus enabling a substantial quantity of bottles to be filled simultaneously. These valves operate on mechanical and pressure actuation whereby the pressure is used to open and the mechanical springs for closing. An open-ended pressure balance tube that projects into the bottle from the valve determines the filling level. The pressure is balanced as liquid enters the bottle, and until the end of the tube is covered, the valve releases to close by spring return [7]. It is crucial for a filling machine to fill the bottles as quickly as possible with a commercially precise measure of product. It is imperative that the quality of the product be sustained during the filling operation, with no mutually inflicted damage occurring between the container and the filling mechanism [8]. The key concerns when filling a bottle are to achieve an accurate fill level, avoid introducing dissolved oxygen and to leave a headspace above the beer with minimum air [9].

Three measures of efficiency that characterise the liquid beverage packaging plants include factory efficiency, adjusted factory efficiency and operating efficiency. Factory efficiency is an output measure, measuring the utilisation of paid shift hours compared to the rated capacity of the plant/line. Adjusted factory efficiency is an output measure as above, when discounting shift hours lost due to external uncontrollable factors. Operating efficiency is an output measure, measuring the utilisation of available productive hours compared to the rated capacity after discounting planned maintenance hours. Another good performance metric for the packaging plants is machine efficiency, which is an output measure, measuring the machine availability, which is a function of unplanned downtime, speed and quality losses [10].

Process efficiency can be enhanced by exploitation of the Deming PDCA Cycle. It is a systematic series of steps for the continual improvement of a product or process. The plan step involves identifying a goal or purpose, formulating a theory, defining success metrics and putting a plan into action. The Do step is then accomplished by implementing the components of the plan. With the Check step, outcomes are monitored to test the validity of the plan for signs of progress and success, or problems and areas for improvement. The Act step closes the cycle, incorporating the lessons learnt into the entire process, which can be used to adjust the goal or change methods. The four steps are repeated as part of a never-ending cycle of continual improvement [11].

A Cause-and-Effect Diagram, sometimes called an "Ishikawa diagram" is a tool that that can be used for identifying, sorting, and displaying possible causes of a specific problem or quality characteristic. It graphically illustrates the relationship between a given outcome and all the factors that influence the outcome. Figure 2 shows a typical cause and effect diagram for beverage loss [12].

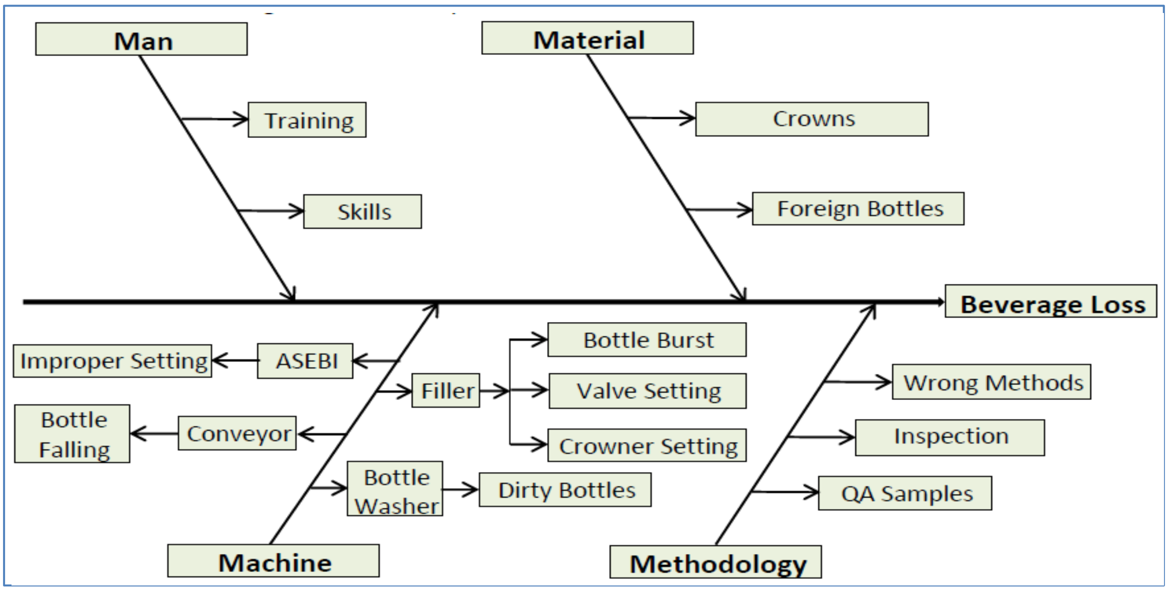

Figure 2: Cause and Effect diagram for beverage loss [12]

Process improvements after the implementation of focused improvement projects can be validated using statistical inferences and two-sample t-Tests, assuming unequal variances can be used to compare the before-and-after scenarios. Means tests can be accomplished by first deciding the type of comparison of means test. When considering two independent sample test, one can use the Welch's t-test if one does not require the assumption of equal variance between populations. One can then decide whether a one- or two-sided test should be conducted, and basing on the based on the assumptions of a given scenario, one can then examine the appropriateness of a comparison of means test, after which the null and alternative hypotheses are established. One would then calculate the Welch's t-statistic, determine p-value from the test statistic and finally interpret the p-value in terms of the hypotheses established prior to the test [13].

3. METHODOLOGY

A detailed, systematic methodology was applied to ensure the reduction of crowner losses for a packaging line. Identifying problems is critical to comprehend the scope of a project and failure to understand or properly define the problem may result in a mismatch between a problem and solutions, thereby yielding solutions that do not effectively or adequately alleviate the case-in-point problem in the long term. Given that background, the first key step in the methodology was problem definition, which commenced with the exploration of the key performance indicators (KPIs) on beer losses followed by a Pareto analysis to identify contributors to the beer loss. The second key step in the methodology embraced troubleshooting of the potential causes for the crowner losses, followed by a root-cause analysis through use of fishbone diagram. The third key step in the methodology was implementation of possible solutions which adopted Deming's PDCA cycle. Lastly, the results were analysed after the implementation of the Deming's PDCA cycle, and the targets and actual values were tracked to check for improvement, to verify if there has been any changes in the crowner loss figures.

4. PROBLEM DEFINITION, TROUBLESHOOTING AND IMPLEMENTATION OF POSSIBLE SOLUTIONS

4.1 Problem definition

A key performance indicator (KPI) can be used to evaluate the success of an organisation or project initiative. The exploration of the KPIs showed that beer losses contributed a substantial amount of waste that adversely affected the company. Beer loss was incurred between the Filler/Crowner discharge and the beer tank due to incorrect measurement in the beer tank or filling process. The rejects and beer losses occurs in the form of overfills, distorted crowns, no crowns, under fills, bottle defects, brand change line flushing, start up, shut down and incorrect jetting. Figure 3 shows the beer loss contributions by the various segments of the beverage packaging line per shift.

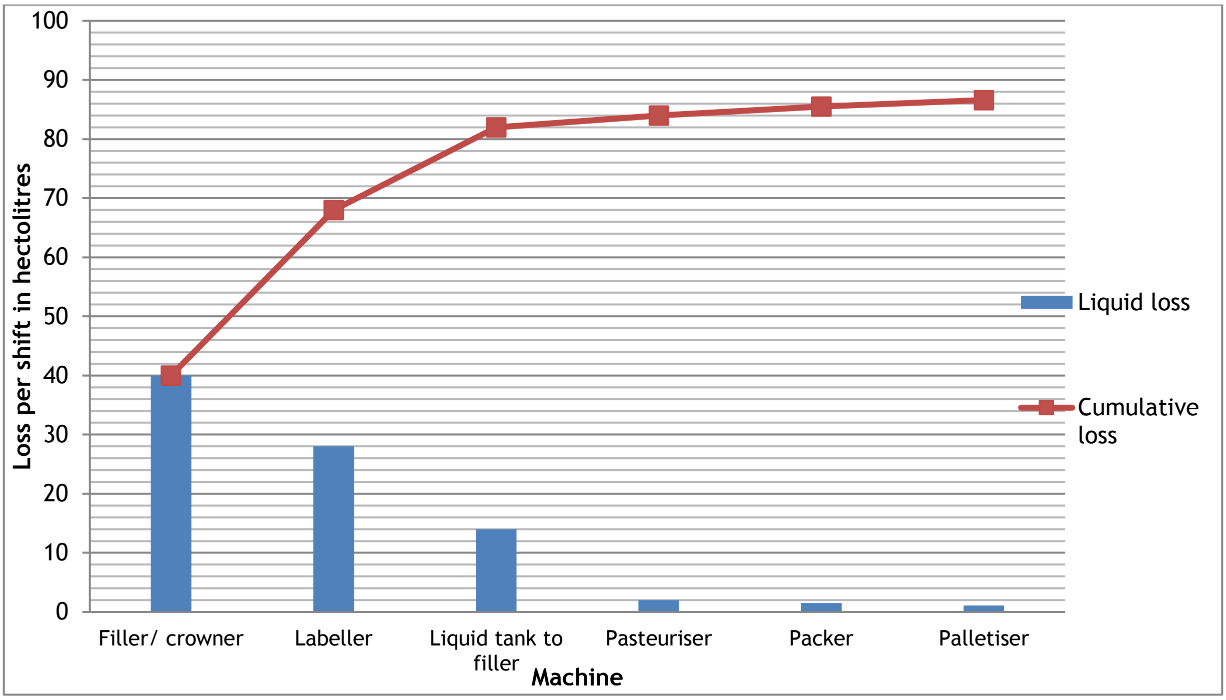

Figure 3: Pareto comparison for beer loss

Due to the fact that the results from a Pareto analysis on beer loss revealed that the filler/crowner contributed a largest beer loss compared to the other segments of the packaging line, this paper focuses on the loss at the filler/crowner. The loss is measured in as a ratio of loss incurred at the respective area against withdrawn volume. Process mapping is a powerful way of visualising the relationships between a sequence of actions required to execute a task, outlining the inputs to the process, the outputs and all the possible wastes. Figure 4 shows the mapping of filling and crowning operations, clearly outlining both the filling and crowning which are both performed by the filler.

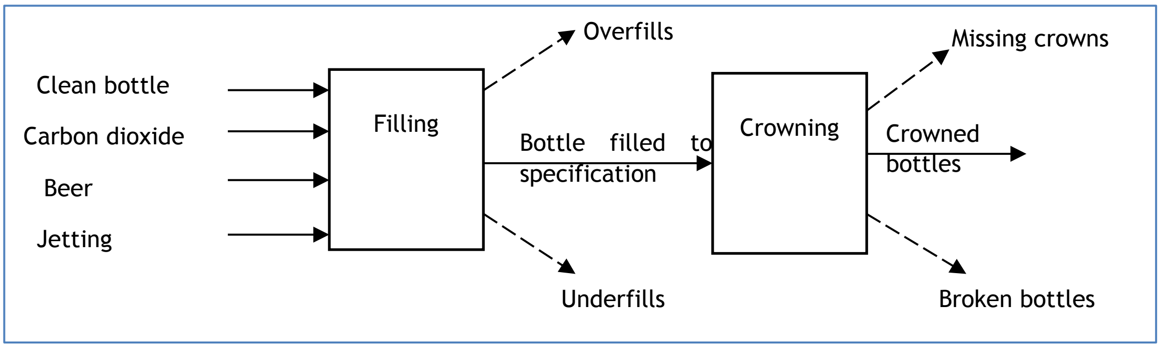

Figure 4: Mapping of filling and crowning operations

A plant walk-through analysis revealed that there was a high loss during the bottle crowning stage for all the 9 brands packaged by the company. Data for crowner losses was collected for a month and it was noted that the company was spending hundreds of thousands of rands towards crowner loss. The beer is packaged in 750ml and 660 ml bottles and Figure 5 and 6 show the day-to-day percentage deviation of the crowner losses from a target of 1% for the two bottle sizes.

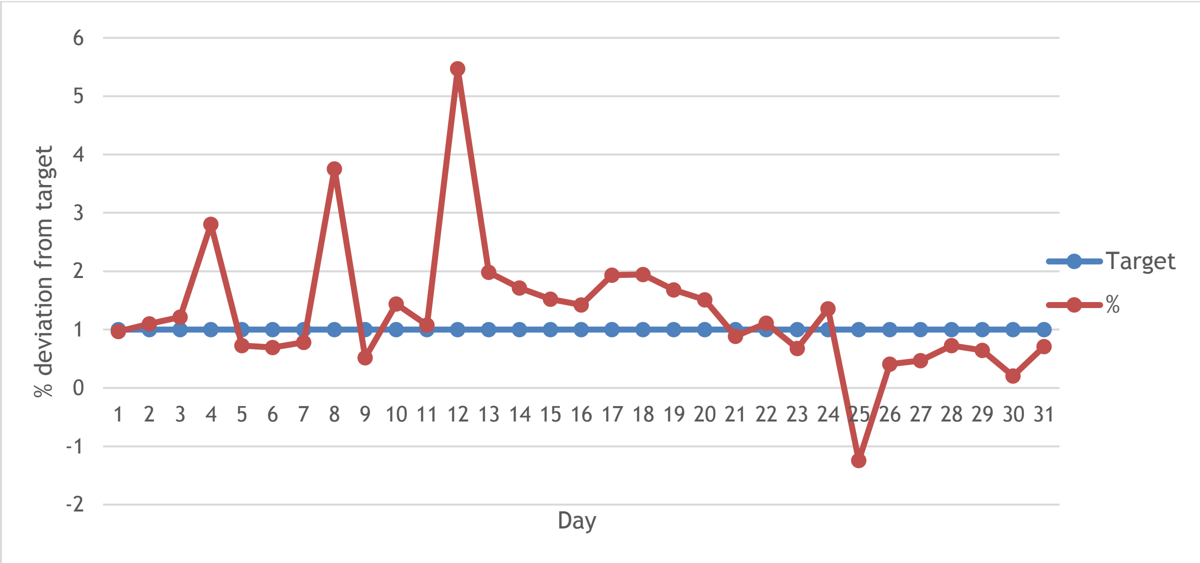

Figure 5: Percentage deviation of crown losses for 750ml bottles

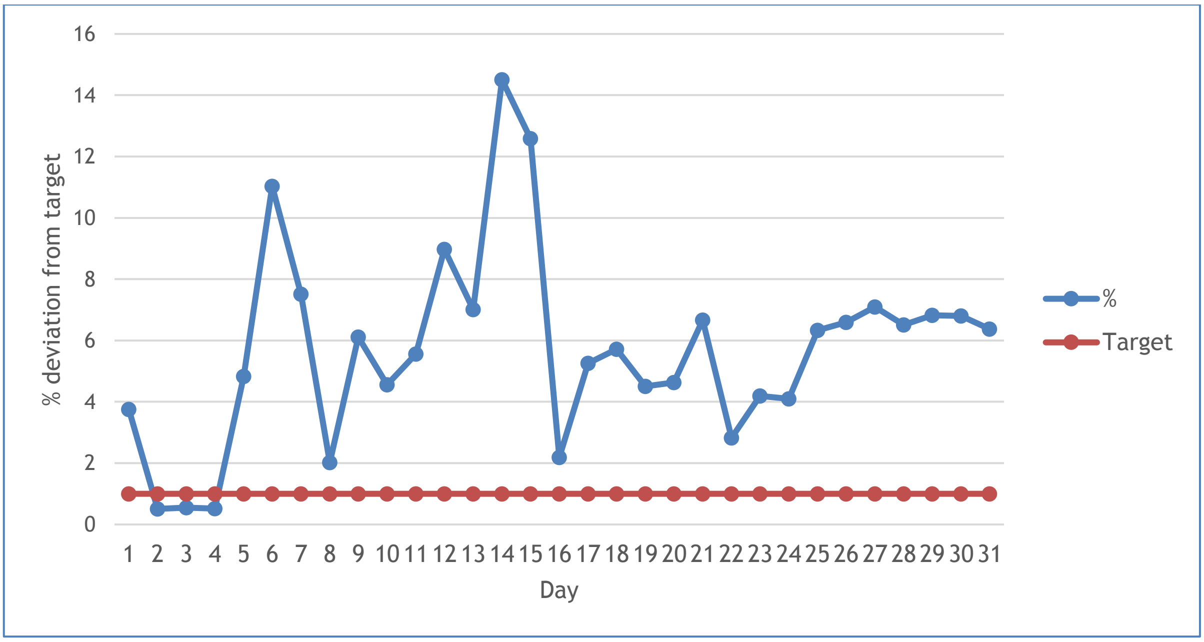

Figure 6: Percentage deviation of crown losses for 660ml bottles

The graphs show that although both bottle modes are failing to meet the target, more losses are being realised from the 660ml bottles. The variation in the percentage deviation from the target and in some instances negative variation for the 750ml bottle in Figure 5 is a pointer that the quality problems could possibly be emanating from operational control issues such as machine setting and machine maintenance.

4.2 Troubleshooting potential causes

The recommended problem solving tools include the Cause-effect (Ishikawa), why-why analysis, questioning technique, Scatter diagrams, and Failure mode effect and criticality analysis. The cause-effect diagram was used in this paper to identify the root causes for crowner loss. Ishikawa diagrams are a strong tool for identifying different causes of a problem and used as a guideline to allocate resources and make necessary investments to fix the problem [13].

According the prescribed standard operating and maintenance procedures it was revealed that the workers may fail to follow the right procedures hence resulting in more waste being produced. The operator mistakes include incorrect filler to crowner timing; incorrect wear strip fitted; crowner not running level; incorrectly setup guides; incorrect neck guide alignment. The machine causes for crowner fallen bottles stoppages would include worn guides; loose guides; burrs on wear strip, incorrect transfer dead plates, worn bottle pads; worn piston springs; worn compensation springs; broken piston rod and worn crowner star wheel. Other material causes for crowner fallen bottles stoppages would include bottle and crown defects.

Figure 7 shows the Ishikawa diagram for bottle crowner.

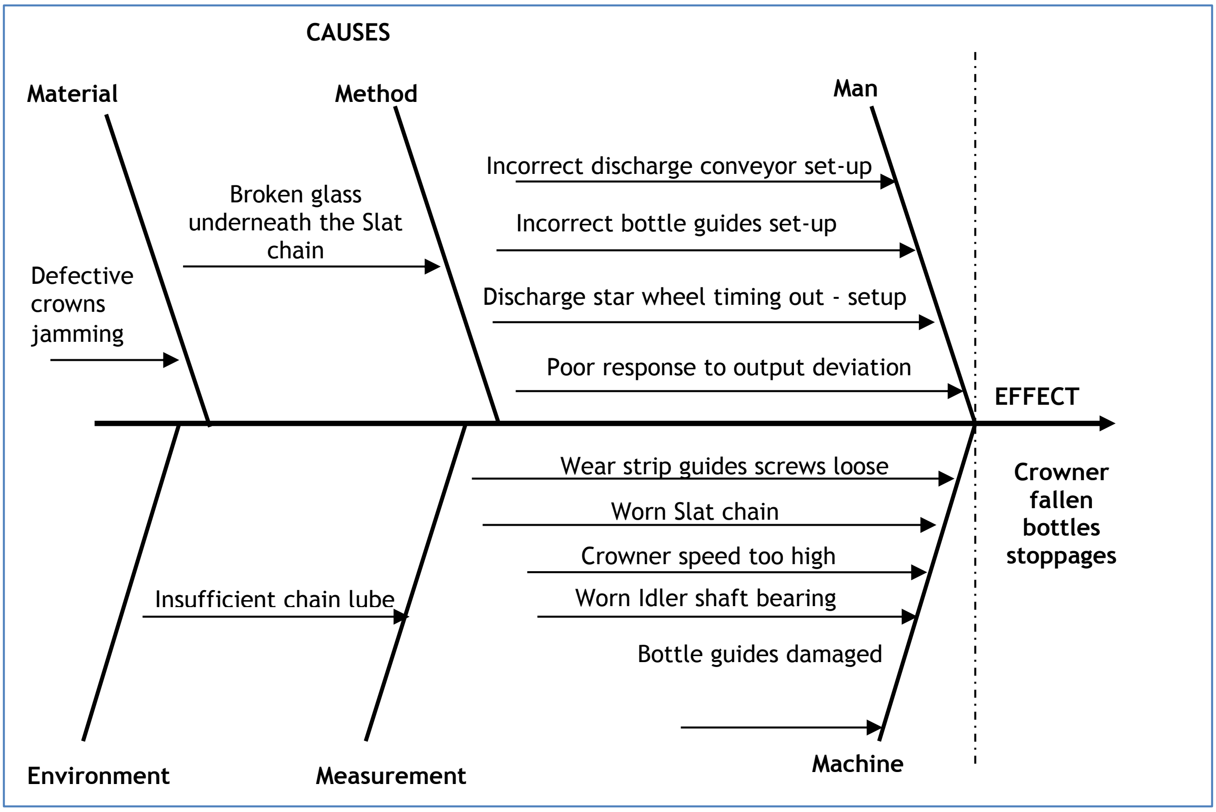

Figure 7: Ishikawa diagram for bottle crowner

Each of the causes were then followed up to check if the standards were taken into consideration during the filling process and to identify if procedures are being followed. Table 1 shows a summary of the potential root causes, the inspection procedure to be executed and the observation made.

Table 1: Troubleshooting potential causes for crown losses

Potential root cause	Inspection	Observation
Incorrect filler to crowner timing	Verify timing after brand pack changes	No problem observed
Incorrect wear strip fitted	Check if correct wear strip are fitted for bottle size	No problem observed
Crowner not running level	Check if the crowner is running level	No problem observed
Incorrectly setup guides	Perform inspection to check if guides are being setup correctly	Guides were setup correctly
Incorrect neck guide alignment	Perform inspection to check if the neck guides are being aligned correctly after brand change	Guides were aligned correctly
Worn guides	Check is bottle guides are not worn	Some guides were worn
Loose guides	Check is bottle guides are not loose	Guides were secured
Burrs on wear strip	Check if there are no burrs on wear strip	No problem observed
Incorrect transfer dead plates	Check if the correct transfer dead plate is used.	No problem observed
Worn bottle pads	Check if bottle pads are not worn	No problem observed

Concerning material causes for crowner fallen bottles stoppages, no defects that were identified for the bottles and the crowns.

4.3 Implementation of possible solutions

These solutions included developing a procedure that embraces proper raw material inspection (crowns) and creating a preventive maintenance schedule to check the condition of guides and repair if necessary. Tradeoffs should also be made with regard to frequency of preventive maintenance since it may cause unnecessary downtime and poor product quality. The procurement and installation of more robust guides would also solve the problem of excessive crown losses. Concerning lean manufacturing process, a poka-yoke is any mechanism that aids to avoid (yokeru) mistakes (poka) from being made by the operator who is using some equipment. By correcting, preventing, or drawing attention to human errors as they occur, poke-yokes can eliminate the occurrence of product defects. In this case, it was noted that pokayokes could not eliminate human error. Deming's PDCA cycle was adopted for implementing the possible solutions. Table 2 shows the PDCA steps which were followed for implementation of possible solutions.

Table 2: Steps for Deming's PDCA cycle

Step	Description	Responsibility	Status
Plan	Developing procedure and train Filler operators	Industrial Engineer	Completed
Do	Develop a procedure that highlight proper raw material orientation - Train all filler operator	Industrial Engineer	Completed
Check	If all operators are trained and adhere to the SOP	Industrial Engineer	Completed
Act	Act on any deviation from the plan	Industrial Engineer	Completed
Plan	Create a maintenance schedule to replace worn guides	Maintenance Planner	Completed
Do	Replace worn guides	Maintenance Technician	Completed
Check	Check if all worn guides are replaced	Maintenance Technician	Completed
Act	Act on any deviation from the plan	Quality inspector	Completed

It was also crucial to make sure that the spare parts for the filler/crowner were always readily available. The crowner was overhauled and all worn components were replaced. We also detected and corrected root causes of overfills and missing crowns at source. It was then imperative to check the bottles for improved sealability during start up as well as for improved filling. A 300 bottle sealability check of the crowns was also conducted. All operators were re-trained to adhere to the standard operating procedures. The maintenance schedules were revised to ensure preventive maintenance of worn guides and the responsible persons were the maintenance planner and maintenance technician.

5. RESULTS AND DISCUSSION

The targets and actual values were then tracked to check for improvement to see if there has been any changes in the crowner loss figures after the implementation of the Deming's PDCA cycle. The target for waste reduction was 1 % of withdrawn volume for the packaging hall. Figure 8 shows the extent by which the crowner loss deviates from the KPI target of 1 % for a 15-week period. It shows a weekly comparison of before-and-after scenarios for percent deviation of crowner loss from target. There is significant improvement after the implementation of interventions although the losses are not meeting the target of 1% deviation. There is room for improvement and hence the need to identify other opportunities for improving the crowner so that the target can be achieved.

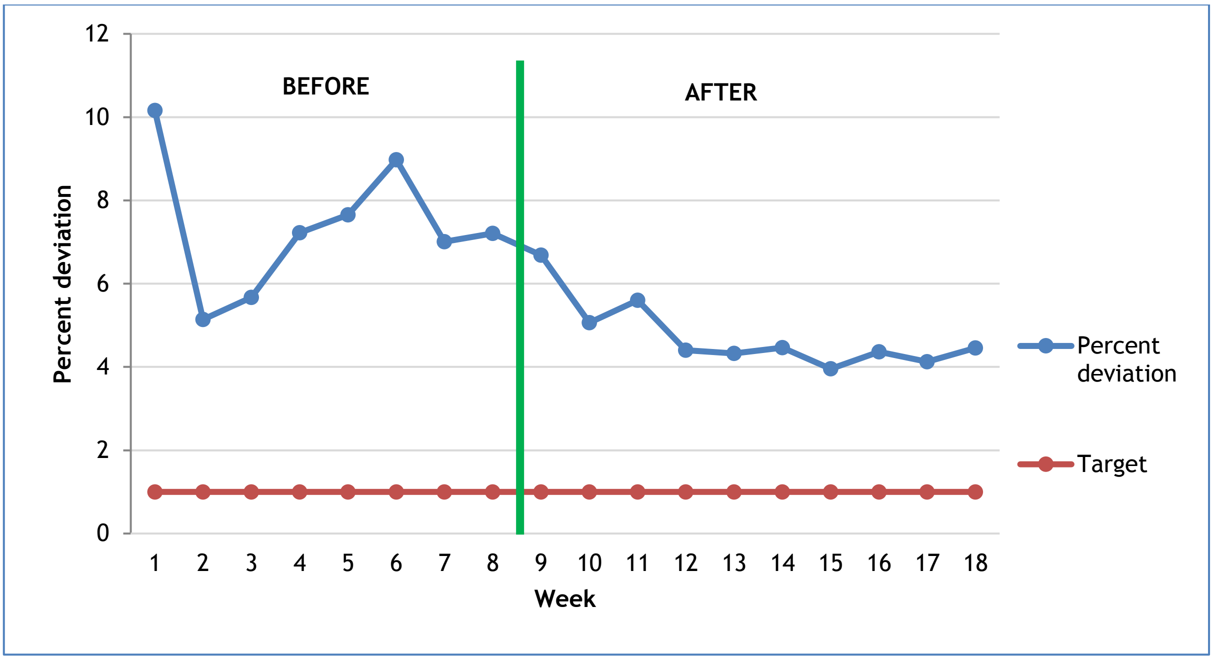

Figure 8: Comparison of before and after scenarios for percent deviation of crowner loss from target

It was crucial to validate whether the effected changes resulted in improvements or whether it was due to chance. Hypothesis testing can be used to determine whether a difference between two observed means is due to stochastic variation and whether the difference is substantial to allow one to draw a conclusion that the two samples come from populations with different means [8]. An independent samples T-test was then conducted by first stating the null hypothesis as population means for the two samples as equal. Significance level (α) was selected at p = 0.05 to reject the null hypothesis if the p-value is less than or equal to 0.05, and that would mean that the two means are significantly different. On the other hand, if the p-value is greater than 0.05 then one cannot reject the null hypothesis.

Table 3 shows the t-test results of the two samples assuming unequal variances.

Table 3: t-test results of the two samples assuming unequal variances

	Before	After
Mean	7,380532	4,743762
Variance	2,64094	0,689127
Observations	8	10
Hypothesized Mean Difference	0	
df	10	
t Stat	4,174163	
P(T<=t) one-tail	0,000953	
t Critical one-tail	1,812461	
P(T<=t) two-tail	0,001905	
t Critical two-tail	2,228139	

Since P (T <=t) for two tail test is 0,001905, thus we reject the null hypothesis and conclude that there has been a significant difference or improvement from the previous scenario to the later situation.

6. CONCLUSION

Focused process improvement can be achieved through root cause analysis. Pareto analysis can be used as tool to identify key areas that would benefit the company in the packaging department. It is crucial to always ensure that the workers comply with the standard operating procedures in order for waste to be reduced. After effecting any changes, statistical analysis can be used as a tool for validating of whether there were improvements made or if the results were due to chance. It is also crucial for companies to implement focused improvement initiatives continuously so as to reduce losses in their production operations.

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IMPLEMENTING CLEANER PRODUCTION METHODOLOGY IN A BREWERY

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ABSTRACT

The brewing industry is challenged by the excessive consumption of costly raw materials such as energy and water as well as huge wastes generated from production processes that lead to exacerbated environmental risks. This paper focusses on developing a framework for implementing Cleaner Production (CP) in a brewery. The methodology entailed performing a detailed analysis of the company's processes, wastes and the environmental problems associated with the processes. Data was gathered for inputs and outputs using worksheets, questionnaires and interviews, with the view to evaluate the environmental performance and production efficiency of the company. Material balances for each section of the plant was carried out in order to ascertain the material losses that occurred during the production process. The causes of wastes and emissions were also evaluated, after which the CP options were generated and screened and analysed for feasibility, after which, a customised framework for CP implementation was then developed for company sustainability and continuous improvement.

OPSOMMING

Die brewing bedryf word uitgedaag deur die oormatige verbruik van duur grondstowwe soos energie en water, asook groot afval gegenereer uit produksie prosesse wat lei tot vererger omgewingsgevare. Hierdie papier focusses op die ontwikkeling van 'n raamwerk vir die implementering van skoner produksie (CP) in 'n brouery toegeval. Die metodologie behels 'n gedetailleerde ontleding van die maatskappy se prosesse, afval en die omgewing probleme wat verband hou met die prosesse uitvoer. Data is ingesamel vir insette en uitsette gebruik werkkaarte, vraelyste en onderhoude, met die oog om te evalueer die omgewing prestasie en produksie doeltreffendheid van die maatskappy. Wesenlike saldo's vir elke afdeling van die plant is uitgevoer ten einde te beraam die materiële verliese wat tydens die produksie proses plaasgevind het. Die oorsake van afval en uitstoot was ook geëvalueer word, waarna die CP opsies was betyds en afgeskerm en ontleed vir die haalbaarheid, waarna, 'n pasgemaakte raamwerk vir CP implementering was dan ontwikkel vir maatskappy volhoubaarheid en voortdurende verbetering.

1. INTRODUCTION

The demand for customised products with short product life cycles has increased in recent years, with customers requiring more credible evidence to support a manufacturer's continual commitment towards environmental protection and sustainable development [1]. Additionally, the transfer of environmentally sound technologies to developing countries has been identified as one of the major elements of the global agenda for the twenty first century (Agenda 21). Sustainable development means adopting and implementing policies concerning issues such as recycling, energy efficiency and conservation for wealthy nations [2]. On the other hand, for the developing nations, sustainable development means policies for equity, respect of the law, redistribution and creation of wealth. In 2013, as its macro-economic blueprint to achieve sustainable development and social equity based on indigenization, empowerment, and job creation, the Zimbabwean government adopted the Zimbabwe Agenda for Sustainable Socio-Economic Transformation (ZIM-ASSET) [3]. Despite, its failure, the goals of the ZIM-ASSET were aligned with the Millennium Development Goals and the concept of Sustainable Development. The strategy of Cleaner Production (CP) fits very well into a broader concept of Sustainable Development, and despite the existence of various international legal instruments and regional initiatives, some companies in Zimbabwe have continued to default on compliance to environmental management best practices for the past two decades. This has largely been attributed to the lack of policing by environmental regulatory bodies, resulting in poor accountability to the environment. The paper was aimed at presenting a framework for implementation of Cleaner Production (CP) for sustainable industrial development at a brewery. It is against the backdrop of much research focusing on CP implememntation focusing on clear beer, that a unique CP implementation plan was required for the case study brewery which produced opaque beer, which generates a lot of spent grain. This required development of a framework for CP implementation through generation of feasible options and a clearly defined sustainable development concept.
The objectives of the study are to:

- Assess the consumption of raw materials and energy
- Establish ways of minimising waste generated from processes and reducing environmental risks
- Identify low cost CP options that could be readily implemented
- Generate sustainable cleaner production options for sustainable utilization of resources.
- Develop a framework for CP implementation

2. LITERATURE REVIEW

Most nations in the world strive for progress that aligned to sustainable economic development without harming the environment or depleting natural resources. In 1987 the Brundtland Report, also known as Our Common Future pioneered a framework for reaching the ultimate goal of Sustainable Development [4]. This report provided the foundation of the CP concept. United Nations Environment Program (UNEP) introduced the concept of CP and defined it as 'the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase eco-efficiency and reduce risks to humans and the environment' [5]. In 1995, UNIDO set up National Cleaner Production Centres and National Cleaner Production Programmes, and in this case, the UNIDO trained CP assessors trained and advise their clients to generate optimal site-specific solutions for their specific problems [6]. However, throughout Southern Africa, the level of awareness, comprehension and implementation of the concept has been very low. It is against this background that, with a view to developing a shared vision and action plan for promoting CP throughout the region Southern African Regional Network on Training and Research in Environment (SANTREN) provided a platform for research, training, dialogue and co-operation amongst all concerned stakeholders. Research institutes such as University of Zimbabwe and SIRDC whose mission is to provide Zimbabwe and the region with technological solutions for sustainable development, have also been involved in research and training of CP methodology [7].

Cleaner production is a preventive strategy that is aimed at minimising the environmental impact of production and products. It focuses on the improvement of the level of material and energy flows as well as preventing emissions at the source and initiation of continuous improvement on organisational environmental performance [8]. The key thrust should be on creating an awareness for pollution prevention, identification of source of wastes and emissions, defining a program for reduction of emissions, and increasing resource efficiency by implementing and documenting CP options [9]. CP can be a practical method for protecting human and environmental health, and for supporting the goal of sustainable development, if it is concurrently applied with other elements of environmental management [10].

Production activities can create water and air pollution, soil degradation, acid rain, global warming and ozone depletion, if the environmental impact of these activites is not taken into consideration. It is thus crucial to shift in attitudes away from control towards pollution prevention and management in order to create more sustainable methods of production [11]. Systems and strategies that reduce and avoid pollution and waste throughout the entire production cycle, from efficient use of raw materials, energy and water to the final product, are now gradually replacing the costly end-of-pipe pollution control systems.[12].

Pollution prevention, source reduction, waste minimization and eco-efficiency are examples of activities that characterise CP. The success of the strategy lies in better housekeeping and management, substitution of hazardous and toxic materials, process retrofitting and modification, and reuse of waste products [13]. The concept of CP is centred on pollution prevention as opposed to pollution control. The CP concept queries the need for a particular product, and focuses on identifying other ways of satisfying the demand and its ultimate goal is to achieve a “closed loop” operation in which all excess materials are recycled back into the process [14].

Sustainable development is advancement that meets the needs of the present generation without adversely affecting the future generations' needs. It represents a versatile approach for management of environmental, economic, and social resources in the long term. It is aimed at relieving poverty, creating equitable standards of living, satisfying the basic needs of all peoples, produce sustainable economic growth and establish sustainable political practices all while taking the steps necessary to avoid irreversible damages to natural capital in the long term in turn for short term benefits by reconciling development projects with the regenerative capacity of the natural environment. [15]. Governments, states, and local governments can adopt this approach to work together to set standards for cooperation between communities, businesses, and governments and attain environmental protection goals. The principles of sustainability can advance competitiveness, stimulate technological innovation, and improve the quality of life. Sustainable development can be described as a process rather than an end goal and can be conceptually split into four constituent subgroups which include environmental, social, economic, and political sustainability [16]. The intent of environmental sustainability is to reduce, eliminate, or reverse the processes that lead to environmental degradation. An unsustainable situation occurs when the sum total of nature's resources (natural capital) is depleted faster than it can be replenished [17].

Some environmentalists have criticized the term “sustainable development”, basing on the fact that economic policies grounded on concepts of growth and continued depletion of resources cannot be sustainable, since the scenario would imply that resources remain constant [18]. Non renewable resources such as coal and petroleum are used at a faster rate that the rate at which they are created by natural processes and thus it is argued that sustainable development has been invented by business to demostarate capitalism as ecologically friendly, thereby placating people promoting environmentalist values. On the contrary, the appropriate application of technologies such as renewable energy, recycling and the provision of services can provide for growth in the economic sense, either without the use of limited resources, or by utilising a relatively few resources with a small impact. In that case, even the use of small amounts of resources may be unsustainable if continued indefinitely [19].

It is worth mentioning that CP has already been depolyed in some breweries and can certainly improve the core process of beer brewing. In collaboration with leading brewers from around the world, UNEP produced a manual for guiding brewers in the implementation of CP. Brewers and investors in countries ranging from Tanzania, Fiji and Panama to Indonesia have shown interest and they committed themselves to implement the CP concept [20]. Decision-making information is also crucial and applying environmental management systems together with CP at Sai Gon Beer has helped the production, environmental and accounting departments to identify drivers of environmental performance and related costs [21].

Implementation of CP at Tínima brewery, located in Camagüey, Cuba, resulted in better quality beer and significant savings in energy (49 %), water (7 %), sugar (4 %), and caustic soda (3 %) consumption. A reduced usage of surplus hot water (74%), waste generation (11 %) and greenhouse gases emission (21 %), was also noted, with beer production capacity increasing by almost three times, and a total saving of US$ 481.83/1000 hL of beer produced [22]. In Austria, against the backdrop of decreasing beer prices, Erste Obermurtaler Brauereigenossenschaft managed to maintain sell its products at a higher prices due to consumer confidence in its beer quality. Their CP project in 1994 encompassed an input/output analysis, material flow analyses, an evaluation of the chemical used and an energy analysis. After CP implementation, the brewery's water consumption was reduced from 6.7 l of water per litre of beer in 1995 to 5.5 per litre of beer in 2000. Industrial waste was also reduced by 66 % and the solid waste from beer production was sold to farmers as animal fodder and to a composting plant. The financial benefits were realised due to reduction of leakages of pressurised air, insulation of several steam pipes, installation of additional meters to more adequately monitor and to control the steam consumption, heat recovery for air compressors, incineration of biogas from wastewater treatment and installation of absorption coolers [23].

3. BACKGROUND OF THE BREWERY

The case study brewery is based in Zimbabwe, The brewery has no environmental policy and there is no framework for adoption of ISO 14001 environmental management system on the ground. The employees have no background knowledge of environmental conscious manufacturing and are paying less attention to the environmental impact of their operations. The company pays fines to the Town Council as a result of non-compliance to trade effluent limits. The company has been focused on primary technological approach to managing environmental pollution. These so-called "end of pipe" technologies were mandated by various Zimbabwean government laws and regulations to bring pollution releases into compliance with government issued pollution permits. These permits were typically based on the best available control technology and the capacity of receiving environmental medium to dilute and assimilate the pollution at levels that science demonstrated to be below levels of concern to human health or ecological systems.

Figure 1 shows the flow diagram for the case study brewing process. The first step is milling whereby a Drotsky grinding mill that has a milling rate of about 30 kg/ min accomplishes the milling of maize and barley. After grinding the meal is forced up the conduit to the cyclone by blower blades. A rotary screw reduces downfall of the meal from the cyclone into the steeping bowl. The second step is steeping whereby circulating water from the municipality combines with the meal in the steeping bowl to produce a mash that will be pumped to the cookers. Lactic acid is also added to reduce the pH of mash form 7 to 5 thus providing an acidic environment conducive for enzyme activity. Boiling or mashing is the process of heating the mixture of milled grain and water, to certain temperatures to allow enzymes in the malt to break down the starch in the grain into sugars, typically maltose. The mash is boiled for 1 hour so that meal is cooked. Under cooling stage, water is added to the boiled mash for primary cooling up to 13000 litres of the tank. After 10 minutes, secondary cooling to a temperature of 54°C is accomplished by circulating water through the coils in the cookers.

During first conversion, about 220 kg of coarse sorghum malt and 40 kg barley malt are introduced into the mash through the steeping bowl, and it is allowed to stand for 50 minutes at 50°C. The activity of enzymes converts the starches of the grains to dextrines and then to fermentable sugars such as maltose. Steam is first introduced into the cookers to raise the temperature of mash to 70°C so as to inactivate the enzymes. The mash is passed through the pre-strainer so as to separate the spent grains from the wort. The wort passes through a screen and flows to the fermenter while some goes to the centrifuge together with spent grains. Under straining, a centrifuge driven by a motor, which puts the mash in rotation around a fixed axis by applying force perpendicular to the axis, is used. It uses the sedimentation principle, where the centripetal acceleration is used to separate spent grains of greater density from the wort of less density. Wort separation is important because the solids contain large amounts of protein, poorly modified starch, fatty material and polyphenols.
Steam is used for pasteurisation by heating the wort in the fermenter to a temperature of 80°C for about 25 minutes so as to kill bacteria and other micro-organisms. The wort is then cooled to about 65°C and water is added up to a volume of 15000 litres.

About 40 kg of sorghum malt are added through the steeping bowl to make up for lost sugars during straining. This is done for 10 minutes at 65°C to cook the malt. It is then allowed to cool to 35°C in 1 hour and this step is the second conversion. The wort is then moved into a fermentation vessel called a fermenter where yeast is added at 35°C (i.e. 3 kg/brew). The yeast converts the sugars from the malt into alcohol, carbon dioxide and other components through a process called glycolysis. Fermentation occurs at 26°C in summer and 28°C in winter.

The beer should be ready for packaging after 15 hours. Empty crates and bottles are passed through the crate washer and bottle washer for cleaning. The bottles are thoroughly cleaned in the bottle washer both inside and out with a hot caustic solution. A conveyor then transfers cleaned bottles to the filler. The beer from the head tank is filled into empty bottles and lids are screwed manually stacking into crates. Quality checks are carried out to ensure strict adherence to quality practices under the packaging operations and recorded on the daily packaging sheet. Temperature and pH for the crate washer and bottle washer water should be checked hourly to ensure effectiveness of the cleaning process. Fill volumes of packaged beer should also be checked hourly to ensure that no underfilling or overfilling occurs. The packaged beer was stacked for dispatch. Daily deliveries range from 48 – 60 hectolitres of beer. Alcohol level should be around 1.8 – 2 %, with total acids of 0.15 – 0.2 %, and reducing sugars of 2.5 – 3 % for the first 24 hours after packaging.

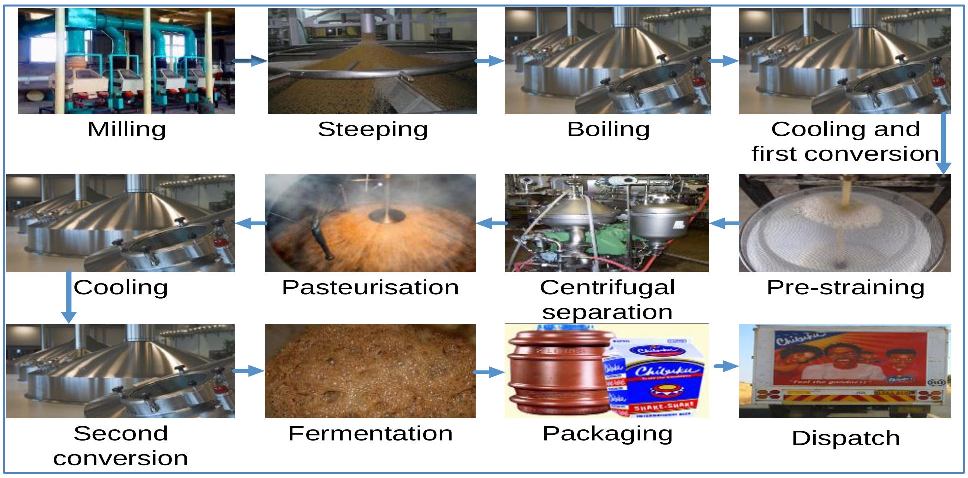

Figure 1: Flow diagram for brewing process

The water usage for brewing and cleaning operations was excessive compared to the world's best practices of around 3 hectolitres of water per hectolitre of beer. The consumption of energy was also high due to poor energy management. Moreover, no end-of-pipe technologies were installed to curb the environmental impact of gaseous emissions such as sulphur dioxide from coal combustion and carbon dioxide from fermentation process. The level of effluent treatment was sub-standard resulting in litigation from municipality authorities and complaints from neighbouring companies since the effluent tank produces bad odour.

Despite the numerous international and regional initiatives and interventions that have been made, Zimbabwe has continued to show negative growth in implementation of environmental management principles since the past two decades. This has been largely attributed to poor economic performance. One of the major reasons for the failure of Zimbabwean economic growth is the poor performance of the manufacturing sector. Zimbabwe has endured gross negative growth rates for ten years, industry is operating at less than 40 % of capacity and the country has seen unmitigated corruption. The industrial sector is characterised by extreme dependence on foreign inputs and less skilled manpower.

4. METHODOLOGY

A scientific research methodology was used to systematically identify and evaluate the Cleaner Production opportunities and facilitate their implementation at the brewery. This was accomplished through proper planning and organization. Worksheets, questionnaires and interviews were used during the CP assessment with the view to evaluate the environmental performance and production efficiency of the company. It is worth mentioning that it is crucial to understand the process prior to generation of CP options. The key inputs and outputs of the brewery process were identified as shown in Figure 2.

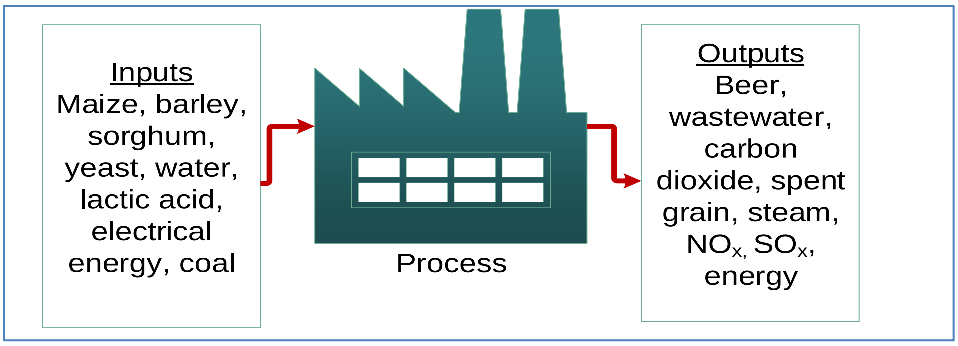

Figure 2: Inputs and outputs of brewing process

The causes of wastes and emissions were evaluated, after which the CP options were generated and screened. A feasibility analysis of the CP options was carried out and both feasible and non-feasible options were documented. A framework for CP implementation was then developed through formulation of a Sustainable Development strategy, clearly defined CP goals, and initiation of training of employees.

5. CP ENVIRONMENTAL CONCERNS

There are several CP environmental concerns that were noted during the plant walk-through assessment. Signs of poor housekeeping were noted in the milling section. Rodents caused damage on the grain bags and this resulted in spills of grain. The spills were also noted on the area surrounding the grinding mill. Spills of lactic acid were also noted, and these spills occurred when the lactic acid was being poured from container to the steeping bowl. The container for lactic acid was poorly calibrated and the move distance (10 m) between the container and the steeping bowl was too large. Lactic acid is corrosive and the employees did not use protective clothing.

Flue gases from the boiler chimney, which indicates that there are material losses. There was no means of measuring the flue gas temperature. A 20 °C reduction in flue gas temperature will improve boiler efficiency by about one percent. The blowdown rate was periodic and did not depend on the levels of dissolved solids in the boiler water. The loss of blowdown water resulted in wasting heat, water and water treatment chemicals. Presence of scale deposits on the fireside and waterside of the boiler tubes reduces heat transfer dramatically. Tests show that a soot layer just 0.8 mm thick reduces heat transfer by 9.5 percent and a 4.5 mm layer by 69 percent. As a result, the flue gas temperature rises, as does the energy cost. Excessive consumption of coal due to reduced efficiency of the boiler. Soot accumulates in the combustion chambers reducing rate of heat transfer. Some of the employees left the boiler operating with no balanced draft resulting in incomplete combustion of the fuel. Uninsulated steam pipes valves and flange joints was also a cause for concern.
High level of noise of above 100 dB were noted from the Drotsky grinding mill and stirrer for the cooker. Excessive consumption of water for crate and bottle washing was caused largely by the leakages of bottle washer. Carbon dioxide from fermentation in the fermenters was not trapped and it was also noted that unpleasant odour were emitted by the effluent treatment plant

6. INVESTIGATION OF RESOURCES AND WASTE

6.1 Quantifying Process Inputs and Outputs

The input and output information were collected in the plant simultaneously even though the audit procedures describe these as discrete steps. Much of the quantitative data for these flow charts were not available, because of lack of in-process monitoring. Some of the data used in the assessment were estimates calculated from the aggregated figures basing on the capacity of unit processes and usage while some of the data were calculated after taking measurements. Ideally, all inputs at each specific unit process were supposed to be determined either by direct measuring during the case study or from process monitoring records. There were no resources and time available to carry out the direct recording, neither were there any specific records available. Fig 4 shows the key inputs and outputs from a brew in the brewery.

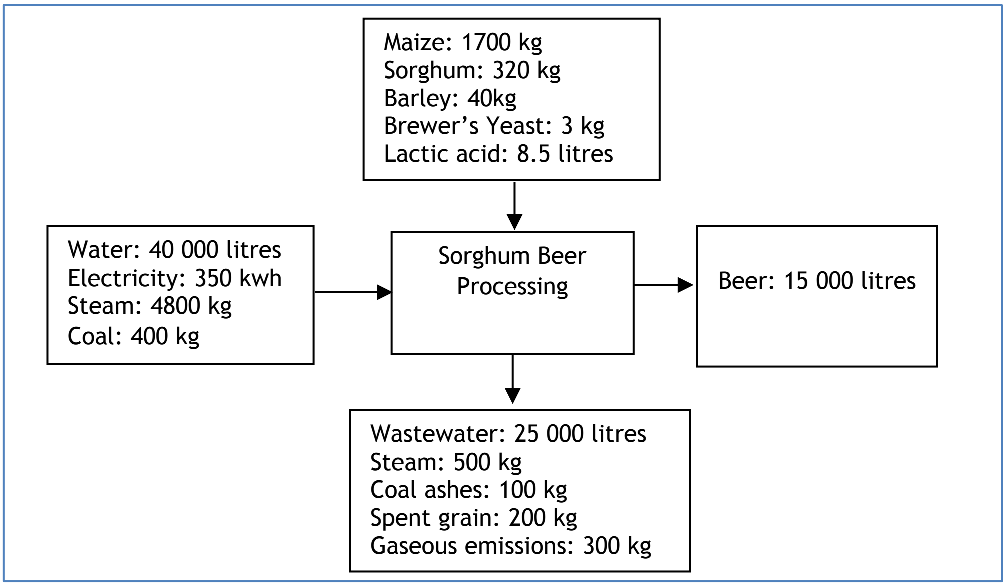

Figure 3: Key inputs and outputs figures for a brew in the brewery

It was noted that most of the raw materials for the brewing process were harmless except lactic acid. However, wastewater and gaseous emissions posed a greater challenge as far as environmental management is concerned. Coal ash was given to the community for free so as to eliminate disposal costs. The average water usage was 2.7 to 3 hectolitres per hectolitre of beer produced and that was far above world standards of around 2.2 hectolitres per hectolitre of opaque beer.

6.2 Material Balance

The objective of a material balance was to account for the use of raw materials, auxiliaries, and energy that go into the process and that is released by the same process. The material balance was not only used to identify the inputs and outputs, but also the costs associated with these. There were several direct and indirect cost components associated with waste and emissions. All the material balances for the sections of the plant were carried out for a standard brew of 15000 litres. It was assumed that an average of 3 brews were made per day, 20 working days per month and 12 calendar months per year. Table 1 shows a summary of of the material balances for the stages in the brewing process.

Table 1: Material balances for the stages in the brewing process

Process	Inputs	Outputs
Milling and Steeping	Maize: 1 700 kg Water: 10 000 litres Lactic acid: 8.5 litres Electricity: 50 kwh	Mash: 11 701 litres Milling dust: 7.5 kg
Cooking	Mash: 11 700 litres Steam: 800 kg Electricity: 35 kwh	Mash: 12 400 litres Steam: 100 kg
First conversion	Mash: 12 200 litres Raw sorghum: 220 kg Barley malt: 40 kg	Mash: 12 460 litres
Straining	Mash: 12 460 litres Electricity: 25 kwh	Wort: 10 960 litres Spent grain: 1500 kg
Second conversion	Wort: 10 960 litres Sorghum malt: 40 kg Steam: 40 kg Water: 3800 litres	Wort: 15000 litres Steam: 20 kg
Fermentation	Wort: 15000 litres Yeast: 3 kg	Beer: 13503 litres Carbon dioxide: 1500 kg
Packaging	Beer: 14500 litres Number of empty crates: 1117 Number of empty scuds: 7000 Water: 50 000 litres Steam: 1500 kg Bath detergent: 16 kg General purpose cleaner: 10 litres Stainless steel cleaner: 2 litres Conveyor lubricant: 4 litres Electricity: 124 kWh	Packaged beer: 14 000 litres Filled crates: 1117 Wastewater: 51 000 litres
Boiler	Coal: 400kg Electricity: 8.3 kWh Water: 4800 litres	Coal ashes: 100 kg Flue gases: 300 kg Steam: 4800 kg

There were no material losses noted in the milling section, except that there were lactic acid spillages on pouring from the reservoir to the container and milling dust collected through the bag filters. The standard boiling time was one hour and steam losses through the chimney of the cooker were noted. Loss of steam meant loss of heat energy and water. There were no notable material losses during the first conversion process. The carbon dioxide produced from fermentation was estimated at 10 kg per hectoliter of opaque beer produced and this cascaded to 10 tonnes of carbon dioxide of the 100 000 hectolitres of beer produced per year. The amount of water in the waste was excessive resulting in greater charges of the water from the town council reservoir. The cost of beer in waste was excessive due to large beer looses in the packaging section. Overfills resulted in beer spills and leakages from a pump that supplied packaging section from the brewing section was leaking. The cost of energy in waste and emissions was excessive. This was largely attributed to poor lagging of steam pipes, unclaimed heat in the flue gases and steam losses during cooking and cleaning operations. About 60 kg of CO_2 in the flue gases was emitted into the atmosphere. The company opted to give the community wastes from coal ashes from the effluent plant, free of charge, so as to combat the costs of transport and disposal of waste.

6.3 Investigation of Energy Usage

Most of the electrical energy was consumed during bottle-washing process as well as the pumps at the cooling towers. The motor used for stirring the mash in the cookers had worn bearings leading to more current usage. Annual usage of the energy from coal was 8 GJ and 288 000 kwh from electricity to produce 10.8 ML of opaque beer per year. The percentages of energy consumed are illustrated in Figure 4 and bottle washer has the highest percentage of 20 %, which is equivalent to 3500 kWh per month.

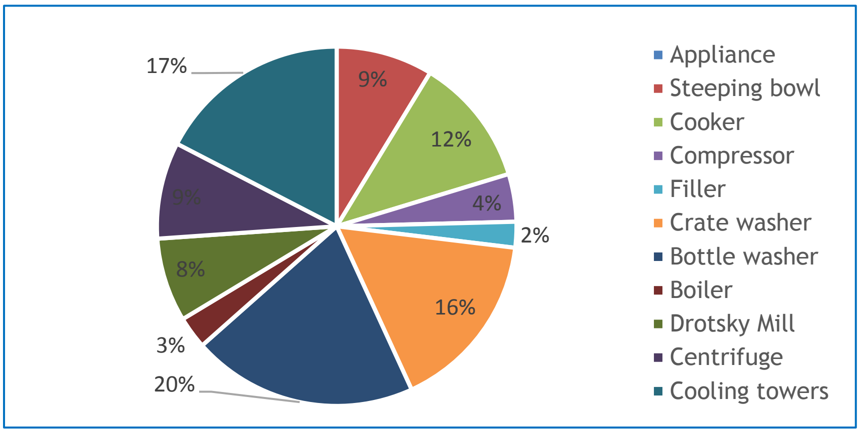

Figure 4: Percentage distribution of electricity consumption

6.4 Investigation of Beer Loss and Wastewater

Most of the beer was lost during the packaging operations, largely due to overfills. A leaking pump due to worn out packing also contributed to beer loss for the period in which the study was undertaken. Some beer was also lost if it was of poor quality especially when left to idle in the head tank. It would then form a thick porridge that had to be discharged to the effluent treatment plant. The beer lost was estimated at 50 L per day, which cascaded to 12 000 L per year, thus implying loss of about US$12000.

Table 2: Classification for effluent standards

Parameter	Blue	Green	Yellow	Red
BOD	≤ 15	≤ 50	≤ 100	< 120
COD	≤ 60	≤ 90	≤ 150	≤ 200
Detergents	≤ 1.0	≤ 2	≤ 3	≤ 5
Grease and oil	≤ 2.5	≤ 5	≤ 7.5	≤ 10
Nitrogen	≤ 10	≤ 20	≤ 30	≤ 50
pH (pH units)	6 - 9	5-6; 9-10	4-5; 10-12	0-4; 12-14
Phosphates	≤ 0.5	≤ 1.5	≤ 3	≤5
Temperature (°C)	< 35	< 40	≤ 40	≤ 45
TSS	≤ 25	≤ 50	≤ 100	≤ 150

The daily effluent water analysis reports constituted of pH, temperature, total settleable solids (TSS) and less tests were made for Permanganate Value (PV). No tests were conducted for BOD, COD, phosphates, nitrogen, detergents and other water pollutants. The effluent discharged into the municipality sewer was too acidic (average pH was around 3.5 to 4) and the PV was in excess of 200, a pointer that further treatment of the effluent was required before it was discharged. Table 2 is a classification table used for effluent standards for discharge in milligrams per litre of effluent except for pH and temperature whose units are indicated in brackets. The blue permit is in respect of a disposal that is considered to be environmentally safe, green permit for low environmental hazard, yellow for medium environmental hazard and red for high environmental hazard. The effluent discharged into the municipality sewer was too acidic (average pH was around 3.5 to 4) and the PV was in excess of 200, a pointer that further treatment of the effluent was required before it was discharged. Coagulants such as alum or sodium aluminate could be added to the effluent so as promote sedimentation and reduce the concentration of dissolved solids.

6.5 Investigation of Gaseous emissions

Figure shows the constituent elements of coal before combustion. Since ambient air contains about 79 percent volume of gaseous nitrogen (N_2), which is essentially non-combustible, the largest part of the flue gas from coal combustion was uncombusted nitrogen. The flue gas also contained carbon dioxide (CO_2), which constituted as much as 10 to 15 volume percent or more of the flue gas.

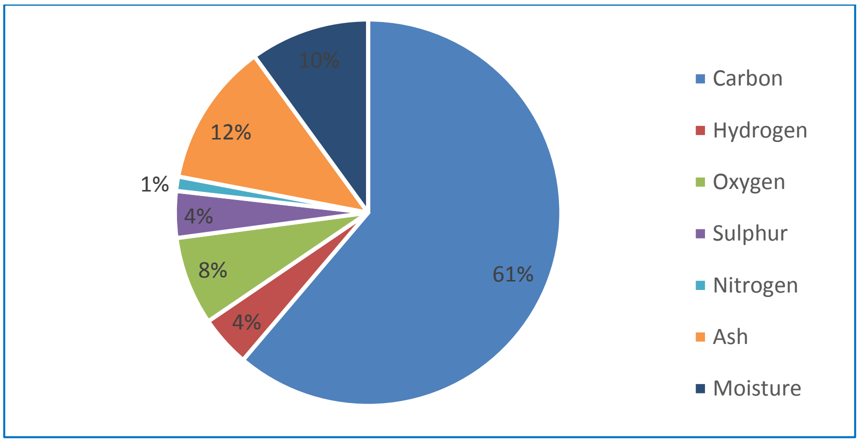

Figure 5: Percentage distribution for constituent elements of coal before combustion

The flue gas from the combustion of coal also contained some very small amounts of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and particulate matter. Nitrogen oxide is a strong irritant and can cause inflammation of the lungs as well as damage to crops and forests when combined with SO_2 from acid rain. The SO_2 derived from sulphur-containing compounds in the coal can be converted into sulphuric acid or sulphates whose adverse impacts include human health hazards, damage to crops and forests, metal corrosion and acid rain. The particulate matter composed of very small particles of solid materials and very small liquid droplets gave the flue gases their smoky appearance. Atmospheric emissions of solid particles during coal combustion usually vary in sizes from 0.01 to 10 micrometres in diameter. These smaller particles are easily respirable and have adverse effect on human health. There was no pollution control equipment at the boiler chimney.

Gross caloric value of coal is about 25 MJ / kg and the amount of dry exhaust gas is 293.6 Nm^3 per gigajoule of fuel. The CO_2 percentage in dry exhaust gas is about 15.0 % and O_2 is about 3.7 %. About 288 tonnes of coal was combusted per year releasing 7.2 million megajoules of energy and 43.2 tonnes of CO_2 per year. CO_2 is responsible for around 50 % of the impact of the various greenhouse gases associated with global warming because of its absorption of infra-red radiation from the earth thus produce the "Green House Effect". Flue gas from coal combustion contained uncombusted N_2, CO_2, (NO_x), SO_2 and particulate matter. Gross caloric value of coal is about 25 MJ / kg and the amount of dry exhaust gas is 293.6 Nm^3 per GJ of fuel. About 288 tonnes of coal was combusted per year releasing 7.2 million MJ of energy and 43.2 tonnes of CO_2 per year.

7. FEASIBILITY ANALYSIS OF CP OPTIONS

The key factors that were used for screening of Cleaner Production options include availability, environmental effect and economic feasibility of each CP option [24]. The key elements under the availability factor include whether the cleaner production option available, availability of green suppliers and suitability of option if it has been previously applied elsewhere.

Considerations for screening of the environmental effects of CP options include the anticipated human and environmental effect, magnitude of the estimated reduction in emmisions or waste streams. Screening of the economic feasibility of the CP options embraced analysis of the anticipated costs and benefits that would be derived from implementing the option. Viable options were ranked and some were not feasible at period of study and were set aside for consideration in the future. Table 3 shows a summary of feasible CP options and their rankings in terms feasibility for implementation. It embraces technical, economic and environmental feasibility of the options. With technical feasibility, focus was on whether the technology was available to the firm, was appropriate, and whether it could achieve the required changes. Economic feasibility compared current savings with costs of implementing the option. The payback method was used for assessing economic feasibility.

Environmental feasibility determined the environmental benefits or effect (positive or negative) of each option on the company's environmental objectives, regulatory requirements, customers, employees and the general community. Based on these considerations, the viable options were re-screened and priorities were set for implementation.

7.1 Feasibility analysis of staff training program

We realised that training of staff was as a viable CP option with several economic and environmental benefits. The economic benefits included reduced consumption of water and energy. It was also noted through proper education, the staff working at high noise level environments would also benefit, since there was negligence on use of earplugs.

7.2 Feasibility analysis of installation fish pond

The free space available (50 m^2) could be utilized by construction of a fish pond. The spent grain from the straining stage of the brewing process would be used as feed for the fish. When treated properly, the wastewater from the effluent plant could also be directed to the fishpond. Assuming that 100kg of fish would be harvested per month of installation and sold at US$3 /kg, income is $3600.

Estimated material cost of fish pond = $1000 Installation cost = $300

Operating costs = $300 Total cost = $1600

$$Payback\ period\ = \frac{Capital\ investment}{Net\ savings\ in\ operating\ costs\ per\ year} = \frac{1600}{3600} = 0.4\ years$$

Employees can be given the fish for free to boost staff morale and enhance productivity.

7.3 Feasibility analysis of efficient spray nozzles

It has been noted that the average water usage was 2.7 to 3 hectolitres per hectolitre of beer produced and the brewery used 45 000 hectolitres of water per year, of which 10% was used for tank cleaning. About 38 hectolitres of water, costing $0.6 per hectolitre, was being used for the cleaning process which took 2 hours of manual cleaning of all the tanks after every three days. The manual cleaning included confined space entry, scrapping and scrubbing which had a significant effect on water usage and tank downtime. The amount of water used by the brewery could be reduced by introducing efficient solid stream nozzles. Solid stream nozzles rotate in multiple axes to provide complete 360° coverage of entire tank and provides tight cleaning pattern and fast cycle times. The key benefits of solid stream nozzles include superior tank cleaning and reduced operating costs. They clean tanks with medium impact while consuming less liquid and they are easy to maintain.

The installation of efficient spray nozzles could reduce cleaning cycle time to 15 minutes using only 6750 hectolitres of water per year that is equivalent to 85 % saving. The brewery will also be able to increase production. Water savings for cleaning operation would be 38 250 hectolitres per year, which costs $22 950 per year.

Estimated material and installation cost of efficient spray nozzles = $6000

Operating cost per year = $500 Total cost = $6500

$$Payback\ period\ = \frac{Capital\ investment}{Net\ savings\ in\ operating\ costs\ per\ year} = \frac{6500}{22950} = 0.3\ years$$

7.4 Feasibility analysis of a biogas digester

A continuous feed biogas digester was suggested. The sludge would be continuously added and vigorously mixed mechanically. The digester would also be heated so as to maintain maximum activity of the bacteria in the mesophyilic region of 30°C to 35 °C. The digester volume depends upon quantity of raw sludge, rate of digestion and period of digestion. It given by the expression,

$$V = \left[V_f - \frac{2}{3}(V_f - V_d)\right] \times T_1$$

where V= Volume of digester, V_f = Volume of fresh sludge added per day,
V_d = Volume of digested sludge withdrawn per day, T_1= Digestion time in days.

Assuming a feed rate of 800 kg per day of volume 0.72 m^3, retention time of 60 days with a volume of 0.2 m^3 of digested sludge withdrawn per day, the volume of the digester required would be 22.4 m^3. This would produce about 6 m^3 per day (at 25 °C) and 10 m^3 per day (at 30°C).
Considering methane content in the biogas to be a minimum of 55%, and assuming the heating value biogas 20 MJ/m^3 [25], the estimated energy value of 10 m^3 of biogas produced per day = 200 MJ/day. This is equivalent to 10 kg of coal (200 MJ/kg) of value $0.5 ($0.05/kg).
Considering 240 working days/year, annual savings from coal substitution = $120. The biogas generated by the system could be directly used in the boiler after modifications for it to us both coal and biogas. The cost of modification of the boiler was included in total estimated cost of biogas digester. Estimated material cost of biogas digester = $600; Installation cost = $400; Total cost = $1000

$$Payback\ period\ = \frac{Capital\ investment}{Net\ savings\ in\ operating\ costs\ per\ year} = \frac{1000}{120} = 8\ years$$

The payback period is long, although one should also considering the environmental benefits of renewable energy derived from use of biogas. Alternatively, biogas can be used in combined heat and power (CHP) generation, also known as cogeneration. About 1 m^3 biogas of biogas produces 2.5 kWh of electricity, and thus considering 240 working days per year, 2400 m^3 of biogas would yield 6000 kWh of electricity. Price of electricity is 11,2c/kWh, and thus annual electricity savings will cascade to $672 per year. Micro-turbine capital costs range from $700 – $1,100 /kW, and including installation and operating costs, capital investment was estimated at $10 000.

$$Payback\ period\ = \frac{Capital\ investment}{Net\ savings\ in\ operating\ costs\ per\ year} = \frac{5000}{672} = 7\ years$$

7.5 Feasibility analysis of CO_2 trapping mechanism, DAF Installation and direct-contact economiser

The installation of carbon dioxide trapping mechanism was economically not feasible since fermentation process took only 15 hours before dispatch to the consumers. If the beer was allowed to stand for a longer period, more trappable CO2 would have been realized. The gas would also require further processing before selling to consumers. Installation of the DAF system was assessed to be technically and environmentally feasible but involved a capital outlay of $15000. The economic constraints that prevailed meant that this option, even though it lowered discharge pollutants and was postponed for further consideration at a later date.
The installation of direct-contact economiser for heat recovery from the boiler was not technically feasible due to the lack of skilled personnel required for installation. The company could afford $65 000 that was required for the installation process.

7.6 Summary of results for feasibility assessment

Table 3 shows a summary of results for feasibility assessment. The CP option for combined heat and power generation (CHP) was economical not feasible due to financial resources constraints. The re-use of lids was not feasible since after use, the consumers removed the rings off the lids resulting in the need to coordinate with the supplier of lids.

Table 3: Results for feasibility assessment

	Action	Technical Feasibility	Economic Feasibility	Environmental Feasibility	Priority
1	CO_2 trapping mechanism	Fair	Fair	Good	7
2	Biogas digester	Fair	Good	Very Good	4
3	Direct-contact economizer	Good	Good	Fair	5
4	Staff training program	Very Good	Very Good	Good	1
5	Efficient spray nozzles	Very Good	Very Good	Fair	3
6	Dissolved air flotation system	Fair	Fair	Very Good	6
7	Fish pond	Very good	Very Good	Very Good	2

8. RECOMMENDATIONS

As a follow-up to the previously mentioned CP environmental concerns, it was recommended that chemicals could be used to eliminate rodents and employees should be advised to take extra caution so as to reduce grain spills on the area surrounding the grinding mill. A properly calibrated measuring cylinder should be used to reduce spills of lactic acid. The lactic acid reservoir container could be mounted adjacent the steeping bowl, fitted with a valve that is directly connected to the measuring cylinder. This is a low cost CP measure. Employees should be advised to wear protective gloves.

It was also recommend that the brewery should increase the number of cleaning operations per week could reduce scale deposits on the fireside and waterside of the boiler tubes. This is a no cost CP measure. Proper maintenance of the shafts and bearing for the power supply of the stirrer would result in reduced noise levels. Heat exchangers could be installed to trap steam emissions from the cooker chimney. These would be used as condensers to cool a vapour to condense it back to a liquid. The latent heat of steam is given out inside the condenser. It was also noted that uninsulated steam pipes valves and flange joints could be lagged using heat resistant fibrous materials.

Excessive consumption of electrical energy by the cookers could be reduced by proper maintenance of equipment. Training the operators since they left the boiler operating with no balanced draft resulting in incomplete combustion of the fuel and staff-training program on CP techniques could also be adopted. Installation of more efficient spray nozzles for cleaning mechanism on bottle washers would also yield substantial water savings and this recommendation, coupled with metering individual equipment separately for water and energy usage would provide quantifiable results.

As a follow-up to the summary of results for feasibility assessment, the brewery can commence with a staff training program on the implementation and benefits of CP. The brewery can then develop a fish pond followed by installation of efficient spray nozzles. The installation of a biogas digester can also be taken into consideration after the implementation of the previously stated viable CP options.

It was noted that there were substantial obstacles to the effective implementation of CP. These barriers include:

- Poor communication within the organisation;
- The poor environmental law enforcement by the brewery, local municipality and at national level. Even fines would become accepted price of doing business if the fines are cheap.
- The general resistance to change from pollution control attitudes to pollution prevention perspective. This relates to satisfaction with the entrenched status quo and resistance to change from already installed end-of-pipe technologies. Even state of the art technologies with old attitudes soon become polluting and inefficient technologies.
- The lack of environmental leadership at the case study brewery.
- The lack of skills and technical expertise to implement CP concept as well as information about specific CP technologies that would be applicable on breweries. They believed that protecting the environment is always a costly process.
- The presence of resource subsidies such as price of coal and electricity at national level, work against the cost-effectiveness of some CP opportunities. Less energy savings would be obtained after adoption of CP.
- Financing CP investments has proven to be an effective barrier to its implementation due to foreign currency shortages. Financial institutions in Zimbabwe have not been supportive as opposed to the developed world where banks would also play an active role in financing CP activities.

In order to have successful implementation, it is therefore recommended that the CP concept be effectively communicated within the organization. Employees at all levels, including senior management, should be actively involved workers, consumers, and communities all have access to information and are involved in decision-making. Form a government policy perspective; tradeoff should be made between the provisions of resource subsidies against the implementation of cost-effectiveness CP opportunities. The government and local municipalities as well as financial institutions in Zimbabwe should also play a crucial role in financing CP activities.

9. FRAMEWORK FOR CP IMPLEMENTATION

Sustainable Development strategy was identified as the initial step in setting up a framework for CP implementation for Sustainable Development as shown in Figure 6. Key sustainable development priorities that were identified include:

- Discouraging irresponsible drinking
- Using less water in the brewery
- Reducing the energy and carbon footprint
- Packaging reuse and recycling
- Working towards zero waste operations

The formulation a Cleaner Production policy was identified as the second step in setting up a framework for CP implementation. The policy was to be formulated in a manner to suit the operational environment that characterised the brewery. It would include a commitment to continual improvement and prevention of pollution as well as complying with relevant environmental legislation. A framework for setting and reviewing of CP objectives and targets was to be clearly stated in the CP policy. It was also crucial that the CP policy be documented and communicated to all employees and available to the public.

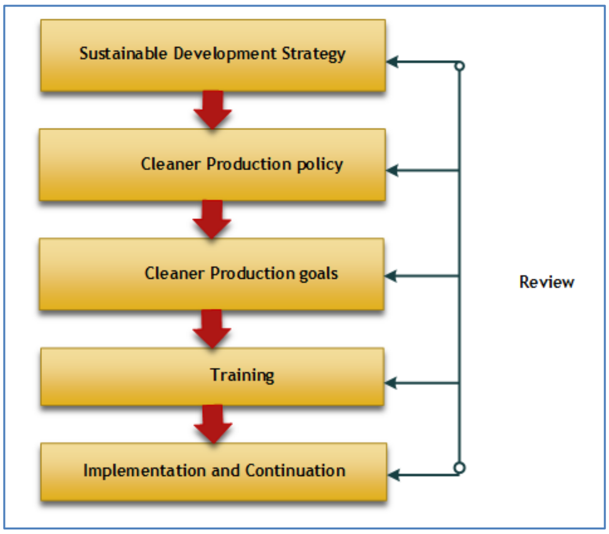

Figure 6: Framework for Cleaner Production Implementation

The third stage in the implementation framework was the definition of CP goals. Plant-wide CP goals for optimising resources utilisation and mitigating pollution problems were to be set. The following goals were to be achieved for sustainability of operations at the brewery.

- Reducing the consumption of raw materials and energy
- Minimising waste generated from processes and trade waste charges
- Reducing costs of waste handling and disposal
- Finding efficient ways of segregating different wastes
- Finding higher price buyers/alternative uses of waste
- Improving the efficiency of production
- Reducing the use of hazardous materials

As a fourth step, the brewery was to identify CP training needs and personnel whose work would create a significant impact in strides to achieving CP goals were to receive appropriate training. The company was to establish and maintain procedures that would make the employees at each relevant function and level aware of the importance of conformance with the CP policy and procedures.

Lastly, the brewery should develop an implementation and continuation plan. The objective of this section was to document the results of the feasibility study and provide a list of CP options that should be considered for implementation. A good starting point would consideration of the results from the feasibility analysis of CP options mentioned in the previous section. Key performance indicators for future monitoring should be set. These would typically relate material, energy, water and waste quantities to the size of the operation, to arrive at indices that could possibly be compared with other operations and establishments. The preferred (cost-effective) CP options were to include targets, actions to be taken, resources required for implementation (human resources, finance and equipment), person(s) responsible for the implementation, timing, performance measures and potential dollar savings.

A system for reviewing and reporting the progress of the project from start to completion was to be put in place. It would be able to review the performance indicators based on the actual performance of the project and reporting the results of the project and its benefits to management and staff. Outcomes of the projects would be assessed and lessons learnt be transferred to other areas of plant operations so to extend its benefits to the whole organization. The implementation plan would need to be included in the brewery's business plan and budget. The no and low cost CP options as well as the feasible CP options would then be implemented according the implementation and continuation plan.

10. CONCLUSION

Implementation of cleaner production methodology results in sustainable utilization of resources and minimisation of waste generated from processes while concurrently reducing environmental risks. Cleaner production requires a new way of thinking about processes and products, and about how they can be made less harmful to humans and the environment. It is imperative to note that there exist vast opportunities in breweries for the promotion of Sustainable Development through the implementation of CP concept. The case-in-point brewery can commence CP implementation by training staff on the implementation and benefits of CP. The brewery can then develop a fish pond followed by installation of efficient spray nozzles. The installation of a biogas digester can also be taken into consideration after the implementation of the previously stated viable CP options. CP provides a roadmap to Sustainable Development. The area of Sustainable Development encompasses social issues such as discouraging irresponsible drinking, respect of human rights, and contributing to the reduction of HIV/Aids. A properly formulated CP policy with clear, and concise goals would result substantial benefits if the employees were trained for the implementation of the CP options. Reviews on training needs, CP goals and policy as well as the Sustainable Development strategy are critical for continuous improvement. There is also need to address the challenges faced by the brewery on trying to implement CP, in order for the company to reap the benefits of its implementation.

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COULD INDUSTRIAL ENGINEERING TECHNIQUES IMPROVE RETENTION OF ENGINEERING STUDENTS IN HIGHER EDUCATION?

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ABSTRACT

By increasing the retention of engineering students at training institutions in South Africa it may be possible to increase the number of engineers in the country. Because of the international demand for engineers, emphasis is placed on engineering in the "list of occupations in high demand" in the Government Gazette in Nov 2014. South African Universities are constrained in terms of funds, infrastructure and teaching staff. The university's resources such as fees are optimised when more students are retained in a course. Many factors affect retention and there are many industrial engineering techniques that could be applied. Several industrial engineering techniques have been applied to improve retention. Some of the techniques that have been used are Six Sigma, Lean, Data Mining, Machine Learning, Quality Function Deployment, Statistical Process Control, Total Quality Management and Supply Chain Management. The purpose of this paper is to look at industrial engineering techniques such as systems engineering, operations research, 20 keys to workplace improvement and value engineering to name a few, and how these techniques could theoretically be applied to improve engineering student retention.

1. INTRODUCTION

Engineering in general and industrial engineering specifically is a scarce skill as indicated on the South African scarce skills list **[1]**. It is potentially possible to increase the number of engineers by increasing the retention of engineering students in higher education. Retention of engineering students is not only a South African concern but also an international concern. In South Africa specifically access to tertiary education is a scarce resource. To optimise this scarce resource it is important to retain the students that enter the university and who have the potential to graduate.

The definition of industrial engineering according to the SAIIE website is: "Modern Industrial Engineering is concerned with the integration of resources and processes into cohesive strategies, structures and systems for the effective and efficient production of quality goods and services." **[2]** Industrial engineering is therefore about making things better, cheaper and faster. Therefore it should be possible to apply industrial engineering techniques to improve retention of engineering students

The objective of this study was:

i. To explore the reported use of industrial engineering techniques to improve engineering student retention

ii. To theorise as to how different industrial engineering techniques can be used to improve retention

The methodology used for this article was a traditional literature review. The qualitative literature review was based on selected articles from relevant databases. Industrial engineering techniques were identified and then databases were searched for specific industrial engineering techniques and factors related to retention e.g. operations research and curriculum development. The motivation for doing this study was to determine what research has been done in order not to duplicate existing research but rather to expand on it. Further research will focus on using industrial engineering techniques to improve retention of engineering students.

2. RETENTION OF ENGINEERING STUDENTS

Retention of students is a concern for most tertiary education institutions. There are three main themes identified in the literature related to retention research [3]. They are firstly the internal and external characteristics of students, secondly the conceptual and predictive retention models and thirdly the interventions to improve retention.

Internal characteristics include academic preparation, mathematics and science ability, self-efficacy, self-confidence, locus of control and different learning styles to name some. External characteristics include community, demographics and the university.

There are many different conceptual and predictive models. Conceptual models of which Tinto's model [4], shown in Figure 1, is cited most often, help to better understand the retention problem.

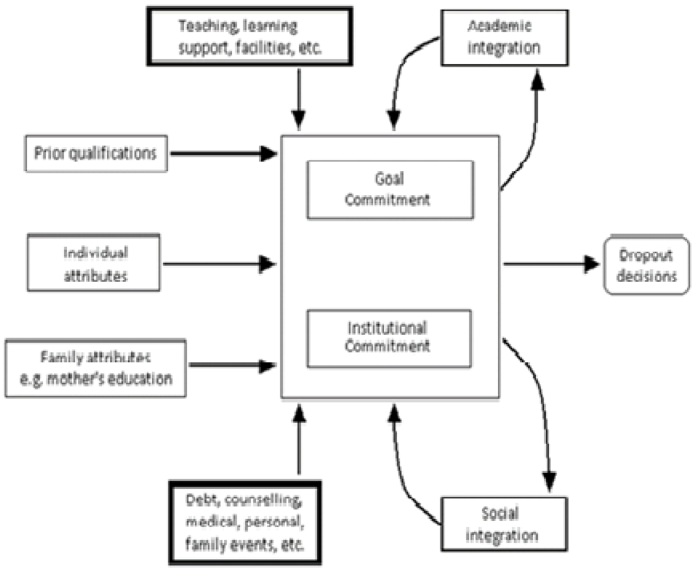

Fig. 1. Conceptual model by Tinto as adapted by Draper [5]

Predictive models use statistical methods to predict which students will be retained and which students are at risk of not being retained within a cohort for different parameter values. Some of the statistically motivated methods used in predictive models are neural networks, logistic regression and discriminant analysis **[6]**.

Interventions that have been suggested to improve retention are:

1) development of the faculty **[7]**;

2) support programs, here students are assisted with development of personal characteristics required for improving retention such as self-confidence and motivation and some programs focus on learning skills. **[8]**;

3) remedial or developmental course work such as improving academic preparation before the start of course work;

4) learning communities put in place to create opportunities for students to interact and learn together **[9]**, and

5) tailored intervention programmes **[10]**.

Retention is defined in many different ways. For the purpose of this article retention is defined as student retained in the faculty in which they initially registered, here specifically the engineering faculty i.e. the student starts and finishes their qualification in the engineering faculty. Measurement of actual total retention is fraught with complexity.

A great deal of research has been done on the retention of engineering students and yet little has been reported that indicates a significant improvement in retention. Further inquiry is therefore justified.

3. INDUSTRIAL ENGINEERING TECHNIQUES USED IN HIGHER EDUCATION

Several industrial engineering techniques have been applied to engineering education and specifically to the issue of retention. Six Sigma has been applied in improving retention of engineering students. Six Sigma is a quality program that is focused on continuously reducing defects and removing variation from a production line or process **[11]**. The aim is to have less than 3.4 defects per million items assessed. Six Sigma is focused on data, measurement and precision **[12]**. Customer focus is critical to the success of any six sigma program **[13]**. Six Sigma is completed in five phases design, measure, analyse, improve and control (DMAIC). Several tools and techniques can be used to achieve improvement such as: Cause and effect analysis, failure modes effect analysis, statistical analysis, project charter, brainstorming, process maps, Pareto analysis , check sheets, histograms, process control charts and the voice of the customer **[14]**

Several articles have been written concerning the improvement of retention by using Six Sigma. Hargrove and Burge **[15]** first step was to identify the attrition factors, based on surveys and applying Quality Function Deployment (QFD), and to determine which factors were responsible for most attrition. They found that three of the ten dominating factors contributed to 45% of student loss. The Six Sigma capability index was calculated to be three. The three factors identified were financial aid, faculty development and improving quality of instruction. They also created a student success model with the dominant attributes of an engineering graduate. This study was conducted over a six year period and therefore the process cycle time was twelve semesters with each semester seen as an opportunity for a defect **[15]**. It is suggested that the use of Six Sigma in academia is not about achieving a virtually defect free environment but rather about using data and statistical analysis to identify the causes of errors and removing those errors **[16]**.

At the West Virginia University, Jaraiedi, Iskander and Agrawal determined characteristics that predicted retention and they deemed defects or failures as students who could not return to engineering **[16]**. DMAIC was applied, in this case improvements could only be suggested and not implemented. They used the Supplier-Inputs-Process-Outputs-Customers (SIPOC) process to identify all the factors that affect retention rates.

In a study by Chow and Downing student focus groups and surveys were used to identify factors that affect retention. With hypotheses testing and linear regression the factors with the greatest impact were identified. In this study more focus was placed on the retention strategies employed **[17]**. Over a five year period they were able to achieve a 2.5% improvement in retention. Six Sigma was proven to be helpful in organising projects and communicating results. Challenges encountered in implementing Six Sigma in academia were defining key customers as well as the relevant process metrics **[17]**.

The lost revenue of students dropping out is significant. Midwestern University estimated that a dropout rate of 20% for a student group of 4000 student exceeded $ 25 million in foregone revenues **[14]**. Determining the root causes of failure is an important step in six sigma. Every root cause needs to be examined to determine whether it is being caused by other more important causes. The goal should always be a significant reduction in defects **[14]**.

Six Sigma has also been used in curriculum development in Malaysia with the aim to produce engineers who are globally minded, can easily adapt to new conditions and are innovative **[18]**.

Another approach has been to combine Six Sigma with Lean. Lean philosophy is about reducing waste and adding value to the customer **[19]**. There are seven wastes that Lean focuses on, they are: over production, over processing, defects, inventory, transportation, waiting and unnecessary motion. The first step is to identify which processes add value. A value stream map is created to determine this. Lean and Six Sigma are suited to be used in conjunction with each other **[20]**. One of the aspects that could benefit from Lean Six Sigma is the curriculum delivery. Universities and training institutions recognise external customers' (those employing the graduates), needs, however, the main customer should always be the students as universities are about preparing students for lucrative employment **[20]**. The universities' relationship with students is in some regards seen as more complex than the relationship with a customer yet the universities want to attract and retain them. Lean Six Sigma could be applied to measure the success of employment placement and the extent of engagement with external customers. Lean Six Sigma could also be used to determine faculty allocation, where faculty should be viewed as a resource to be applied to the benefit of the customers and the career path of the faculty. Lean Six Sigma could also potentially improve the revenue cycle, specifically the timing of receipt of tuition and fees. Reducing expenses is another area Lean Six Sigma could be applied to. There are opportunities to apply Lean Six Sigma in the process of admissions, enrolment as well as marketing **[20]**. All these factors impact student retention from curriculum development to marketing, and therefore improvements of these processes could potentially improve retention.

Data mining has been used to predict student attrition **[21]**. Data mining is the process of finding patterns in large data sets. Data mining has also been used to explore student characteristics associated with retention that leads to graduation in higher education **[22]**. This study found that it was possible to predict retention leading to graduation as early as at the end of the first semester. Decision tree and logistic regression models identified first semester Grade Point Average (GPA), earned credits at the end of the first semester, full or part time status of the students as well as high school GPA as the most important factors.

Machine learning, a process of automated learning from existing data by using models and algorithms. Machine learning was used at Oklahoma State University to predict and understand the institution specific nature of the attrition problem by using five years historical data **[23]**.

An industrial engineering approach has been used to develop an industrial engineering curriculum **[24]**. Here the voice of the customer, Quality Function Deployment (QFD), process mapping and design, process optimisation, lean design, product customisation an operations strategies were used to develop the curriculum. This lead to a competitive curriculum and processes aligned with the specific university strategy. Operations research was used to design the curriculum at the University of Connecticut **[25]**. As the curriculum is central to what students are taught and this directly impacts student retention, it is important to carefully consider what is taught, what is not taught and at what level to teach the content. This study used dynamic programming to optimise their curriculum. Mathematical solution systems are beneficial for rational decision making in complex situations. The mathematical goal is usually to optimise some function. The problem here is to identify the function that will guarantee improved retention when optimised.

Statistical Process Control (SPC) has been used to improve classroom practice **[26]**. This approach was used in a quality improvement course with the goal of continuous improvement of lectures. Students generated the data by evaluating the lecture after the presentation was completed and then students analysed this data using SPC. The standardised lecturer assessment form was used as a starting point, with input from the students the form was consolidated and a new assessment form developed. The new form had a response scale from 1 – 10, where 1 indicated strong disapproval and 10 indicated strong approval. The assessment was divided into three general categories: the professor, the material and the course. This form was then given to students at the end of each lecture starting at the second week of lectures and ending midterm. To ensure students remained anonymous students chose fictitious names and used those the entire semester. The assessment data provided daily feedback to the lecturer and demonstrates SPC concepts to students. Control charts were used to determine whether the process was “in control”. Low points were investigated using other SPC techniques, such as cause and effect diagrams, to determine the root cause. High ratings were also investigated to determine what the lecturer did well. The lecturer could then use the information to monitor effectiveness of lectures and make adjustments as required **[26]**.

Total Quality Management (TQM) has been used to improve quality of education. Sakthivel and Raju developed an instrument to measure the quality level of the education offered **[27]**. They identified seven critical factors of education service quality they are: 1) Commitment of top management and leadership, 2) Customer focus, 3) Course delivery, 4) Communication, 5) Campus facilities, 6) Congenial learning environment, 7) Continuous assessment and improvement. They also identified two performance variables: 1) customer value and 2) customer satisfaction. One of the outcomes of improved quality would potentially be improved retention.

In India, technical educational institutions, used Tagushi’s quality loss function and analytic network process (ANP) to develop a conceptual model for campus placement **[28]**. By selectively matching student’s skills through ANP the total loss in terms of opportunity costs can be minimised.

The state of Kentucky embarked on a state-wide educational reform program. Welsh, Petrosko and Taylor found that the educational reform effort had very little impact on the retention of undergraduate students **[29]**. They suggested high schools and colleges may be able to improve retention by developing a student information system based on the concept of “supply chain management”. Supply chain management is about the management from supplier to customer. Interaction with suppliers is important to optimise final products, organisations need to understand how they impact each other and what is required for success. Universities need to learn more about their suppliers namely high schools. Supply chain management requires the sharing and collaboration of appropriate data. Improving the relationship between high schools and universities provide opportunities to improve student retention. **[29]**.

4. THE APPLICATION OF INDUSTRIAL ENGINEERING TECHNIQUES TO IMPROVE RETENTION THEORETICALLY.

Key aspects to focus on have been identified at the University of Johannesburg in the strategy for teaching and learning **[30]**. The aspects are: a) Recruitment, b) Curriculum c) Assessment practices d) Pedagogy (method of teaching) e) Costs f) Interventions g) Facilities, lecture venues and study areas h) Failure rates i) Leaving the course j) Success rate in industry k) Staff qualifications and l) Learning needs of first generation students.

As seen in the section above many different industrial engineering techniques have been applied to many different aspects of teaching and learning specifically with the aim to improve retention. More industrial engineering techniques could theoretically be applied to improve various aspects of teaching and learning.

Systems engineering focuses on using techniques and modelling to better understand and improve systems as they grow more complex. These concepts: systems, systems thinking and systems approach are used across many different disciplines **[31]**. Systems thinking requires an understanding of the whole system as solving separate parts of the problem may not solve the whole problem **[32]**. A system level model is created, which becomes the conceptual model of the system. As many conceptual models of retention exists it may be possible to apply systems engineering to improve retention by using already existing conceptual models. Business process re-engineering is often seen as a subset of systems engineering **[31]**.

Value engineering is a systematic approach to improve the value of a product or process by improving the value to the customer by analysing the relationship between the function and the cost. Value engineering is particularly useful at the design stage of the process **[33]**. However it can also be applied to other stages of any process. Attention should be given to key value adding activities. This approach could be used in improving retention by isolating the value adding activities and focussing on their improvement. Value adding activities could be interventions to improve retention, teaching and learning aspects and identifying students at risk for attrition early. As retention of students is a multi-faceted problem it is difficult to even understand what the various value adding activities are. The philosophical question is how to identify with certainty the correct activities that would form the basis of the intervention proposed.

Operations research uses advanced analytical methods to make better decisions. Assignment models could be used to assign staff to subjects. Decision theory and decision trees could be used to optimise both the University as well as students' resources.

Twenty Keys to workplace improvement is another holistic approach to improving involvement, productivity and quality of a system **[34]**. There are five levels for each of the 20 keys, the status for each of the keys are determined and then action is taken to move the key from its current level to the next level.

The Theory of Constraints is a methodology of finding the factor that most limits, or constrains, the achievement of the goal. In manufacturing these constraints are called bottlenecks. Then to focus attention on optimising the constraint **[35]**. This could also be applied to the retention problem by identifying the major constraints in the curriculum as well as in the characteristics of students that leads to lowered retention and then working on reducing the impact of the identified constraints.

Lean philosophy could also be applied more comprehensively to the retention problem. By identifying the value and removing all waste from the value stream retention could in theory be improved.

5. CONCLUSION AND RECOMMENDATION

The problem of retention of engineering students is a complex problem with many contributing factors and a university's system of teaching and learning is an equally complex system. It can be seen that different industrial engineering techniques were applied to different components of the problem with some success. It may however be that significant improvement have not been realised as the problem and system as a whole has not been addressed. In all likelihood this failure in the past was due to the complexity and scope of the retention problem.

Industrial engineering techniques most often used in improving retention are Quality Engineering techniques such as TQM and Six Sigma.

The researchers believe that many of the industrial engineering techniques could be beneficial to solving this problem and many of the systematic problem solving approaches could be applied. These different tools should be compared and a selection should be made on what suits the environment which needs to be improved as well as the culture of the organisation **[36]**. To successfully implement any improvement methodology the support of all role-players will be required. This may be difficult to achieve in a large organisation such as a university.

The most relevant techniques are probably Six Sigma, Lean, Systems Engineering, Data Mining and Twenty Keys to workplace improvement. All of these techniques are able to address complex problems holistically.

The main contribution of this paper is to identify industrial engineering technique that have been used and could potentially be used to improve retention of engineering students. It is clear that industrial engineering can improve retention of engineering students. By improving retention, resources are optimised and it may potentially lead to increasing the number of engineering graduates finishing their studies each year in South Africa. South Africa will benefit from this as engineers and specifically industrial engineers have an important role to play in the economic growth and competitiveness of the country.

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LOCALISATION OF SILICA SANDS FOR ADDITIVE MANUFACTURING APPLICATIONS

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ABSTRACT

A South African Strategy for Additive Manufacturing (AM) is available since 2016. This strategy aligned with the National Development plan (NDP) envisions the AM process as an enabler of competitive advantage for the South African manufacturing industry including Metal Casting. One of the four priority focus areas identified in the AM strategy is the development of new materials and technologies. This paper investigates a possible implementation of the AM strategy for the sand casting industry. The study appears to confirm the prospect of silica sand localisation for rapid sand casting applications.

OPSOMMING

'N Suid-Afrikaanse Strategie vir Additiewe Vervaardiging (AM) is sedert 2016 beskikbaar. Hierdie strategie in lyn met die Nasionale Ontwikkelingsplan (NDP) beoog die AM-proses as 'n voorstander van mededingende voordeel vir die Suid-Afrikaanse vervaardigingsbedryf, insluitend Metal Casting. Een van die vier prioriteitsfokusareas wat in die AM-strategie geïdentifiseer is, is die ontwikkeling van nuwe materiale en tegnologie. Hierdie artikel ondersoek die moontlike implementering van die AM-strategie vir die sandgietbedryf. Die studie blyk die vooruitsig van silika sand lokalisering te bevestig vir vinnige sandgiet toepassings.

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1. INTRODUCTION

Additive Manufacturing (AM) is the fabrication of solid parts, layer-by-layer directly from three dimensional files of computer generated models [1]. The main benefits of AM processes have generally been a reduction of lead design time, quick time to market of new products, decrease in manufacturing cost for low volume production and the ability to produce complex shapes [2]. Examples of well-established AM processes include Sterolithography (SLA), Laminated Object Manufacturing (LOM), Three Dimensional Printing (3DP), Fused Deposition Modelling (FDM), Laser Sintering (LS) and Metal Printing Process (MPP) [3]. These technologies have applications in many different scientific disciplines such as medicine, tool and die making, polymer technology and metal casting [4].

Despite the AM technology being available in South Africa for almost two decades, a comprehensive AM strategy was only finalised in 2016 [5]. In this strategy commissioned by the Department of Science and Technology (DST), prioritised focus areas are identified and programmes defined that can guide public and private sector investment in AM research, development and innovation (RDI) in South Africa for the period 2014–2023. The Strategy also expands on the required enabling factors including technological capability and education system to ensure its success. The four main priority focus areas listed in the Strategy document are:

- Qualified AM technology for final part manufacturing for the medical and aerospace markets;
- AM technology for impact in the traditional manufacturing sectors;
- New AM material and technology development; and
- SMME development and support programmes.

The SA AM strategy supports the implementation of the National Development Plan (NDP). The latter is the strategic plan of South Africa launched in 2012 whose main goal is to eliminate poverty and reduce inequality in the country by 2030 [6]. One of the NDP's key objectives is improving education, training and innovation. Innovation or technological change in particular is seen in the NDP as necessary for the development of a middle income country and a catalyst for economic growth and job creation. As such, AM as a disruptive and innovative technology has the potential to significantly contribute to the rejuvenation of the small, medium and macro-enterprise in South Africa.

The South African foundry industry is one manufacturing sector that could really benefit from AM as pointed out in the SA AM strategy. The industry produces castings that are used in several engineering components. Applications of AM to Metal Casting include tool and die making and direct fabrication of sand moulds and cores [7]. The latter application, generally referred to as Rapid Sand Casting [8] technology is available in South Africa in the forms of 3DP and LS. 3DP using Voxeljet technology can be found at the Advanced Manufacturing Precinct (AMP) of the Vaal University of Technology Southern Gauteng Science and Technology Park [9]. LS in the form of EOSINT S system is obtainable at the Centre for Rapid Product Development (CRPM) of the Central University of Technology, Free State [10]. These rapid casting technologies are well established in the realm of additive manufacturing processes [3].

Rapid sand casting equipment available in South Africa are still making use of imported raw materials such as refractory sand, resin and catalyst chemicals. This is despite the country possessing large natural resource of some of this raw material namely silica sand suitable for foundry applications [11]. This unfortunate situation makes AM technology expensive to operate locally. In addition, this state of affair possibly prevents the full adoption of the AM technology by South African sand casting foundries.

In line with the third priority focus of the SA AM strategy, there is need for localisation of raw materials use for AM in order to render it affordable to users. Initiatives already exist in South Africa in support of local silica sand use for the production of three dimensional printed mould and cores at AMP. These attempts followed a research project that was undertaken to prove the suitability of a silica sand from Cape Town for 3DP applications [12]. This refractory sand was found to have better shape of grain morphology and mechanical properties of parts than the imported sand.

This paper expands on the research mentioned above by considering three additional local silica sands for possible 3DP applications. These sands were compared in laboratory conditions to the imported sand currently used on the Voxeljet VX 1000 available at AMP in terms of size distribution, grain shape and mechanical properties including tensile, bend strengths and friability. These sand properties have a profound influence on the quality of sand mould and cores [13]. The experimental work and test results of the investigation are presented in the sections below.

Table 1 AFS and Total clay content of silica sand

Sand Parameter	Imported Sand	Cleaveland	Delf Coastal	Sandy Sand
AFS Grain Fineness	65	53	49	50
Total Clay Content [%]	0.6	0.9	0.4	0.5

2. EXPERIMENTAL PROCEDURES

Four types of silica sand were assessed in this investigation. The first one, referred to as imported sand, was sourced from overseas and recommended by Voxeljet, which manufactures the VX 1000 3DP system [14]. This sand is supplied as pre-coated with sulfonic acid activator. The other three types of sands were South African sourced namely Cleveland, Delf Coastal and Sandy. The local sands were selected due to their good reputation within the traditional sand casting industry [11].

Two types of sand testing were performed on the sands in the foundry laboratory at the University of Johannesburg (UJ), namely: characterization of raw materials and determination of resin bonded sand mechanical properties. Characterisation sand testing included the sieve analysis test to determine the sand size distribution and scanning electron microscopy to assess the sand grain shape. Resin bonded sand testing, on the other hand, consisted of bend and tensile strength tests and friability. The latter sand test, in particular, is aimed at determining the resistance of the resin bonded sand to mould erosion by the liquid metal during the casting process. Test procedures recommended in the American Foundry Society (AFS) handbook were followed during sand testing [15].

Moulding sand used for the determination of foundry properties was prepared in a 5 kg laboratory mixer. The sand was mixed for five minutes with addition of 1% by weight of sand of furfuryl alcohol-based resin and 50% by weight of resin of sulfonic acid activator. The moulding sand was hand-rammed in an appropriate wooden sand pattern to produce the final sand testing specimens. Sand specimens were allowed to self-set for 24 hours prior to testing.

3. RESULTS AND DISCUSSION

3.1. Sand characterisation

Table 1 shows the fineness number and percentage clay of the sands. Local sands with AFS fineness numbers ranging between 49 and 53 are coarser than the imported sand with an AFS number of 65. Coarser sands offering a better compromise between high permeability and acceptable surface finish of castings are preferred for traditional sand moulding applications. A finer sand recommended for the Voxeljet VX 1000 printer only intends to emphasize the production of castings with smooth surface at the possible detriment of gas defect prevention in components [16]

Figure 1 shows the actual grain size distribution of the sands. It can easily be noticed that local sands have a wider grain size distribution compared to the relatively narrow grain size distribution of the imported sand. The grain size distribution of local sands spreads between 850 to 53 µm while the one for the imported sand only ranges between 300 and 75 µm.

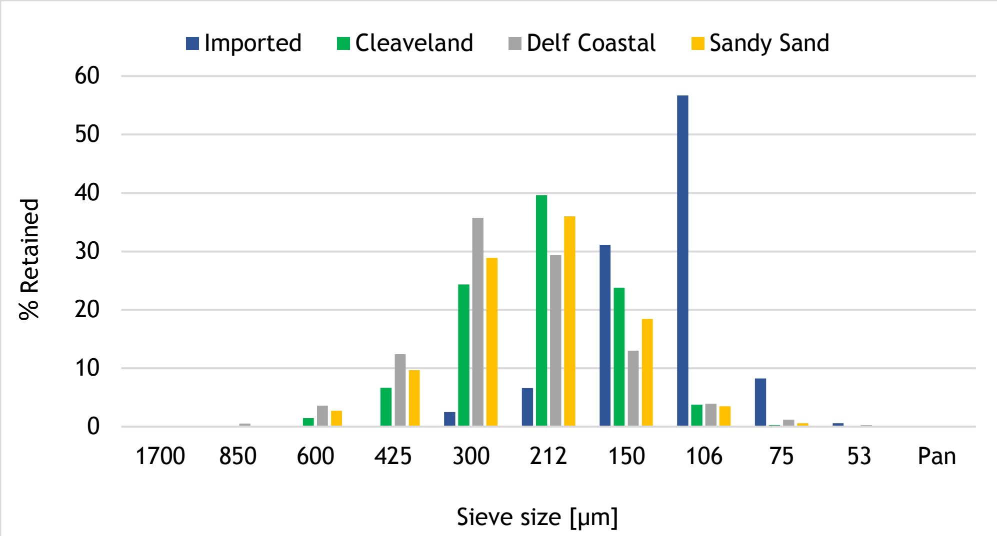

Figure 1. Size distribution of silica sands

In general, narrow size distribution is preferred to prevent sand grain segregation. The latter phenomenon could cause mobility of coarser sand grains during the three dimensional printing. This will result in AM recoating fault and visible ditches on printed parts. In addition, sand segregation could be responsible for rough surface finish of sand parts, which could be transferred to the final casting. On the other hand, sand with wide spread size distribution such as the local ones have better resistance to sand casting expansion defects including scabs and hot tears [13].

Figure 2 shows the shape of the sand grains as obtained by scanning electron microscopy (SEM). The grain shape of sands could be characterised as angular with medium sphericity.

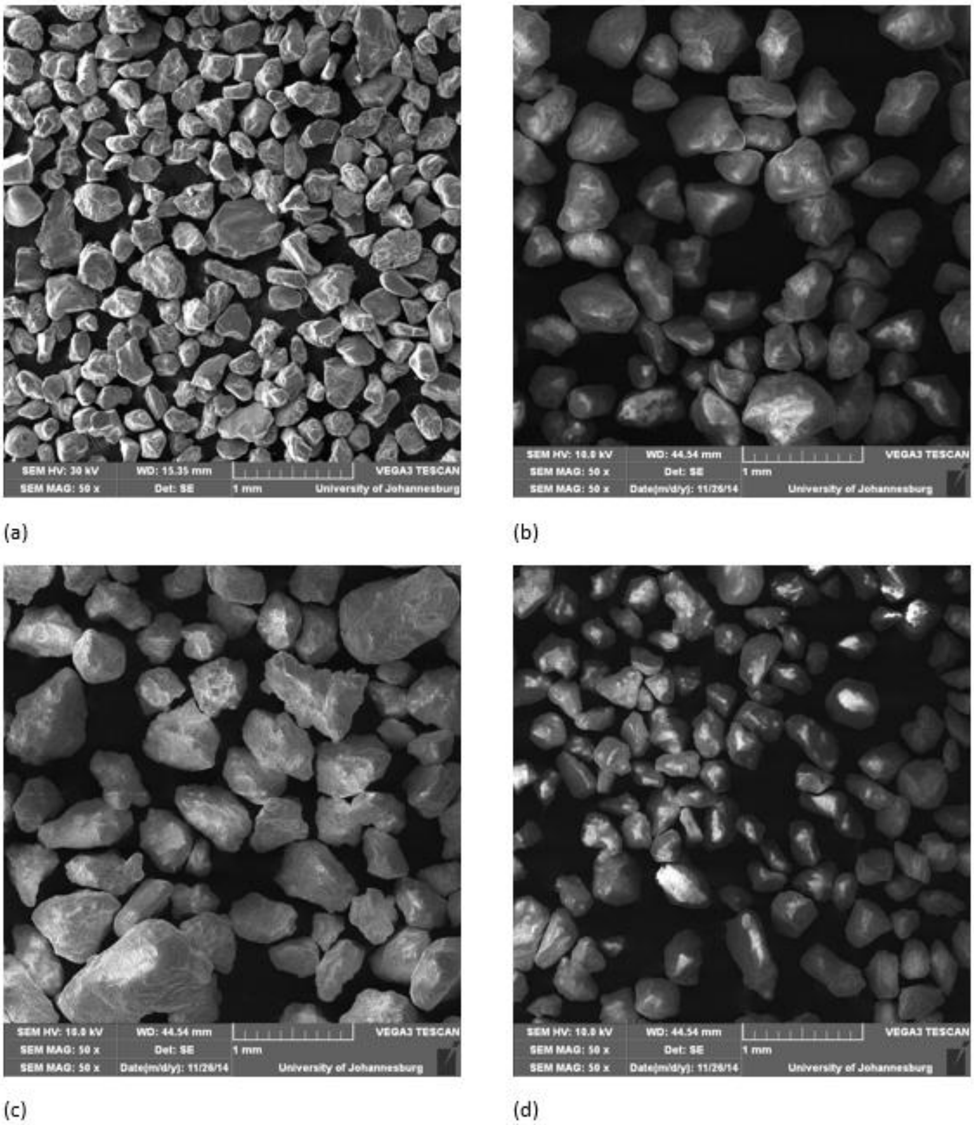

Figure 2 Grain shape of silica sands – (a) Imported sand; (b) Sandy sand; (c) Delf coastal sand; (d) Cleveland sand

There is no material difference in terms of grain morphology between the four sands. In general, the best foundry sands have grains, which are rounded with medium sphericity giving good flowability and permeability with high strength at low binder addition [12]. In addition, round sand grain packed better during the AM process to provide denser parts with higher strength [13]. The grain shape analysis of sands does not indicate any advantage of the imported sand compared to local sands.

3.2. Resin bonded sand properties

The mechanical properties of the various sands in terms of tensile and bending strengths are shown in Figure 3.

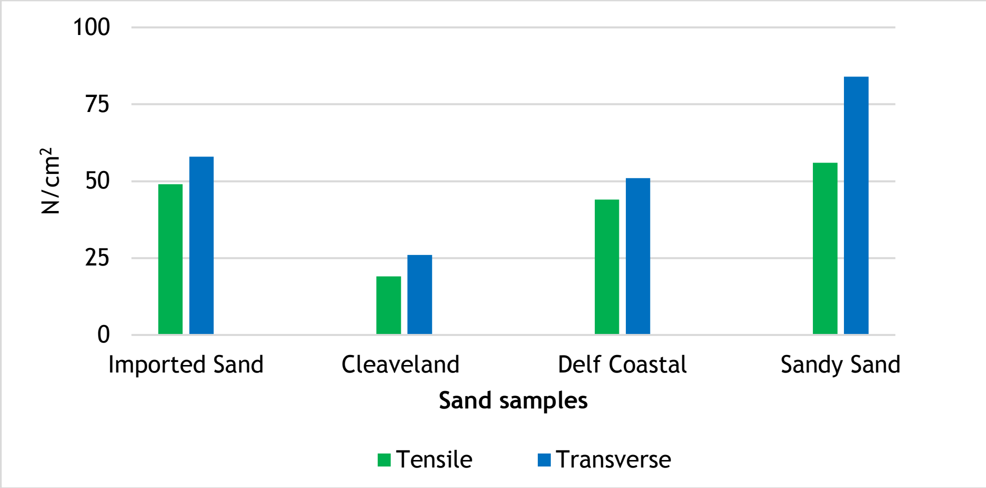

Figure 3 Tensile and bending strength of the different sands.

It can be observed that the imported sand does not produce the strongest sand specimens in the un-cured state. Sand specimens with the highest mechanical properties are obtained with Sandy sand. Delf coastal sand has comparable test results with the imported sand. Many factors inherent to the refractory sand influence the final mechanical properties of the sand specimen including the grain size, grain shape, acid demand value of the sand and the clay content.

Figure 4 shows the test results of friability for the different sands. The lower the friability test value, the higher the resistance to mould erosion of the sand.

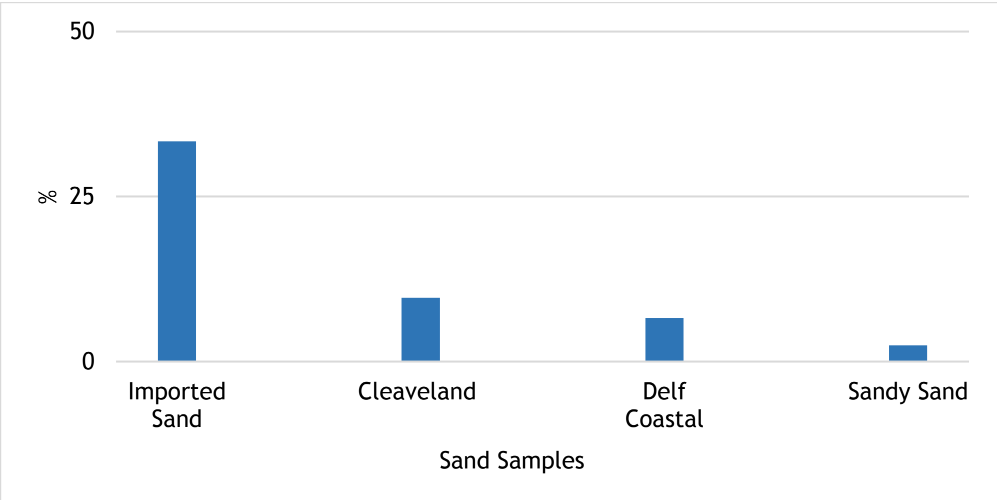

Figure 4. Friability test results of the different sands

The resistance to mould erosion is by far better with the local sands compared to the imported sand. Sandy sand appears to be the best of all the sands assessed. The local sands exhibit lower friability test results than the imported sand. This marked difference between the imported sand and the local sands, in terms of friability, is complex to explain but constitutes an important advantage of local sands.

4. CONCLUSION

The aim of this investigation was to compare three local sands to an imported sand in terms of properties relevant to rapid sand casting applications with the view of possible raw material localization in line with one of the priority focus of the SA AM strategy. The laboratory test results appear to indicate that some local sands have fairly matching properties to the imported recommended sand by a 3DP equipment manufacturer in terms of size distribution and grain shape. In addition, the performance of sand specimens prepared with local sand with regards to casting properties is higher than the specimens obtained from the imported sand. In terms of the local sands considered in this study, the test results of this investigation represent a first significant step towards their possible use for 3DP applications thus reducing the cost of operating the technology and enabling possible buy-in for it by local foundrymen. However AM trials need to subsequently be conducted in order to confirm the use of local sands for AM applications. Behavior and performance of local sands during Three-Dimensional Printing could be the object of future studies.

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TOWARDS A SYSTEMS-BASED CAPABILITY MATURITY MODEL TO SUPPORT SUSTAINABLE BUSINESS DEVELOPMENT

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ABSTRACT

Sustainability is recognised as one of the primary challenges of modern times in an organisation. Subsequently, the pressure on businesses to incorporate all aspects of sustainability to perform in terms of social equity, economic efficiency and environmental performance, has increased over the last decades. A number of researchers have developed frameworks and approaches to incorporate these three elements of sustainability into business processes. However, we argue for the case of a system-based Industrial Engineering approach to incorporate sustainable development into organisational goals and objectives.

This paper thus evaluates existing measures of sustainability, sustainable business frameworks and definitions within business environments, as well as existing models that are aimed to improve business sustainability through shared value. The aim is to highlight the value of a systems-based business sustainability maturity model approach, and the required capabilities to support sustainable business development. The outcome of this research inquiry will facilitate the process to develop a capability maturity model aimed at evaluating the sustainability performance of businesses.

OPSOMMING

Volhoubaarheid word erken as een van die primêre uitdagings van die moderne tyd. Vervolgens, ervaar besighede spanning die afgelope dekade om alle aspekte van volhoubaarheid in terme van maatskaplike billikheid, ekonomiese doeltreffendheid en omgewingsprestasie, te inkorporeer in besigheids-aktiwiteite. Verskeie raamwerke is al reeds ontwikkel om hierdie drie elemente van volhoubaarheid in sakeprosesse op te neem. Dus volg die argument vir 'n stelselgebaseerde Bedryfsingenieurswese-benadering om volhoubare ontwikkeling in organisatoriese doelwitte en doelstellings in te sluit.

Hierdie artikel evalueer bestaande maatstawwe van volhoubaarheid, volhoubare besigheidsraamwerke en definisies binne die sake-omgewing, sowel as bestaande modelle wat gefokus is op verbeterde volhoubare besigheid deur gedeelde waarde. Die doel is om die waarde van ń stelselgebaseerde besigheids volhoubare model benadering te beklemtoon, asook die nodige vereistes om die volhoubare besigheidsontwikkeling te ondersteun. Die uitkoms van hierdie navorsingsvraag sal die proses ondersteun om die 'capability maturity model' te ontwikkel met die einddoel om volhoubare prestasie van besighede te evalueer.

1. INTRODUCTION AND BACKGROUND

Sustainability was popularised in the early 1980's when *"A global agenda for change"* was formulated by the General Assembly of the United Nations. In 1987, a world-known report was established, titled "Our Common Future" by the World Commission on Environment and Development. This report is also known as the Brundtland Report which is named after the chairman of the World Commission on Environment, Gro Harlem Brundtland. Sustainability and sustainable development are two terms that are used interchangeably and is defined by the World Commission on Environment and Development (1987) [1] as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*. To date, this definition is the most commonly used definition globally [2].

Another concept of sustainable development, that the Brundtland Report highlighted, was that in essence, to become sustainable implies to not only focus on environmental aspects but also on social and economic aspects, and that these three aspects do not limit one another, but are integrated and has interrelations with one another [3]. Building on this three-way perspective of sustainability, another synonym of sustainable development, namely "*Triple Bottom Line*" (TBL), was introduced by John Elkington in 1994, and he argued that businesses should develop three different bottom lines [4]. Figure 1 demonstrates the overlap of these three bottom lines and indicates where sustainable development originates. Another important point represented by the Venn diagram is the fact that trade-offs take place between the dimensions in order to improve one or the other. Lozano [5] emphasizes that the figure shown in Figure 1 does not show change over time, which is considered a critical aspect of sustainability.

Figure 1: A Venn diagram representing triple bottom line [4].

Over the years, an extensive need for business sustainability developed, and businesses promoted the idea of sustainable business strategies. Businesses are experiencing increasing pressure to incorporate environmental and social development goals and performance measures into their strategies and business operations, and thus the dynamics that surround the term "business sustainability" should be fully understood [4].

The next section provides an overview of the approach taken in this research inquiry; a systematic review of available literature in order to address the research objective (see section 2.1), which argues for the case of a system-based Industrial Engineering approach to incorporate sustainable development to organisational goals and objectives. The article concludes with a discussion on how to measure sustainability with the aim to highlight the value of a systems-based business sustainability maturity model[1], and the required capabilities to support sustainable business development.

[1] The definition per se of a sustainable maturity model in this inquiry will be demonstrated by the maturity of an organisation's business environment that affects the ability to successfully implement process improvement by either implementation of incremental change or by totally radical novel idea.

2. SYSTEMATIC REVIEW METHODOLOGY

A systematic review is defined as *"a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyse data from the studies that are included in the review"* [5]. A systematic review thus aims to establish existing research that has progressed towards a clarifying problem. Systematic reviews are characterised by being unbiased, methodical, transparent and replicable. It therefore involves a methodical search process to locate studies which address a particular question, as well as the findings of the results of this search. Titles, abstracts, keywords, geographical locations, and year published, are used to distinguish a large group of research to a smaller group that are used in this study. Figure 2 indicates the five steps that are executed during a systematic review, followed by an in-depth discussion to ensure the results are unbiased and transparent [6].

Figure 2: Systematic review procedure [6].

2.1 Research objective(s)

This paper analyses literature concerning sustainability assessment frameworks in a universal context with the aim of addressing the following research objective:

Review existing sustainable assessment frameworks that promote sustainable actions in order to incorporate sustainable development into organisational goals and objectives.

2.2 Search for relevant studies

The search for relevant studies was initially conducted using the known online search tools, Scopus and google scholar. The initial search included single word phrases. For sustainability, the keywords "triple bottom line", "sustainability" and "sustainable development" were used. Keywords such as "indicators", "business models", "business development" and "maturity models" were used for the capability maturity model approach. Due to a large amount of data gathered, a criterion was established to narrow down the documents. The first step in the criteria was to combine the above mentioned single word phrases with one another to narrow down the search with the focus to be on sustainable measurement frameworks. The primary focus of the documents should entail the overall theme of sustainability, methods or indication on how sustainability can be measured. The combined search terms gave a total of 543 documents that was used for further analysation. Table 1 illustrates a summary of the combined search terms.

The titles and keywords listed were evaluated to ensure this criterion correlates to the overall theme. The next filtering process included publications after the year 2000 and thus narrowed down the research data to 200 documents. These 200 documents were further analysed by changing the mode of publication and ensuring the titles and keywords are aligned with the overall theme. The titles and keywords should be aligned with the following phrases: "sustainability frameworks", "sustainability measurements", "sustainable development assessment" etc. This analysation process resulted a total of 70 documents. Thereafter the 70 documents were analysed by reviewing the abstracts and identifying sustainability measurement approaches and proposed results. A total of 35 documents were selected after the abstract reviewing process. Additionally, to the 35 documents 7 documents were handpicked which supported the sustainability theme. **Error! Reference source not found.** illustrates the narrowing down of the documents throughout the criteria process.

Table 1: Results of the combined search terms.

Combined Search terms	Results
TITLE-ABS-KEY (“triple bottom line”) AND TITLE-ABS-KEY (indicators))	165
TITLE-ABS-KEY (“triple bottom line”) AND TITLE-ABS-KEY (“business model”))	40
TITLE-ABS-KEY (“sustain*”) AND TITLE-ABS-KEY ("business model”) AND TITLE-ABS-KEY (“framework”)	149
TITLE-ABS-KEY (“sustain*”) AND TITLE-ABS-KEY (“maturity model”)	189
	543

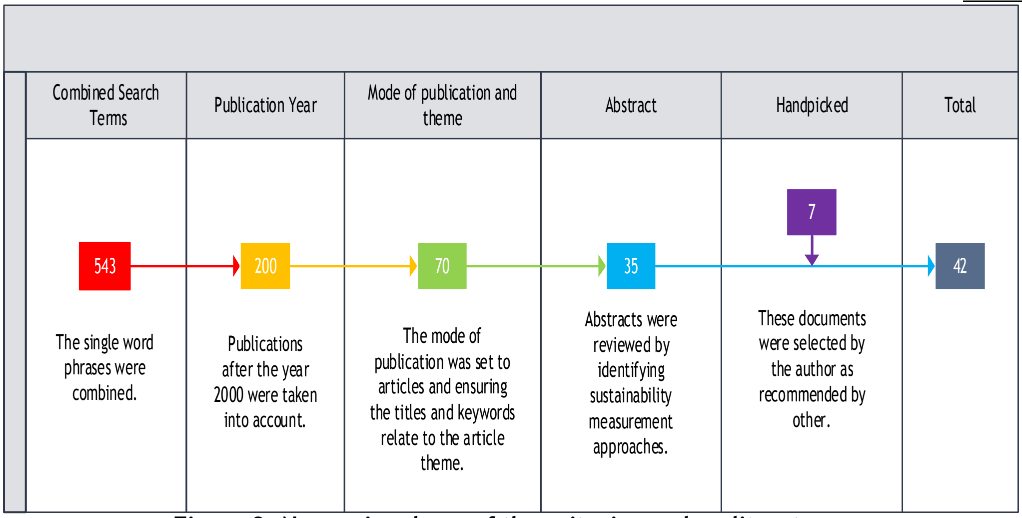

Figure 3: Narrowing down of the criteria used on literature.

2.3 Mode of publication

The document search outlined above was extensive, and ultimately resulted in a total of 42 documents being selected to use for the remainder of this research inquiry. Of these 42 documents, the majority are journal articles, and a small fraction are reports. These papers and articles address the overall literature concerning sustainability within the context of the formulated research objectives. Table 2 illustrates the search structure conducted during the systematic review. The 42 documents are compiled of 31 journal articles, four reports and seven web pages.

Table 2: Mode of publication classification.

Type of data	Results
Journal articles	31
Reports	4
Web pages	7

2.4 Synthesising the data

The documents were analysed and synthesised according to the overall theme it addresses around sustainability. In order to have a comparison between the different sustainability measurement frameworks, a criterion was identified. Firstly, throughout the review of the frameworks, dimensions were identified. These dimensions are discussed in detail in the following section. After the dimensions were identified, the key performance indexes were set out at each framework according to the sustainability factors. Table 4 and **Error! Reference source not found.** illustrates a summary of these dimensions. Section 4 describes the assessment that was used to find the best or most suitable sustainability measurement framework for future use.

2.5 Findings

The eight measurement frameworks of sustainability, obtained from the systematic review will be discussed in section 3. These 8 frameworks are identified by the research conducted by Williams & Hickey [7] about sustainability measurement frameworks Williams & Hickey [7] is one of the 42 articles obtained throughout the systematic review, and are deemed the most prominent sustainability measurement frameworks; this research inquiry, however, builds on the work produced by Williams & Hickey [7] by means evaluating the remaining 41 articles that resulted from the systematic literature analysis outlined above.

3. MEASUREMENTS OF SUSTAINABILITY

The evaluation of sustainable development within business environments, enables businesses to identify areas which already achieved sustainable goals and objectives, as well as areas that requires improvement initiatives in terms of any of the three pillars of sustainability. Sustainability indicators are a simple instrument that allows businesses to evaluate economic, social and environmental objectives as well as the social and environmental impact of their business. An indicator that includes the necessary features of a system or show how maintenance or improvements can be done on a system is classified as a good indicator [7].

By now it should be clear that sustainability measurements are required to support the implementation process of sustainability goals in any organisation [8]. In order to understand the measurement of business sustainability, the aim of such measurements should be clearly defined. The aim of a business sustainability assessment or measurement include the following [9]:

- It generates information for better understanding of the meaning of sustainability and its contextual interpretation;
- The integration of sustainability challenges into decision-making efforts by identifying and assessing the past or current sustainability impacts; and,
- It promotes sustainability objectives throughout the organisation.

The above-mentioned aims should be considered in all sustainability enrolment decisions in any business. Several sustainability assessment frameworks exist, which include the above mentioned aims to varying extents, and can be used as guidance for the measurement of sustainability. A framework is defined in simple terms, as a structure that is composed of components which are framed together to support a subject [10]. Thus, a sustainability assessment framework, which supports sustainable development consists of elements such as indicators, models, and policies or other frameworks [10].

Waas et al. [9] identified two methodological approaches that exist in sustainability measurements. The first approach is a top-down approach and also referred to as 'reductionist' and developed by experts which uses explicit methodologies. The second approach is a bottom-up approach and also known as 'conversational' and developed by stakeholders which uses implicit methodologies. A top-down approach is distinguished by quantitative indicators and a bottom-up approach by qualitative indicators [10] [12].

Parallel with the above outline, the following dimensions which allow for a systematic comparison of various systems approaches to sustainability assessment frameworks has been gathered:

- System boundaries: The system boundaries are based on the sustainability domains the assessment framework focusses on. The sustainability domains include the economic, social and environmental dimensions. A fourth domain that contributes additionally to the system boundaries are institutional programmes that are controlled by governmental bodies [12];
- Actors and networks: Actors are the different groups that are connected to each other in a network. Actors can be humans or non-human objects. A network is the outcome of when two or more actors are connected [13]; and,
- Discipline: The discipline of the assessment framework refers to the specific academic discipline the framework is applicable to. The framework can range from a generalised framework or to a more specific discipline framework that focuses on certain commitment initiatives [14].

Table 3 illustrates the occurrence of the eight identified sustainability measurement frameworks in the 42 articles obtained from the systematic review.

Table 3: Framework findings.

Sustainability measurement Framework	References	Fin-dings
Global Reporting Initiative G4 Sustainability Reporting Guidelines	Carter et.al. [2]; Williams et. al. [7]; Fonsenca et. al [10]; Bonini et. al.[15]; Azapagic et.al [16][17]; Elkington [18]; Singh et.al [19]; United Nations Global Compact [20]; Illankoon et. al. [21]; Labuschagne et. al [22]; Lozano [243; Joyce et. al. [24]; United Nations Global Compact [25] UNDESA [26]	15
CDP Environmental Disclosure System	Williams et. al. [7]; CDP Worldwide [28]	2

United Nations Commission on Sustainable Development	Williams et. al. [7]; Division for sustainable development [12]; Singh et. al. [19]; Illankoon et. al. [21]; Labuschagne et. al. [22]; Shrivastava et.al. [29]	6
International Union for Conservation of Nature	Williams et. al. [7]; Division for Sustainable Development [12]; Mebratu [30]; Lele [31]; Umthania [32]; IUCN [33]	6
Environmental sustainability index	Williams et. al. [7]; Waas et. al. [9]; World Economic Forum [34]	3
Global Scenario Group	Williams et. al. [7]; Global Scenario Group [35]	2
Sustainability Accounting Standards Board	Williams et. al. [7]; SASB [36]	2
United Nations Global Compact Communication on Progress	Williams et. al. [7]; Bonini et. al. [15]; United Nations Global Compact 2012 [20], United Nations Global Compact 2017 [25] United Nations Global Compact 2015 [27]; UNDESA [26]	6

Williams & Hickey discussed other frameworks as well, but due to the unavailability of data or the scope of the frameworks made it impossible to include it.

3.1 Global Reporting Initiative G4 Sustainability Reporting Guidelines

The United Nations Environment Programme (UNEP) formed a partnership with the Coalition for Environmentally Responsible Economics (CERES) and established the Global Reporting Initiative (GRI) in 1997. The aim of the GRI is to enhance the quality, rigour and utility of sustainability reporting [19]. Sustainability reporting as mentioned by the GRI standards is an organisation's application of reporting on the organisation's economic, environmental and social impacts and contributions towards the end goal of sustainable development [37].

The fourth generation of the guidelines was launched in May 2013. The aim of G4 is to support reporters to prepare sustainability reports that are valued and to make sustainability reporting a standard practice. G4 provide guidance through a designed compatible range of different reporting formats. It supports businesses on the strategic journey and encouraging businesses to only provide information on the issues and challenges that are critical to sustainable development, in order to achieve the organisation's goals for sustainable development [37].

The G4 guideline is user-friendly and enables businesses to better inform markets and the society on sustainability matters. This guideline is designed to be universally applicable to all enterprises; small, medium and large, globally. The G4 guideline provides extensive guidance on how sustainability disclosures in different report formats should be presented. Figure 3 presents an overview structure of the G4 reporting guidelines. The second row presents the system boundary dimension (economic, environmental and social), the third row presents the subsequent categories in each subsequent system boundary and the last row presents the number of important aspects (list of subjects covered by the guidelines) that needs to be considered in the allocated categories.

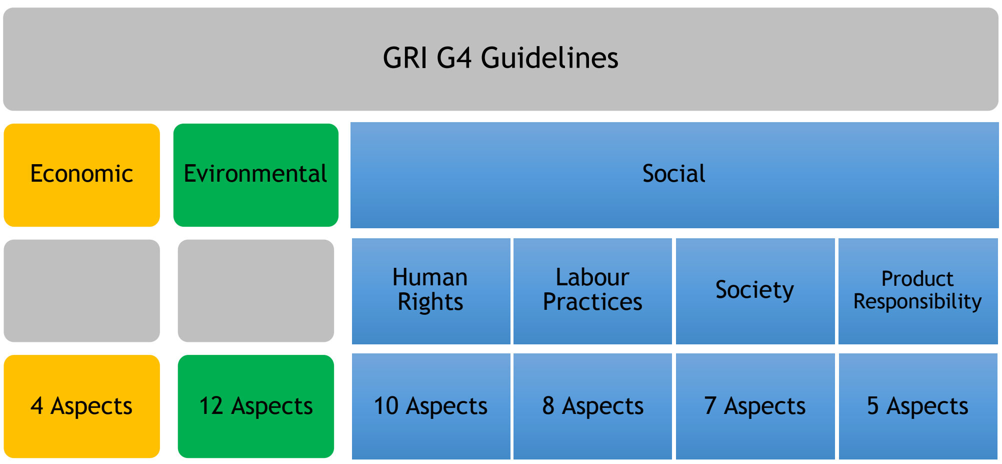

Figure 3: Overview of GRI G4 reporting guidelines [38].

The guidelines are presented in two parts, the reporting principles and standard disclosures and the implementation manual. The first part encompasses the reporting principles, standard disclosures, definitions of key terms, and the criteria which should be followed by an organisation when preparing its sustainability report. The second part, encompasses explanations of how the reporting principles should be applied, how to prepare the information to be disclosed, and how to interpret the various concepts in the guidelines [38].

GRI consists of a global network, which includes reporters, experts and advisers in sustainability reporting around the world. This global network has a multi-stakeholder approach which serve as the actors. The governance body are formed from a diverse range of experts in the sustainability reporting field. Reporters that use GRI guidelines have access to the following global strategic partnerships of GRI; Organisation for Economic Co-operation and Development, the United Nations Environment Programme and the United Nations Global Compact [38].

GRI guidelines are developed in order to be applicable to any discipline. Additionally, to this generalised guideline, GRI has developed guidance on sector-specific issues, aiming to increase the number and quality of reports and to improve sustainability performance in the sectors covered. The following sectors have additional guidelines: airport operators, food processing, construction and real estate, electric utilities, financial services, media, mining and minerals, non-governmental businesses and oil and gas sector [38].

3.2 CDP Environmental Disclosure System

The Carbon Disclosure Project (CDP), is an organisation based in the United Kingdom which enables companies, cities, states and regions to measure and manage their environmental impacts. It contains a comprehensive collection of self-reported environmental data in the world [28]. CDP asks companies, cities, states and regions for data of their environmental performances. These data are transformed into a detailed analysis about critical environmental risks, opportunities and impacts. There-after the investors, businesses and policy makers use the data and insights to improve decisions, manage risk and capitalise on opportunities. CDP focusses on climate change, forests and water programmes, which support businesses to capture the accredited data and to submit it to the investors [28].

The Climate Disclosure Standards Board (CDSB) and CDP work together to provide a complete, reliable and verified system for climate disclosure. The CDSB has developed two frameworks for the process of reporting environmental information or natural capital and climate change-related information in corporate reports. These frameworks support investors with essential decisions about environmental information while considering capital allocation.

CDP creates a network between companies, cities, states and regions, investors, purchasers, non-governmental businesses, intergovernmental businesses and governments to exchange environmental information for any further actions. Similarly, to GRI, CDP developed a generalised guideline to support the environmental system boundary. Additionally, a supply chain programme is developed. The programme supports the in taking of a new approach to climate change, water and forest-risk management, by collaborating and encouraging transparency in the value chain, businesses can demonstrate engagement, tackle the risks, take advantage of opportunities, and ensure business continuity [28].

3.3 United Nations Commission on Sustainable Development

The United Nations Commission on Sustainable Development (CSD) was established by the UN General Assembly in 1992 to be ensured of effective follow-up of the Earth Summit. During the Earth Summit, indicators has been recognised as an important role when supporting countries to make informed decisions concerning sustainable development (social, economic and environmental) [12]. Agenda 21 specifically focus on efforts to develop sustainable development indicators at national, regional, and global levels, including the incorporation of these indicators that are in common, ensuring it is regularly updated and widely accessible.

The main objective of the CSD programme is to ensure the indicators of sustainable development are accessible to decision-makers and to clarify their methodologies and to provide training and capacity building activities within the context of business sustainability. The CSD programme consists of the following key elements [12]:

i. Information should be exchange among all interested actors on research, methodological and practical activities that are associated with the indicators; and,
ii. Methodology sheets must be developed, which describes the indicators individually and their relevance to policies that are available from governmental bodies.

Countries at national level, as well as international governmental and non-governmental businesses forms part of the network and serve as actors when methodology sheets[2] are drafted. These businesses serve as agencies to guide the overall process of the methodology sheets. Individuals whom have experience in establishing/ evaluating sustainability serve as advisories when indicator information is required. Together with these actors and networks, the CSD has developed multi-stakeholder partnerships that focus on certain initiatives.

The CSD programme is based on general sustainability programme and the following partnerships: Higher Education Sustainability Initiative, Partnerships for Small Island Developing States, Every Woman Every Child and Global Water Partnership. These programmes will increasingly be tied to their ability to manage and share knowledge and expertise about the issues, processes, and solutions that they are promoting business sustainability in all countries and all sectors [26].

3.4 International Union for Conservation of Nature

The International Union for Conservation of Nature (IUCN) was established in 1948 between the partnership of the government and civil society businesses. The purpose of the IUCN is to provide public, private and non-governmental businesses the knowledge and tools that enhances human progress, economic development and nature conservation [39]. The IUCN has developed in the world's largest and diverse environmental network with approximately 1300 member businesses and 1600 inputs from experts. IUCN's mission is to encourage and assist societies globally to safeguard the diversity of nature and to ensure the use of natural resources is sustainable.

IUCN's experts are divided into the following six assignments: species survival, environmental law, protected areas, social and economy policy, ecosystem management, and education and communication. By facilitating these assignments, IUCN supports governments and institutions at all levels to ensure universal goals are achieved. IUCN consists of a credited group of best practices, conservation tools, and international guidelines and standards to support the sustainable assessment framework [39].

The expertise network of IUCN provides a stable foundation for a large and variety portfolio of conservation projects, globally. The aim of these projects is to reverse habitat loss, restore ecosystems, and improve human wealth. To ensure this aim is accomplished, the latest science, with knowledge of local communities should be gathered and incorporated in the projects on a continuous basis. The actors (governments, non-governmental businesses, scientists, businesses, local communities, indigenous people's businesses) contribute to these networks of projects and the contribution of knowledge and policies [40].

The IUCN provides a framework for planning, implementing, monitoring and evaluating the sustainable development initiative. The programme has three primary matters [40]:

i. The valuing and conserving work on biodiversity and emphasising tangible and intangible values of nature;
ii. Supporting and promoting effective and fair governance of natural resources combining IUCN's projects about people-nature relations, rights and responsibilities, and political and economic matters; and,
iii. Developing nature-orientated solutions to societal challenges which expands projects about nature contribution by addressing problems of sustainable development.

The IUCN has 15 themes or discipline areas where in-depth analysis in terms of social, environmental and environmental issues are executed. These themes include business and biodiversity, climate change, economics, ecosystem management, environmental law, forests, gender, global policy, social policy, species, water, and world heritage [39].

3.5 Environmental sustainability index

Environmental sustainability index (ESI), an initiative developed by the World Economic Forum, and is composite index published during the period between 1999 to 2005. ESI measured progress toward environmental sustainability for 142 countries. The measurements consist of 20 indicators, each with eight variables for a total of 68 data sets. The following five core components are the successes measured in the different countries: environmental systems, reducing stresses, reducing human vulnerability, social and institutional capacity, and global stewardship. [34].

ESI executes a cross-functional comparison of environmental sustainability in a systematic and quantitative manner. It therefore promotes a more analytically diligent and data driven manner to environmental decision-

[2] Methodology sheets contain the basic information of the indicators, the purpose and usefulness of the indicators and definitions and measurement methods [12].

making. ESI therefore enables, identification of issues where national performances are below or above expectations, priority-setting among policy areas within countries and regions, the tracking of environmental trends, quantitative assessment of the success of policies and programmes, and the investigation into interactions between environmental and economic performance, and the factors that influence environmental sustainability [34].

The World Economic Forum thus forms partnership with governments, the private sector, communities and individual citizens to gather the information and data required to execute the ESI measurements. A broad overview is given by the measurements that focus on a general discipline.

3.6 Global Scenario Group

In 1995, the Global Scenario Group (GSG) was convened by the Stockholm Environment Institute. The GSG is an independent, international body which engages in the process of scenario development. The central theme around this scenario development was the identification of policies, actions and human decisions required to ensure a more sustainable and equitable future. The GSG provides a unique framework to researchers, decision-makers and the general public. A scenario method is used to clarify and understand concepts to a greater degree, in which direction the progress is headed and the flow of events towards a more desirable future. These scenarios are pursued at global, regional and national level. This in-depth analysis ensures that all sets of issues and opportunities are analysed in terms of social, economic and environmental system boundaries [35].

GSG scenarios has four discipline areas: market forces, policy reform, fortress world, and great transition. Market forces is a market-driven scenario in which demographic, economic, environmental and technological trends are discovered. World development are characterised by globalisation and convergence, which ensures that the adjustment of institutions is executed gradually without major disruptions. The integration of economic proceeds rapidly and the socio-economic structures of poor regions grow into a developed model of the rich regions. Lastly, the significant factor in global affairs is the environmental transformation which shows progress in the desired direction [35].

Policy reform emphasises on the disclosure of strong political will for taking prompt actions to ensure a successful transition to a more equitable and environmentally resilient future. This scenario is designed to achieve a set of future sustainability goals where the development pathways for reaching the goals are clearly identified. Both policy reform and market forces explores simultaneously the requirements to achieve social and environmental goals under high economic growth conditions [35].

The fortress world scenario, a variant of the barbarization scenario of GSG, manage critical natural resources. The great transition scenario evaluates solutions to the sustainability challenge, including new socio-economic arrangements and fundamental changes in values. This scenario enhances transition to a society that preserves natural systems and provides high level of wealth through material sufficiency [35].

3.7 Sustainability Accounting Standards Board

Sustainability Accounting Standards Board (SASB), an independent standard-setting organisation was founded in 2011. SASB focusses on industry-specific sustainability factors that most likely have material impacts and maintains sustainability accounting standards for 79 industries. The standards are designed in a manner to support companies to comply with existing regulatory commitments, using the existing framework within United States laws. SASB's mission is to ensure the existence of natural evolution in corporate reporting. SASB maintains sustainability standards that support public corporations to drive value and improve sustainability outcomes [36].

What differentiates SASB standards from other initiatives is the fact that the standards are decision useful, they provide industry-specific, reliable data and comparable material. The standards are the only sustainability standards that are developed according to the 'materiality' definition, defined by security laws. To gather accurate data, SASB deepens industry participation in terms of social, environmental and economic, to ensure the market's needs are met. The transparent process of SASB consists of two phases. The provisional phase includes industry research, evaluation of the research, standards development, public comment and provisional standards release. The codification phase consists of two steps, consultation and codification of the standards. This transparent process forms the network between the partnerships and engagement with investors, regulators, accountants, the engagement with issuers, and the education of market actors [36].

SASB has developed groups based on material sustainability risks and opportunities where investors can effectively understand the impact of sustainability risks on certain disciplines and effectively analyse these sustainability issues. These groups are consumption, healthcare, infrastructure, financials, non-renewable resources, services, renewable resources and alternative energy, technology and communications, resource transformation and transportation [36].

3.8 United Nations Global Compact Communication on Progress

In 2000, the United Nations Global Compact (UNGC) was established as a policy platform and a framework which businesses can use to conduct business in a sustainable and responsible way. UNGC supports businesses that aims to have responsible business actions assuring the business strategies and operations are aligned with the ten principles of human rights, labour, environment and anti-corruption. UNGC also encourage businesses that takes strategic actions to advance broader societal goals with the emphasis on collaboration and innovation [25].

UNGC addresses environmental risks and leverage opportunities, emphasising that businesses are tied to the planet. Opportunities and impacts effecting employees, workers in the value chain, customers and local communities are managed in terms of the social aspect, UNGC addresses. UNGC supports the economic development of societies and enhances good governance and stability.

UNGC's 2030 vision, which is their new global strategy, aims to mobilise a global movement of sustainable businesses and stakeholders to create the desired world. This strategy includes existing work around the ten principles as well as enhancing new directions including driving business action in support of the sustainable development goals. The focus areas will include responsible business and leadership practices, impact analysis, measurement and performance, global to local platform and connectors, and the sustainable development goals as the 'lighthouse'.

The UNGC network consists of 12000+ businesses in 170 countries, who uses the provided framework, exchanges sustainable development information among others and ensures full commitment to their sustainability strategy. Oil and gas, chemicals, basic resources, media, retail, health care, are just a few of the many sectors these businesses operate in. The ten principles are the following disciplines: human rights, decent work, gender equality, anti-corruption, peace, humanitarian action, food and water, climate action, breakthrough innovation, sustainability reporting, supply chain, and financial innovation.

3.9 Summary of the sustainability measurement frameworks

Table 4 and 5 provide an overview of the dimensions; system boundaries, actors and networks and discipline of each of the eight sustainability assessment frameworks.

Table 4: A summary of the system boundaries dimension at the different assessment frameworks.

Sustainability measurement framework	Dimension			
	System boundaries			
	Economic	Environmental	Social	Institutional
Global Reporting Initiative G4 Sustainability Reporting Guidelines	x	x	x	-
CDP Environmental Disclosure System	-	x	-	-
United Nations Commission on Sustainable Development	x	x	x	x
International Union for Conservation of Nature	-	x	-	-
Environmental sustainability index	-	x	-	-
Global Scenario Group	x	x	x	-
Sustainability Accounting Standards Board	x	x	x	-
United Nations Global Compact Communication on Progress	-	x	x	-

Table 5: A summary of the actors and networks and discipline dimension at the different assessment frameworks.

Sustainability measurement framework	Dimensions	
	Actors and networks	Discipline
Global Reporting Initiative G4 Sustainability Reporting Guidelines	Business, governmental, non-governmental organisation (gold community, knowledge unit, GRI and governments).	Any discipline, and additional to the following sectors: airport operators, food processing, construction and real estate, electric utilities, financial services, media, mining and minerals, NGO, oil and gas etc.
CDP Environmental Disclosure System	Companies, cities, states and regions, investors, purchasers, non-governmental businesses, inter-governmental businesses and governments.	General and supply chain
United Nations Commission on Sustainable Development	Countries at the national level, as well as international, governmental and non-governmental businesses.	General, Higher Education Sustainability Initiative (HESI), Partnerships for Small Island Developing States, Every Woman Every Child, Global Water Partnership etc.
International Union for Conservation of Nature	Governments, NGOs, scientists, businesses, local communities, indigenous people's businesses.	Business and biodiversity, climate change, economics, ecosystem management, environmental law, forests, gender, global policy, social policy, species, water, world heritage etc.
Environmental sustainability index	Governments, the private sector, communities and individual citizens.	General
Global Scenario Group	Researchers, decision-makers, general public.	Market forces, policy reform, fortress world, great transition
Sustainability Accounting Standards Board	Public corporations, market actors, investors, accountants.	Consumption, health care, infrastructure, financials, renewable resources and alternative energy, technology and communications, resource transformation, transportation etc.
United Nations Global Compact Communication on Progress	Government groups, local networks, private working groups.	Human rights, peace, humanitarian action, food and water, climate action, breakthrough innovation, sustainability reporting, supply chain, financial innovation etc.

The eight mentioned assessment frameworks will support guidance when the capability maturity model approach is developed. The capability maturity model offers the possibility for businesses to individually assess its position regarding five sustainability maturity levels and, to incorporate sustainable development into organisational goals and objectives to progress towards higher levels of sustainability. The maturity model is based on the belief that business sustainability is a continuous process of evolution in which a business will be continuously seeking to achieve its vision of sustainable development in uninterrupted cycles of improvement, where at each new cycle the business starts the process at a higher level of business sustainability performance.

4. ASSESSMENT OF THE SUSTAINABILITY MEASUREMENT FRAMEWORKS

This section aims to evaluate the above sustainability measurements in order to find an appropriate requirement criteria to find the most appropriate sustainability measurement for future use. Analysing the sustainability measurements and setting out each assessment's type of measurements in terms of social, economic and environmental, made the identification of the requirement criteria possible. Du Plessis & Bam [41] conducted a study about a scoping phase comparison, and was used as a reference when the requirement criteria were identified.

I. Data disclosure

The required indicators that are gained from the sustainability measurement frameworks will contribute strongly to the development of the proposed sustainability framework. It would be beneficial if the accumulated data is used only in an aggregated framework [41]. The data should have a clear and concise description of what is expected of the accumulated data.

II. Flexibility

The description of the indicators should be of such a nature or generalised form that the indicators are of use in any industry. It would be beneficial if any of the sustainability measurements consist of additional documentation that explains the sustainability measurements to a more specific industry.

III. Indicators

The indicators of the different sustainability measurement frameworks should consider all aspects of sustainability. Indicators that address the equivalent opportunities should be compared to find the most prominent indicator. Frameworks that consists of standardised indicators will be beneficial when valuing the frameworks to find the most suitable framework. The description of the indicators should be clear and concise.

IV. Measuring method

Different measurement methods must be analysed in depth to eliminate confusion in the represented indicators. Each indicator must consist of clear and concise targets. Numerical values or descriptions are assigned to ensure that organisational goals are aligned. These measuring methods are represented in terms of economic use of revenue, quantity, units, risk, percentages or impact.

The sustainability measurement frameworks mentioned in Section 0 that considers all three aspects of sustainability were used in the above assessment process. Frameworks that focussed on a specific sector were eliminated due to the proposed framework that will be developed for a more generalised industry. Table 6 illustrates the outcome of the requirement criteria towards the selected sustainability measurement framework that assess all three aspects and focused on a general concept.

Table 6: Summary of the international sustainability measurement frameworks according to the requirement criteria.

	Global Reporting Initiative G4 Sustainability Reporting Guidelines	United Nations Commission on Sustainable Development	Global Scenario Group	Sustainability Accounting Standards Board
Data disclosure	Available	Available	Limited	Limited
Flexibility	Adaptive	Adaptive	Non-adaptive	Adaptive
Indicators	Comprehensive	Standardised and comprehensive	Limited to non-comprehensive	Standardised and comprehensive
Measuring method	Detailed comprehensive	Comprehensive	Non-detailed	Comprehensive

Colour key:	Strong	Acceptable	Weak

From this table, it is noticeable that none of the sustainability measurement frameworks can be considered as a strong candidate but three of the four frameworks are an acceptable to strong candidate. The GRI G4 Sustainability reporting guidelines and the United Nations Commission on Sustainable Development both performed strongly in the criteria. The depth of the detail at the measuring methods from both frameworks are inadequate, but the description of the methods is of such a matter that it is still possible to measure the accurate information.

5. CONCLUSION

The systematic review clarifies the different universal assessment frameworks that can be used when measuring sustainability. It also categorises and emphasises the different dimensions identified at the assessment frameworks. These eight assessment frameworks were primarily selected based on their international awareness and the level of understanding their vision and end goal, respectively. This paper mainly served as a high-level study, and the insights gained and learnt from the sustainability approaches will facilitate the process of developing a capability maturity model aimed at evaluating the sustainability performance of businesses.

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ENERGY METABOLISM IN MULTI-STRUCTURED URBAN INFORMAL SETTLEMENTS IN SOUTH AFRICA

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ABSTRACT

Municipalities and government at different levels are faced with the challenge of establishing energy policies and strategies for urban informal settlements, which are mostly located in marginal areas. This study undertook a literature review to examine the challenges of energy access and provision in urban informal settlements from a resource flows perspective. This was achieved by reviewing the concept of urban metabolism, with a specific focus on energy flows in urban areas, examining the relevance of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach, and identifying gaps and limitations of assessing energy metabolic pattern of an urban informal settlement. The paper argues that, MuSIASEM is one of the appropriate approaches for examining and understanding energy metabolism in urban informal settlements. This is because, the MuSIASEM approach analyses the society under investigation across various scales and at different hierarchical levels, and then proposes an energy accounting method to measure the quantity of energy required (demand) by the society in relation to what is available, produced and consumed. In addition, it defines the energy flow characteristics expressed in terms of the funds generated and flows metabolised in the system.

Based on the MuSIASEM approach, a conceptual framework was developed, which will be utilised to examine energy metabolism in a multi-structured urban informal settlement. The framework consists of five stages, which include; project definition, data clustering, pattern development, analysis of trends, and results presentation. The implication of applying the MuSIASEM conceptual framework will provide an insight into the reality of materials and energy consumption in urban informal settlement at different hierarchy of the settlement.

Keywords: MuSIASEM, Urban Metabolism, Energy Metabolism, Urban Systems, Informal Settlement.

1. INTRODUCTION

Cities globally are under an enormous pressure to provide basic services such as water, electricity, and sanitation, due to increasing urbanisation demanding more resources and generating more wastes [1, 2]. In 2016, it was estimated that 54.5 per cent of the world's population lived in urban areas [3], [4]. Furthermore, by 2050, an additional 2.5 billion people are expected to live in urban areas, which will result in the percentage of population living in cities to reach about 66 per cent [5], [6]. In Africa, it is projected that the proportion of urbanisation will reach 58 percent by 2050 , which will result in the number of urban dwellers increasing from about 400 million in 2010, to 1.26 billion by 2050 [4], [7].

UN-Habitat [7] projects that a quarter of the world's population now live in slums, the majority of which spring from the developing countries [3, 6, 8]. With sub-Saharan Africa having a high prevalence of slum dwellers, the majority of added population in cities is expected to end up being part of slum population [9]. City planners and decision makers in developing countries are mostly unable to meet the high demand for providing basic services such as: security, employment, water system, energy, housing, and waste or sanitation management systems. In particular, informal settlements and/or slums, are left to provide most of these services by themselves [10], [11].

At the same time, continued urbanisation has been accompanied by an increasing flow of energy in and out of communities as fuel , food, waste and electricity, which through these input-output activities is concentrating itself within and outside the urban city boundaries [12].

With the above expected urbanisation and growth of slums, sustainable urban development has become more relevant for urban planners than ever before. The challenge for urban planners is how to expand, provide and increase access to resources (energy and other materials) while at the same time reducing resource flows. Urban metabolism provides an approach for examining the sustainability of cities by investigating their energy and material flows.

According to Kennedy et al. [12] urban metabolism is: *"the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste"* [12]. Further, Kennedy and Hoornweg [13] identified that: *"If cities are to take sustainability seriously, then collection of urban metabolism data has to become a mainstream activity for all large cities"*.

Analysing urban metabolism constitutes statistical analysis of a city's intake, output, energy storage, nutrients, materials, water and production of wastes [13]. Urban metabolism provides a framework to examine how flows of resources sustain the cities. Urban metabolism involves quantifying the inputs, outputs and energy storage, materials, nutrients, waste and water for an urban area [14], and is a useful way for conceptualising energy consumption patterns [15].

The majority of studies on urban metabolism have mainly been undertaken at national level [16]. Whilst the number of studies on urban areas has been increasing in recent years, the focus has mainly remained on cities in the Global North [12], [17]–[19].

However, most of these studies ([12], [15], [17], [20]–[22] have been criticized as omitting important information on social and institutional drivers, as well as geographical specifics [16]. Kennedy et al. [12] suggest that for full urban sustainability assessment, a comprehensive scope of analysis is required, whereas Pincetl et al. [15] suggest an expansion of the urban metabolism method to include the analysis of the biophysical, material, and energy parameters of cities.

Despite a call for comprehensive analyses of urban metabolism [13], [15], [23], [24] , existing studies on metabolic pattern analysis of developing countries generally exclude the understanding of the functionality of slums and their contribution to the biophysical and energy flows.

Thus far, only limited studies have analysed the societal metabolism of urban informal settlements [16], [25]–[28]. For instance, Smit et al. [16] showed how when considering cities as a complex system, with a subsystem of informal settlements, it might be challenging to provide inferences about the present and/or future resource requirements. In other words, carrying out an implementation plan for informal settlements should not just be based on a one-size fits all approach, as its disregards the social and institutional drivers, which lead to creation of slums. Therefore, it only examines the symptoms without investigating the causes of their emergence [16], [27]. Therefore, an in-depth understanding and recognition that there are different typologies of slums as illustrated in Smit et al. [16], is required to support informed implementation plans and interventions.

This paper aims to address the following question: how can the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach contribute to the understanding of the energy metabolic pattern in urban informal settlements. This was achieved through a critical review of: i) the concept of urban metabolism in the study of sustainable development and its shortcomings; and ii) the contribution of MuSIASEM in understanding the energy flow in urban informal settlement. Furthermore, the relevance of studies on energy flow in urban informal settlement to policy-makers and practitioners is provided.

2. METHODOLOGY

The procedure of the literature review was by using narrative review strategies. The selection process involved checking through relevant references by using their date, language, sources and source material (e.g. book, article, thesis, web article or writings as well as patent). The search was performed through web-based search engines, primarily Google Scholar and ResearchGate. The focus of the search was on the publication title, abstract, and the following keywords: MuSIASEM, Urban Metabolism, Energy Metabolism, Urban Systems, Informal settlement. The results of the search were filtered according to different subject areas, with those considered unrelated to the definition on urban and energy metabolism excluded; examples are health and biological sciences.

The literature were reviewed and categorised, presented in Section 3. The reviews on each of the topics were conducted for understanding and describing concepts relating to metabolism of multi-structured urban informal settlement. Section 4 describes the conceptual framework designed, which can be used when analysing energy flows (total energy consumption) in urban informal settlements using MuSIASEM. Figure 1 illustrates the literature-reviewed process.

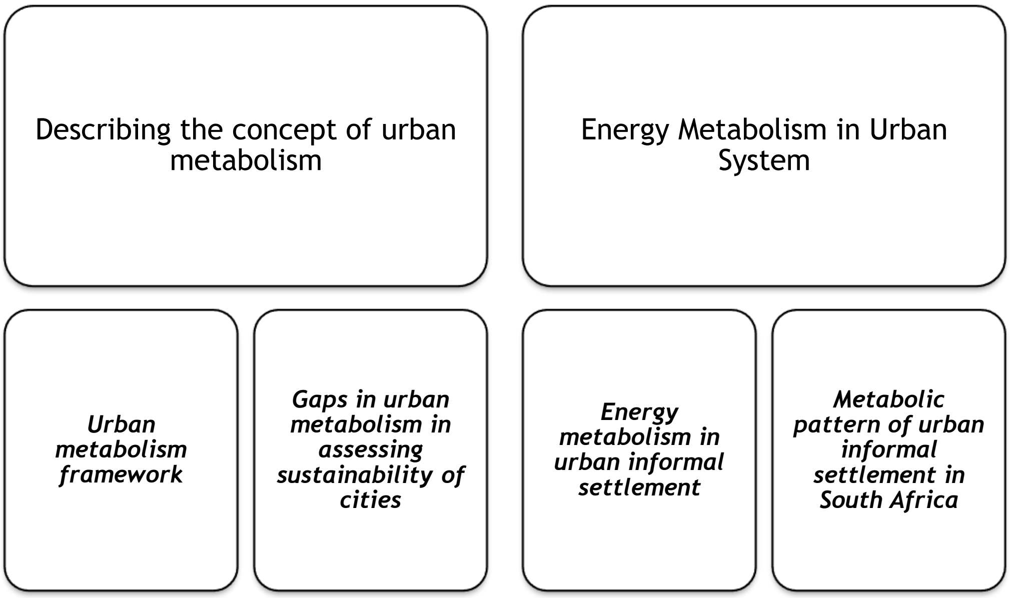

Figure 1: Literature reviewed

3. REVIEW OF LITERATURE

3.1 Urban metabolism

The theory of urban metabolism (UM) is now widely used by different disciplines; for example, in urban ecology, industrial ecology, ecological economy, and political ecology, to name a few. It considers activities that are present within cities, which can either be observed based on the economic, social or physical factors [12]. The most cited definition of urban metabolism is that of Kennedy et al. [12]. However, their definition only reflects the concept from an industrial ecology context. Currie and Musango [29] thus elaborated on the concept by referring to it as ‘*the collection of complex sociotechnical and socioecological processes by which flows of energy, materials, information and people shape the city, service the populace needs, and impact the surrounding hinterland*’.

In broad terms, urban metabolism can be defined as the analysis of factors and indicators, which can either be economical and/ or technical, of materials and energy flows because of production and use activities within an urban region. This includes the importation of materials needed from other ecosystems or societies, exportation of materials out of the city boundary, which can include greenhouse gas emission (GHG), and the disposal of waste and by-products [12], [30], [31].

Urban metabolism has become one of the frameworks, which enables the analysis of how energy and material flows are linked with production and consumption. Most importantly, cities are seen to transform their social organization with regards to energy and materials through their extreme use and production actions within the society.

One of the main objectives of urban metabolism, as demonstrated by Newman [32], [33], is to inform state of the environmental (SOE) reporting. Urban metabolism analysis provides very significant information on energy efficiency, how materials can be recycled, adoption of a dynamic way of managing waste, and planning of infrastructure within urban systems [1].

3.1.1 *Urban metabolism framework*

Urban metabolism is a concept through which a better understanding of materials and energy flows within an urban society can be analysed. The purpose of this section is to provide an overview of the core concepts of urban metabolism as well as its applicability to assessing urban sustainability.

Understanding urban metabolism of a society can guide and support communities and the public in building resource-efficient and knowledge-driven urban environments. This biology-inspired concept has been useful in the study of urban development, since Wolman [34] proposed a significant analysis of the energy and material metabolism of a hypothetic American city with a population of one million [34]. From then on, ecologists and urbanists have been in search of information and pragmatic methods of treating cities as metabolic organisms for appraising their structure and function embedded in the metabolism processes in various regions of the world [35].

Abel Wolman's study was pivotal to highlight the various system-wide impacts of consuming materials and generating waste within an urban environment [36]. Awareness has grown extensively on the application of urban metabolism in assessing questions on energy and materials consumption of cities. One of the major reasons for which urban metabolism was developed was because of concerns on how non-renewable energy resources are depleted. With increasing urbanisation, land-use changes, including urban settlements, is displacing biodiversity and their respective ecosystem services. Green infrastructure is thus emerging as one possible strategy for mitigating urban displacement.

More detail on urban metabolism can be seen in texts provided by Ferrão and Fernández [22] and Baccini and Brunner [2]. The issues surrounding material and energy flow within cities are discussed by Weisz and Steinberger [37], while Keirstead et al. [38] , highlight the gaps and weakness existing between the accounting frameworks and policy tools.

Figure 2 shows the conceptual urban metabolism framework that can be used, by specifying an urban system boundary, which indicates the input, represented by inflows (I), output flows (O), storage (S), internal flows (Q), and production of biomass, including other materials - water (W), minerals (M) and energy (E). Therefore, urban metabolism measures are essentially required in order to address the impact of global resource flows, many of which are used to support life in cities.

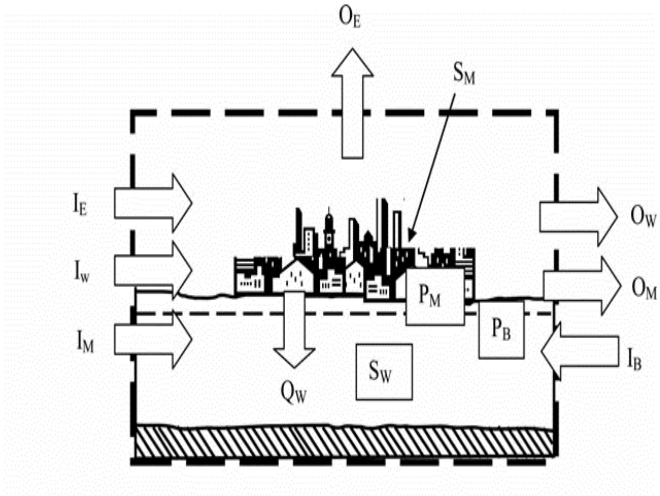

Figure 2: Urban System Boundary showing energy and material [13]

According to Barles [39], different urban metabolism approaches can be employed in analysing the metabolic pattern of a system [39], such as Ecological Footprint Analysis [40], [41], Life Cycle Analysis LCA [42], Input-Output Analysis [43], Material Flow Analysis MFA [44]–[46], and Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) [47]. Each of these methods has their strengths, weaknesses, and specific field of application as indicated in Beloin-Saint-Pierre et al. [19].

3.1.2 *Gaps in urban metabolism in assessing sustainability of cities*

One of the major gaps in the application of urban metabolism in assessment of cities sustainability is data availability and its accuracy. Often, information at city level is not in formats that would enable utilisation of the existing standardised urban metabolism approaches. Decker et al. [36] detailed how the data for their study were made available, as well as gaps entailed in the data. These gaps highlights the need for an integrated data analysis and a more cross-cutting research [36].

An additional limitation of urban metabolism is the tendency of emphasis majorly on the biophysical environment without little highlights on the economic and social problems. Where its usefulness is of more relevance to decision and policy makers if social and economic issues were taken into consideration, Newman [32] proposed an extended metabolism model that contains an inclusion of measures of living, such as indicators of work (human activity), money (income), health, household, education and community activities.

Also within the context of urban energy metabolism, considerable challenges have been faced in the process of highlighting the components available for energy systems [48]. According to Weisz and Steinberger [37], some of the specific limitations relevant in understanding the metabolic pattern of urban informal settlement includes :

Table 1: Limitations of Urban Metabolism approach

Limitation	Explanation
No available data	Although, there is recognition of the significance of cities in providing the total quantity of socio-economic energy and material consumption, synchronized datasets are generated yearly by the office of statistics mainly exclusively on a national level. Therefore, attempts to use literature in generalizing patterns and trends shown in the use of specific urban resources struggles with incomplete or incommensurable data.
Cities openness	With cities involved in specific transformation, production, and consumption rather than conduct their own extraction of resources. Which thus makes them depend on their surrounding areas for resource provision as well as goods and services. Whereas, this surrounding areas has a global dimension. And these exact openness of cities with respect to their materials and energy flows that brings about difficulty when specifying what the specific urban flows are [37]

However, through the study of urban energy metabolism, key links in cities energy metabolism can be monitored. There is also the possibility of defining the function and status of components of urban metabolism. Which is practically and theoretically significant for achieving sound development and can guide policies development for effective energy management and infrastructure planning.

Before reflecting on potential transition towards a sustainable energy path in urban informal settlement, as a possible solution to energy poverty, it is essential to understand the nature of energy flow in an urban environment. In particular, to gain knowledge and information on ways of energy production and use across various sectors in an urban setting.

3.2 Energy metabolism in urban system

Long-term infrastructure developmental change in urban energy systems comprise of distinct setbacks [1] (e.g. energy access, environmental issues, planning for housing and infrastructure upgrade, water and waste management) as well as opportunity (e.g. sustainable development, inclusive policy planning and implementation, social development, and economic growth). Therefore, analysis on urban infrastructure systems is directly linked with urban metabolism, as the infrastructures conduct the flow of energy and other materials.

Energy is a focal point because out of every flow that urban metabolism takes account of, energy plays an important role in sustainable social and economic development as well as achieving all Sustainable Development Goals (SDGs) [49]. Furthermore, in order to understand cities resource and energy flow, and gain knowledge on their future growth with expansion of informal settlements, the concept of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) has therefore become a practical approach. MuSIASEM approach treats the urban informal settlements as a distinctive case of socioecological systems. The MuSIASEM approach is important, when dealing with various uncertainty levels affecting urban informal settlement analysis, which therefore, introduces socio-technical solutions.

Energy serves as a major input for both economic and social growth of cities. A fast growing informal settlement requiring an improved living standard, which implies that the amount of energy required in urban areas comprising this settlement, is also rapidly increased. This in turn implies intensifying exploitation, transformation and use of energy, which ultimately affects the urban ecosystem. Given that cities are generally energy users in a country, it is essential to examine the function and structure of urban metabolic system (which is significant research as part of energy saving policy) [48].

Different studies have been carried out to understand the metabolic pattern of urban systems (this at national level) using different approaches (see for example [12], [50]). Although, critics have accused many of these approaches as being broad with their representation only as ‘static accounting’, which generally lacks an interdisciplinary approach with valuable information on social and institutional drivers as well as specific geography omitted [12], [15], [22].

Suggestions from Pincetl et al. [15] have been made to extend the studies to analysis of biophysical materials and energy parameters of cities including their social, human, economy, policy and relating systems. Whereas, suggestion from Kennedy et al. [12] requires carrying out a wide scope of analysis in order to obtain a complete evaluation on urban sustainability.

3.2.1 *Energy metabolism in urban informal settlements*

Informal settlements are fast-changing and dynamic systems [16]. The sporadic increase in their population size and demography increases the challenges of lack of data on informal settlements, which can cause surveys carried out to become quickly invalid [27].

United Nations Human Settlement programme [51] describes slums at global level as the spatial and physical manifestation of urban poverty and intra-city inequality [16]. Although, despite a slight regression in the global population of urban slums, sub-Saharan Africa continues to have the highest prevalence of slum conditions, whilst most of the projected population of world cities are expected to end up in slums [9].

Energy consumed in informal settlement is generally less affordable due to the use of low grade fuels [52]. Informal settlement dwellers are low-income earners and usually spend almost one third of their income on energy [3]. In addition, the energy purchased is not capable to meet all energy services required in the informal settlement households. The low-grade fuels, such as biomass and kerosene, which causes indoor air pollution, resulting in health-related problems. Investigations into the energy flows and its related wastes in urban informal settlements are limited.

Despite in-depth available literature that links energy and urban cities [20], [37], [53], [54], very few of these researches focused on urban informal settlement looking at them comparatively [16], [27], [28], [55]. The few that have looked at urban informal settlement examined their material and energy use pattern, and its implications for contributing to sustainable development of cities.

Although these studies are useful and lay a foundation on energy flows assessment in urban informal settlements, their application only considered the urban informal settlements as a whole system without considering the energy flows in the different housing structures of the settlement, which this paper refers to as multi-structured urban informal settlements. Hence, examining energy flows in multi-structured informal settlements becomes essential.

3.2.2 *Metabolic pattern of urban informal settlement in South Africa*.

As seen in the cases of many developing countries [56], South African cities are also faced with an increase in urban growth, which is one of the compelling forces for the increasing expansion of informal settlements at the peripheral of urban regions. However, South Africa urban informal settlements is relative as to other African countries [57]. With the growth of many of these unplanned informal settlements resulting in several environmental and land relating issues.

Smit et al. [16] developed a typology of slums or settlement types in South Africa that considers the societal and political aspects influencing informal settlements in the country. These different types of settlement identified by Smit et al. [16] are: (i.) Category A: Formal, Legal, Planned, Legitimate. Examples for these are Township/location/RDP suburb, (ii.) Category B: Formal, Illegal, Unplanned, Legitimate /Illegitimate. An example of this category is a Housing-turned-slum, (iii.) Category C: Informal, Illegal, Unplanned and Illegitimate. An example is Squatter camps, (iv.) Category D: Informal, Legal, Planned, Legitimate. Examples for this are Transit Camps, Site and service informal settlements and (v.) Category E: Formal /Informal, Legal/ Illegal, Planned/Unplanned, Legitimate/Illegitimate. This category represents the Hybrid and or Multi-structured settlement, which is the focus of this study.

Human society metabolism is a means of characterising processes involved in energy and materials conversion within a society or ecosystem, needed for its continuous survival and life [16], [27], [56]-[58]. The metabolic dimension of MuSIASEM can be applied to analyse the energy structure, pattern and consumption of urban informal households presenting different building structures or topology. Urban informal settlement biophysical characteristics and societal metabolism can be examined at different levels, which includes at individual, household and the whole settlement level for various resources. MuSIASEM therefore provides a comprehensive analysis that can be suited for examining energy and material flows in urban informal settlements.

MuSIASEM approach, was developed by Giampietro [61] based on Georgescu-Reogen's flow-fund model. Its initial application has been at national scale (e.g. [62]), and only recently has its application in informal settlements become relevant (e.g. [16], [27], [28]. MuSIASEM allows one to examine the feasibility, desirability and viability of adjustments (transitions).

MuSIASEM can enable analysis of different flows namely, food, energy, money, and water, especially when considering the different factors such as, dynamics in population, greenhouse gas (GHG) emissions and changes in the use of land at different levels in the economy [63].

Unlike most conventional approaches of urban metabolism such as an economy-wide material flow analysis [64], [65] ecological footprint analysis [66], and input-output analyses [67], MuSIASEM approach can characterize informal settlements at different levels and scales in terms of funds and flows and across multiple dimensions. Fund elements include: (i) human activity measured in time; (ii) exosomatic devices in the form of technology and infrastructures; and (iii) Ricardian land measured in terms of land use. Whereas flows, normally represented by the elements metabolized in the system, include food, energy, water, waste, and money.

Essentially, the MuSIASEM approach is an analytical tool as well as multidisciplinary for analysing human society development with respect to sustainability [68]. It is capable of integrating variables relating to non-equivalent descriptive domains and equipped to incorporate data from specific hierarchical levels [68].

As an analytical tool, the accounting system of MuSIASEM can be used in describing and presenting the characteristic of the actual pattern of metabolism in a social economic structure. The analysis provides integrated quantitative information based on:

- Demography; which comprises of total working population, technological capital, land use and availability of land (defined as fund elements, which are those variables that remain unchanged; flows consisting of water, energy, money and food (defined as flow elements).
- In the case of each flow, the consumption of the end users, losses present, internal supply including amount imported and exported are all defined;
- Ratio of the flow per fund which explains the rate in one hour of activity, and energy intensity of the flow across various hierarchy (including the entire system) are defined [69].

Comparison is then made using these ratios against indicated standards (benchmarks) by defining various types of socio-economic organisations [69]. With the review of methods that relate to urban metabolism assessment, the MuSIASEM approach is deemed most relevant in capturing household and informal activities within informal settlements, which are then utilised to examine energy and other material flows.

4. ANALYSIS ON ENERGY METABOLIC PATTERN IN URBAN INFORMAL SETTLEMENT

The societal and metabolic pattern of an urban informal settlement and its biophysical characterisation can be examined using the MuSIASEM approach at different scales, which includes individual, household level, and the whole settlement level and for different resources.

However, after dividing the settlement into hierarchy level or scales, it proposes an energy accounting method to measure the quantity of energy that is required (demand) by the society in relating to what is available, generated and consumed. Using MuSIASEM variables, an analysis carried out on the overall increase in energy consumption, human activity, population size and added value within the urban informal settlement can be undertaken. The probable energy access challenges faced in this settlement can be outlined, and then strategic plans can be made for solutions and improvement.

In addition, the most relevant information that can enable integrated assessment of energy flows in urban informal settlements include, time allocated for human activity, funds, waste emissions, and land use changes.

The analysis can be done at different levels scales, expressed as individual (n − 2), household (n − 1), and informal settlement or community level (n) as represented are described in Table 2.

Table 2: Different hierarchical levels used in MuSIASEM analysis

Level	Description
Level (N)	Which consist of the whole society, describes population demography of the settlement with respect to the hours in total available per a single year
Level (n-1)	Describes the human activities which can further be divided into • paid work (PW): refers to the total hours worked by the working population in a year • household activities (HA): refers to hours spent on doing non-paid work (usually calculated from both the non-working and working population)
Level (n-2)	Both household activities and paid work types are broken down into categories of leisure and social activities, physiological overhead, unpaid work, formal work and informal work.

4.1 Conceptual Framework

A conceptual framework was developed which describes the analysis process for energy metabolism in multi-structured urban informal settlement using MuSIASEM, as shown in Figure 3. The framework is briefly described in the sub-sections that follow.

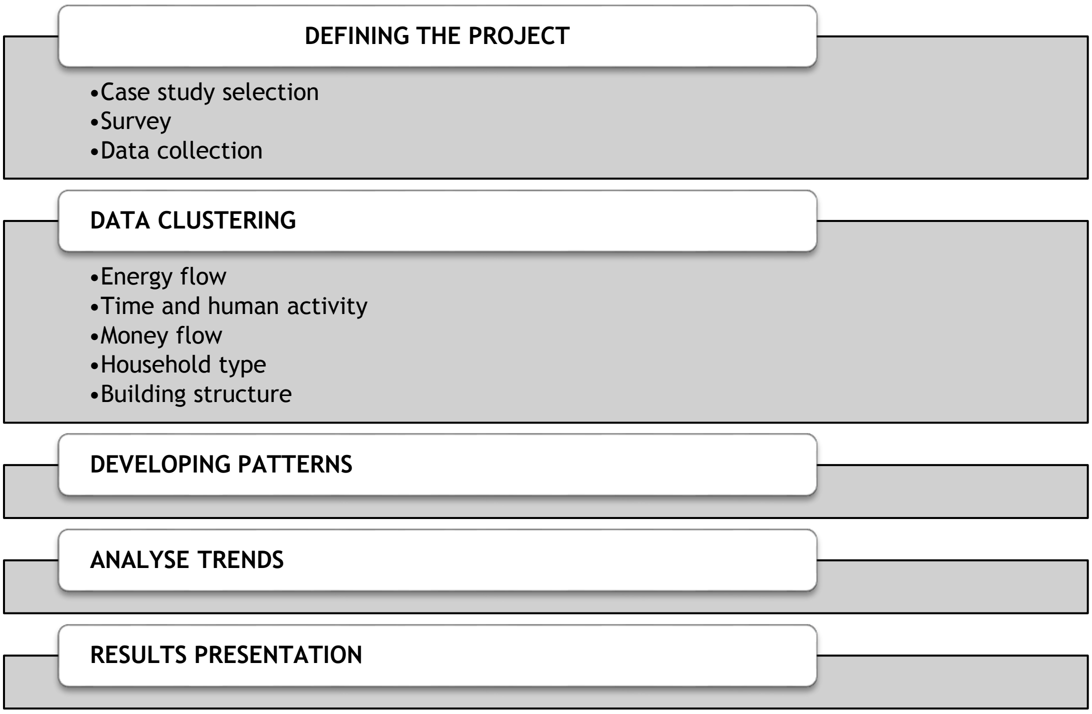

Figure 3: Conceptual framework for the analysis of energy metabolism in urban informal settlement using MuSIASEM

4.1.1 *Defining the project*

This involves selecting a case study, undertaking a survey and data collection. The case study selected should be clearly identified based on the typology of slums. For this study, the focus would be on a hybrid / multi-structured settlement. The case study data can be collected using a questionnaire, covering different household samples of the informal settlement. The questionnaires are designed to check for missing information and for compiling information based on their flow-fund elements namely:

- Flow element namely: energy (which includes energy fuel type, fuel source, energy access, amount of energy used, and type of appliances used, and their hours) and money (which includes all forms of income, expenditure, cash surplus, and shortages and;
- Fund elements namely: number of hours for human activities accounted for at different categories, paid work and non-paid work, household type, and building structures; metabolised by the urban informal settlement.

4.1.2 *Data Clustering*

This involves compiling and grouping data collected from the survey into different clusters when applying MuSIASEM. These clusters relate to the use of Time, Money and Energy.

4.1.3 *Developing patterns*

This involves mapping out the different factors that influence energy flow (energy consumption and access), money flow, time and human activity in urban informal settlement.

Several factors influence the total energy consumption (which brings about the flow of energy) in urban informal settlement, these different factors therefore include:

- Access to electricity and how electricity is supplied;
- Cost of electricity;
- Energy type of fuel for different household activities;
- Source of energy fuel type used;
- Percentage and or proportions of energy fuel type (all used for different household activities); and
- Type of energy appliances used for different household services and activities.

With the information and data on these different factors, pattern of the energy flow can be represented as illustrated in figure 4.

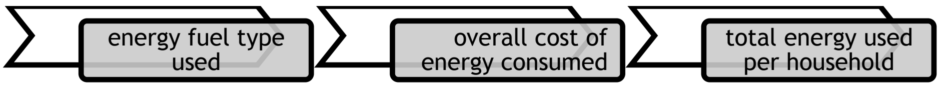

Figure 4: Factors that influence energy consumption in informal settlement

Other factor that influence energy fuel consumption as described by Kovacic et al.[28], is based on the population dynamics (resulting from their household composition or types). They suggested that the household composition (n-1 level) has a major impact on the fuel type and quantity consumed in a household[1].

For the human activity, and time use, other factors needs consideration for better understanding on how they contribute to the sustainable growth of cities in which they are present. These factors include the following:

- Paid work (PW) activities.
- Non-paid work (NPW) activities.
- Household cash surplus and shortfalls management.

Information on these activities yield insights into how much time workers spent on travelling to and from work, as well as time spent on carrying out household activities that are non-paid work (such as leisure, sleeping, cooking, eating, food gardening etc.).

Other patterns requiring their development are monetary flow within the settlement, which includes both total income (from all sources) and total expenditures per household. Furthermore, household type and or composition patterns needs to be developed and defined, equally they influence energy use in a household [28]. Factors that can be included as part of the required data under this segment as represented in figure 5:

[1] For the detailed description of household effect on overall energy consumed , see [28]

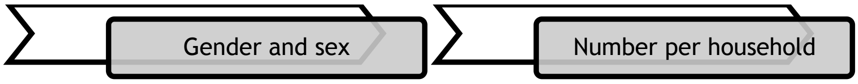

Figure 5: Factors inclusive in household composition in informal settlement

In addition, it is essential to examine the type of building structure. As described by Smit et al. [16], there are different categories of slums exhibiting different building or housing types (which are also present in South Africa informal settlement context).

4.1.4 *Analysis of trends*

With the available data, the following trends can be determined:

- Type and quantity of energy consumed by household of the same and different building structure.
- Total energy consumption in the whole society (informal settlement)
- Infrastructure transition.

4.1.5 *Results presentation*

In order to plan policies which can target ways on how to improve household energy consumption (based on their demand) in informal settlement, policy planners and makers need better understanding not only on just consumption per household but also on the energy consumption behaviour. The framework developed will provide some insights into the behaviour of energy consumed in informal settlement households. This paper is motivated due to limited research on the energy flow in urban informal settlement and their connection to the wider urban areas and cities in which they are present, given that there is an expected rapid increase in urbanisation in developing countries in coming years.

Therefore, based on the different variables and/ or factors obtained from the trends developed in an urban informal settlement, it may be able to shed new insights into the energy and resource flow in this settlement and their connection to the larger urban system. Also, this characterisation of urban informal settlement moves beyond just their physical understanding but includes and considers the material reality of informal settlement and its dwellers, as well as what influences the dwellers ability and/ or capacity to metabolise these resources. Furthermore, the analysis focus will then be on energy flows, money flows and human activity. Therefore, the relationship between these flows can be presented and how they inform development (infrastructure and building types) and energy access relating challenges in the urban informal settlement.
Finally, the results of the analysis on the metabolic pattern can assist in determining the following:

- Energy demand per household of different building types (structures) categories. In addition, the driving forces behind energy use (as this helps in following the patterns and trends).
- Urbanisation pattern in urban informal settlement in South Africa and;
- Level of income in different households.

The results will therefore provide insights into the societal metabolism of urban informal settlements and their connection to the larger urban system. Which goes beyond understanding informal settlements only based on their physical and legal characteristics, but rather considers the state of resources and energy in urban informal settlements and its dwellers based on specific characteristics.

5. DISCUSSION AND CONCLUSION

This paper reviewed the literature to examine the challenges of energy access and provision in urban informal settlements, from a resource flows perspective. The paper argues that the MuSIASEM approach is one of the appropriate approaches for examining and understanding energy metabolisms in urban informal settlements. Although initially developed and utilised at a national level, its relevance and application in urban informal settlements is becoming recognised. Depending on the categories of the household and the population composition, the flows of energy and materials in urban informal settlements can be estimated, as well as related to the total amount of paid work time. Thus, a linkage can be established between households and the rest of the economy through the assessment of labour hours of human activity allocated for paid work (labour hours). Paid work required should be compatible with the one supplied by households.

Establishing a link between economic growth and energy consumption is possible. However, in order to explain the producing part of the economy, accounting of time allocation for activity (labour/work) in various aspect of the economy is required. In which way, it is possible to set benchmarks of what is required in technical capital and exosomatic[2] energy to boost the efficiency of one labour hour in the economy.

The application of MuSIASEM in the urban informal settlement metabolism can be argued to enhance the possibility of achieving sustainable development in urban informal settlements, when they are analysed from their metabolic pattern perspective. In that regard, MuSIASEM was found appropriate, most in particular with respects to the following aspects:

- Providing comprehensive information and/ or data on the different levels (hierarchy) of the informal settlements.
- Providing an in-depth understanding on the reality of materials of the informal settlements and their dwellers.
- Highlighting areas requiring policy intervention;
- Which is useful as an essential tool for supporting decision, for a socially equitable and sustainable urban planning.

In conclusion, the importance of understanding the energy metabolism in urban informal settlement to the overall sustainable development of urban cities was provided through the literature reviewed. Furthermore, the relevance of MuSIASEM approach was provided and how it can be used to investigate deeper into the situation of energy and materials of urban informal settlement, which is very useful towards the development of a more efficient and effective energy policies in urban informal settlement and cities in which they are present. Finally, the development of a framework that can be used in the analysis of urban informal settlement energy metabolism.

5.1 How can decision-makers and/or policy-makers apply MuSIASEM?

Urban development and management of local economy face huge challenges concerning expected urbanisation and growth of informal settlement. Neglecting the understanding of informality and informal settlements in urban areas will not address these issues, therefore urban planners and decision-makers need to accept that the urban informal settlement plays a significant part in achieving inclusive sustainable economic development at local level. Inclusion of informal settlement in urban energy planning will be key to improving energy access and reducing energy poverty in these spaces.

Several global and government agencies have used energy intensity as a measuring indicator in determining the energy efficiency of countries. Whereas, energy intensity does not provide a detailed descriptive analysis of an energy sector [70]. MuSIASEM can provide analysis of system components across different scales and economic sectors, which is much more effective and better than using energy intensity where one uses a single aggregate unit for measuring energy efficiency.

Furthermore, MuSIASEM provides insights into the complexities and challenges surrounding energy consumption through the detailed analysis in different levels of scale. This can thus guide policy makers in the planning for specific energy related interventions.

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REMOTE CONDITION MONITORING FOR FAULT INDICATION IN ELEVATORS USING IoT TECHNOLOGY FOR IMPROVED MAINTENANCE

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ABSTRACT

Remote Condition Monitoring (RCM) of machines is gaining popularity in industries through augmented automation as it offers the benefit of reduced manning of machines as well as the Just-in-Time fault indication in machines and processes. This paper employs a Remote Condition Monitoring approach of two elevator parameters, vibration and machine room-temperature, using an Internet of Things (IoT) device for Remote Data Acquisition (RDA) and Remote Fault Indication (RFI). A remote monitoring set-up was developed comprising of augmented sensors networked connections and Arduino Yun microcontroller, installed on the elevator system. The set-up was configured to remotely monitor the conditions online, as the data would be posted to the email at a decided intervals and email notifications are sent when severity level conditions prevail. The RCM enabled faster repair decisions and maintenance.

1. INTRODUCTION

Maintenance of machines and facilities is gaining more attention as it helps to increase productivity and competitiveness through reduction in machine downtime and reduced maintenance cost. Augmented automation alongside reduced manning and increased operating tempos in production machineries have given rise to rapid increase in machinery sensors installed to make repairs faster and equipment operates reliably for long periods [1]. The lifts should be subjected to scheduled maintenance and minimum down time [2]. The research efforts focus on the construction of a remote monitoring device which applies the emerging IoT technology in reporting the state of the elevator system and indicating the severity level of the conditions for proactive maintenance and deterioration pattern/history before breakdown maintenance. Since the lifts and elevator systems are not manned, the maintenance policy mostly adopted is scheduled maintenance. The device is configured to monitor parameters which are instrumental to indicate malfunction of the system.

2. LITERATURE REVIEW

Recently, intelligent elevators systems that can be remotely tracked for maintenance has come into existence [3]. However, the need for an augmented maintenance monitoring system still cannot be ruled out as system interaction with its environment are peculiar and dynamic. This research seeks to adopt remote condition monitoring of lifts and elevator systems for earlier detection of abnormality in the system's condition. Several remote monitoring approaches are now being adopted which may include a self-test remote machine monitoring system as well as remotely monitored conditions through augmented automation using IoT devices. Datta et al. developed a self-testing software that remotely analyses the industrial machine condition to detect abnormality during operation, and thereby generating a report according to this analysis [4]. The software was interfaced with the USB modem for sending multimedia message during abnormality of the machine condition. This would assist in providing faster machine maintenance as compared to breakdown maintenance.

In elevator systems, parameters such as the vibration of the elevator car, sound from the drive system and temperature from the machine room could signify impending fault in the elevator system [5]. Remote condition monitoring and pre-alarm system are gradually being developed based on Internet of Things (IoT) and cloud computing (CC) accomplished with the ability of real time monitoring [6]. IoT technology and devices grants the privilege of remote condition monitoring, diagnoses and reporting, hence keeping the maintenance team abreast of the condition of the system. In the elevator system, vibration of the elevator car would indicate a malfunctioning drive system or the misalignment of the elevator car on the guide rails [7].

Vibration of the elevator Car or Lift car is a major condition which indicates the condition of the drive system while the machine room temperature may indicate the functioning of the control system [8]. A malfunctioning drive system, guides, controls, elevator car and hall equipment would generate a side sway, oscillation or vibration of the elevator car [9]. Kwashaka and Mariani performed vibration analysis on traction elevators using 3 axis accelerometer sensors, Endevco 66A11, to determine the excitation of the system and obtained five (5) experimental modal analysis [10]. The vibration and temperature parameter is monitored remotely and the data logged on cloud while evaluating the current conditions against the severity level of the parameter. Arduino Yun IoT microcontroller is used as the principal component for the monitoring system while SPF 3-AXIS Accelerometer ADXL335 BD vibration sensor is used for capturing the vibration data and LM 35 temperature sensor is used for the machines room temperature. The data is captured remotely on the cloud using the email choreo and the email alert is generated and sent at each severity level of any of the parameters.

3. SYSTEM ARCHITECTURE FOR REMOTE MACHINE CONDITION MONITORING

System architecture for remote machine condition monitoring accomplishes the requirement of monitoring and measuring the condition of machines, processing the data from the instrument and accessing the conditions remotely without physical presence. Our approach adopts the emerging technology of Internet of Things (IoT) and cloud computing in building the remote monitoring system. IoT concepts with cloud computing have found enough application in smart home (SH) environment which enables the user to measure home conditions (such as temperature, humidity, luminosity), manipulate HVAC (Heating Ventilation and Air Condition) of home as well as the home security [11]. The approach in this research makes use of micro-controller enabled sensors for measuring the parameters of the elevator, the powered IoT compliant microcontroller for controlling the whole system connection as well as the data transmission from the sensor and to the cloud database which in this case is the emailing choreo. The microcontroller work as the CU, thereby carrying out some logical reasoning and arithmetic on the read sensor data. The platform is therefore categorized into three layers, which are the Sensors layers for data capturing, the API/Data transmission layer and the web application client. Figure 1 illustrates the system architecture for the remote condition monitoring maintenance for a machine using the IoT technology. It has microcontroller-enabled sensors, API/Control Unit and Cloud Services/Web Application as its major components.

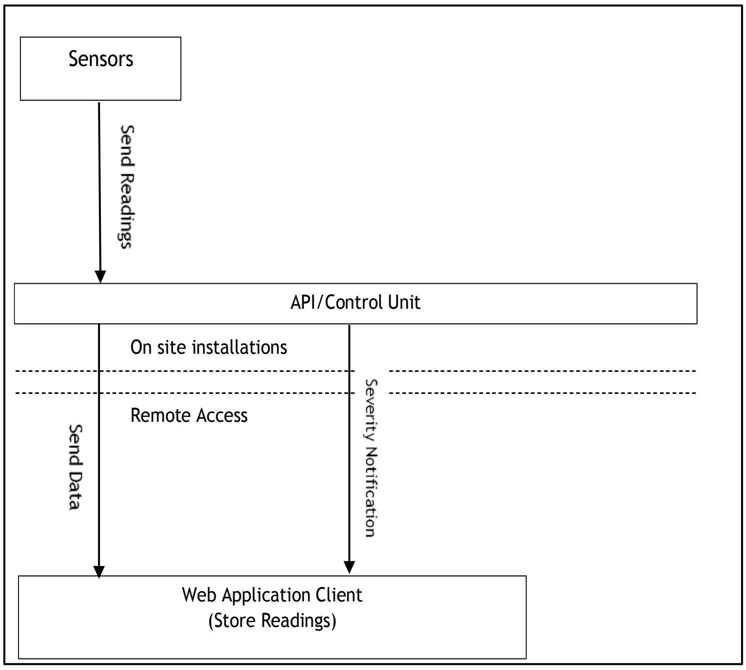

Figure 1: System Architecture for machine Remote Condition Monitoring

Microcontroller-enabled sensors: These measures the conditions of the machines for both the vibration parameter and the machine room temperature parameter. Spark Fun SPF 3 Axis Accelerometer ADXL 335 BD SEN-09269, from analog devices with low noise and power consumption of 32µA and sensing range of +/-3g is the sensor for measuring the vibration of the elevator car. The angle of inclination of the system as relative to the installation of the sensor is also taken into consideration by the sensor. LM 35 temperature sensor is also used for measuring the temperature of the machine room.

API/Control Unit: this unit monitors the sensed signal from the sensor, converts it to digital value which are readable to the operator. The major component in this unit is the microcontroller which is an IoT enabled microcontroller named Arduino Yun. The controller connects to the cloud through a third-party web application known as Temboo, through which the sensor data and notifications are sent using the email Choreo application. The data read is transmitted to the cloud web service and stored in the cloud where it can be accessed remotely.

Cloud Services/Web Application: This is the Internet end of the whole set-up that provides the remote link for the data being monitored by the device. This serves as the database for storing the data from the sensors as well as a remote access for the data and medium of event notifications. Cloud hosting has significant benefits such as improved
Reliability and physical security. The website is hosted on a virtual partition instead of being hosted on one single physical server and this feature spreads the risk since the pooled cloud resource is drawn from multiple data centres in different locations.

4. DESIGN OF REMOTE CONDITION MONITORING SYSTEM FOR ELEVATOR PARAMETERS

The system architecture was designed to relay the conditions of the elevator system remotely to the maintenance team for prompt proactive and preventive maintenance of the machinery. Alkodmany [12] explained the elevator maintenance system at one World Trade Center (WTC) using Microsoft Azure Intelligent system which responds to faults proactively by sending service engineers real-time data so that total breakdown of the elevator can be prevented by feeding the data into a dynamic predictive model. The approach used in this research however uses the intelligent ability of the microcontroller for carrying out the logical operation of the read values against a predetermined severity condition level of the system while using the its IoT capability in both sending the data and notification in case of abnormality of the system. Several technologies are emerging on Industrial machines manufacturing for better efficiency and maintenance. Asset monitoring has enabled remote tracking of machine that has emerged from the technology of Machine-to-Machine (M2M) communication to Internet of Things configurations [13]. This has gradually evolved the adoption of Internet of Things as augmented automation for remote condition monitoring maintenance of machine. The configured system therefore measures the machine room temperature, measures the vibration of the elevator car and the drive system, and sends the data to the cloud using a third-party web service known as Temboo.

Machine room temperature: The machine room temperature is considered important as it houses the controls for the system. Since high temperature may give rise to malfunctioning of the system, the temperature condition in the room is important especially, since the machine room is poorly ventilated, hence, its temperature is measured and recorded.

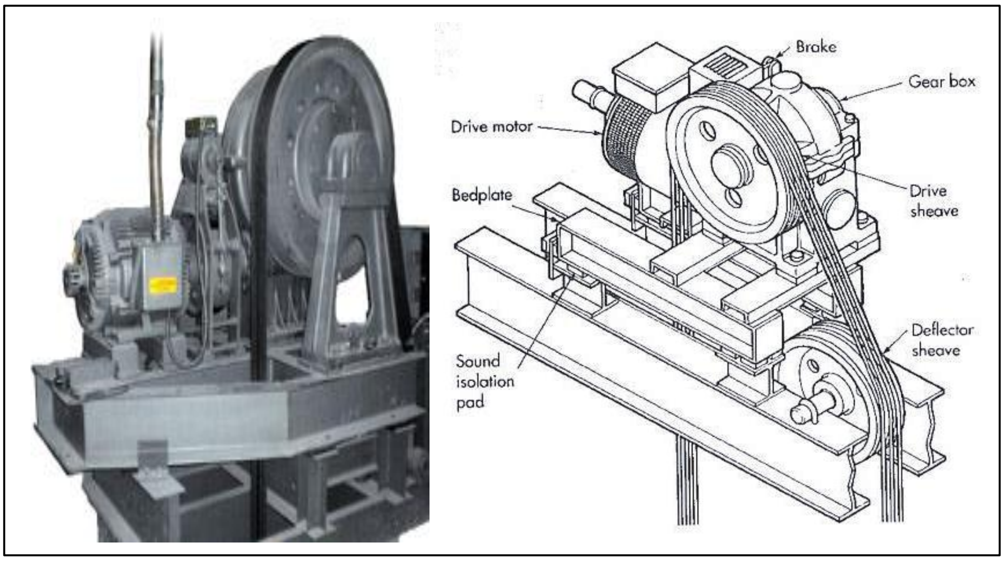

Figure 2: Geared Drive System of a Traction Elevator

Vibration of the elevator car and the drive system: This vibration takes into consideration the guide rails, the drive sheave, the lubrication of the gear box, braking system as well as the deflection of the cable. Figure 2 shows a geared drive system of a traction elevator which has components which are susceptible to vibration. The braking system due to wear and tear and shock, the gear due to friction and lubrication and the drive sheave which propels the cable. Sending the data to the cloud: A third-party web service known as Temboo was used for sending of the data to the cloud. This web application links and configures the controller to the cloud for IoT devices. It consists of different internet applications called choreos, which are Google email, Twitter, SMS, Instagram, Yahoo, PayPal, Amazon and over 30 more cloud choreos. The Google email choreo was configured on Temboo as well as run on the microcontroller for sending the data to the cloud.

4.1 Hardware components and connections

The hardware used for the device are the sensors, microcontroller, the LED, 5V power source, and jumper wires. The two sensors used in this project is LM 35 temperature sensor, breadboard connector, and ACM 3 axis Accelerometer ADXL 345. The microcontroller used is Arduino Yun board, which is the recent IoT board from Arduino with powerful accessories such as the WIFI connectivity, Ethernet, USB connectivity and Micro SD card port, making it dynamic and robust in usage and application. The board is powered by 5V voltage source, and the 5V power pin on the board is connected to the power rail on the breadboard. The ground pin on the board is also connected to the ground rail of the breadboard.

4.1.1 Temperature sensor

LM 35, has 3 pins which are the power, the ground and VCC. The power is connected to the power rail, the ground to the ground rail and VCC to the analog pin A0. The schematic of the connection is shown in Figure 3.

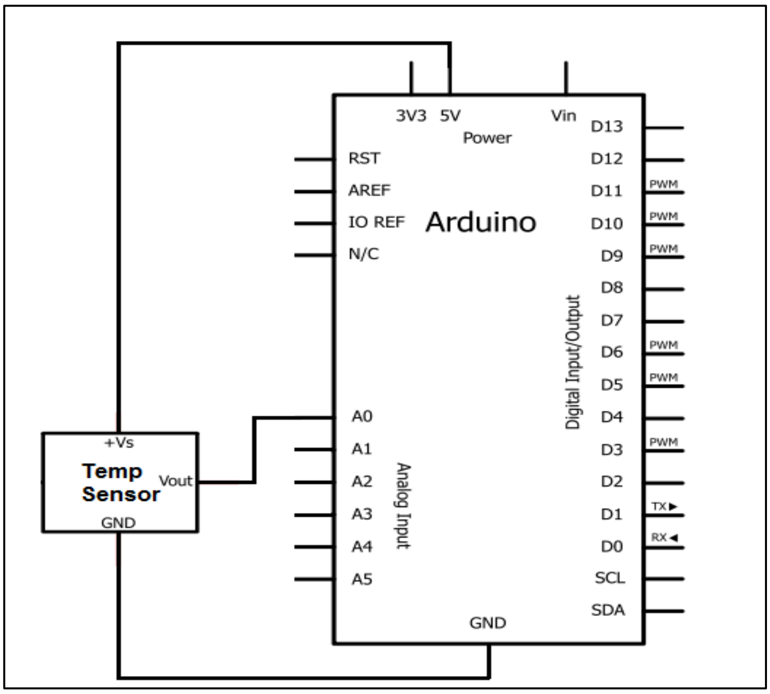

Figure 3: The connection of temperature Sensor to the controller

4.1.2 The vibration sensor

ACM 3 Axis Accelerometer ADXL 345, is connected to the microcontroller through the breadboard. It has 8 pins and connections were established to the board using the jumper wires, from the power rail to the power pin, ground rail to the ground pin and three (3) VCC pins for the 3 axial space dimensions to analog input pin 1, 2 and 3. The connections can be shown in the image in figure 4 below. ADXL 345 has an adjustable measuring range of ±16g and a high resolution of up to 13 bits, with sensitivity of 40mg/LSB in all ranges, equivalent to an accuracy higher than 1° [14]. This enables events such as detection of fast strokes and vibrations and detection of 0-g free fall conditions.

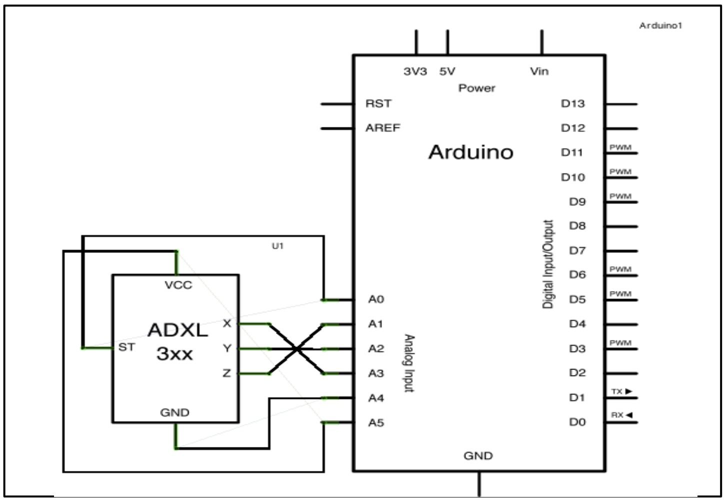

Figure 4: ACM 3 Axis Accelerometer connection

Source: https://www.arduino.cc/en/Tutorial/ADXL3xx

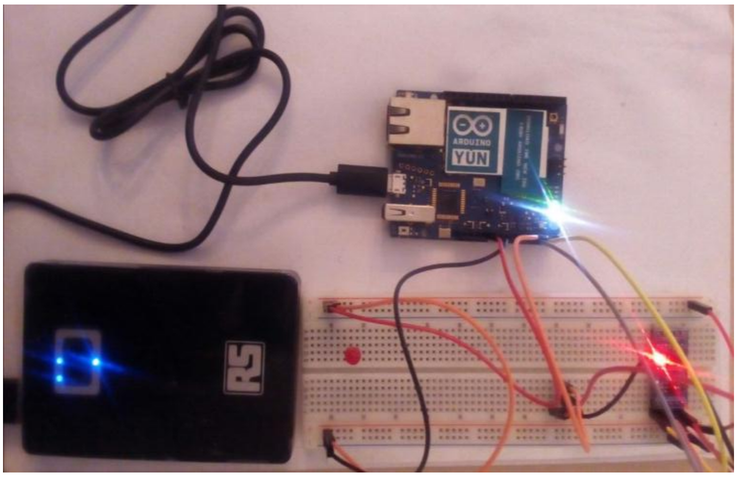

Figure 5: Set-up connections for the controller and sensors

4.2 Configuring the Arduino Microcontroller

The controller is a major component of the remote monitoring device as it interprets the signals from the sensors and controls the actuators. The Arduino Yun microcontroller is configured for two (2) settings which are the network settings and the sensor data acquisition settings which make remote condition monitoring possible unlike site-based on-condition monitoring. The network settings on the microcontroller is configured using the Wi-Fi connectivity or the Ethernet. Security is a concern for internet of things devices, therefore, the default password of the microcontroller, the Wi-Fi network for the internet access as well as the password access is changed. These are imperative because security attacks are problematic for IoT because of the minimal capacity of devices being used and the physical accessibility to sensors and actuators together with the microcontrollers at the installation sites [15].
Configuring the microcontroller for reading the values from the sensors involves coding using the Arduino IDE. The recent IDE is downloaded and installed on the PC and the communication port is initialized with the mac address of the microcontroller. The codes is run on the sketch page and it consist of three parts which include the declaration of variables, setting up the code and comparison of current condition with the severity level.

4.2.1 Calibration of the variables

The variables being considered are the room temperature as well as the 3axial vibration of the elevator car. The temperature variable name for the read signal is tempIn which is the sensor signal at varying conditions. The power input is 5V, the output signal tempIn is also in voltage which is converted to temperature unit in Celsius. The temperature in Celsius is given by the equation below;
Temperature(^{0}C) = (500.0*tempIn)/1024.0;

The vibration parameter is read using the 3 axial ADXL 345 accelerometer which is an analog sensor which works with the ADC (Analog to Digital Converter) module of the microcontroller. The output value from the accelerometer can be calibrated to values in meters per second or G-force (g). The conversion is done using the equation below;

$$R_x = \left(AdcR_x * \frac{V_{ref}}{2^n - 1} - V_{Zero\ G}\right) /Sensitivity$$

Where $AdcR_x$, is the signal value from the sensor, V_{ref} is the reference voltage which is 5V, $V_{Zero\ G}$ is the voltage at zero gravity, n is the number of bits of the sensor, and the sensitivity of the sensor.
The microcontroller reads in the signal from the sensor, processes it through the codes and sends the values out for condition monitoring analysis. The bridge.H which is the protocol that listens and connects the sensor values and the also responds to REST API calls for the sensor values from the controller [16].

4.3 Comparison of current condition with the severity level

On-condition monitoring maintenance policy of machines monitors the condition of a system for early detection of deterioration thereby preventing critical breakdown of the system. Unlike proactive maintenance where actions are taken whenever system failure occur, on-condition monitoring maintenance checks the condition of the system against the limit threshold which is the severity limit of each condition of the machine. The limits are determined by the machine manufacturer or through machine data learning algorithms. The excitation and vibration signature during a normal good working condition of a system can be used as the baseline for developing severity level from events. The condition of the system is diagnosed by reconciling the current machine condition with the severity limits and indicating a decision for proactive maintenance before critical breakdown of the system. This is executed using some lines of code for the sketch that executes the events and logic operations on the controller.

The line of code executes a logic operation which compares the current condition with the severity level as indicated by the machine manufacturer or from expert knowledge. Once the severity limit is reached, there is a notification that is sent out.

5. Programming Internet of Thing Using Arduino Yun

Programming the Internet configuration of the device makes the monitoring set-up unique and accessible remotely for monitoring purposes and fault diagnoses. This is because all IoT devices adopts a mechanism to send or receive data such as wired or wireless, Bluetooth, cellular network and many more [17]. Wireless connection is established between the microcontroller and the internet, and the email cloud service is used. The data read is sent to the email cloud through the third-party web service earlier mentioned called Temboo. Temboo web-service assist in connecting Arduino micro-controllers and Arduino-compatible devices to a vast array of web-based resources and services [18]. The third-party service configuration is in two parts and which are the configuration on the web page as well as the configuration on the sketch environment of the Arduino IDE. The google email account is first created. The most important settings for the Gmail account to connect to the Temboo web-account was to get the App specific password. This is peculiar to individual email account. To get the App specific password, there was need to activate the 2-Step verification by turning it on. An account is created on the Temboo web application, registered with the email address created. The google option is chosen and then "send email" option chosen as well. On the same page, the board type is selected which is Arduino Yun, the App specific password of the email is typed into the Temboo account set-up and the run button is clicked. This automatically generates some lines of code which is copied and pasted on the Arduino IDE. The code or sketch also have some input variable such as the data to be sent to the mail and the email address to be sent to and the variable declaration and inclusion. The email address, username, password, and message-body were replaced with the information peculiar to this research, the email created, username and Temboo-data password generated. The header file which is also generated from the Temboo app configuration is also copied to a separate tab on the Arduino IDE sketch and the sketch is compiled.

6. DATA CAPTURING

Brittain designed a data capturing engine with automatic target data location, extraction and storage at an interval of fifteen (15) minutes, similarly, the set-up is configured to capture and send the data to the email at an interval of 15 minutes [19]. In case of severity in any of the machine parameters, the message notification is sent along with the machine data. In this light, the machine experts can respond immediately to what the fault indication may be through remote access to the data history on the cloud (email).

The temperature, and the 3 axial vibrations were sent to the email from the set-up in 15-minute interval. The temperature value is read out in degree centigrade as calibrated through the code while the vibration data were also calibrated by the code run by the microcontroller on the signal values from the sensor chip. The serial monitor outputs the read data from the sensors. The normal room temperature picked by the sensor is; tempC = 27^0C.

However, National Elevator Industry states that there is a level of temperature at which there is high chances of malfunctioning of the controls [20]. Therefore, elevator manufacturers mostly specify temperature limits for the machine room which is typically in the 85 to 95^0F (30 to 35^0) range and must be maintained in the controller cabinets for proper functioning of the solid-state devices used in the control system [21]. It was crucial to evaluate the data in terms of severity and the severity limit is therefore set as 36^0C. Hence, the logic statements is used which applies the expert knowledge for decision making for fault and condition monitoring in the elevator system. Whenever the values indicate a deviation in the normal condition of the machine, it implies that the system is faulty, hence, the need for maintenance before total breakdown.

7. CONCLUSION

IoT is gaining more application in the industries spanning from embedded system to augmented automation of machines. This paper explored remote condition monitoring approach for monitoring the condition of an elevator system remotely without a physical presence. This helped to avoid machine breakdown by responding just in time during damage initiation. Furthermore, since the data from the machine is stored in the cloud and could be assessed remotely, this provided a faster maintenance service as the maintenance team can access the data online and study the deterioration pattern to project the likely mean time to failure. This approach can also be used or adopted for monitoring components or machine parts located remotely in machine assembly and in hazardous environment.

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A SYSTEMATIC REVIEW OF MICROTRANSIT SYSTEMS TOWARDS DEVELOPING A MONITORING AND EVALUATION FRAMEWORK

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ABSTRACT

According to the National Development Plan (NDP) of South Africa the development and maintenance of an efficient and competitive transport system is a key objective for the country's development. Microtransit can be described by small vehicles operating on demand with a short-distance range. This type of transport is typically used for small scale inner-city transport of passengers or goods.

In this paper, we conduct the first stages of a systematic literature review including scoping, extensive data analysis, and data categorization of studies concerning microtransit and monitoring and evaluation (M&E). We systematically review evaluation studies to extract useful information and identify main themes.

Future work will include continuing from data categorisation to concept identification and categorisation and qualitative analysis to identify the links between the two focal concepts: Microtransit and M&E towards creating a conceptual M&E framework.

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1. INTRODUCTION AND PROBLEM STATEMENT

The need for and importance of transportation systems are evident. Transportation has contributed significantly to economic, political and social development over the years as it enables trade through carrying people and goods from one place to another, creates jobs, and promotes personal freedom. Without transportation there would be no mass production, distribution of goods or trade. Transportation is thus one of the primary drivers of economic growth since the demand for and production of goods increases substantially. Existing markets can be expanded and new markets created. Without it market would be limited to local areas and only local demands will be satisfied without consideration of global demands. The economy of every country will not be able to grow and stay in an isolated neutral state [1].

Aside from the economic value that it adds transportation also contributes towards social, political, and cultural development. Globalisation is encouraged as modes of transport are becoming faster, cheaper and more effective thus narrowing geographical distance. Relationships with foreign countries can be established and people experience more personal freedom. The development of autonomous driving would for example enable elder people, children and physically challenged people to travel more easily without assistance. Other benefits include circulation of knowledge, uniformity and the strengthening of national security [1].

Modes of transport are continuously evolving and growing to adapt to changes and find optimal ways to contribute to these economic, social, political and environmental developments. It is undeniable that continuous research has to be conducted on transport as it contributes to an enormous variety of areas. However, since microtransit is a contemporary concept, little in-depth research has been conducted in this area. It is thus important that research has to be done on microtransit to fill this gap in literature concerning transportation and add to the body of knowledge.

In light of the previously stated, this article conducts the first stages of a systematic literature review on microtransit systems. It includes scoping, planning, and identification of related and relevant articles, followed by a qualitative data analysis thereof. It confirms the gap in literature regarding microtransit and uncovers the big picture of what focal themes have been researched regarding microtransit and monitoring and evaluation (M&E) considering all relevant literature. The future aim of the research is the development of a generic M&E framework that explores the links between microtransit systems and economic, social and environmental development. The purpose of this framework is to provide a decision support tool for small scale transportation organisations and similar companies to build a realistic and profitable value proposition economically, socially and politically and will enable the validation of decisions through continuous monitoring and evaluation. According to the NDP of South Africa planning and implementation should be informed by evidence-based monitoring and evaluation [2].

2. PURPOSE OF A MICROTRANSIT M&E FRAMEWORK

In order to understand what is meant by 'microtransit', it is firstly broken down by defining the word 'transit'. The Oxford English Dictionary (OED) defines the term as follows ('OED', 2017): ***Transit refers to*** the passage or carriage of persons or goods from one place to another.

From the definition of transit, the term microtransit can be developed. After addressing various literatures concerning microtransit, the following characteristics thereof are provided: Microtransit can be described by vehicles operating on demand usually within a short-distance range. This mode of transport lies somewhere between collective public transport and individual private transport. An important characteristic is connecting supply and demand through the use of information and communication technology (ICT) [3]. This type of transport typically provides flexible ride services for small scale inner-city transportation of passengers or goods [4].

According to Fund & Carbone, the Sacramento Area Council of Governments ("SACOG") defines microtransit systems as: "...fleets of privately-owned vans and shuttle buses with flexible routes based on user demand. Most microtransit systems are focused on commuter routes….For long-term planning in the region's more suburban communities, microtransit services could act as feeder routes that help connect people to destinations or major transit hubs." [5].

Monitoring and evaluation (M&E) is a method used to increase performance and succeed in reaching goals and achieving results by assessing the performance of activities and projects of organisations and state-owned enterprises (SOE's). The major goal of M&E is to improve the management of outcomes and outputs by establishing links between past, present and future procedures and decisions [6].

The United Nations Development Programme (UNDP) has identified the following as key objectives of results-oriented M&E [6], [7]:

- To promote organizational and development learning from results and evaluative thinking;
- To guarantee that informed decisions can be made;
- To align the M&E model with results-based management;
- To collect valuable information from current or past activities that can be used for future planning, and reorientation and adjustment of current policies and strategies;
- To simplify current procedures and strategies;
- To generate evidence of accountability and create transparency;
- To ensure consistency in long-term planning.

The United Nations Development Programme states that the overall purpose of M&E is to measure and assess performance in order to increase the effectiveness of managing outputs and outcomes. The 2002 version UNDP handbook was however replaced in 2009 for the reason that UNDP realised planning to be an essential prerequisite for developing an effective M&E system and incorporated planning throughout the handbook [6], [7].

Determining whether work is moving in the right direction, whether progress is made effectively or whether future work can be improved upon is nearly impossible without applying monitoring and evaluation [8]. It is thus important to have some sort of support tool or framework that can assist in determining these outcomes. An example thereof is an M&E framework also referred to as an Evaluation Matrix. This practical tool will guide the user towards achieving their end goal by achieving the key objectives mentioned previously [6].

The focus when developing an M&E framework should be results oriented since it will be used by management to improve performance and achieve goals. The M&E framework will assist in improving the management of outputs, outcomes and impacts.

3. SYSTEMATIC LITERATURE REVIEW METHODOLOGY

The research approach is conducted in a systematic manner. This process that is followed in identifying relevant articles to the proposed problem is discussed in this chapter. A systematic review approach towards building a framework of existing literature is essential in ensuring all relevant existing literature at the time is considered.

Characteristics of systematic literature reviews include: objectivity, replicability, and transparency [9]. There are various stages in conducting a systematic literature review. Various authors have proposed different approaches in conducting these reviews and divide them into different phases/stages [9]–[13]. These authors' respective frameworks (stages of undertaking a systematic literature review) were broken down and combined into a systematic literature review process illustrated in Table 1. This suggested framework contains all the required steps in performing a proper systematic literature review. Each stage is completed in different sections of this research paper as indicated in Table 1.

Table 1 Proposed framework for the systematic literature review process

Stage	*Steps*	*Additional Comments and Objectives*	*Section*
Stage 1: Scoping and Planning	a. Identify need for review b. Formulate / Frame / Specify research questions c. Break research questions down into key search terms (Define search terms) (Data categories) d. Prelim identification of inclusion and exclusion terms	• Indicate whether the review has been conducted previously • Confirm that a gap exists in the body of knowledge regarding the proposed topic.	Section 1 & Section 4.1
Stage 2: Identification (Searching)	a. Choose data sources b. Identification / Data collection from chosen data sources	• Develop a system to keep record of obtained data in a systematic manner.	Section 4.2

	c. Data selection criteria and data selection	• Ensure that all potential relevant published and unpublished work is located. • Assess quality of obtained data (published vs unpublished) • Mapping	
Stage 3: Extensive reading and categorisation of data	a. Extensive reading & data extraction b. Categorisation of data	• Extensive reading of identified studies and understanding of relevant terms • Categorisation and organisation of data from studies	Section 4.3
Stage 4: Results, Analysis and Interpretation	a. Data summaries (Results) b. Interpretation of findings	Summarising and interpretation of findings: • Number of publications per document type • Literature publications timeline (# of publications per year) • Geographic analysis • Relevance of publications • Publications per theme/concept • Citations (# of citations per author – who is the main author/contributor)	Section 4.4
Stage 5: Conceptual Framework	a. Identifying and naming concepts b. Deconstructing and categorisation of concepts c. Integrating concepts d. Synthesis and resyntheses e. Validating the conceptual framework f. Rethinking the conceptual framework	• The categorised data is analysed and broken down into concepts • The summarised data and concepts is synthesised in the form of a conceptual framework to tell us more about the "real" world [13] • The approach for developing the conceptual framework is through qualitative analysis • Validation – does the conceptual framework make sense to external parties? Make use of feedback • The model is adjusted in order to make sense across multidisciplinaries.	N.A. to this paper - Future research
Stage 6: Writing the review	a. Reporting the review b. Evaluation c. Conclusions d. Recommendations for future research e. References	• Writing of the review is a continuous process done throughout all stages since observations must be documented immediately and new understandings explained once discovered. • Evaluate the systematic literature review methodology – is it adequate? • Indicate whether missing stages and/or steps were identified • Concluding statements are made and recommendations are given for future research • A complete list of all different references is given	Sections 4 - 5 and Future research

Throughout the process of performing the systematic literature review it is important to note that the researcher must continuously take notes, document work and give explanations as new discoveries are made and concepts are understood. It is essential to make use of external inputs and feedback to ensure that objectivity is maintained. This will guarantee critical analysis and improve consistency [14]. The comprehensive understanding and process overview provided in the methodology of this section will now ensure a proper systematic literature review approach when conducting the review.

4. CONDUCTING THE SYSTEMATIC LITERATURE REVIEW

Following the description of the process towards conducting a systematic literature review in Table 3 this section now proceeds with presenting the review stages 1 to 4.

4.1 Stage 1: Scoping and Planning

The objective of the first stage is to both determine whether the review has been conducted previously and to confirm that a gap exists in the body of knowledge regarding the proposed topic of monitoring and evaluation of microtransit systems. In order to do this, focal research questions are firstly defined in Table 2 based on the problem statement. Secondary questions are also included in addition to the primary research questions.

Table 2 Primary and secondary research questions

Primary research questions	*Secondary research questions*
A. What is microtransit?	i. What are defining characteristics of microtransit? ii. Does a gap exist in the body of knowledge of contemporary microtransit and how can this gap be filled? iii. What benefits does microtransit present?
B. What is a monitoring and evaluation (M&E) framework?	i. What is the major goal and key objectives of monitoring and evaluation? ii. What are the key indicators and measures of an M&E framework?
C. What research has been conducted regarding M&E of microtransit systems?	i. From research conducted relevant to M&E of microtransit systems, what are the main themes identified regarding transportation? ii. From research conducted relevant to M&E of microtransit systems, what are the main themes identified regarding monitoring and evaluation? iii. What impacts regarding M&E of microtransit systems have been researched? iv. What are the current methods / tools / models / frameworks / policies that exist for monitoring and evaluation of transport systems?
D. How can an effective M&E framework be developed concerning microtransit using all available literature?	i. How can the effectiveness of the M&E framework be tested towards validation of the framework?

From the research questions keywords are derived describing main themes that are identified. These keywords are typically used as search terms when documents relevant to the scope of the research are gathered from data sources. The derived keywords include: Microtransit; Monitoring and Evaluation (M&E) framework; Evaluation model; Decision support; Urban; and Sustainable.

In order to guide the research, the scope of the study is established by identifying limitations and assumptions of the study. In the final step of stage 1 the limitations are set for this research by identifying including and excluding terms/concepts since the research will mostly be of a qualitative nature. The including and excluding terms are presented in Table 3.

Table 3 Limitations: Including and excluding terms

Themes	*Including terms*	*Excluding terms*
Microtransit	• Micro-transport • Micro transportation • Small scale transport • Urban / Inner city • Electric • Sustainable	• Micro-Transport Protocol (μTP) • Electrodes, Electro thermal • Fluid • Autonomous Driving
Monitoring and Evaluation (M&E) Framework	• Evaluation Matrix • Model	• Agricultural & Rural development • Food

	• Decision support • Planning, Assessing, Reporting • Transportation • Sustainable • Development • Results-based Management (RBM)	• Health & Safety • Software

4.2 Stage 2: Identification (Searching)

The second stage in conducting the systematic literature review includes developing a system to keep record of obtained research data in a systematic manner, ensuring all relevant published and unpublished data is located and considered, and to assess the quality and relevance of the obtained data.

Initially, five sources of research publications were identified to be used for collecting publications. These five internet sources include: academic databases ScienceDirect, Scopus, EmeraldInsight and ResearchGate as well as search engine Google Scholar.

An initial literature search of the internet data sources revealed that ResearchGate did not provide any useful or topic related data. This source was eliminated and not considered for any further research. The remaining sources were searched with search terms derived from the keywords as seen in Table 4. The table shows the number of search results found at the respective data sources when certain search terms were used.

Table 4 Search results for different internet data sources

Search terms	*ScienceDirect*	*Scopus*	*Google Scholar*	*Emerald Insight*
Micro + Transit	23 163	698	411 000	6019
Microtransit	**3**	**2**	79	0
Monitoring + Evaluation + Framework	163 857	5 700	3 190 000	25 155
Monitoring + Evaluation + Framework + Transportation	22 249	**119**	859 000	5 560
Monitoring + Evaluation + Framework + Model + Decision support + Transit + Transportation + Urban + System	1104 (refined search: **176**)	1 (irrelevant)	39 100	417 (access to and refined search: 123)
Monitoring + Evaluation + Framework + Microtransit	0	0	78	0
Monitoring + Evaluation + Framework + Microtransport	**3**	0	141	0

As indicated in Table 4, initial search results yielded several thousands of research documents. The need to establish a data selection criteria model is essential to ensure working objectively and systematically. Figure 1 illustrates a framework developed for eliminating data from the search results that are both unrelated and irrelevant to the scope of study.

Referring to Figure 1, using different combinations of search terms and refining the initial searches delivered a total of 869 documents from four chosen internet data sources. Google Scholar results consists of a wide variety of papers of which several are irrelevant. Due to this factor and the inability to export documents from Google Scholar and EmaraldInsight, these results were eliminated from consideration. A total of 301 results from ScienceDirect and Scopus thus remained that are related to the research topic.

The 301 related documents were analysed in an excel spreadsheet. The abstracts and keywords of each of the documents were studied to further classify the related documents as relevant, somewhat relevant, or not relevant to the scope of the study.

Exclusion criteria was applied to the remaining relevant documents in order to exclude all papers that are inaccessible, duplicates, or of a foreign language. Finally, a final data set of 62 relevant publications is found with the possibility of adding any individual papers at a later stage. No grey literature was added at this stage. The data selection criteria do however allow the addition of grey literature that is related to and relevant to the scope of study.

The final data set will be used for an in depth literature study in future research. For the statistical analysis of the systematic literature review however, all 71 relevant papers were used for analysis as well as the somewhat relevant papers in certain cases. A list of the 71 relevant publications is available in APPENDIX A. The statistical analysis, results and interpretations are completed during stage 4 in section 4.4 of this paper.

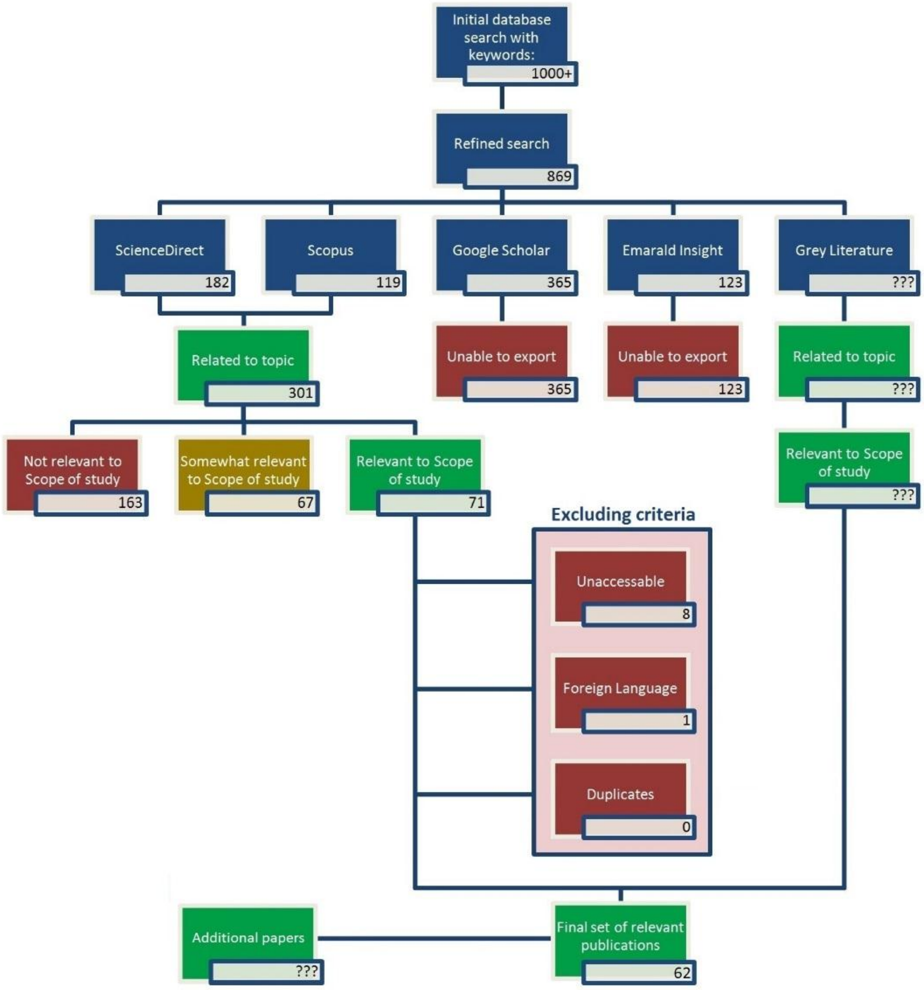

Figure 1 Data selection criteria and process

4.3 Stage 3: Extensive reading and categorisation of data

Through extensive reading of the identified papers during the third stage of the systematic literature review, a comprehensive understanding is gained of the relevant terms that are identified.

In order to properly analyse obtained data extensive reading is necessary to review identified relevant studies and gain a comprehensive understanding of the research outline. An in-depth qualitative analysis of the abstracts and the detailed exported information allowed classification of the papers into four main categories specified in Table 5. The key themes (components) identified under each of the categories are also listed in the table.

Table 5 Data collection main categories and components

Main Categories	*Components*
I. Publication paper characteristics	• Document Title • Author(s) • Year of publication • Document type • Source of document • Citations • Language • Geographic focus • Relevance of paper • Focus of paper
II. Transportation	• Urban • Public Transport • Sustainable • Congestion & Travel time • Pollution (GHG emissions) • Railway • Bus • Safety / Security • On demand / Flexible • Shared Mobility • GIS & GPS • Land-use • Freight • Microtransit • Bike • Inclusivity • ITS • Battery / Electric Vehicle
III. Monitoring & Evaluation	• Framework • Strategies, Tools & Planning • Policies / Government • Monitoring • Service Quality & Customer perception / satisfaction • Decision support • (Key performance) Indicators • Model • Survey / Interviews • Cost Benefit Analysis (CBA)
IV. Impacts	• Social • Economic • Environmental • Political

4.4 Stage 4: Results, Analysis and Interpretation

During this stage descriptive statistical analysis is done on aspects of the documents regarding publication document type, year of publishing, geography, relevance, and main themes that are identified.

4.4.1 Number of publications per document type

The analysis of the papers by document type was done on all the papers that were deemed relevant equaling a total of 138 papers. Out of these papers, the majority (84%) are journal articles followed by conference papers (10%) seen in Figure 2.

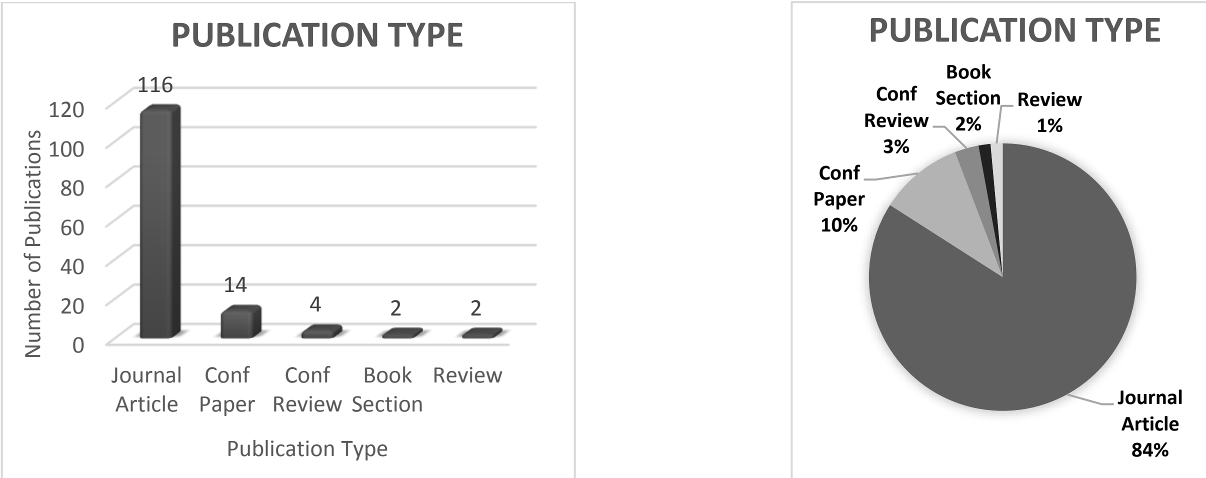

Figure 2 Number of and percentage publications per document type

4.4.2 Literature publications timeline

Both the relevant as well as the somewhat relevant papers were again used in the analysis of the publication timeline seen in Figure 3. We conclude from the timeline of an almost exponential increase in publications released each year until 2016 with the exception of 2014 and 2015. This escalation in research publications each year provides evidence of an increase in interest in the topic in recent years.

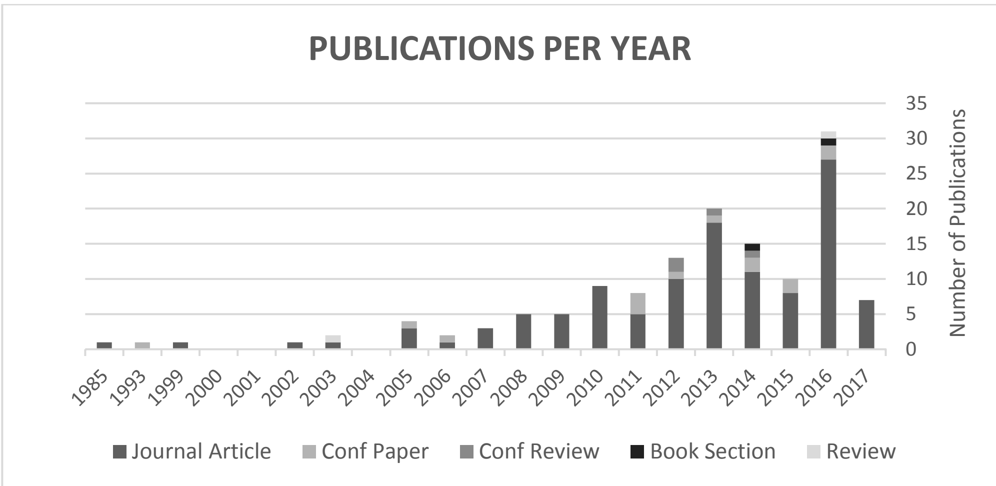

Figure 3 Publications timeline for all document types

4.4.3 Geographic analysis

A geographic analysis was done on the different author focus areas of the identified relevant publications. A summary of the geographic analysis is illustrated in Figure 4 where the numbers in the bottom left corner equals the amount of studies published by authors with a geographical area focus of the corresponding country.

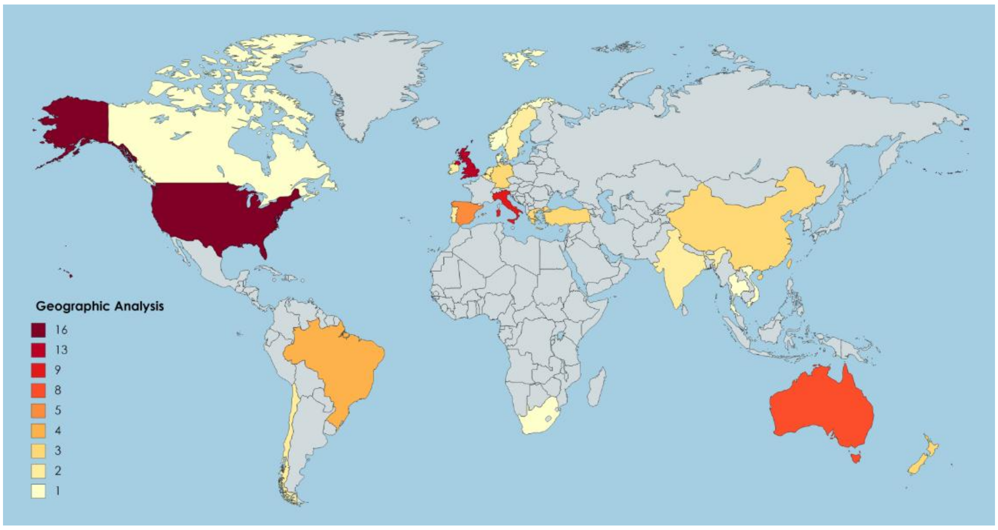

Figure 4 Geographical representation of focal research areas

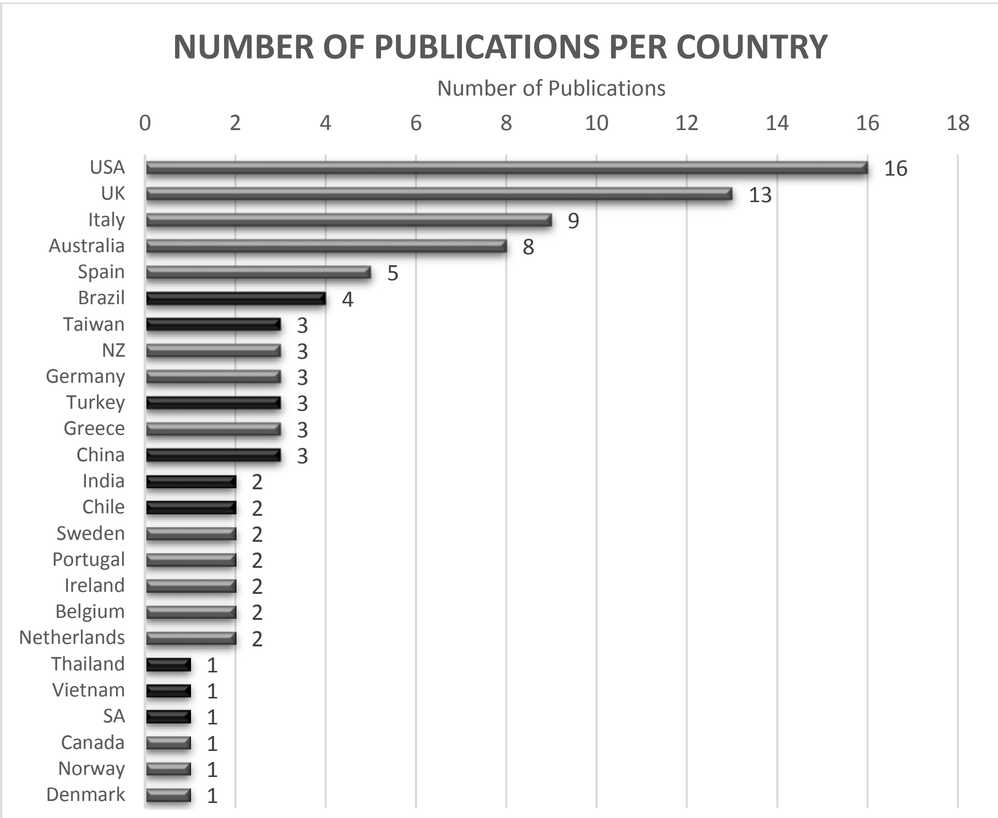

Figure 5 Countries ranked according to number of publications per country

The number of publications that is conducted by authors form a specific country is shown for every country in Figure 8. Authors from the top five countries conducting research in the development of strategies, tools and policies for an innovative and sustainable transportation system like the microtransit initiative, are located in developed countries. The top contributor is the United States of America (USA) with a total of 16 publications. The highest contributor from developing countries is Brazil with a total of 4 publications.

The 71 identified relevant publications were conducted by research institutions from 25 countries globally. Out of the 25 countries, 16 (64%) of these are developed countries and 9 (36%) are developing countries as illustrated in Figure 9. The 16 developed countries have published more research documents, contributing 78% of the identified relevant publications, regarding the identified topic than developing countries, contributing only 22% of the identified relevant publications as illustrated in Figure 10.

From these figures we can deduce that authors from developed countries are more focused than authors from developing countries are on developing research for innovative ways in which they can even further improve their transportation systems which will indirectly have positive economic, social and environmental impacts. Since developing countries are still in development, this type of research could however prove to be particularly beneficial towards making economic, social and environmental improvements.

4.4.4 Relevance of publications

The abstracts of these 71 relevant documents were considered carefully and the relevance of each were rated according to a Likert scale of between 1 and 5, where 1 represents the least relevant documents and 5 the most relevant documents. This was done to narrow the search down to an even lower amount of publications that can be handled easily and to be able to start working through the most relevant papers first.

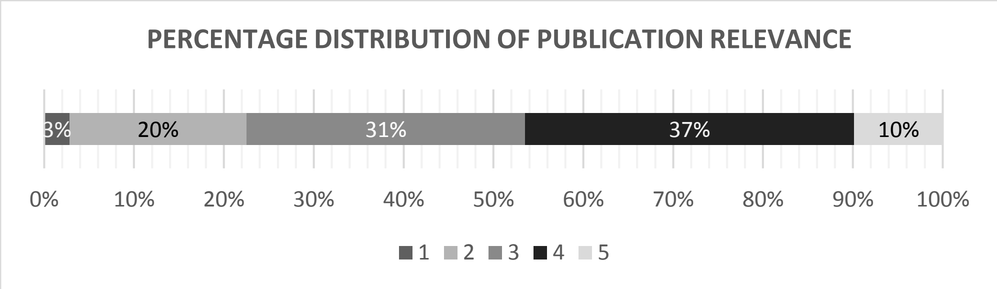

Figure 6 Percentage distribution of publications according to their relevance

4.4.5 Publications per theme

The 71 relevant publications were given unique identification (ID) numbers as illustrated in Appendix A to be able to easily distinguish between them.

A comprehensive analysis of every paper's abstract and keywords enabled the identification of main components/themes under each of the following three categories: Transportation, Monitoring and Evaluation, and Impacts as mentioned in section 3.3.1. A matrix was then created to indicate which of these themes were identified in each of the 71 relevant publications. Referring to Figure 7, the papers are firstly ranked according to their irrespective relevance ratings. Thereafter, the themes were ranked in each of the three categories according to frequency of appearances with the most common themes listed first.

	Paper ID	3	12	19	21	28	44	65	2	6	7	8	9	14	15	17	18	23	24	26	29	30	32	33	36	38	42	43	52	56	57	58	61	67	1	5	10	11	16	20	22	25	27	34	37	40	45	47	49	50	53	59	62	64	69	71	4	13	31	35	39	41	46	48	51	54	55	60	66	68	63	70	
	Relevance	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	Total
Transportation	Urban	1	1			1		1	1	1				1			1			1			1	1			1	1			1	1	1		1		1	1			1	1					1		1	1	1		1		1		1	1		1		1	1	1			1	1		1	1		37
	Public transport			1					1	1	1		1	1	1	1		1	1	1	1	1	1	1		1		1		1	1	1			1			1			1				1					1	1				1				1		1	1	1				1				1		33
	Sustainable	1		1			1	1								1		1		1		1					1		1		1	1	1	1			1		1		1	1		1					1			1								1				1			1			1	1		26
	Congestion & Travel time			1			1														1					1										1	1					1									1		1		1				1							1		1				1	14
	Polution (GHG emmisions)			1		1				1	1					1			1																		1					1					1				1				1											1						12
	Railway		1			1				1					1	1		1			1																				1				1																				1	1						11
	Bus					1			1	1									1					1				1										1								1										1			1														10
	Safety / Security	1		1		1															1				1											1	1									1												1											1				10
	On demand / flexible			1						1	1										1	1													1							1						1																									8
	Shared mobility			1						1	1									1							1															1												1													1						8
	GIS & GPS																						1		1										1	1		1															1				1																7
	Land-use		1																			1																							1															1							1			1	1		7
	Freight																														1																						1		1									1		1	1						6
	Micro- transit			1						1	1																								1																																						4
	Bike					1														1															1							1																															4
	Inclusivity	1									1									1																						1																															4
	ITS																																				1																								1												2
	Battery / Electric Vehicle																																							1							1																										2
Monitoring & Evaluation	Framework	1	1		1			1	1			1									1				1	1			1	1	1			1		1	1			1	1		1	1		1		1			1	1	1	1		1	1	1		1		1			1	1		1	1		1	1	36
	Strategies, Tools & Planning		1				1	1	1			1	1	1	1	1		1	1				1				1		1	1			1	1			1	1	1		1			1			1		1		1	1								1	1	1		1				1	1	1	1	1	35
	Policies / Government	1	1	1		1	1		1	1	1		1				1			1				1						1	1		1	1				1			1	1			1	1	1		1							1				1	1	1		1	1		1	1		1		1	33
	Monitoring				1	1		1				1					1				1				1				1				1	1		1				1		1		1							1	1	1			1	1		1	1					1	1		1	1			1	26
	Service Quality & Customer perception / satisfaction					1									1		1	1			1	1	1	1	1	1	1	1		1	1	1						1																				1			1												18
	Decision support	1	1		1	1	1					1			1	1		1															1										1									1	1												1	1		1					16
	(Key Performance) Indicators	1	1			1	1	1										1			1		1				1							1				1											1											1					1								14
	Model															1		1		1				1											1							1		1				1					1		1				1					1						1			13
	Survey / Interviews																1																		1												1											1						1							1		6
	Cost Benefit Analysis (CBA)		1										1								1																							1										1	1																		6
Impacts	Social	1		1		1	1		1	1	1		1	1	1	1		1	1		1	1					1							1	1	1	1		1			1				1				1	1			1				1		1				1					1				30
	Economic	1		1	1	1	1				1		1	1		1	1	1		1			1				1		1					1					1			1					1				1			1	1								1	1	1	1	1						27
	Environmental	1		1		1	1			1			1			1				1		1												1			1									1	1						1			1				1		1					1				1		19
	Political			1					1				1																	1							1				1					1																		1	1		1					1	11

Figure 7 Summary of publications analysis regarding relevance and identified main themes

In Figure 8 the main themes in the 'Transportation' category are ranked according to frequency of appearance. The dominant three main themes is identified: 'Urban', 'Public transport' and 'Sustainable'. The fact that microtransit appears in only 4 publications supports the notion that there exist a large gap in the literature of transportation regarding microtransit. Several of the publications have however done research on other modes of transport including busses, railways, and bikes.

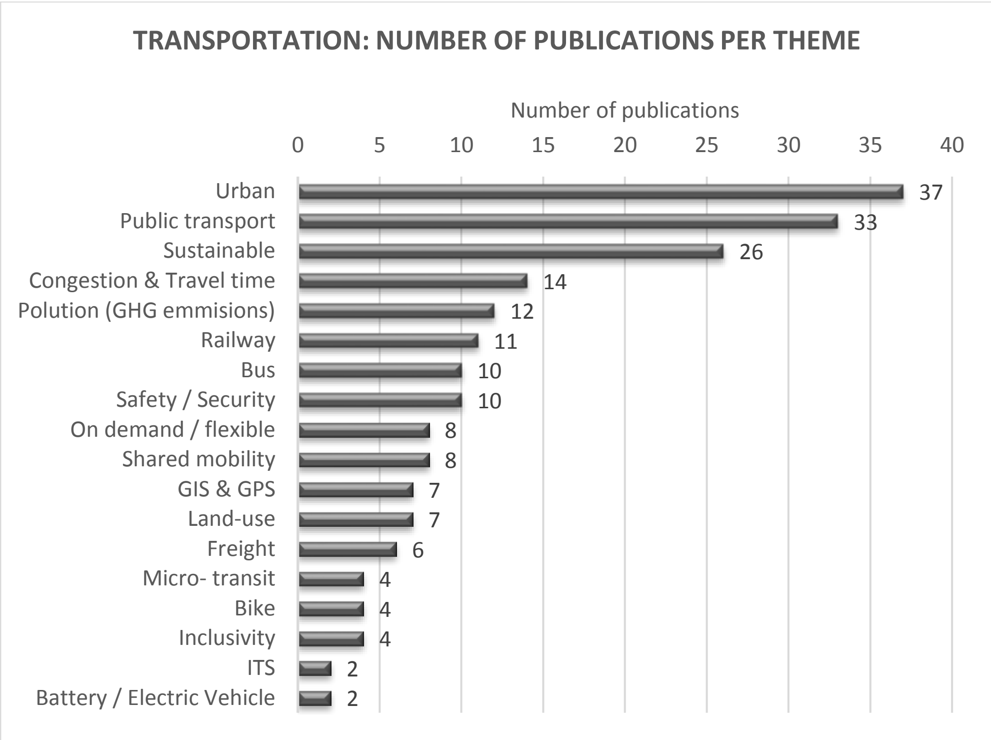

Figure 8 Transportation: Number of publications per theme

In Figure 9 the main themes in the 'Monitoring and Evaluation' category are again ranked according to frequency of appearance. The dominant three main themes identified as 'Framework', 'Strategies, Tools & Planning' and 'Policies/Government' each appears in about 50% of the 71 relevant publications. The theme 'Monitoring' is also quite common as it appears in 37% of publications.

It is however expected that themes 'Monitoring' and 'Framework' will be in several of the publications since they form part of the keywords used as search terms. Overall, a bigger variety of themes were identified in the 'Transportation' category than in the 'Monitoring and Evaluation' category.

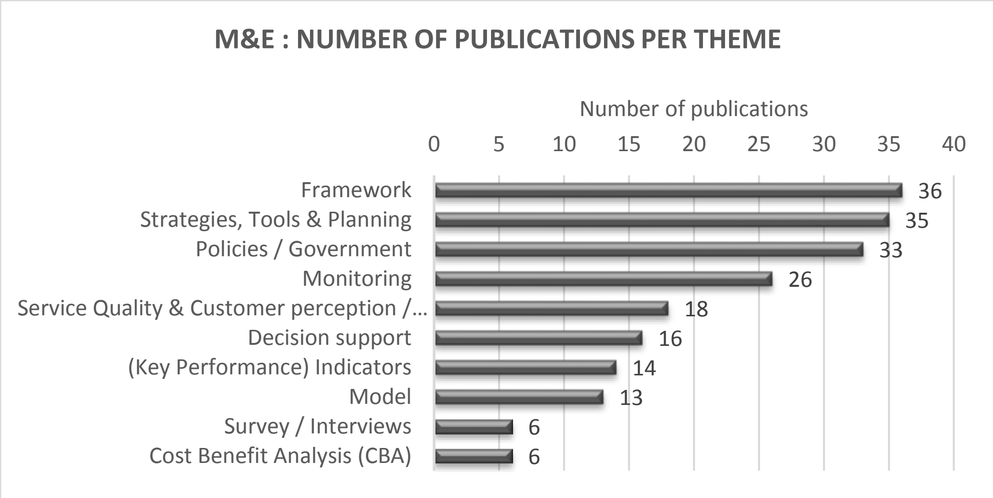

Figure 9 Monitoring & Evaluation: Number of publications per theme

In Figure 11 the main themes in the 'Impacts' category are ranked according to frequency of appearance. The dominant theme is 'Social' impacts appearing in 30 publications (42%) following 'Economic' impacts in 27 publications (38%).

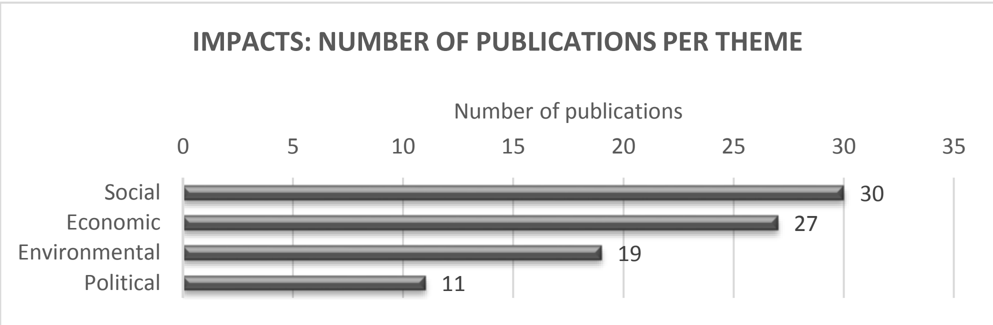

Figure 10 Impacts: Number of publications per theme

5. CONCLUSIONS & RECOMMENDATIONS

In order to extract useful information from the publications and continue from data categorisation to concept identification and categorisation, the data in Figure 8 is divided in further categories since the 'Transportation' category is a wide upper level theme consisting of several lower level themes. A further classification thereof is indicated in Figure 11 where the data from the 'Transportation' category is divided into 3 levels and linked to the identified impact themes in Figure 11. The broad concept of transportation is considered as the primary level 1 and consists of four identified transport types. In level 2, it is identified that transport can be of either freight or people. Transportation of people are either via private or public transport and can be shared transport or individual transport. These factors are then used to plot the four transport types on a graph [3]. Level 3 lists all themes identified in publications regarding transport that are more specific and are then linked with the four impacts: social, economic, environmental and political. This is useful when considering the big picture and determining what the focus of research has been regarding microtransit and M&E to date. Common themes are identified as factors to consider when creating a conceptual framework. The links between these themes and their respective impacts should prove useful when creating a conceptual framework that will provide guidance and decision support.

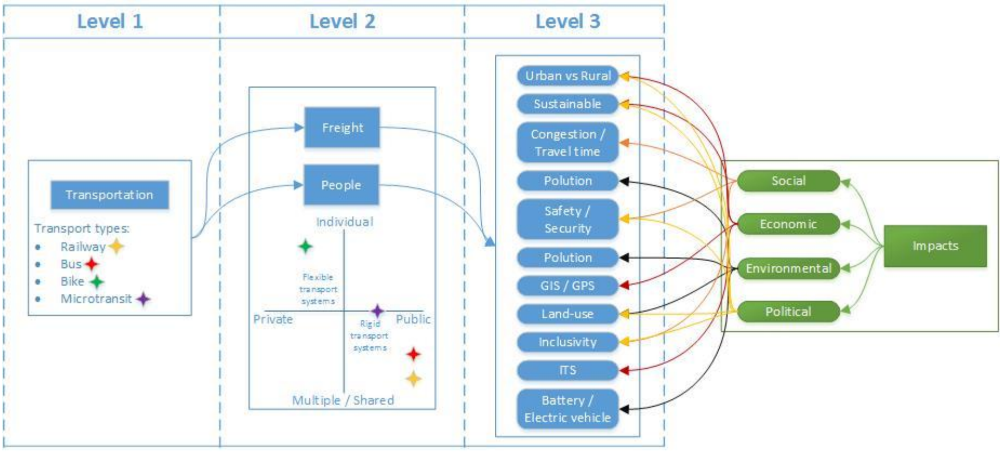

Figure 11 Data categorisation and analysis

Now that the search for papers relevant to the scope of study has been narrowed down and organised, the data analysed, and a brief introductory overview has been given on microtransit and monitoring and evaluation frameworks, the next step would be to determine how to extract data from the relevant publications in order to link the two focal concepts towards creating a conceptual framework. This will be done during the literature study through qualitative data analysis and further concept identification and categorisation.

Following the first stages of the systematic literature review and qualitative data analysis of the gathered literature papers, the notion is proved that microtransit is a novel field of which not much research has been done. The development of an M&E framework would therefore be beneficial and contribute to fill the gap in the body of knowledge of transportation.

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APPENDIX A

ID	*Year*	*Authors*	*Title*	*Reference*
1	2017	C. Frei, M. Hyland, H. Mahmassani	Flexing service schedules: Assessing the potential for demand-adaptive hybrid transit via a stated preference approach	[15]
2	2017	Lin, Liang-Tay	Role of governance in the achievement of 20-fold increase in bus ridership - A case study of Taichung City	[16]
3	2017	Munira, Sirajum	Examining public perception over outcome indicators of sustainable urban transport in Dhaka city	[17]
4	2016	Rohde J., Völz B., Mielenz H., Zöllner J.M.	Precise vehicle localization in dense urban environments	[18]
5	2016	Lanka S., Jena S.K.	On-road vehicle information processing framework for Advanced Traveler Information Systems	[19]
6	2016	Shaheen S., Chan N.	Mobility and the sharing economy: Potential to facilitate the first-and last-mile public transit connections	N/A
7	2016	Cheyne, M. Imran	Shared transport: Reducing energy demand and enhancing transport options for residents of small towns	[20]
8	2016	Reynolds J.H., Knutson M.G., Newman K.B., Silverman E.D., Thompson W.L.	A road map for designing and implementing a biological monitoring program	[21]
9	2016	Mulley, Corinne	Workshop 8 report: The wider economic, social and environmental impacts of public transport investment	[22]
10	2016	Boltze, Manfred	Approaches to Achieve Sustainability in Traffic Management	[23]
11	2016	Gschwender, Antonio	Using smart card and GPS data for policy and planning: The case of Transantiago	[24]
12	2016	Ustaoglu, Eda	Integrating CBA and land-use development scenarios: Evaluation of planned rail investments in the Greater Dublin Area, Ireland	[25]
13	2016	Hernandez, Sara	Urban transport interchanges: A methodology for evaluating perceived quality	[26]
14	2016	Emerson, David	A theoretical analysis of business models for urban public transport systems, with comparative reference to a Community Franchise involving Individual Line Ownership	[27]
15	2016	Machado-León, José Luis	The role of involvement in regards to public transit riders' perceptions of the service	[28]
16	2016	Fuggini, Clemente	Towards a Comprehensive Asset Integrity Management (AIM) Approach for European Infrastructures	[29]

17	2016	Yang, Chih-Hao	Incorporating carbon footprint with activity-based costing constraints into sustainable public transport infrastructure project decisions	[30]
18	2016	de Oña, Juan	Index numbers for monitoring transit service quality	[31]
19	2016	[No author name available]	Between public and private mobility: Examining the rise of technology-enabled transportation services	N/A
20	2015	Allam A., Onori S., Marelli S., Taborelli C.	Battery Health Management System for Automotive Applications: A retroactivity-based aging propagation study	[32]
21	2015	Born P.H., Dumm R.E., Eger R.J., III	Developing a framework for financial achievability of department of transportation research and development projects	[33]
22	2015	Imran, Muhammad	Auckland's first spatial plan: Ambitious aspirations or furthering the status quo?	[34]
23	2015	Placido, Antonio	A Methodology for Assessing the Feasibility of Fleet Compositions with Dynamic Demand	[35]
24	2015	Corazza, Maria Vittoria	The European Bus System of the Future: Research and Innovation	[36]
25	2015	Ricci, Miriam	Bike sharing: A review of evidence on impacts and processes of implementation and operation	[37]
26	2015	Jennings, Gail	Finding our balance: Considering the opportunities for public bicycle systems in Cape Town, South Africa	[38]
27	2015	Macharis, Cathy	Reviewing the use of Multi-Criteria Decision Analysis for the evaluation of transport projects: Time for a multi-actor approach	[39]
28	2014	Onatere J.O., Nwagboso C., Georgakis P.	Performance indicators for urban transport development in Nigeria	[40]
29	2014	Kesten A.S., Öğüt K.S.	A New Passenger-Oriented performance Measurement framework for public Rail transportation systems	[41]
30	2014	Stanley, John	Workshop 6 Report: Delivering sustainable public transport	[42]
31	2014	Georgiadis, Georgios	Measuring and improving the efficiency and effectiveness of bus public transport systems	[43]
32	2014	Isabello, Andrea	Reviewing Efficiency and Effectiveness of Interurban Public Transport Services: A Practical Experience	[44]
33	2014	Liou, James J.H.	Improving transportation service quality based on information fusion	[45]
34	2013	Ozbay K., Bartin B., Mudigonda S., Iyer S.	ASSIST-ME	[46]
35	2013	López-Lambas M.E., Corazza M.V., Monzon A., Musso A.	Rebalancing urban mobility: A tale of four cities	N/A
36	2013	Şimşek B., Pakdil F., Dengiz B., Testik M.C.	Driver performance appraisal using GPS terminal measurements: A conceptual framework	[47]
37	2013	Stanley, John	Workshop 3A: Governance, contracting, ownership and competition issues in public transport: Looking up not down	[48]
38	2013	Zhao, Jinhua	Unified estimator for excess journey time under heterogeneous passenger incidence behavior using smartcard data	[49]

39	2013	Nelson, John D.	The impact of the application of new technology on public transport service provision and the passenger experience: A focus on implementation in Australia	[50]
40	2013	Tsamboulas, D.	Transport infrastructure provision and operations: Why should governments choose private-public partnership?	[51]
41	2013	Gwilliam, Kenneth	Cities on the move – Ten years after	[52]
42	2013	Klinger, Thomas	Dimensions of urban mobility cultures – a comparison of German cities	[53]
43	2013	Freitas, André Luís Policani	Assessing the quality of intercity road transportation of passengers: An exploratory study in Brazil	[54]
44	2013	Zheng, Jason	Guidelines on developing performance metrics for evaluating transportation sustainability	[55]
45	2012	Zheng, Jie	Strategic policies and demonstration program of electric vehicle in China	[56]
46	2012	Medda, Francesca	Land value capture finance for transport accessibility: a review	[57]
47	2012	Politis, Ioannis	Integrated Choice and Latent Variable Models for evaluating Flexible Transport Mode choice	[58]
48	2012	Lindholm, Maria	Challenges in urban freight transport planning – a review in the Baltic Sea Region	[59]
49	2012	Miranda, Hellem de Freitas	Benchmarking sustainable urban mobility: The case of Curitiba, Brazil	[60]
50	2012	Diana, Marco	Measuring the satisfaction of multimodal travelers for local transit services in different urban contexts	[61]
51	2011	Yi-Zhong F.	Performance measurement of the U.S.'s service management and its enlightment to China: Examples from the transportation service subsidy of the United States	N/A
52	2011	Moreland K., Ogle J., Chowdhury M.R., Dunning A.	Transit-system evaluation process: From planning to realization	[62]
53	2011	Skordylis A., Trigoni N.	Efficient data propagation in traffic-monitoring vehicular networks	[63]
54	2010	Eisele W.L., Schrank D.L.	Conceptual framework and Trucking application for estimating impact of congestion on Freight	[64]
55	2010	Behrendt, Hannah	Part II: Policy instruments for sustainable road transport	[65]
56	2010	Stanley, John	Workshop report – A successful contractual setting	[66]
57	2010	Macário, Rosário	Competing for level of service in the provision of mobility services: Concepts, processes and measures	[67]
58	2010	Muñoz, Juan Carlos	On the development of public transit in large cities	[68]
59	2009	Borzacchiello M.T., Torrieri V., Nijkamp P.	An operational information systems architecture for assessing sustainable transportation planning: principles and design	[69]
60	2009	Gudmundsson H., Ericsson E., Hugosson M.B., Rosqvist L.S.	Framing the role of Decision Support in the case of Stockholm Congestion Charging Trial	[70]
61	2008	da Silva, Antônio Nélson Rodrigues	Multiple views of sustainable urban mobility: The case of Brazil	[71]
62	2007	Barceló J., Grzybowska H., Pardo S.	Vehicle Routing and scheduling models, simulation and City Logistics	N/A

63	2007	Tricker, Reginald C.	Assessing cumulative environmental effects from major public transport projects	[72]
64	2006	Van Geldermalsen T., O'Fallon C., Wallis I., Melsom I.	Travel behaviour change evaluation procedures and guidelines	N/A
65	2005	Costa M.S., Silva A.N.R., Ramos R.A.R.	Sustainable urban mobility: A comparative study and the basis for a management system in Brazil and Portugal	N/A
66	2005	Loo B.P.Y., Hung W.T., Lo H.K., Wong S.C.	Road safety strategies: A comparative framework and case studies	[73]
67	2005	Jeon C.M., Amekudzi A.	Addressing sustainability in transportation systems: Definitions, indicators, and metrics	[74]
68	2005	Hull, Angela	Integrated transport planning in the UK: From concept to reality	[75]
69	2002	Proost, S	How large is the gap between present and efficient transport prices in Europe?	[76]
70	1999	Turner D., Dix M., Gardner K., Beevers S.	Setting traffic reduction targets for London	N/A
71	1985	Pake Bruce E., Demetsky Michael J., Hoel Lester A.	EVALUATION OF BUS MAINTENANCE OPERATIONS.	N/A

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FRAMEWORK FOR THE DEVELOPMENT OF A LEARNING FACTORY FOR INDUSTRIAL ENGINEERING EDUCATION IN SOUTH AFRICA

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ABSTRACT

Learning Factories (LF) are model factories that are used to simulate the production environment for educational and experimental applications. In order to manage the impact of new industrial concepts such as Industry 4.0 on Industrial Engineering (IE) education curriculum requirements, realistic teaching and learning infrastructure such as a learning factory are required. A LF has been established in the Department of Industrial Engineering at the University of Stellenbosch. The aim of this paper was to describe the chronological development process embarked on, to establish the Stellenbosch Learning Factory (SLF) framework and the implementation thereof according to desired Industrial Engineering curriculum outcomes. The process documents the project evolution from clean-slate status, where the project specifications and requirements were deliberated, to the fully functional academic manufacturing environment of today. The SLF framework is established in a South African context and introduces a product of medium assembly complexity to be utilised for learning and workshop exercises. The framework includes the curriculum for undergraduate industrial engineering and Industry 4.0, the product that can support the learning curve of implementing theory in practice, and the facility to enable participants to achieve success. Future finer tuning of the SLF layout and exercises for maximum learning experience are also discussed in the South African industry context.

OPSOMMING

Leerfabrieke (LF) is model fabrieke wat gebruik word om die produksieomgewing vir opvoedkundige en eksperimentele toepassings te simuleer. LF bestuur die impak van nuwe nywerheidsbegrippe soos Industrie 4.0 in Bedryfsingenieurswese se kurrikulumvereistes wat realistiese onderrig en leerinfrastruktuur soos 'n leerfabriek vereis. 'n LF is in die Departement Bedryfsingenieurswese by die Universiteit van Stellenbosch gestig vir die voorgeneomde rede. Die doel van hierdie dokument is om die chronologiese ontwikkelingsproses wat aangewend was te beskryf en die Stellenbosch Leerfabriek (SLF) raamwerk en die implementering daarvan op te stel volgens verlangde bedryfsingenieurswese kurrikulumuitkomste. Die proses dokumenteer die projek se evolusie van skoon-vlak status, waar die projek spesifikasies en voorvereistes gevestig moes word, tot die ten volle funksionerende akademiese vervaardigingsomgewing van vandag. Die SLF-raamwerk word in 'n Suid-Afrikaanse konteks gevestig en stel 'n produk van medium kompleksiteit voor wat aangewend word vir ‘n leer- en werkswinkelsoefeninge omgewing. Die raamwerk sluit in: die kurrikulum vir voorgraadse bedryfsingenieurswese en Industrie 4.0, die produk wat die leerkurwe van die teoretiese toepassing van klaskamer tot praktyk kan ondersteun, en die geleentheid om deelnemers in staat te stel om sukses te behaal. Toekomstige fyner afwerkings van die SLF-uitleg en oefeninge vir maksimum leerervaring word ook in die Suid-Afrikaanse bedryfskonteks bespreek.

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1. INTRODUCTION

Universities and training facilities are challenged with identifying future job profiles and correlated competence requirements and have to adapt and enhance their education concepts and curriculums accordingly. Learning Factories (LF) are education tools that are used to simulate the production environment for educational and experimental applications [1]. These production environments facilitate the opportunity for students and employees to experience the manufacturing industry with the goal of understanding and integrating knowledge into contextual circumstances. The term "learning factories" is used for systems that address both parts of the composition of the two words "learning" and "factory". Hence, it should include elements of teaching and learning, as well as a production environment. The word "learning" in the term emphasizes the importance of experiential learning [2]. In the last decade or so, a number of learning factories for education, training, and research have been established in industry and academia. However, only recently have learning factory initiatives been elevated from a German level to a worldwide level [1].

In order to manage the impact of new industrial concepts such as Industry 4.0 on industrial engineering (IE) education curriculum requirements, realistic teaching and learning infrastructure such as a learning factory are required [3]. One example is the Stellenbosch Learning Factory (SLF) at the Industrial Engineering department at Stellenbosch University. The SLF is regarded as still in the process of being developed, but can already facilitate production line setup and streamlining exercises. Therefore, the initial exploratory research design and implementation framework of the SLF will be discussed in detail to present the development and incremental improvements from clean slate to current state. Similar to the process taken by Tisch et al. [4], this study will cover the curriculum that was used as a basis of the SLF framework and how the product and facility was used to support the curriculum for student and industry workshops.

Popular topics for the LF exercises include optimisation of production activities and LEAN management of production processes and methods [5]. The initial vision for the SLF was to create an educational environment where current Industry 4.0 and industrial engineering theories and methodologies could be experienced with the use of the "learning by doing" approach. The mission was to produce a facility with modular workstations that can be customised to any academic circumstance whilst being robust and complex enough to resemble actual manufacturing environments [4]. In this study the existing Industrial Engineering modules at Stellenbosch University are analysed and relevant key focus areas, revolved around the Industry 4.0 value drivers, are revealed.

2. LITERATURE STUDY

2.1 South African Industrial Context

When the South African workforce is compared to the likes of the German workforce, South Africa's workforce is the complete opposite of that of a first world country like Germany. South Africa is known for its low skilled, low cost and unproductive workforce [6]–[8]. Therefore, the working environment and training has to be specifically designed to target these attributes and focus on creating possible solutions within the manufacturing environment. Now, with the LF being a synthetic factory environment, these possible solutions can be implemented for research purposes. Research can be designed to target information flow in a manual process and show how more effective, a digital equivalent can be. Research can also be designed to investigate the use of visual aids to help the workforce to comprehend their productivity level and use them to increase their salary incentive using IoT technologies. These types of studies, together with the others that investigate automating labour intensive tasks, which are not value adding, can be investigated all in the SA industrial context with the use of a learning factory.

2.2 Industry 4.0

The fourth industrial revolution, or Industry 4.0 (Industrie 4.0), is a German campaign that is being driven by the advancements of the information age [9], [10]. Academia and industry partners are investigating how information is gathered from clients, users and/or industries and how this data can be used to create smart services that support each other. These smart services will enable a factory's capacity and production rate to sync up with customer needs, or customer needs and requirements will influence product specifications [10]. All of these services will stretch over the financial industry, insurance, manufacturers, marketing and smart cities or electrical grids. Industry 4.0 is trying to integrate all aspects of commerce within each other under one cloud based, big data solution [11]–[13]. Thus, to keep up with this movement, industrial engineering should embrace the campaign and learn how to use the data generated to process and produce the optimal condition for every logistical, production or risk evaluation.

2.3 Learning Factory

As previously mentioned, learning factories are educational tools that create a platform where theory can be implemented in a mock manufacturing environment for maximum knowledge transfer to the participating students or workers. Initially, the idea for a learning factory at Stellenbosch University was realised by Van Schalkwyk [14] around 2013 when a case study for the Learning Factory MicroManu at the IE department was introduced. Some of the concepts introduced by Van Schalkwyk are apparent in the current Stellenbosch Learning Factory. Before any official documentation for the SLF was drafted, an investigation into how others built their LF to achieve their envisioned outcomes, was explored. This was accomplished by visiting two LFs situated internationally by the development team. The team that help develop the SLF consisted of three senior lecturers and twelve masters' students. The students were sent to Germany as part of a knowledge exchange program mostly funded by the German Academic Exchange Service (DAAD). The students attended the learning factory summer school in order to recreate or copy the following learning factories:

1. LPS Learning Factory, Ruhr-University (Bochum, Germany), small batch manufacturer and is used by the students to investigate process flow and value adding activities. The layout is similar to that of a workshop and contains all the necessary equipment for complicated metal component manufacturing. LEAN and energy analysis of each process can be investigated in a semi-automated environment and has been in operation since 2009 [15],[16].
2. ESB Logistics Learning Factory, Reutlingen University (Reutlingen, Germany), is a small production environment that incorporated current technology within the production process. There was an unmanned inventory replacement vehicle that could refill empty workstation components from a supermarket inventory. It also made use of complicated conveyor setups to help the operators with distribution of work in progress (WIP). This LF also had a robot that can perform Human Machine Interaction (HMI) or human-robot collaboration [17].

After visiting the above mentioned learning factories the following became clear: a learning factory is an educational and an investigational tool that enables combined theoretical and actual implementation learning methods [15], [4]. A learning factory provides a platform where students can learn theory with real world examples, but can also implement and investigate current technology in a controlled and functional production environment. This dual purpose created the mind-set of incremental design opportunities that provide a platform for manual operations to be digitised with the use of Internet of Things (IoT) and related technologies. This provides the necessary platform for creative and futuristic digital factories that utilise Industry 4.0 concepts.

3. FRAMEWORK DESIGN AND IMPLEMENTATION

This section details the development and implementation activities of the Stellenbosch Learning Factory (SLF). It will discuss the framework and its elements followed by the chronological development of the process that discusses each stage of SLF's progressive establishment stages.

3.1 Funding

Funding is one of the most important aspects when it comes to any project. In order to take the learning factory from concept to what it is now, substantial funding had to be secured. Partnerships were key to secure the necessary funding. In order to establish any learning factory, substantial funding should be secured first.

3.2 Framework

The framework for the SLF consist of three integrated layers to produce the final SLF production environment focussed on the solution generating context of South African industries' problems. In Figure 1, the three layers are curriculum, product, and facility, and can be treated as an implementation plan for the framework from top-to-bottom or bottom-to-top approach. This is due to the integration of each layer and how each layer element is dependent on exactly how other layers are implemented. However, to create a fully functional LF according to the development team, the entire framework had high importance to the success of the SLF and it was decided to use a middle-out approach where the product will be used as focal point to fulfil the other framework layers.

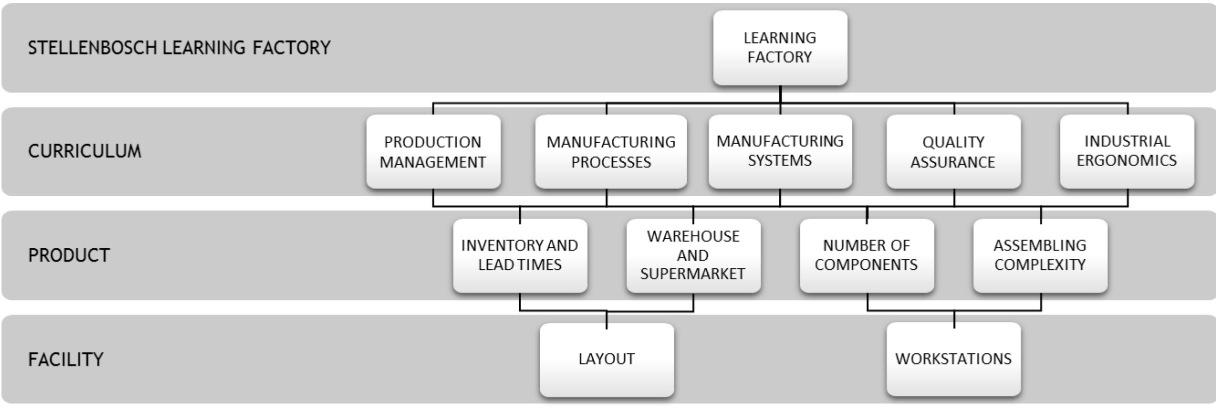

Figure 1: Stellenbosch Learning Factory implementation framework

The process undergone by the development team, therefore, investigated a product that could fulfil all the curriculum prerequisite elements, such as those discussed in the next section, and then design a facility that will support the product being manufactured. This process is known as the middle-out approach and creates a full circle mind-set that can incorporate the entire framework. This process thus enabled the development team to choose a product that can satisfy all the necessary activities to achieve all the curriculum outcomes whilst still being assembled in the same facility using the same equipment. This approach was also followed due to Passenger Rail Agency of South Africa (PRASA) sponsoring some of the product, so the product was aimed at the rail industry.

3.2.1 Curriculum

At the Department of Industrial Engineering the requirements for the learning factory curriculum should be aligned with the current undergraduate courses as well as future concepts such as Industry 4.0. According to Sackey, Bester, and Adams [3] some of the key areas for IE student knowledge, competency development and demonstration in an Industry 4.0 environment are:

- Production Systems and Management
- Physical and digital assistance systems (researching, developing, or implementing guidelines)
- Data acquisition, conversion, interpretation, decision-making, and feedback processes
- Systems perspective and integration

The modules that best cover these four key areas are Production Management, Manufacturing Processes, Manufacturing Systems, Industrial Ergonomics, and Quality Assurance. Table 1 shows these modules at the Department of Industrial Engineering at Stellenbosch University alongside the concepts covered and required Engineering Council of South Africa (ECSA) competencies [18].

Table 1: Industrial Engineering Courses and Module Competencies adapted from [19]

IE Modules	**Concepts Covered** [20]	**Broad Competencies** [18]
Production Management	Operations management, lean management, logistics, process optimisation, supply chain management, personnel requirements, materials handling, inventory control, cost accounting, just-in-time, and quality management	Competency to manage complex engineering activities.
Manufacturing Processes	Properties of materials, casting processes, shaping of plastics, metal forming, bulk deformation of material, sheet metal working, principles of metal machining, cutting tools for machining, welding processes, mechanical assembly, rapid prototyping, and economic considerations for machining.	Competency to design and develop solutions to complex engineering problems.

Manufacturing Systems	Manufacturing systems, CAD, concurrent engineering, rapid prototyping, CNC technology, part inspection, material handling, group technology, manufacturing cells, flexible and reconfigurable manufacturing	Competency to design and develop solutions to complex engineering problems.
Industrial Ergonomics	Operation analysis, work standards, reduction of setup times, training practices, remuneration, anthropometry, workstation and tool design, man/machine interfaces, the work environment, cognitive work, shift work, aspects of occupational health and safety	Competency to make ethical decisions.
Quality Assurance	Definition of quality, methods and techniques for quality assurance, statistical process design, identification of quality noise factors, synthesis and selection of design concepts for robustness	Competency to meet standards expected independently in employment or practice.

It is important that the curriculum is updated in order to keep up with modern industrial trends such as Industry 4.0. Sacky and Bester [21] described how important it is to reform the curriculum in order to prepare industrial engineers for industry and avoid greater shock than that caused by the information technology identity crisis of the 1990s. Figure 2 illustrates the 8 value drivers of Industry 4.0 and their corresponding industry levers. According to Sackey and Bester [21] the key functional features of an Industry 4.0 system include: a modular structure for increased flexibility; virtualisation, with a strong emphasis on simulation and decentralised decision-making; real-time capability for fast response; interoperability, whereby entities communicate seamlessly with each other. Several of these features are currently present in the SLF.

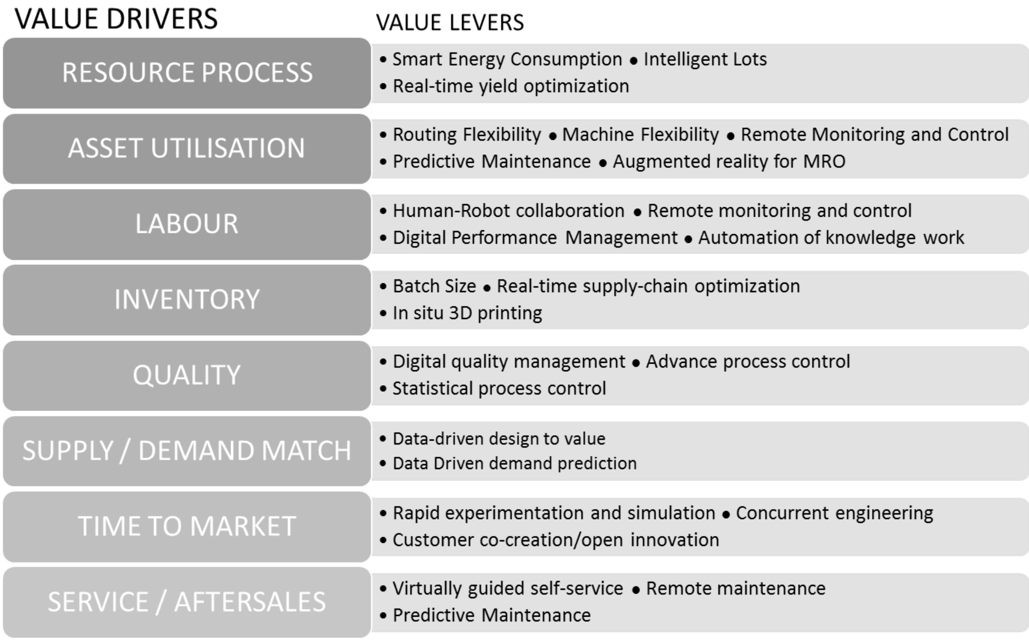

Figure 2: Industry 4.0 value drivers and levers, adapted from Baur and Wee [22]

The five Industrial Engineering modules at Stellenbosch University were deconstructed and each aspect that contains an Industry 4.0 value lever was identified. The five modules and their common connections to the Industry 4.0 value drivers are displayed in Table 2.

Table 2: Industry 4.0 value drivers linked to IE module content

		Industrial Engineering Modules				
Value Drivers	**Industry Levers**	**Production Management**	**Manufacturing Processes**	**Manufacturing Systems**	**Industrial Ergonomics**	**Quality Assurance**
Asset Utilisation	Routing flexibility			X		
	Machine flexibility		X	X		
	Remote monitoring and control					
	Predictive maintenance	X				
	Augmented reality for MRO					
Labour	Human-robot collaboration		X	X	X	
	Remote monitoring and control					
	Digital performance management	X		X		
	Automation of knowledge work				X	
Inventories	Batch Size	X		X		
	Real-time supply-chain optimisation	X				
	In-situ 3D printing		X	X		
Quality	Digital quality management			X		X
	Advanced process control			X		X
	Statistical process control					X
Supply/ Demand Match	Data-driven design to value	X				
	Data-driven demand prediction	X				
Time to Market	Rapid experimentation and simulation					
	Concurrent Engineering			X		
	Customer cocreation/ open innovation					
Service/ Aftersales	Predictive maintenance	X				X
	Remote maintenance					
	Virtually guided self-service					
Resource/ Process	Smart energy consumption	X				
	Intelligent lots	X				
	Real-time yield optimisation	X				

Table 2 was used to identify possible didactics for future implementation or alignment of modules in the learning factory. All the necessary educational outcomes that were part of the SLF framework from the industrial engineering curriculum can then be investigated. Currently the SLF has implemented the following IE concepts: Logistics; Material handling; Motion Time Management (MTM); Ergonomics; Cycle times; Line balancing; Work breakdown; Bottleneck investigation and 3D printing inventories. These concepts can provide students with the ability to assess the manufacturing line and produce logical and informed improvements for increased production capacity, which they can upscale to overcome industry sized problems. They were specifically chosen from the curriculum to provide the most extensive use of both the product and the facility.

3.2.2 Product

The product chosen for the SLF is an O-scale train set, consisting of two varieties. The average amount of components to complete a train are 61 individual parts, which increases the logistical and material handling complexity of assembly. A collaboration with the PRASA Research Chair was initiated in order to procure the physical rail wagon models for the Stellenbosch Learning Factory [19]. The development team decided to keep the number of parts per variant relatively high, but manageable. Therefore, they created a product complexity scale that was directly related to the amount of components necessary to complete a product and incorporated this scale within the product selection process for the SLF. The scale had a lower limit of 20 parts that was governed by the product to be successfully used to implement within the curriculum and an upper limit of 100 parts that would be unable to be accommodated by the SLF facility. Together with this complexity scale, the assembly steps, different assembly tools and size of each component were taken into consideration to supplement the curriculum with proper case studies for students. The assembled and partially assembled train models can be observed in Figure 3 below. The figure shows two different variants of the train, the figure on the left is the Driving Carriage and the figure on the right is a Passenger Carriage.

Figure 3: O-Scale Metrorail train set product for SLF with (left) driving carriage and (right) passenger carriage

The specific train model was therefore chosen due to its coherence to the complexity scale while using a variety of methods of assembly steps. The O-scale was large enough to handle during assembly, but small enough to fit into containers that can sustain logistical and storage capacities.

3.2.3 Facility

The objectives were to create a manufacturing environment from a clean-slate to the optimum facility in which a product is successfully assembled. In Figure 4, the SLF environment can be seen, developing from clean slate state (left) to the current setup (right) that is currently being used to facilitate workshops.

Figure 4: Progression of SLF facility construction and layout (left to right)

The SLF infrastructure was constructed in a sequence that started parallel to the product being manufactured by an external supplier. The facility layout and constructed workstations were decisively developed with the purpose of future expansion in production line setup and technology incorporation. Therefore, all of the workstations are mobile, operating on wheels that can be locked. The workstations were constructed to be filled manually out of the warehouse or supermarket, or can be semi-automatically loaded from a mobile supermarket. Currently, the facility includes ten workstations, two supermarkets, a warehouse, a rework/scrap table together with a shipping table. The workstations consist of multiple assembly workstations in a process chain configuration together with a quality check, order, delivery and rework stations. The learning factory infrastructure is also a very important aspect. The infrastructure of any learning factory should be flexible and modular in order to cope with the everchanging external environment. This will ensure continuation and sustainability of the learning factory project as the infrastructure is able to adapt to changes with little capital input.

3.3 Chronological Development

The next section will detail the development process of the SLF over the course of the past two years. The chronological growth of the project can be observed in Figure 5. It shows the date of clean slate start, the date when the proposed framework was achieved, and the current and future state of the SLF.

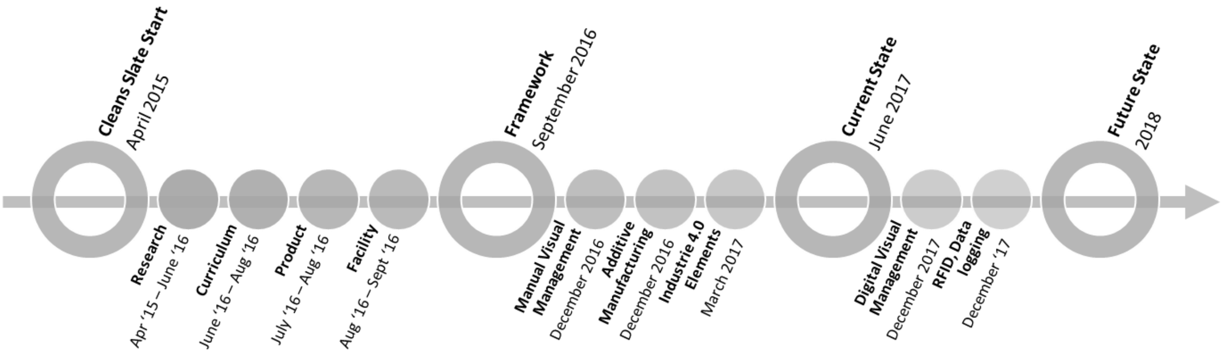

Figure 5: Chronological development process of the Stellenbosch Learning Factory

As can be seen from this timeline, the SLF project officially started in April 2015 and matured to its current state. The timeline is broken up into four distinct sections that started with the clean slate start. This section was dedicated to fulfilling the prerequisites of the SLF framework.

3.3.1 Framework State

The framework state of the LF was achieved in September 2016 and was benchmarked by the incorporation of every aspect by the developed framework. It was achieved by the very determined development team in just three short months. In this time, all the workstations were constructed to every process steps' needs. The product had been deconstructed into sections which are assembled at each workstation. Following this, the first workshop or SLF Summer School was held at the Stellenbosch Industrial Department in October 2016. This Summer School comprised of mostly German students in order to benchmark the SLF to what they were used to in Germany.

3.3.2 Current State

Since September 2016, additional projects have been completed in the LF as part of academic studies. The first was an undergraduate student that investigated the use of manual visual management tools that can be incorporated into the manufacturing environment to display production information. Students and faculty members were able to track production information that was required by the curriculum on key performance indicator (KPI) boards. Additive manufacturing investigation into rapid part generation instead of lengthy logistical process was investigated in regards to time management and feasibility studies. Lastly, Industry 4.0 elements have been implemented into the SLF work environment to gather more accurate data and produce real time information. The learning factory is slowly progressing into the classroom and IE curriculum as some modules are adapting to the times and incorporating a learn by doing aspect.

3.3.3 Future State

The future educational goal of the SLF is to host more sections from IE modules at the learning factory and actively measure the impact of this. This will give IE graduates from Stellenbosch University the upper hand when transitioning from the classroom to industry, as the gap could be adequately bridged by the learning factory. A research goal of the SLF is to investigate technology and how IoT can simplify data gathering and processing. These new technologies can be integrated in the manufacturing environment and interact with the worker, work piece or work space to increase the productivity of the worker and increase the production output capacity of a factory. This is the future investigation potentials, especially in the SA context where the productivity improvements will greatly affect our country's overall prosperity. This includes bringing digitalisation into the factories and investigating how digital visualisation management, RFID, WiFi communication, and data logging can influence the workforce and traceability of their output.

4. CONCLUSION

A framework for the SLF was successfully developed. The learning factory facility was built on the premise of integrating the "learning by doing" experience into the Industrial Engineering curriculum. The study also investigated the existing Industrial Engineering modules at Stellenbosch University, and the relevant key focus areas revolved around the Industry 4.0 value drivers, were revealed, and can be included in curriculum moving forward. The SLF framework was developed starting with the importance of academic output, then the product that can supply the necessary complexity to demonstrate production line improvement possibilities and the manufacturing environment where production lines can support the need of incremental improvement by being modular and mobile. The SLF can also be utilised to supply students with the opportunity to develop solutions to industry sized problems in an artificial factory environment. With this as a platform premise for its conception, the SLF can thus provide the necessary support for future development in the technology incorporation and integration of Industry 4.0 and related concepts into the manufacturing environment. The SLF's clean slate start to current state and future possibilities were discussed with the use of a chronological development process explanation.

Looking back, the developmental framework for the SLF followed similar morphology to those described by Tisch et al. [23], [4], [24], and Sackey et al. [3]. The SLF also has all of the key characteristics described by Metternich et al. [25]. This indicates that even from a South African perspective, a generic framework does exist. However, it is apparent that there are several variations in terms of workforce and economic needs, between Germany and South Africa, and this is apparent in the Learning Factory curriculum and infrastructure. Learning factories in Germany are more focussed on Industry 4.0 and are far more advanced in their implementation of it. The SLF however is keeping to a pace that is indicative of the current industry in South Africa, and their adoption of Industry 4.0. The future goals of the SLF are clear and implementation of new infrastructure is done on an annual basis through student projects. Further work, through student exchange programs, should benefit the SLF and bring it to the forefront of Industry 4.0 implementation in South Africa.

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DEVELOPMENT OF A BIG DATA ANALYSIS DEMONSTRATOR

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ABSTRACT

It is widely agreed that the amount of data being generated and stored online and in industry is increasing. The purpose of this study is to develop a Big Data demonstrator to illustrate what is required to conduct Big Data Analytics, which is built on an architecture proposed herein. The demonstrator is comprised of various components, methods and tools researched to analyse a large amount of data. The development of this demonstrator is aimed to provide a platform on which further research in the Big Data environment could be conducted, specifically looking at the value Big Data analytics holds for the industrial engineering industry.

OPSOMMING

Daar word saamgestem dat die hoeveelheid data wat gegenereer en gestoor word op die web en in industrie teen 'n geweldige pas toeneem. Die doel van hierdie studie is om die potensiaal van 'Big Data' te demonstreer wat gebou is uit 'n argitektuur voorgestel hierin. Die voorgestelde demonstrasie model bestaan uit 'n verskeidenheid komponente, metodes en gereedskap wat in hierdie studie nagevors word, om 'n groot hoeveelheid data te analiseer. Die demonstrasie model is ontwerp om te dien as 'n platform vir verdere navorsing in die 'Big Data' veld, spesifiek gemik op hoe 'Big Data Analytics' waarde toevoeg tot die bedryfsingenieurswese veld.

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1. INTRODUCTION

Analytics (discovery, interpretation, and communication of meaningful patterns in data) form part of many enterprises, as it allows for problem identification, performance tracking and future planning. In the past, sample data was used along with inference to draw conclusions on business performance and utilisation. With modern day computing and the relatively low cost associated with storing large amounts of enterprise data as of late, it became possible to perform an analysis of business processes by looking at a larger portion of data and create improved predictive models, thereby increasing business output. *Russom* [1] describes Big Data Analytics as the *application of advanced analytic techniques for business intelligence* (BI).

The ever-growing need to capture and analyse a growing amount of data in order for a business to maintain or develop a competitive edge has fuelled the growth of the data analytics sector. The need for businesses to remain competitive is the origin for the existence of 'Big Data'. The growing trend in data analytics means that eventually, according to [2], no area is going to be untouched by big data and analytics.

Collecting and analysing large amounts of data in different application domains are being driven by various factors identified by [3]. These factors range from system complexity which is increasing, guiding decisions such as to improving efficiency of enterprises, interactive or client-orientated systems which are guided by results of big data analytics as well as providing analytics which promote sustainability.

This research aims to provide the necessary components in order to develop a Big Data Analytics demonstrator using current knowledge and technology which would analyse data at rest. A brief overview of relevant literature is given regarding Big Data Analytics, a method of storing and processing Big Data, the architecture required to develop a Big Data system and current features. After this, a proposed architecture is outlined which is used to develop the Big Data model, which conducts the analysis and makes use of analytics processes and techniques outlined in literature. Before concluding the research, an overview is given of the current status of Big Data and the future trends of Big Data have been identified and could provide a shift in the manner in which Big Data analyses are conducted.

2. LITERATURE REVIEW

The literature researched provides background as to what is Big Data, Big Data Architecture, Big Data Analytics and features found in Big Data. From this knowledge attained, the proposed architecture is presented in Section 3, from which a demonstrator of a Big Data system can be developed.

2.1 Big Data Definition

Big data can be defined by four components, known as the four Vs, according to [4] namely, *volume*, *variety*, *veracity* and *velocity*. The definition from [1] does not include veracity when defining what constitutes a big data system, but is included in this definition for completeness.

- *Volume* refers to the amount of data being stored.
- *Variety* is the different data types captured, from structured data (data which conforms to a certain structure such as sensor data), semi-structured data and unstructured data (data which does not conform to a given structure such as text, video or audio data).
- *Velocity* is the rate at which data arrives and is processed.
- *Veracity* refers to the quality and trustworthiness of the data. Untrustworthy data is seen as noise and needs to be discarded in order for make meaningful conclusions to be made.

Katal *et al.* [5] makes use of the four Vs to define Big Data, but also includes the following to the definition:

- *Complexity:* The nature of Big Data, where various processes are used to filter, transform, link and match data.
- *Value:* The results and insights obtained from the analysis of Big Data.
- *Variability:* Inconsistencies that exist within data flows, such as with unstructured data arriving at varying rates and volumes.

2.2 Big Data Analytics

Before the advent of Big Data, to conduct an analysis, sample data along with statistical methods were used to indicate trends, means, correlations *etc*. With Big Data, an entire dataset can be analysed instead of making use of sampling which in turn increases the accuracy of results, and providing more effective decision making, [1].

Big Data Analytics is seen as a process that is undergone shown in Figure 1, involving different phases that after completion, provide results and insights. Fayyad *et al.* [6] discusses the link between 'knowledge discovery' and data mining and the processes that are followed in order to attain knowledge from data. Data mining according to [7] is about solving problems through the analysis of data already in a database. By analysing patterns distinguishing characteristics can then be identified and conclusions made. Fayyad *et al.* [6] continues by discussing the KDD (Knowledge Discovery in Databases) process which originated in 1989 to highlight that knowledge is the final product of data-driven discovery. The SEMMA and CRISP are methodologies derived from KDD are briefly discussed. Because all of these methodologies make use of analysis tools and techniques which fall under *machine learning*, these are discussed briefly thereafter.

Figure 1 was developed to visually illustrate what is understood under Big Data Analytics, and will be used as a visual guide throughout Section 2.2.

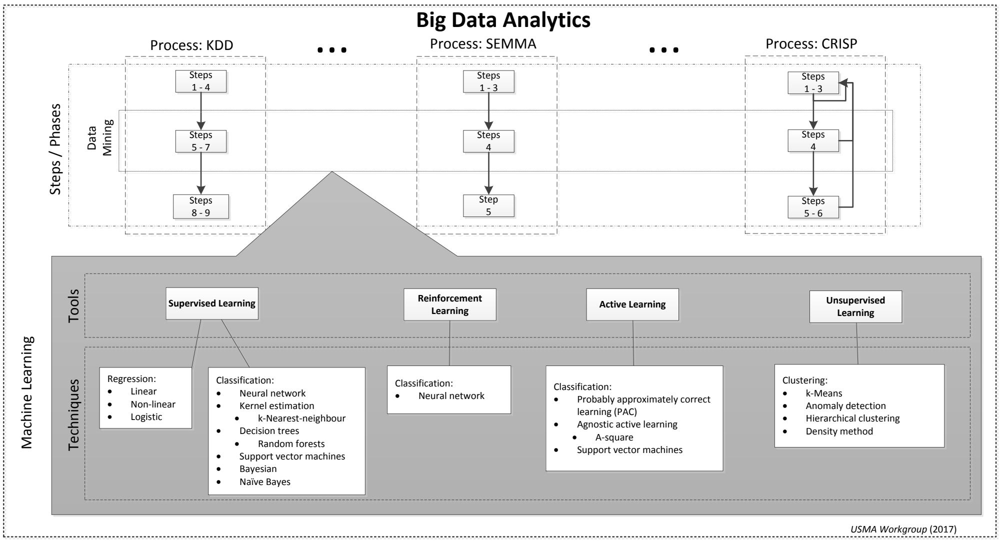

Figure 1: The processes, tools and techniques involved in order to conduct Big Data Analytics [36]

2.2.1 Analytics Processes

The three analytics processes discussed are, KDD, SEMMA and CRISP. Using [7], [8], [9] and [10] the steps/phases outlined in each process were found. There are other analytic process methodologies, but these three are the most widely used and recognised processes and are thus discussed.

KDD (Knowledge Discovery in Databases): The discovery of patterns within data is given a variety of names from *data mining*, *knowledge extraction, information discovery etc*. Fayyad *et al.* [6] and [8] both regard *data mining* to be a single phase/step within the KDD process as well as in SEMMA and CRISP. This understanding that data mining is a step/phase within the process of knowledge discovery and not a process itself, is accepted in this article. Fayyad *et al.* [6] continues further by stating that conducting data mining without conducting the steps/phases before, can lead to "data dredging" which leads to the discovery of meaningless patterns. The steps/phases in KDD are the following ([6]): 1) Developing and understanding of the application domain, the relevant prior knowledge, and the goals of the user, 2) Creating a target dataset, 3) Data cleaning and pre-processing, 4) Data reduction, 5) Matching of KDD process goals to a data mining method(s) (regression, classification *etc.*, 6) Choosing of the data mining algorithm(s), 7) Data mining, 8) Interpretation of the mined patterns, and iteration of phases 1—7 if required and finally 9) Consolidating discovered knowledge.

SEMMA (Sample, Explore, Modify, Model and Assess): A data mining methodology developed by SAS institute [11] which allows for the understanding, organisation, development and maintenance of projects, aligning the business goals therewith. [10] states that this methodology is integrated into SAS tools and should only be used with enterprise miners (data mining tool) while KDD is applicable to broader applications and environments. The SEMMA process is a five-phase process, 1) Sample, 2) Explore, 3) Modify, 4) Model and finally 5) Assess.

CRISP (Cross-Industry Standard Process for Data Mining): This process methodology was developed through a consortium from Daimler, Chrysler, SPSS and NCR [9] to provide a uniform framework and guidelines for data mining activity [11]. The process consists of the following six sub phases: 1) Business understanding, 2) Data understanding, 3) Data preparation, 4) Modelling, 5) Evaluation and finally 6) Deployment.

The SEMMA methodology is not considered for the analytics component of the research project as it has limited applications and linked to the SAS enterprise miner software. The CRISP process methodology [9] concludes to be an implementation of the KDD process. Following from this, the next section briefly discusses the various *machine learning* 'tools' and 'techniques' that are used in all three of the processes shown in Figure 1.

2.2.2 Machine learning

Pattern recognition and making predictions involve various techniques from, multivariate statistics, data mining, pattern recognition, and advanced predictive analytics. All of these techniques are considered under machine learning (ML). Machine learning is applying algorithms which allows for machines to learn without being explicitly programmed to fulfil the desired outcome [12]. The applications of machine learning range from identifying user preferences and providing recommendations, identify spam and non-spam email to the probability of winning a lottery. Machine learning is divided into four 'tools' [13]. These are:

Supervised learning: Supervised machine learning involves algorithms which learn to best fit/match the known input with the known output data. The method then predicts future data outputs given sufficient input training data [13]. In supervised ML, regression and classification tools are used and there are a wide variety of 'techniques' available depending on the application/requirements listed in Figure 1. Regression can be used to make predictions using continuous numerical data. Estimations/predictions are conducted by using known/predicted values and establishing the relationship between these predictor values to that of independent values. Linear (one predictor and target value), non-linear and logistic regression are the three common regression techniques available. The classification technique uses an algorithm which groups different data and data types to specific classes. The classification methods available are divided into two groups, I) Artificial intelligence and II) Statistics. Within artificial intelligence there are logic-based (Decision trees) and perception-based techniques, whereas in statistics, Bayesian networks, as well as instance-based techniques are used, as outlined in [14].

Unsupervised learning: Algorithms are presented with examples from an input space whereby a model must fit these observations [13]. The distinguishing factor from supervised learning is that there is no prior knowledge of the input variables with regards to the output. Because there is no knowledge of the output, the input data is organised and clustered to identify groupings/patterns and trends, and through this conduct inference on what the clusters of data describe. Clustering is otherwise known as the unsupervised classification of patterns (observations) into groups, [15]. A comprehensive list of various clustering techniques are given in [16] from hierarchal, partitioning to density-based techniques *etc*. Properties typically of concern in clustering are 1) whether or not the algorithm can handle a type(s) of attributes, 2) scalability to larger datasets, 3) the handling of outliers, 4) finding irregularly shaped clusters, 5) data order dependency [16].

Reinforcement learning: This is based on a sequence of correct actions that are assessed for goodness/correctness by learning from 'bad' actions, in order to reach a goal thus learning from actions and generating the correct actions [17]. Another definition is given by [18] which states that it is how an agent learns to approximate the optimal behavioural strategy whilst interacting with the environment the agent is in. Reinforcement learning is also termed *conditioning/condition learning* for this reason. Reinforcement learning can according to [19] be divided into two categories namely, *classical* and *instrumental*. The differentiating factor is that in *classical*, the outcome does not depend on the agents actions. In *instrumental*, agents learn from stimuli and have a response, given a positive response the connection between stimuli (S) and response (R) is strengthened (system is rewarded), and *visa-versa*. Fundamental elements of a reinforcement learning problem are *states*, *actions*, and *reinforcements*. The goal is to learn which *actions* to select to maximise long term *reinforcement* [19].

Active learning: Instead of passively being given a training set, the algorithms generate the values and request the analyst to provide output values from which the system would learn [17]. Olsson [20] states that active learning is a method by which a learner controls the data from which the system learns and classifies instances based on input from the user on what were correct or incorrect predictions. Olsson [20] continues by discussing three approaches to active learning, 1) *Query by uncertainty* (when queries are made of data points the hypothesis is least confident of), 2) *Query by committee* (similar to *query by uncertainty* only that it is a multi-classifying approach) and 3) *Active learning with redundant views* (instead of randomly sampling and testing, a dataset with certain attributes is split into sub-sets/*views* to then describe the underlying problem).

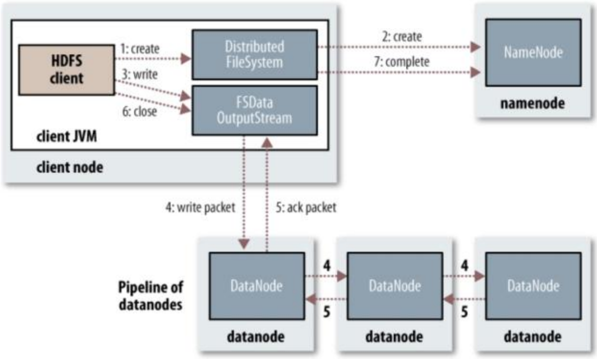

Figure 2: The HDFS allow data to be stored and distributed across multiple nodes [23]

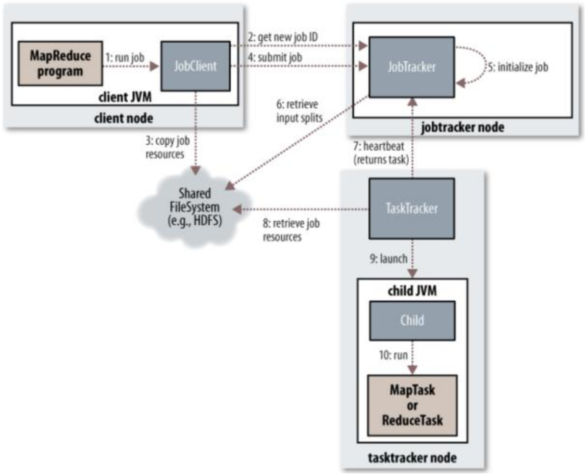

Figure 3: The MapReduce process in Hadoop [23]

2.3 Big Data Storage and Processing using Hadoop and MapReduce

Using the defining characteristics of Big Data (the Vs), there was a need for a way in which to manage data intensive applications that are fault tolerant, scalable, be able to do parallel processing, load balancing and have a high availability [21]. This lead to *Hadoop/Apache Hadoop* which is a framework/software solution (developed in JAVA programming code) to meet these needs. Apache Hadoop makes use of a Hadoop Distributed File System (*HDFS*) shown in Figure 2 and *MapReduce* methodology in **Figure 3**, to store (*HDFS*) and process large files in parallel. *Apache Mahout* is a software/framework developed to incorporate ML into Hadoop's *MapReduce* processing methods. Ghazi & Gangodkar [21], [22] and [23] discuss further the origin of both Hadoop and MapReduce, and noted in [23] there are many other Hadoop projects, but only Apache Hadoop HDFS and MapReduce will be discussed as they are frequently implemented. The following is a brief overview the *HDFS* and *MapReduce* used in *Apache Hadoop*.

2.3.1 Storing Big Data using HDFS

Apache Hadoop makes use of five daemons/processing nodes (processing and storage units) in the *HDFS* to distribute data (known as 'master nodes') to store, filter and categorise data [21] shown in Figure 2 and **Figure 3** namely, 1) *NameNode*, 2) *DataNode*, 3) *Secondary NameNode*. As part of the *MapReduce* layer in *Apache Hadoop*, 4) *JobTracker* and 5) *TaskTracker* daemons are used in computation executions.

Firstly, the storage component (*HDFS*), *NameNode* stores and manages metadata (set of data which describes other data) of file systems, how files are distributed across nodes *etc*. The *DataNode* runs on multiple 'slave' nodes (multiple nodes executing requests of a master node) and are primary storage elements (where the data is stored) that service read/write requests and are controlled by a *NameNode* shown in Figure 2. Dwivedi & Dubey [22] discusses further each aspect of the *HDFS* briefly mentioned. The *SecondaryNode* periodically reads all changes made to each *NameNodes*, then logs and updates the changes made to *NameNode* (ensures speedily response of the system) [23] while running on a separate node. The *HDFS* is a self-healing distributed file system because of this ability to accept data of any file format and distribute it across multiple nodes as seen in Figure 2 using this *Node* structure. The following is a discussion of how HDFS works and how data is written and distributed within.

A client/user creates a file (1) (using the *create()*) function and an appropriate name (2) for all data contained within the file. Checks are made to ensure no other *NameNode* with the designation exists, thereafter the data is written to FSData OutputStream (3) which then splits the data into packets/blocks. *NameNode* allocates suitable *DataNode*s to which to write the data to. After the packet arrives at the first *DataNode*, it is sent on to the next, until the packet is distributed across the allocated *DataNodes* (4). The *ack* (acknowledge) *packet*() (5) returns packets waiting in queue (*ack queue)* to be allocated to a *DataNode*. If data packets have not been allocated to a *DataNode* due to a *DataNode* failure, the *ack queue* stores the order of packets that need to still be stored (ensures no packet loss). The *close()* function is called by the user after completing copying the data to all *DataNodes* and the *NameNode* is notified of completion (7).

2.3.2 Processing Big Data with MapReduce

***MapReduce* is a method in which parallel computations are conducted in two stages, a *Map* of input data and *Reduce* stage, where results are consolidated and output as shown in**

Figure 4. Firstly, the process undergone by the different nodes to prepare the data for *MapReduce* is discussed which is visually depicted in **Figure 3**, thereafter the *Map* and *Reduce* itself, using the example from [23].

Following from section 2.3.1, the *JobTracker* component is the master node which manages the MapReduce process executed by 'slave' nodes. The *JobTracker* locates from *NameNode* the *HDFS* files to be processed as *input data*. The *TaskTracker* monitors and executes the process on slave' nodes (nodes controlled by *TaskTracker*) and governs *MapReduce* executions.

From **Figure 3**, a job is submitted and a *Job-ID* is created (1). Together with a *job-ID*, a JAR-file containing metadata of the *job* and where to split the data is created (2). The *JobTracker*, i.e. the *job-ID* requests the data from the HDFS store and the data is then stored within (3) and a conformation is sent for the *MapReduce* to begin (4). The different jobs are then executed via the *JobTracker* (5). The number of tasks is the number of splits to be mapped and reduced sent to the *JobTracker* JAR-file (6) and assigned according to a *schedule* (top-down, random-order executions *etc.*) (7). A *heartbeat* is periodically sent to the *JobTracker* to notify of correct *Map* and *Reduce* executions. A local directory is created where the *MapReduce* task is run and the JAR-file and *DataNode* data is copied over. A JVM (virtual computer) is created within each *TaskNode* (9) where the tasks are executed (10). *JobTracker* receives notification from *TaskNode* of successful completion of all *MapReduce* tasks.

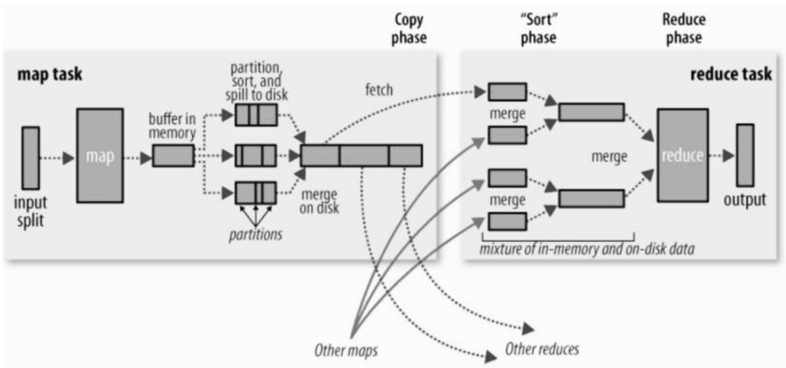

Figure 4: Map and Reduce Tasks [23]

The *Map* and *Reduce* tasks are executed as shown in

Figure 4, within a *TaskTracker*. *MapReduce* makes use of key-value pairs to ID and link common data pairs as to know where to conduct sorting and joining function of the split data. The split lines of data are sent into the *Map* (allocated memory) where the data is partitioned and sorted called *spills* (key-value pair). The 'spill data' is then merged with other data matching that specific 'spill data' (sorting and joining). The *Reduce* task executed which takes the sorted data values and captures and stores only the desired results as with the example in [23] (discussed later), the maximum air temperature for each year.

2.4 Big Data Architecture

An architecture is a conceptual model describing a system made up of a set of structures which work together to fulfil the desired objective(s) [24]. The reference architecture shown in Figure 5 was researched, and will be used to guide the development of a Big Data Architecture for this project/demonstrator. Each of the components in the reference architecture of [25] are subsequently discussed.

Data Extraction: This includes methods by which to extract data from various sources to be processed at a later stage. The data collected is not limited to a specific type and can be structured, semi-structured and/or unstructured forms. Data mining methods such as data sorting and filtering are also included in the extraction processes.

Stream Processing: A process to collect and analyse data from different sources at close to real-time. [25] divided the stream processing into two parts, first the *data stream acquisition* and second is the *data stream analysis*. The *acquisition* involves collection of data from relevant sources and storing of the data, then applying a filtering process before final batch analysis (at rest analysis) is done, and then final storage/removal. The *stream analysis* involves analysing data in near real-time such that the analysis process is fully automated due to the rapid nature of stream processing. The reader is referred to Aggarwal & Wang [26], [27] and [28] who provide methods and algorithms for stream processing analysis.

Information Extraction: After data extraction is completed, the information which holds value needs to be extracted. This includes extracting from all data types and when working with semi-structured (e.g. XML and HTML) and unstructured data (e.g. MP4, MP3). This process involves imposing a structure to the data by means of classification, clustering, entity recognition and relation extraction [29].

Manage data quality/uncertainty: Data cleaning, data correction, data completion and identification and elimination of errors and noise in the datasets have to be managed. This component differentiates itself from Data Integration where data integration makes use of techniques to reconcile data from different data sources. Statistical and Machine learning (ML) techniques are employed to clean data to a given point dependent on the data source. A data quality management objectives overview is provided, as from [25] and includes discussion of *value completion*, *duplicate filtering*, *Outlier detection and Smoothing* and *Inconsistency Correction*.

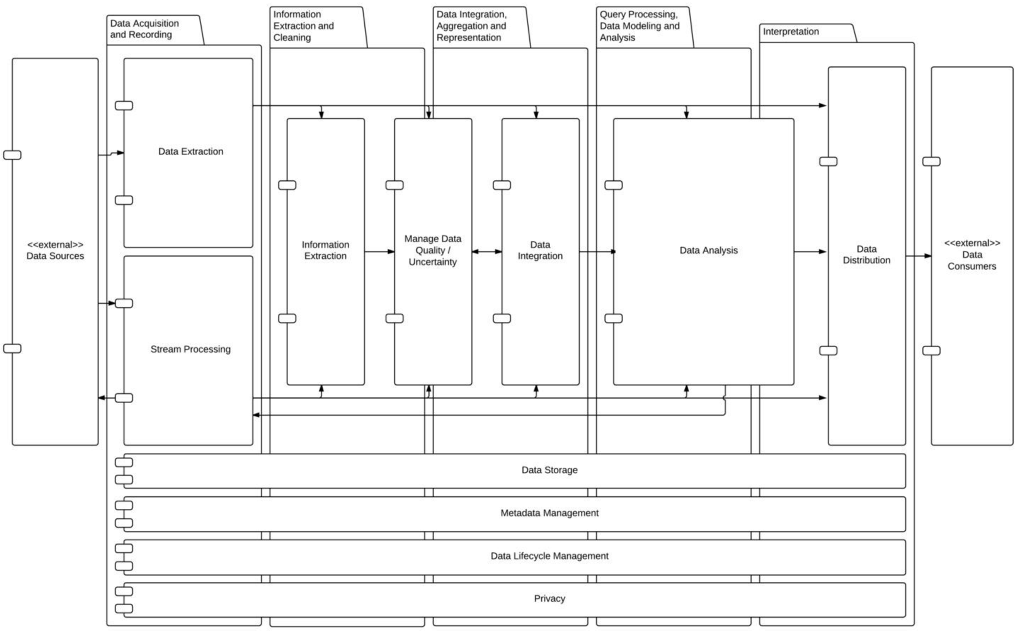

Figure 5: A reference architecture for Big Data projects, developed by [25]

Data Integration: Different data sets are integrated into an 'overarching schema' to conduct a single query, therefore this shares similarities with data warehousing, which also involves pre-processing to provide a "data repository that is maintained separately from an organisations operational databases", [30]. For lower level integration of data points/entities, 'entity resolution' which joins/reconciles data that refers to the same entity can be used. [31] and [32] provide entity matching and resolution approaches to join data. Merging data sources when entities share attributes with contradictory values, 'data fusion' techniques need to be applied which are researched by [33] and [34].

Data Analysis: Using the data extracted and integrated, through analytical techniques results are generated and conclusions made. Data analysis according to [25] can be end-user facing or involve data preparation, calculation of results and storage. The results can then be presented to the end-user. *Value deductions* and *Deep analytics* tasks are typically separated from presentation, to allow for high-performance computations (largely batch processing/computations). *End-user facing* analytics provide fixed reporting and dash-boarding solutions or *free ad-hoc analysis*.

Value Deductions in analytics involves adding information with a single or small record as input. This would entail adding key figures or the enrichment of master data, otherwise seen as data transformation and transferral of the data to data stores. Through batch processing, *Deep Analytics* tasks are conducted (statistics and machine learning), providing results/insights, rules and models are developed. *Reporting and Dash-boarding* is the component whereby after analysis, results and insights made are communicated through visualisation methods typically aimed towards providing an overview to executives.

Free Ad-hoc Analysis provides a user with the flexibility to freely query data sources, allowing a user to extract speedily a response. [25] notes that it requires the user to have the necessary skills and knowledge in the area of machine learning, statistics and declarative languages (SQL, Python, HiveQL *etc*.).

Data Discovery and Search is more focused on sifting through data stores and sources. It allows for the user to then decide what analysis to conduct.

Data Distribution: The functionality required to provide the results from the analytics process, either through a user interface or application interface. User interfaces can provide reports which are used to present results graphically along with descriptions. An application interface is typically a separate application which accesses the results and provides a technical interface to then derive meaning and make informed decisions.

Data Storage: This component includes all data storage, from temporary to caching. The data storage is a supporting function and has no influence on the analysis, storage is done on input data and results [25]. Further reading of sub-functions includes *staging*, *data management orientated storage*, *sandboxing* and *application optimised storage* [25].

Metadata Management: This component refers to the extraction, storage, creation and management of structural, process and operational metadata according to [25]. Metadata management is a vertical function comprised of *metadata extraction*, *metadata storage*, *provenance tracking* and *metadata access*.

Data Lifecycle Management: The activities pertaining to the management of data across its lifecycle (creation to discarding). The overarching component that forms part of data lifecycle management is Rule-based data and Policy tracking. Lifecycle management tasks are automated through the use of rule-based techniques, data archiving, compression and discarding [25].

Privacy: Privacy ensures the security and privacy of the data collected by means of authentication, authorisation, access tracking and data anonymization methods. *Authentication and authorisation* measures require the user to provide identification, to limit the user's ability to search and extract data. *Access tracking* is used to track user 'requests'/log files to ensure access control is upheld. *Anonymization* is used to protect customers/employees etc. by manipulating data fields, changing values, aggregation *etc*.

3. PROPOSED BIG DATA ARCHITECTURE FOR DEMONSTRATOR

The intended purpose of this research is to develop a Big Data Analysis demonstrator, which is to take in a small simulated dataset and use this to test and validate the demonstrator. Thereafter the demonstrator is to be tested using larger real-world datasets and compare the results with what would be expected in industry, thereby also validating the demonstrator's ability to analyse larger datasets. In order for the demonstrator to do this, a demonstrator and the required components thereof need to be included in the design. In this section, an architecture is proposed which will be used in the development of the Big Data Analysis Demonstrator.

For the development of the architecture, a unified and well defined method for systems development was used, namely OPM (Object-Process Methodology) which is a framework developed in order to effectively communicate a systems architecture. The OPM makes use of graphical and natural language means to communicate the architecture and is an ISO standard (ISO/PAS 19450:2015). The OPM makes use of *objects* which are static and change due to *processes* undergone. For this reason, the OPM was chosen to develop the demonstrator architecture. The following is an overview of the proposed Big Data Architecture at a high-level that would be used in the development of the demonstrator. This includes how each object, process and state work together in order to provide analytical results to an analyst. Figure 6 shows the high-level architecture, illustrating dataflow throughout various steps towards obtaining results from conducting an analysis.

Firstly, the following is how each object, process and state relate to one another.

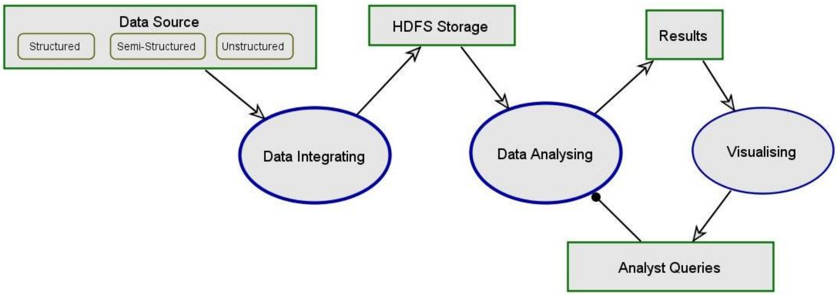

Figure 6: The proposed Architecture high-level view

A Data Source can be Structured, Semi-Structured, or Unstructured. The data is stored in *HDFS* format to be analysed in parallel by running the data through the *Data Integrating* process in
Figure 7, thereby *Data Integrating* consumes the Data Source object, resulting in *Data Integrating* yielding HDFS Storage. The Analyst Queries handles *Data Analysing*. An analyst sends in queries, while *Data Analysing* consumes HDFS Storage which is required, which in turn yields *Results*. To communicate the results from the analysis of the data, the *Visualising* process consumes *Results* which in turn *Visualising* yields Analyst Queries in which the process visually communicates the results to the analyst.

A more detailed view of the *Integrating Data* process is shown in

Figure 7, with the following processes executed to provide a central, filtered data warehouse, *HDFS storage* for use in the *Data Analysing* process.

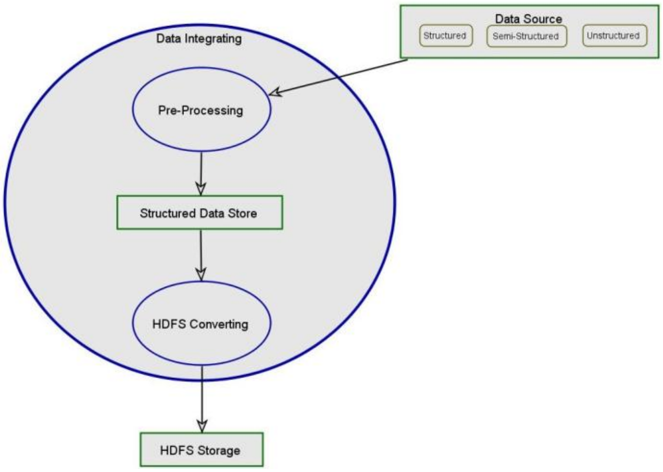

Figure 7: Processes executed within *Integrating Data* to yield results

The *Data Integrating* process consists of a *HDFS Converting* and *Pre-Processing* processes, where *Pre-Processing* consumes Data Source object, yielding a temporary Structured Data Store. *HDFS Converting* process then consumes Structured Data Store which yields HDFS Storage. This is then the data store to be used during the *Data Analysing* process.

A zoom-in of the *Data Analysing process* is provided in Figure 8, where data mining techniques are used to provides results according to a user's queries. *Data Analysing* consists of *Data Mining* and *Information Extracting*.

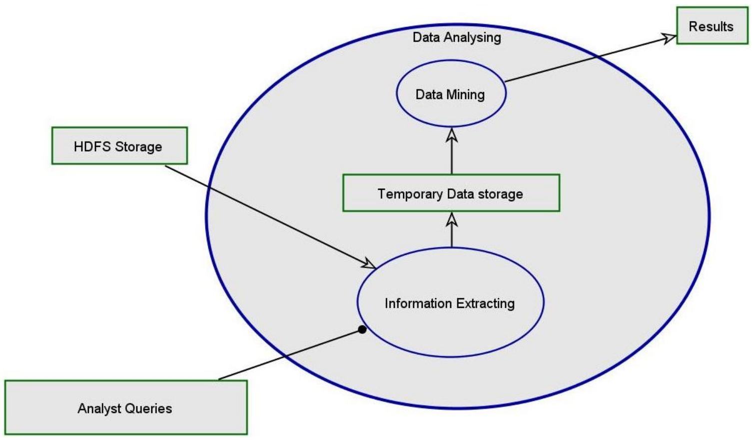

Figure 8: Processes executed within *Analysing Data* to provide results

The Analyst Queries handles *Information Extracting* by taking in the queries and according to the query, the relevant information is extracted from the *HDFS Storage*. After the *Information Extracting* process, a *Temporary Data Storage* object is created along with the user query and relevant data. Data Mining then consumes Temporary Data storage in which the Data Mining process yields Results. The *Data Mining* process involves ML tools and techniques along with *MapReduce* processing to analyse the data and provide *results* dependent on the data and query provided by the client/user.

4. CURRENT STATUS

To illustrate current technology with regards to storage and processing of Big Data, two problems are discussed. The following is a problem developed by the researcher to illustrate the process undergone when storing large volumes of data in a *HDFS* format across multiple nodes (Figure 9) where a data file of 4TB is broken up into *blocks* and the *blocks* are stored across multiple nodes. The second problem is from literature, where data is collected and *MapReduce* is conducted on the data to extract the maximum temperature for each year.

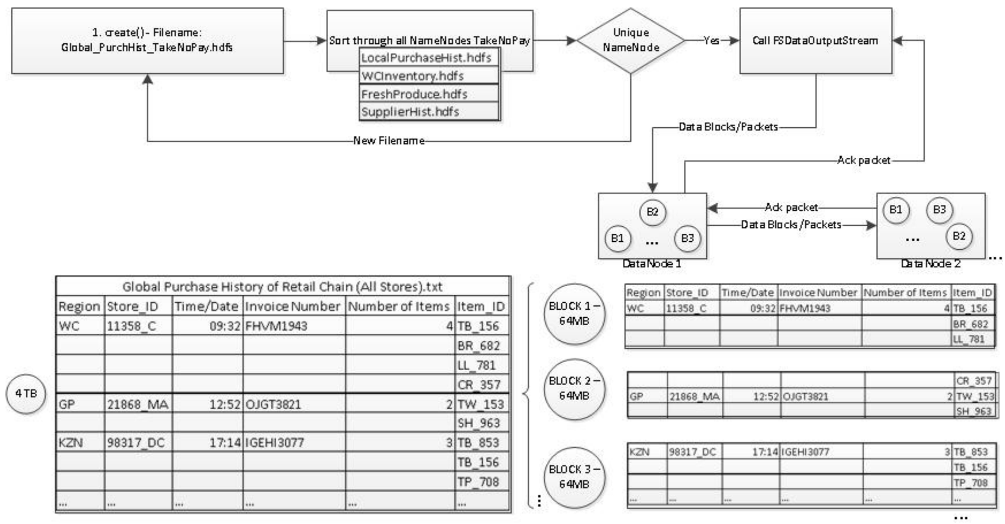

Figure 9: Example problem of distributing and storing data in HDFS

For the first problem shown in Figure 9, the process in section 2.3.1 is used. The data file is given a unique name *Global_PurchHist_TakeNoPay.hdfs*. The *HDFS system* then breaks the data file up into multiple *blocks/packets,* without taking the file structure into consideration. To show how the *HDFS* ignores file structure and creates these *blocks,* the file called *Global_Purchase_History_of_Retail_Chain(AllStores).txt* which contains multiple invoices (an invoice contains a list of multiple items purchased) with each having a unique ID, is broken up into *block1* to *block3*. As shown, some items of invoice *FHVM1943* are contained in *block1* and *block2*. These *blocks* are then finally stored across multiple *DataNodes*.

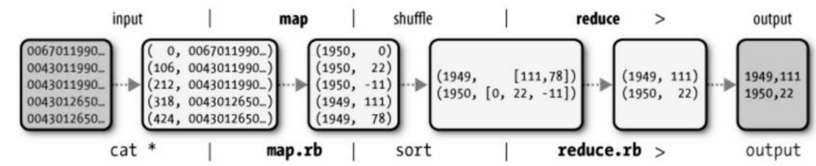

Figure 10: An example of a MapReduce process to extract data from a dataset [23]

The Processing of Big Data is commonly done through the use of *MapReduce* as discussed in section 2.3.2. The following is a problem taken from literature [23] to illustrate *MapReduce*.

Suppose weather data (air temperature, humidity, elevation at which reading was made and wind direction) is collected from various weather stations between 1901 and 2001 and concatenated into a single file [23]. The goal is to extract from this weather data the maximum air temperature for each year. The results from the *Map* and *Reduce* tasks are shown in Figure 10 to illustrate how the data is mapped and that the reduction gives the desired output.

The input data (file with all weather data converted in HDFS format) is given in Figure 11 with ellipses illustrating values not shown (reduced to fit example to page). Each line has a set of key-value pairs which is an assigned *DataNode* identifier sent to the master *NameNode*, which would be the filename. Firstly, a query to run a *MapReduce job* on the desired file is submitted (1) and metadata (where splitting occurs) regarding the *job* is stored (2) in *JobTracker* together with the weather data in a JAR-file format (3). After this is completed, the *MapReduce* is ready to be executed (4).

```
0067011990999991950051507004...9999999N9+00001+99999999999...
0043011990999991950051512004...9999999N9+00221+99999999999...
0043011990999991950051518004...9999999N9-00111+99999999999...
0043012650999991949032412004...0500001N9+01111+99999999999...
0043012650999991949032418004...0500001N9+00781+99999999999...
```

Figure 11: Input weather data [23]

```
(0, 0067011990999991950051507004...9999999N9+00001+99999999999...)
(106, 0043011990999991950051512004...9999999N9+00221+99999999999...)
(212, 0043011990999991950051518004...9999999N9-00111+99999999999...)
(318, 0043012650999991949032412004...0500001N9+01111+99999999999...)
(424, 0043012650999991949032418004...0500001N9+00781+99999999999...)
```

Figure 12: The input weather data with the date and air temperature shown in bold [23]

The jobs are initialised and scheduled (5) via the *JobTracker*. The list of *Tasks* (number of map and reduce) to run are received by the *JobTracker* (6) which is the number of splits (each line in Figure 11) from the JAR-file which is linked to filename (*NameNode)*. The *Tasks* are now assigned (7) according to *JobTracker*'s schedule (service tasks according to list) to empty *Map* slots (system memory dependent) to run/execute a *Map* task, and *visa-versa*. Each *TaskTracker* also sends a *heartbeat* to the *JobTracker* used to monitor (progress and status of a task) and execute the following tasks. Tasks are executed by copying the JAR-file and *DataNode* data to a local directory (8). A Java Virtual Machine (JVM) is created (Hadoop built/implemented on JAVA) (9) wherein the *Map* and *Reduce* task (10) is executed. The *JobTracker* receives a notification from the last *TaskTracker* of final task completion. The results show maximum temperatures for only two years (1949 and 1950), but this process is executed for the entire dataset from 1901 to 2001. A further *Reduction* could also be executed to only display the single year with the highest temperature.

5. CURRENT FEATURES AND TRENDS

The following is a brief overview of popular current features used in the Big Data space and trends that are becoming popular ([3]). Current features include hardware such as DRAM (Dynamic Random Access Memory) used for fast access and is typically used in caching. Storage is done through the use of traditional hard-disc due to their low cost and high storage capability. Apart from the various software packages available within the Hadoop environment and other solutions such as SQL and NoSQL, other software limitations are the CAP-theorem, which states that it is impossible for a storage solution to provide guaranteed consistency and high availability whilst having large amounts of data partitions/splits. Current network limitations are of concern as well, with data volumes growing faster than processing power, networks are the limiting factor between accessing and processing data. This then requires more duplicates to improve availability of data for fast processing, leading to more energy being consumed to store data.

Trends in Big Data according to [35] include the following, 1) novel technique improvements to *data mining*, 2) cloud-based storage and transmission, 3) a Big Data solution focused on control and monitoring, 4) Big Data solution for supply chain and risk management systems, 5) a Big Data solution for smart grids and clean power stations and finally 6) Big Data in *smart* products (smartphones and other future smart devices).

6. FUTURE WORK

The architecture is to be expanded to include all components identified from literature, as of current, the overarching components, privacy, management *etc*. systems are not designed into the *proposed* architecture. Further research of the current technology (Open Source Big Data software packages and analysis techniques) is to be completed, thereafter implementing the current knowledge in the demonstrator, which is to be tested using simulated Big Data sets.

7. CONCLUSION

Big Data involves multiple facets that have to work together in order to provide a user with valuable insights for effective decision making. The literature addresses the methods by which to conduct the analytics, the requirements for a Big Data Architecture used to develop such an analysis system and how current Big Data methods/technologies and knowledge are used to store (*HDFS*) and process (*MapReduce*) such large volumes of data. The proposed Big Data Architecture was developed in order to meet the project goals of analysing Big Data at rest and is a high-level view of the different components that have to work together in the system. The current status demonstrates techniques available to store and analyse Big Data at rest. This research therefore provides a platform which is to be used in the development of a Big Data Analysis demonstrator, considering all the components required. Industrial engineers are well-equipped to develop Big Data solutions due to their understanding of systems, interfaces and the value of information. This Big Data demonstrator is therefore a valuable tool available to industrial engineers to further the understanding of a system and communicate the systems performance, through Big Data Analytics and visualisation techniques to other stakeholders.

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USE OF PROXIES TO INVENTORY IN OPTIMIZING SERVICES

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ABSTRACT

Services are generally more customized and unique in contrast to manufacturing which is considered more standardized and industrialized (especially with regards to mass production). The customized nature of service is however changing as services evolve from customized to standardized units of output making the methods of optimizing manufacturing more relevant to services. To address the problem of the intangible product, the general approach is to use a Proxy to Inventory, an item chosen to represent the flow that makes the manufacturing technique applicable. Various Proxies to Inventory are used within the services industry to apply optimization to services. This study explores literature around the Proxies to Inventory with examples of their practical implications in modelling services.

OPSOMMING

Dienste word oor die algemeen as klient-spesifiek en uniek geag. Dit is in kontras met vervaardiging wat as meer gestandardiseerd beskou word. Die unieke aard van dienste is besig om deur 'n transisie te gaan, net soos vervaardiging transformeer het van klient-spesifieke produkte tot massa vervaardigde produkte. Om die probleem van die nie-tasbare aard van dienste aan te spreek word die benadering van Plaasvervangers tot Voorraad voorgestel. Hierdie studie ondersoek en bespreek die gebruik van Plaasvervangers tot Voorraad soos gevind in literatuur studies. Die praktiese implikasies van hierdie plaasvervangers op die modelering van dienste word bespreek.

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1. INTRODUCTION

The market is experiencing a change in services and the approach to services. We are seeing an evolution in services from very bespoke and unrepeatable products towards standardised and repeatable products or outputs. The changes in services differ by industry. Service industries in banking and insurance have seen these standardised back office processes for a few years now. Techniques traditionally linked to the manufacturing industry, like lean, have recently become more common in services industries. Banks were one of the early adopters of these principles applying these techniques to their back-office processes which naturally evolved to include their customer facing processes. The common misconception has been that the use of techniques and the drop in the cost of the process would lead to a reduction in service quality, but this has in fact not been the case. The application of these manufacturing principles to the services industry had resulted in an increased productivity but also an improvement in quality (Löffler and Reinshagen[11]).

At the same time, researchers point out that manufacturing techniques should not simply be applied to services. Services are seen as complex and the field of service management is difficult to improve. This is due to the difficulty of visualising services. Services are concretised and defined through service level agreements and statements of work. These service level agreements and statements of work are not easily defined as precisely as specifications for manufactured goods. There is also a general belief that service quality and performance are not as easy to measure and specify objectively as product quality and performance (Ellram, Tate, and Billington[6]).

When considering the technique of supply chain management, it is easily understood and grasped in the context of manufacturing as the general approach in supply chain management is to find the items that flow, and in manufacturing these items are tangible and usually easy to identify. The essential difference between a product and a service is that a service requires involvement from the customer to be produced and that services are intangible in nature (Grimme and Kreutter[8]). Other authors reach a similar conclusion that services are intangible, labour intensive, heterogeneous, cannot be stored and transported because the fulfillment and the consumption occur simultaneously, are influenced by the customer at a high level, and make it difficult to judge the quality (Akkermans and Vos[2]). According to Kathawala and Abdou[10] a major difference between manufacturing and services is the lack of a physical product. The implication of this difference is that you cannot put it as inventory, because the product sold is the number of hours of the professionals and employees involved in the assignments.

Sampson[14] concludes that services and manufacturing are markedly different with a different managerial approach. Akkermans et al[2] take a slightly more conservative view but still warn that not all principles applied successfully for products can automatically be assumed to be relevant in service environments.

The differences between manufacturing and services, and the views that manufacturing techniques should not simply be applied to services, leaves the challenge of what techniques can be applied to services and under what conditions these techniques can be applied to services. A core challenge in the differences between services and manufacturing is the intangible nature of the service or product. It should be possible to more readily apply manufacturing techniques to services if the intangible nature of the product could be overcome. For this, the concept of a proxy to inventory is envisaged. When researchers apply manufacturing techniques to services, the researcher finds some form of proxy to inventory for the techniques to be relevant.

This paper considers several approaches observed relating to proxies to inventory allowing the application of manufacturing techniques to services, especially in the context of supply chain management. The paper first considers the changing nature of services currently underway and the similarity to the changes previously observed in manufacturing. This is followed by a description of the benefits to the concept of proxies to inventory. Proxies to inventory are then described in the context of several categories to give examples where the concept has been used and the implications thereof. This is followed by a description of the various categories and how these categories may be correlated to the type of service being considered.

2. CHANGING NATURE OF MANUFACTURING AND SERVICES

Manufacturing as an industry is seen as extremely standardised and process driven, but we have not always had such a level of standardisation. Initially the items we now regard as standardised or mass produced were produced by craftsman that could be likened to artists. The work we now see as standardised would have been regarded as not capable of standardisation and difficult to define. The manufacturing industry has gone through a transformation to the level of mass production and standardisation we now accept as a characteristic of physical product production.

Similarly, services have been and to a large extent still are regarded as difficult to standardise and something only accomplished by a very skilled practitioner for which there is not set formula or process. There is a global shift in industries from the agriculture industry towards services (Spohrer, Maglio, Bailey, and Gruhl[16]). This is supported by Sampson[14] who remarks that as more developed countries moved from agrarian based to manufacturing based, these economies have continued to progress to becoming predominantly service-based and that services now account for two-thirds of the output of the advanced economies of the world. With this shift, we are seeing a transformation of services towards more standardised services that follow set processes or higher standardisation.

This is also emphasized by Uebernickel and Brenner[17] who point out the similarities between the information technology sector and the developments in the manufacturing industry. Industrial manufacturing has passed a number of milestones as it has matured over the past 100 years. The first stage was the standardisation and streamlining of process flows followed by a strong focus on quality and eventually an end to end focus on the customer in the production process (Uebernickel et al[17]). As these industries matured over the last 100 years, industrial manufacturing passed a number of milestones, starting with standardisation and then streamlining of process flows, continuing with the explicit assurance of quality, and culminating in an end-to-end customer focus in production.

3. CHALLENGE TO SERVICE OPTIMISATION

From the foregoing paragraphs, it is shown that services are going through an evolution. A similar evolution has been experienced in manufacturing and there is a view that services have and are going through such a transformation of industrialisation. Within this there is the tendency to apply manufacturing principles to services. At the same time, there are challenges to this approach in that researchers warn that

1. Services are markedly different to manufacturing and that techniques from manufacturing should not be applied to services, or at least applied with caution.
2. Services are different in that it involves an intangible nature in the lack of a physical product.

Although services differ to manufacturing, the level of difference may only be applicable to certain cases. There are types of services that may be more similar to manufacturing concepts. One such example is the industrialisation of IT. Industrialisation of IT refers to the use of management concepts and methods from industrialised manufacturing to IT. (Grimme et al[8]). Four pillars of industrialization are given for the industrialization of IT:

1. Standardisation and automation
2. Modularization
3. Continuous Improvement
4. Concentration on core competencies

Grimme et al[8] further explains that this industrialization results in an attempt at treating services as products. This industrialisation of IT supports the concept of a changing nature of services and further the application of manufacturing techniques to services.

There is thus an attempt to apply manufacturing principles to services. It is true to say that there are services to which these techniques do not apply easily, but by the same token there are services to which the techniques may be applied more easily.

4. THE CONCEPT OF PROXY TO INVENTORY

Despite the warnings of not applying manufacturing techniques to services, there is benefit in this approach. Manufacturing techniques have the benefit of receiving years of research and attention. The use of these techniques to services has the potential to make use of these techniques rather than establishing techniques for services in isolation.

The changing nature of services, like the changes that have been experienced in manufacturing, further points to the benefits of applying manufacturing concepts to services. One of the largest problems in applying manufacturing techniques to services is the intangible nature of services.

Many of the manufacturing optimisation techniques relate to the presence of a physical product. This is not the case with services. An example of this is the concept of supply chain management. There is a trend toward the use of supply chain management in services, referred to as service supply chain management. The challenge lies in that the supply chain for services cannot be grounded around a physical flow of a product. More importantly, many of the manufacturing principles used in supply chain management and other manufacturing techniques rely on the concept of inventory.

Application of the manufacturing techniques thus require some form of translation from the manufacturing dependent product or inventory to an approach that allow these techniques to be used in services. To remedy this, researchers use a substitute to the physcal product or inventory when applying the manufactuirng techniques to services. This paper refers to this concept of substitution of the product when applying the manufacturing techniques as the Proxy to Inventory.

The role of inventory here is not around the state of inventory, but rather the physical manifastation of inventory. Inventory within manufacturing can be grouped into a number of states. As an example of the states of inventory: inventory may be the raw material; inventory may be a work in progress (WIP) or inventory may be the finished good. One of the roles of inventory in its various forms is to buffer against the variability in the production process and in so doing improve efficiencies. Inventory cannot be used to buffer variability of demand in services as in manufacturing (Allen and Chandrashekar[1]). Baltacioglu, Ada, Kaplan, Yurt, and Kaplan[3]) propose two strategies to cope with these variabilities within services: i) influencing demand not to exceed a desired level, and ii) influencing demand to decrease the impact of peaks and valleys. The use of inventory for this paper will be around inventory being an observable item that can be used to track the flow through the supply chain process.

The purpose of this paper is to highlight the different approaches researchers have taken to abstract their supply chains through proxies to inventory. The benefit of the research is to provide examples of the type of approaches researchers may take when optimising service supply chains.

The research is followed by a postulation of the abstract nature of the proxy to inventory based on the type of service being considered.

5. BENEFITS TO PROXY TO INVENTORY

The value in proxies to inventory lie in the ability to aid the practitioner in applying techniques used to optimise manufacturing cases to services. This becomes even more relevant as services are changing and as changes are evolving to show characterestics similar to manufacturing.

A further benefit is that researchers use different approaches when applying manufacturing techniques to services by substituting the product in the manufaturing context with some other concept to apply the manufacturing concept to the service. By categorising the various proxies to inventory, providing examples of proxies to inventory and by describing characteristics of the various proxies to inventory, practitioners may more easily identify proxies to inventory that are more suited to their application.

6. CARTEGORIES OF PROXIES TO INVENTORY

The approach in this study is to consider literature that have used proxies to inventory in modelling service supply chains and then looking at what these researchers use as the proxy to inventory in their modelling of the supply chains.

The outcomes of services differ greatly and services cannot be regarded as a single concept but rather has outputs that vary greatly. As examples: for repairs the output is physical; for education, the output is knowledge intellectual; for churches, the output is spiritual; and for motion pictures, the output is experiential (Ellram, Tate, and Billington[5]).

Lovelock[12] describes how all services can fit into one or more of four categories:
1. services that act on people's minds (e.g. education, entertainment, psychology);
2. services that act on people's bodies (e.g. transportation, lodging, funeral services);
3. services that act on people's belongings (e.g. landscaping, dry cleaning, repair);
4. services that act on people's information (e.g. insurance, investments, legal services)

In considering the different types of inventory, in the context of supply chain management, Sampson[14] provides examples of single and bi-directional supply chains with the involvement of the customer.

Table 1: Examples of service supply chains (Sampson[14])

customer- supplier	supplied input	service provider	supplied output	customer
companies or individuals	financial transaction records	tax accountant	tax statements	the companies or individuals
passengers	selves and baggage	airlines	transported passengers and baggage	the passengers
home builders	design preferences	architects	blueprints	the home builders
car owners	broken cars	auto repair shops	fixed cards	the car owners
individuals	money	banks	money and interest	the individuals
companies	business problems	consulting firms	analysis and reports	the companies
individuals	blueprints and preferences	customer home builders	a customer home	the individuals
patients	teeth	dentists	drilled teeth	the patients
students	minds	educational institutions	enlightened minds	the students
spectators	attention	sports teams	excitement	the spectators
constituents	community issues	governments	community action	the constituents
clients	legal problems	law firms	legal answers	the defendents
homeowners	buring house	fire departments	drenched house	the homeowners
land owners	property to sell	real estate agents	sold property	the land owners
patrons	empty stomach	restaurants	full stomach	the patrons
customers	questions about products	retailers	answers	the customers

The table above provides a useful reference for various forms of supply chains that exist for services with references to different forms of proxies to inventory that tie the actors together. Based on the above table, and literature studied, the major classification of proxies to inventory are grouped in the categories of capacity; value; intellectual property; the customer; the case; and a physical product. These are then discussed in the paragraphs that follow.

It should be noted that this list is not all encompassing. Looking at different manufacturing techniques applied to services, other classification may be found. The classification provided in here is based on the research done around the modelling of service supply chains with a categorisation based on these supply chains. The various researchers also do not refer to proxies to inventory. The concept of the proxy to inventory is one that is observed in explaining how researchers are modelling the service supply chains and that underlying to this there is always the use of some form of analogous concept to inventory to apply supply chain management to the specific case being modelled.

6.1 Capacity as Proxy to Inventory

In modelling the supply chain of a consulting service, Giannakis[7] explains the problem related to the management of capacity through the perishable nature of services, which makes the adoption of the manufacturing supply chain model difficult for services. The upstream amplification of service activity, because of the bullwhip effect, is analogous to the amplification of upstream inventories in manufacturing companies. The outcome is that the fluctuation in demand from upstream providers or actors in the supply chain have an unpredictable impact on the capacity of the process. Capacity is thus seen as the proxy to inventory. Optimisation of the supply chain is around the optimisation of capacity. Giannakis[7] considers the capacity at the various points in the supply chain as the item that flows. What the customer eventually receives is the capacity of the consultants.

In this case capacity thus has dual role in the supply chain. It is modelled in the traditional capacity perspective but is also viewed from the perspective as the inventory. The outcome from Giannakis[7] is that the developed model conceptualises the capacity of service firms as a resource inventory to build a service offering.

Ellram et al[5] comment that no goods are transferred in professional services but rather the transfer of service utilising the supplier's assets and staff. In effect this is a transfer of the service capacity of the supplier to the customer in the form of a service.

Capacity can be used as a proxy to inventory as here the view is that capacity should be transferred to the eventual customer. In the case of consulting the customer is receiving the consultant time, and thus this is what flows. The challenge with the approach of using capacity as the proxy to inventory is that both capacity and the flow of a product or inventory are applicable in a normal manufacturing model. When considering some machine or server, we model the flow of the product through its arrival and processing time as well as model the capacity of the machine. Translating this to services, the capacity of the manufacturing concept as well as the inventory from the manufacturing concept are translated into a single capacity concept in services. Manufacturing techniques may thus not all be applicable if the proxy to inventory chosen is capacity.

6.2 Value as Proxy to Inventory

A further popular proxy to inventory is to study value as through the very popular value chain analysis. In the service supply chain, service value is created for customers by means of planning, organizing, implementing, and controlling the capacity flow, information flow, value flow and service process flow of service supply chain (He, Ho and Xu[9]).

Supply chains are sometimes viewed as value chains (Kathawala et al[10]) where the value of goods or services are enriched as they move through the chain. This view on value added applies to both services and goods.

In studying service dominant logic, Maull, Geraldi, and Johnston[13] see that value changes from manufacturing to services in that manufacturing is centred around value-in-exchange which changes to value-in-use for services. In relation to services specifically Spohrer et al[16] define services as

> *"the application of competences for the benefit of another, meaning that service is a kind of action, performance, or promise that's exchanged for value between provider and client "*

Baltacioglu et al[3] define supply chain management as

> *"the integration of the key business processes from end user through original suppliers of products, services and information that add value for customers and other stake holders."*

Both the definitions of service as well as the definition for supply chain management which includes services here refer to the value transferred to the customer. Value is thus considered as a product that flows and is delivered to the customer.

In the case of value, most researchers view that even in manufacturing the product does not flow but rather value flows or is enriched. The challenge in taking a value approach is that it is still very abstract. From Table 1, the excitement of spectators at a sport event can be seen as an example of value. It is not easy to measure and quantify the concept of excitement and value. Value is also very specific to the recipient of the value as it depends on their view in determining if the recipient will value the outputs of the service (Maull et al[13]).

Using value as the proxy to inventory allows for a conceptualisation of the supply chain but when using techniques for optimisation, value may be too abstract. As an example, when optimising a supply chain for time or delivery performance or quality, the concept of value added may be too abstract to apply the manufacturing techniques easily.

6.3 Intellectual Property as Proxy to Inventory

Knowledge or Intellectual Property is also an item that is considered to flow and takes the place of the product within a service supply chain. In studying consulting services, Giannakis[7] considers that as part of the consulting work. Intellectual property is moving between consultants and eventually applied to the customer. Giannakis[7] goes further to classify intellectual property as having the characteristic that it can be used indefinitely. This is then a special type of inventory that can never be depleted.

In considering Table 1, Sampson[14] provides several cases where the proxy to inventory can be considered to be Intellectual Property. In the case of the home builders that bring preferences, the preferences can be seen as intellectual property being transferred (the preferences may also be considered to be part of a larger case which is discussed in a later section). As with Giannakis[7], Sampson[14] refers to consulting with business problems as the proxy to inventory which is intellectual property. For students the product in the supply chain is chosen as minds, and then enlightened minds in Table 1. Here it is the enrichment of the minds that acts as the proxy to inventory again pointing to knowledge or intellectual property. Intellectual property is also the proxy to inventory in the case of the customers with their questions and then receiving answers from Table 1.

Intellectual property or knowledge is thus shown to be used as a product that flows within service supply chains and is seen as the product or inventory that moves through the supply chain. Intellectual property is thus a dimension of proxies to inventory. As with value as a proxy to inventory, it assists with identifying flow within multiple parties delivering a service, but it is a very abstract term which makes it difficult to apply many manufacturing principles such as using intellectual property as the inventory or product that flows.

It should be noted that researchers often refer to the flow of information within the supply chain. This can be seen as part of the category of intellectual property or knowledge that flows. The use may be more broad but the same principles apply. Ellram et al[5] highlights the importance of information flow in the supply chain for identifying demand, sharing information, ensuring management through a service level agreement or statement of work, and clearly defining the scope of the work, the skills required of service providers, and feedback on the performance. Spohrer et al[16] list three key types of shared information: language, laws and measures in the service supply chain.

6.4 Customer as Proxy to Inventory

The customers themselves may be the product that flows through the supply chain or manufacturing process in the case of services. The customer may thus be the proxy to inventory. In using service dominant logic where the customer plays an active role in the supply chain, Maull et al[13] consider scenarios for customers as inventory, where customers are waiting in line or waiting for their belongings or information. As an example, consider passengers traveling on an airline. In identifying queues and flow, the passenger (or customer) can be modelled to improve the overall service supply chain. A shortage of service capacity is the primary reason that customers are kept waiting in a service because service capacity is insufficient and customer inputs arrive before the server is ready to handle those inputs, which is similar to the reason for inventories to be carried in the manufacturing context (e.g. goods arrive before the system is ready to process them or not enough goods are available for the server to process). In this case the customers are in fact inventory and the techniques one would apply to inventory in the manufacturing context are then applicable to the service supply chain but while considering the customer as the inventory (Sampson and Spring[15]).

There are various ways in which the customer waiting is similar to inventory in manufacturing:

1. both incur holding costs, although the former is usually measured in minutes and the latter measured in months,
2. both require a storage location, although customer inventory may require more comfortable facilities than physical goods inventories, and
3. both are an outcome of inadequate capacity planning, scheduling, and coordination.

A difference between the treatment of inventory in the manufacturing context and the customer as inventory in services is in deciding how to deal with excessive waiting, which includes psychological dimensions (Sampson et al[15]).

Referring to Table 1, Sampson[14] provides two scenarios where the customer is also the inventory or product in the service supply chain. This is the case with the passengers traveling on an airline which was discussed earlier in this paragraph. A further example from Table 1 is the scenario where the patient must see the dentist. Again the product in this scenario is the tooth which is attached to the patient or customer. The customer may thus exhibit waiting time (queuing time), being stored as inventory, processing times, and other concepts typically observed in manufacturing. Similarly the example of the patron in the restaurant is an example where the customer is the product that flows through the service supply chain.

Instances where the customer acts as the proxy to inventory make the application of manufacturing optimisation techniques very relevant.

6.5 Physical Product as Proxy to Inventory

The categories in the previous paragraphs considered services where there is not necessarily a physical product involved in the chain. Akkermans et al[2] refer to these services as pure services where pure services are defined as:

“intangible, labor intensive, heterogeneous, cannot be stored and transported because production and consumption occur simultaneously, have a high level of customer influence, and have a quality dimension that often is difficult to judge.”

Wang, Wallace, Shen, and Choi[18] refer to two types of service supply chains. The first are what Wang et al[18] refer to as Service Only Supply Chains which is similar to the pure services described by Akkermans et al[2]. The second type of service supply chain is Product Service Supply Chains where the service supply chain is the application of services on a physical product.

This is similar to the concept of Product Service Systems. Maull et al[13] list three types of Product Service Systems:

1. Services such as advice and consultancy add extra services to the product referred to as Product-orientated services;
2. Use-orientated services where the provider owns the asset and provides a service through leasing it to the customer;
3. Results-orientated services where there is often no predetermined product, and the service provider uses their resources to provide service outcome.

Here the third item of results-orientated services are the pure services as referred to by Akkermans et al[2]. Table 1 provides a number of examples of service supply chains that involve a physical product. Car owners that require the repair of their broken cars is one such example. Home owners where a burning house is rescued by the fire department is further example. Real estate agents selling a physical house is a further example.

In finding a definition for service supply chain management, Ellram et al[5] find that definitions from manufacturing easily fit to certain instances of services, specifically when the service relates to a repair. This repair usually acts on a physical product. Application of manufacturing principles to a service involving a physical product are thus easily relevant.

6.6 Case as Proxy to Inventory

From Table 1, there are several examples that cannot be explained by the categories already described. These examples are financial records in the case of the tax consultants, building designs and blueprints in the case of the home builders, money in the case of the bank, requirements and blueprints for the architects, clients with legal problems and communities with community action plans.

All these examples can be regarded as a case that flows through the system. These cases typically have some unique identifier associated to them and are treated as a group or collection that is tracked through the system. Other examples of such cases may be a case at the local police or authorities, it may be a request at the call centre of a service provider, or insurance policies and insurance records in an insurance company.

Barnard[4] models the flow of patient health records as a case in modelling the service supply chain in healthcare. Weyers and Louw[18] consider the flow of an incident in support of a customer’s information technology devices after the customer has requested assistance.

These cases are contained as a quantified grouping and, as with the customer, allows for the application of manufacturing techniques to the case for optimisation.

It is interesting to note, that money may be a physical product that flows. This approach is less relevant today as the concept of money has moved from a physical item to information flowing. Information is however abstract, as has been discussed previously in considering intellectual property. The alternate form of considering the money is rather to track the transactions associated to the flow of money, in this was being more aligned to the concept of a case to which manufacturing principles may be more easily applied.

7. SUMMARY AND CONCLUSION

Researchers apply manufacturing techniques to services. The application of these techniques increase as more and more services evolve to become industrialised and exhibit characterestics similar to those of services.

In applying manufacturing techniques, there are characteristics of services that complicate the application of manufacturing techniques to services. One of these characteristics is the absence of a physical product or inventory. A significant difference between services and manufacturing is the intangible nature of services. An example of this is the characteristic that service cannot be stored as inventory. The largest consequence of the intangible nature of services is the ability to visualise the flow of inventory and thus conceptually apply techniques targeted at the flow of inventory. It is with this inability to visualise the flow of services that the technique of proxies to inventory is used to bridge this conceptual difference between services and products.

Researchers use various techniques to subsitute the absence of a product or inventory. This substitution happens on a case by case basis. The process of finding a substitute for the product for inventory is referred to as a proxy to inventory. Little literature exists to describe the concept on its own. The concept of proxy to inventory is used intuitively as researchers model their supply chain. Examples of this is Giannakis [7] that uses capacity as the proxy to inventory or Maull et al[13] that use the customer as a proxy to inventory. Research into describing the concept of proxies to inventory in a more structured approach may be of use to researchers modelling service supply chains rather than deriving these proxies to inventory intuitively.

This paper has provided categories observed within which this substitution takes place. The proxies to inventory are categorised as either, capacity, value, intellectual property, customer, physical product or a case. Each of the categories are described and examples are provided for each category.

By understanding the categories and considering the categories when applying manufacturing techniques to services, practitioners can derive proxies to inventory that may be more suited to the specific scenario that the manufacturing technique is applied too. Proxies to inventory can for example be used to assist in modelling the service supply chain.

8. MANAGERIAL IMPLICATIONS

This study has shown that manufaturing techniques are applied in research to services. There are researchers that warn that this should be done with caution, but the use of well established manufacturing principles on services is useful when optimising services.

This study further showed that there are multiple approaches to substituting the role of the product or inventory used in manufacturing techniques when applied to services. The various techniques further may be more suited to specific scenarios or cases. Practitioners should consider the categories of proxies to inventories that may exist and identify the category more suited to their specific application.

The study has further shown that a specific service may fall into a number of categories. The categories given may thus be considered for a specific case and by being cognisant of these cartegories, the practitioner may identify proxies to inventory that are more suited to their specific need.

Each category also generalised characteristics of the specific category based on the examples. In general the categories of the customer, case or physical product as proxy to inventory represent more quantifiable examples of a product or inventory that flows through the system. The characteristics of being quantifiable relates more to the characteristics experienced in manufacturing, which should make manufacturing techniques more easily applicable to these categories of services. Capacity further is an approach that may cause confusion as translating the concept of inventory or the product to capacity, while the origional use of capacity from the manufacturing principles already exists, makes the concept hard to translate in applying manufacturing techniques to servces.

Practioners are thus encouraged to be aware of the various proxies to inventory and seek proxies to inventory that fit into the categories of the customer, the case or the physical product when applying manufacturing techniques the services.

9. FURTHER RESEARCH

This paper groups various approaches to substituting the role of the product or inventory in applying manufacturing techniques to servcies. The approaches are based on the study of service supply chain management and observing the proxies to inventory used.

As further research, the relevance of the observed proxies to inventory to other manufacturing techniques need to be studied. It was described that techniques, like Lean or Theory of Coinstraints is relevant to service industries like banking or insurance. The wider application to further techniques may enhance the categories for further application of the optimisation techniques.

The characteristics of the categories may be further elaborated through further study. Description of charactertics are given on a general level for the categories, with the major observation being around the quantifiable nature of each proxy to inventory. Understanding further characteristics may enhance the use of the proxy to inventory. An example of such a characteristic may be the time based nature of each of these categories.

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A SYSTEMATIC REVIEW OF BUSINESS ECOSYSTEMS TO SUPPORT AND IMPROVE SURVIVABILITY OF SMES IN SOUTH AFRICA

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ABSTRACT

Small and medium enterprises (SMEs) contribute significantly to the GDP and employment of South Africa, remaining a powerful tool to fight poverty and advance rural development. SME failure rates however remain exceptionally high. Business ecosystems are a platform driven approach that creates a network of interdependent, symbiotic businesses. This approach could enable SMEs to access resources and markets and to create value that they could not achieve individually. In this paper the authors explore fundamental concepts of business ecosystems, the characteristics and the capabilities required to facilitate ecosystem development. The findings will be used towards a conceptual framework to support and improve successful SME participation in South African business ecosystems.

OPSOMMING

Klein- en medium-ondernemings (KMOs) dra aansienlik by tot die bruto binnelandse produk (BBP) en werkgewing van Suid-Afrika, en bly een van die kragtigste maniere om armoede te beveg en landelike areas te ontwikkel. Ten spyte daarvan, bly die versuimkoers van KMOs besonders hoog. Besigheid-ekosisteme werk d.m.v. 'n platform om 'n netwerk van interafhanklike, simbiotiese besighede te skep. Die benadering stel KMOs in staat om nuwe markte en hulpbronne te verkry, en om waarde te skep wat nie moontlik op hul eie sou wees nie. In hierdie artikel verken die outeurs die fundamentele konsepte van besigheid-ekosisteme, en bepaal die eienskappe en funksies wat benodig word om ekosisteme te ontwikkel. Die bevindinge sal gebruik word om by te dra tot 'n konseptuele raamwerk wat KMO deelname in Suid-Afrikaanse besigheid-ekosisteme ondersteun en bevorder.

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1. INTRODUCTION

Small and medium enterprises (SMEs) lie at the core of the economic development of a country. It not only fulfils a role of contributing to the country's gross national product (GNP) [1], but plays another important role of encouraging entrepreneurship, efficiently creating jobs and being the seed of big businesses [2]. By counteracting larger enterprises, SME development encourages the process of both inter- and intra-regional decentralisation. In a broader sense, it can be said that SMEs are an accelerator of achieving wider economic and socio-economic objectives such as poverty alleviation [3].

In the Republic of South Africa, it is estimated that formal business entities are comprised of 91% SMEs. SMEs also contribute between 52% and 57% to gross domestic product (GDP) and provide about 61% of employment [1] [2]. However, the failure rate of SMEs is estimated to be between 40% and 80%, depending on the source, and less than half of newly established businesses survive more than five years [4]. SMEs are faced with numerous challenges that are, amongst others, environmental, financial or managerial in nature. Management cannot control external challenges that occur in the macro environment. Challenges that can directly influence SME success include the state of the economy, resource scarcity, HIV/AIDS and rapidly changing technology [4]. According to Brink [5] entrepreneurs in previously disadvantaged townships experience problems to understand the impact of technological development on the success of their business. They also tended to have a lack of knowledge of their competitors and their customers, resulting in problems with low demand [5].

The digital 'revolution' has created a society that is almost entirely dependent on information and technology [6]. The impact of technology is not doubted, however researches have questioned whether it will affect different categories of business (e.g. small businesses) and certain regions (e.g. rural) evenly and whether it may have any adverse effects [7] [8]. Technological changes will provide both new opportunities and new threats to small businesses, especially in rural communities [9]. Spatial proximity, both in terms of geography and activities, provides several economic benefits and positive location-specific externalities to the concentrated firms [10]. However, the use of new communication technologies are extending geographical boundaries and opening up new markets to businesses that were previously not accessible. This means that rural businesses can directly compete with urban counterparts while having the advantage of lower overhead and labour costs [11]. In return, this creates new possibilities for urban businesses to take advantage of cheaper resources and potential rural markets [12].

Communication technology has also given businesses the unique opportunity to partake in a community of many different companies working together to gain comparative advantages [13] [14]. Such a community, called an ecosystem, will allow and support companies to create new value that any company on its own would not be able to achieve [15]. Ecosystems are gaining ground by digitalizing products, services and business processes. Enterprises with a business model that leverage the power of ecosystems have grown dramatically in both size and scale over the past decade [16]. This strategy is no longer only suitable for tech or digital companies, but the opportunity is opening up to every company in every industry [17].

Business ecosystems are a network of businesses designed to co-operate and co-evolve around a software platform [18]. It is most widely used because of the growth opportunities it presents by increasing local and global market access [10]. It does this by connecting SMEs to new business partners, customers and potential investors with whom it would have been much more difficult to interact otherwise [18], [19]. The business ecosystem brings many buyers and sellers together, increasing the value offering by integrating services offered by a number of SMEs [20], [21]. If designed and managed correctly, the benefits can reach far beyond market access. One of the most powerful uses of business ecosystems is in sharing key resources such as information, capital, goods and services [21]. SMEs often experience considerable resource constraints regarding R&D and innovation, especially due to the lack of internal expertise and managerial resources. External sources of knowledge and information together with close interaction with customers will help SMEs reach and maintain higher innovation performance [10], [22].

Both business ecosystems and SMEs present their own set of challenges in the adoption of this approach. The literature related to business ecosystems for South African SMEs is severely limited. This means that a key objective of this paper is to enhance the conceptual understanding of the functional capabilities of business ecosystems.

This paper presents the findings of a systematic literature review that is guided by the following research questions:

i. What does the architecture, processes and support structures of a business ecosystem look like?
ii. What are the unique characteristics and limitations of SME participation in business ecosystems that will need to be considered?
iii. What are the capabilities of a business ecosystem that supports the internal and external processes of SMEs?

2. METHODOLOGY

2.1 Systematic review

The main purpose of a systematic literature review is to provide an exhaustive summary of the literature that is currently available on a specific topic, while ensuring that it remains unbiased [23]. Systematic reviews are conventionally understood to have specific characteristics, including [24]:

- Addressing pre-specified, highly focused questions;
- Explicit methods for collecting studies;
- Appraisal of studies to determine scientific qualities; and
- Explicit methods to combine findings across a wide range of studies.

The advantages of this method are mainly seen in its rigour and transparent process [24]. The findings of the studies are systematically interpreted against a range of expert criteria that represents the meaning of the work. Judgement-based conclusions are then drawn from the research [25]. A sequence of steps is typically defined to perform the systematic review. These steps are displayed in Figure 1 [25].

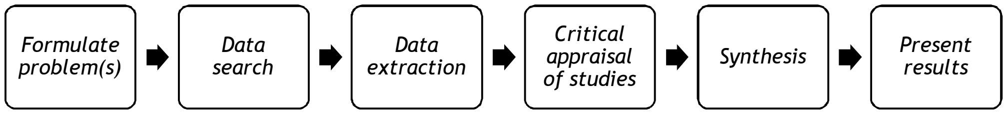

Figure 1: Systematic review process

2.2 Data search

Data was collected through the use of web based services, primarily Scopus. The search was completed by using a combination of the keywords “business ecosystem” and “SME”. The search delivered a total of 38 documents, which was then filtered through a series of criteria. This process is displayed in Figure 2.

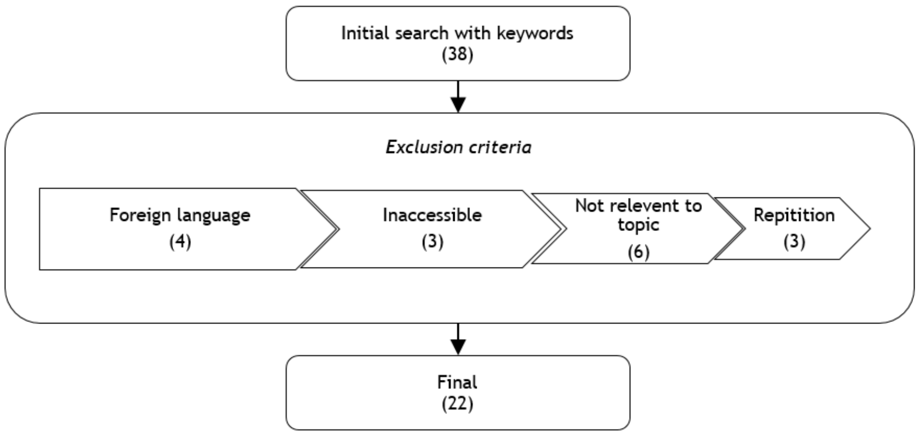

Figure 2: Data filtering methodology

2.3 Data analysis

After the initial screening process displayed in Figure 2, the final 22 documents were critically analysed according to the categories described in
Table 1. The findings of the analysis were then used to attempt to answer the research questions stated in previous sections.

Table 1: Data collection categories and components

Main category	*Component*
Paper characteristics	• Title of document • Author(s) • Year document was published • Document type • Document source • Citations • Geographic focus of study • Application level • Focus of paper • Type of paper
Empirical elements	• Methodology employed in paper • Validation techniques • Gap in literature addressed in paper
Business ecosystem foundation	• Structure of business ecosystem • Actors and role players • Driving force behind ecosystem formation • Purpose of ecosystem • Ecosystem characteristics • Behavioural mechanisms of ecosystem • Characteristics of SMEs • Barriers for SMEs
Business ecosystem capabilities	• Communication • Knowledge and information management • Technology integration • Dynamics and reconfiguration • Self-organisation and evolution • Service offerings • Open innovation
Observations	• Conclusion drawn by authors of paper • Oversights in paper

3. INTRODUCTION TO BUSINESS ECOSYSTEMS

Globalization is increasing the intensity of competition between and across different regions. Due to falling transportation and communication costs, larger segments of regional economies are exposed to heightened global competition. This drives the need for businesses to extend their network beyond geographical boundaries [10]. SMEs often lack the expertise and resources to manage a complex, global supply network, and to respond adequately to emerging challenges and opportunities in this regard. Large corporations have the advantage over SMEs due to scale, higher capital and negotiation power to obtain better alliances with other organizations [10], [18].

Business ecosystems were first introduced by Moore [26] and defined as "an economic community supported by a foundation of interacting organisations and individuals – the organisms of the business world." In a business ecosystem companies (producers, suppliers, service providers) and institutions (research laboratories, educational institutions, and other institutions in a given economic field) are linked through relations of interdependence and complementarity [10]. Several other terms are used in literature that describe concepts similar to business ecosystems, such as dynamic clusters, collaborative networked organisations and virtual organisations [10], [27]. The term most commonly used to describe business ecosystems for SMEs are digital business ecosystems (DBEs). DBE is an infrastructure that supports the flexible development and composition of business services and integrates them with peer organizations to turn their services into offerings [20], [28]. SMEs are represented in a digital environment where loosely coupled agents interact through a well-defined software platform, to dynamically exchange, offer and demand information, services and resources according to their capacities [18], [29].

Different from traditional business ecosystems, an SME ecosystem is self-sustaining and self-organizing with no central governance mechanism but is embedded in supportive, legal, regulatory and governance frameworks. This implies that the ecosystem has the ability to optimise itself through differentiation and selection of its components on a long time scale [10], [30], [31]. The ecosystem facilitates network based relationships through a cohesive information system that has the ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments. External P2P relationships are mainly based on the willingness to share information. Interaction and the sharing of knowledge supports innovation and enables all partners to adapt to market changes more effectively [10], [32], [33]. Internal tasks are designed to require low levels of coordination. This approach decomposes complex tasks into simpler elements so that they can be managed independently but still operate as a whole [21].

4. REVIEW ANALYSIS AND RESULTS

A comprehensive analysis and summary of the 22 selected, applicable studies will be included in this section. An empirical analysis will be followed by a qualitative analysis.

4.1 Descriptive statistics

The empirical elements of each selected study include year published, publication type, citations and geographical area of focus. The domains of the studies vary across a broad range, but each study is focussed on SMEs. The analysis of the empirical elements follows below.

4.1.1 Timeline of studies

The studies included in this paper are strongly technology-oriented. Due to the rapid pace of technology change, technological solutions can quickly become outdated. The timeline of the papers (Figure 3) indicates that a more than 50% of the papers were written in 2011 or before. The studies do however still provide relevant information on the operation and behaviour of both SMEs and business ecosystems. South African SMEs often experience considerable technological constraints that will mean that more modern solutions may be inaccessible. This means that 'outdated' technological solutions should not be disregarded, and can prove to be valuable to South African SMEs.

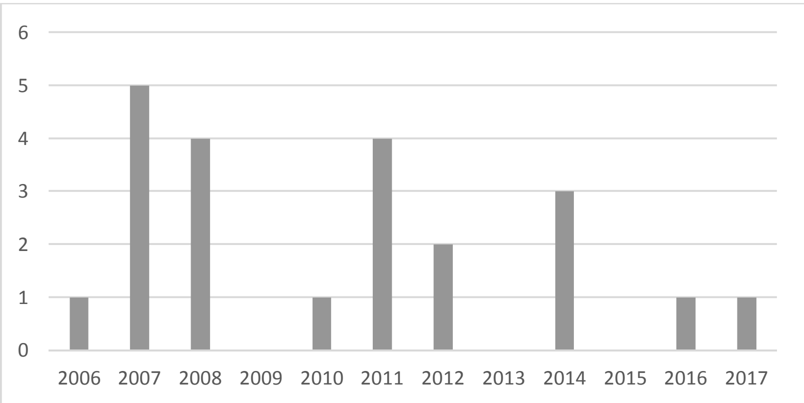

Figure 3: Timeline of studies included in paper

4.1.2 Citations breakdown per publication type

The number of citations (Table 2) is fairly limited. This could be accounted to the immaturity of the research field, as well as the specified nature (discussed in section 4.1.4) of the selected studies.

Table 2: Citations of publications

Type of publication	*Number of Citations*
Article	31
Conference Paper	33

4.1.3 Geographic area of focus

As indicated by Figure 4, an overwhelming majority of the studies focusses on European SMEs. Conditions for European SMEs will differ greatly to South African SMEs with regards to economy, technology, available resources, markets etc. In future work, special care will be taken to incorporate South African conditions where applicable.

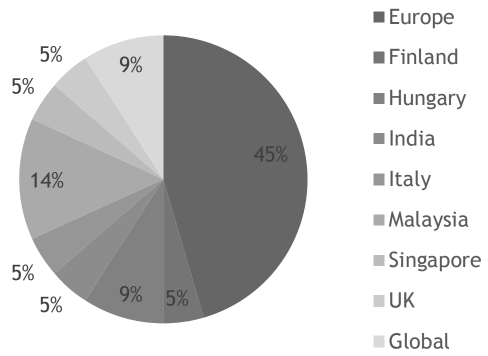

Figure 4: Geographic are of focus of studies

4.1.4 Focus of publication

The publications were categorized according to the perspective of the study and the level to which it was applied. Descriptions of each of the categories are included in Table 3. The categories are all interrelated, meaning that elements of each one appears in most of the studies. The study was divided into a category based on the main focus of the content.

Table 3: Domain and level of application

Domain focus	
Business Ecosystem (BE)	These publications are mainly focused on the ecosystem as a whole. It most commonly takes the perspective of the ecosystem owner, designer or facilitator.
SME	These publications are from the perspective of the SME participating in the ecosystem. It mainly discussed elements relevant to each individual SME.
Relationship	These publications focus on the relationships within the network. It contains elements of both the SMEs and the ecosystem, focusing specifically on the interaction.
Level of application	
High level (HL)	High level publications mainly discuss behavioural aspects with the purpose to enhance the understanding of the specific topic. They do however, not contain detail about why it behaves that way and how to facilitate or manage it.
Conceptual level	These publications include high level observations together with insight as to why they occur and how it should be managed or facilitated. Solutions at a conceptual level are included.
Detailed level (DL)	Detailed level publications mainly provide technical solutions to very specific applications. These publications normally discuss a case studies or specific examples.

From Figure 5 it can be seen that the large majority (68%) of the publications are applied at a detailed level. Another large section of the publications is analysed only at a very high level (27%). This shows that the conceptual understanding that is required for detailed level analysis is absent. Many of the concepts and design decisions that have been explored in the literature are based only on a high level understanding, which is insufficient for designing a functional and sustainable system. Figure 6 shows the breakdown of the domain focus. From this figure, it is clear that a majority of the publications focus on the ecosystem as a whole (64%). Even though all the papers are applied to SMEs, the unique characteristics and requirements of SMEs are often ignored in the literature reviewed.

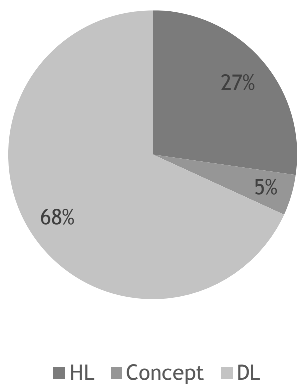

Figure 5: Level of application

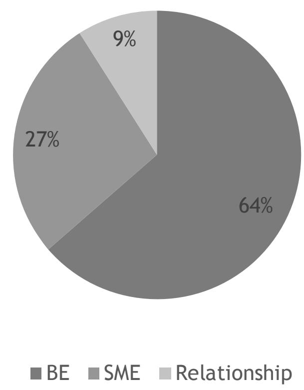

Figure 6: Domain focus

4.2 Discussion of results of qualitative analysis

The publications were analysed according to Table 1 to answer the research questions using a sample of relevant and available publications. A discussion of the results is included in the following sections.

4.2.1 Structure of business ecosystems

The structure of a business ecosystem is based on concepts commonly employed within ecological sciences. Business concepts are translated to ecological concepts to inspire a set of social rules to imitate interaction similar to that in a natural ecosystem [18]. Just like natural ecosystems, the structure of a business ecosystem is complex and consists of several dynamic elements. Nachira [34] described the structure of a business ecosystem in four levels. These levels are described in Table 4.

Table 4: Ecosystem structure levels

Levels	*Description of level*
Governance and policy	The self-organizing nature of a business ecosystem requires a higher order capability [35]. Reliable systems of governance are required to develop and implement support structures to guide technological development and communal decision making [28]. Furthermore, regularity policies should be established to determine level of data sharing (for both B2B and B2C) that does not violate data protection regulations [35].
Human capital, knowledge and practices	Knowledge and information are critical assets in a business ecosystem. The ecosystem builds relation-specific assets and knowledge sharing routines that allows companies to leverage the network for knowledge acquisition and exploitation [21], [35]. This interaction and sharing of knowledge enhances innovation capabilities for all partners [20]. The interaction also enables companies to integrate their services with peers to increase the value offered to customers. Each company will have established their own operational processes to deliver their services. The more complex and time or cost-critical these processes are, the more challenging the management and integration processes are [20], [27].
Service and technical infrastructure	The ecosystem uses a digital infrastructure that allows companies to create, integrate and operate services [20]. The infrastructure is a well-defined software platform that creates a digital environment where SMEs can dynamically interact [18], [29].
Business and financial conditions	The nature of SMEs creates special conditions that should be considered for the ecosystem they operate in. SMEs generally depict more flexibility and adaptability to own the technology, making them the ideal candidates to operate in a dynamic environment [20]. However, they are often under severe resource constraints (e.g. time and money) and have a lack of internal expertise [18], [22]. This means that they are not able to invest a lot of time and money into studying and selecting from the ever-growing technologies that are best suited for their activities [29].

As shown in Figure 7, existing literature strongly focusses on service and technical infrastructure. This becomes problematic as many attempts are made to design the infrastructure of a business ecosystem without a deep understanding of a foundation of lower levels to make the system functional, and without the higher levels to make the system operational and sustainable. The infrastructure is most commonly designed around a central hub [18], [20], [28], [29]. However there is also a strong emphasis that a business ecosystem for SMEs does not contain a dominating company [28], [36]. This contradicting element displays the gap in literature discussed in earlier sections.

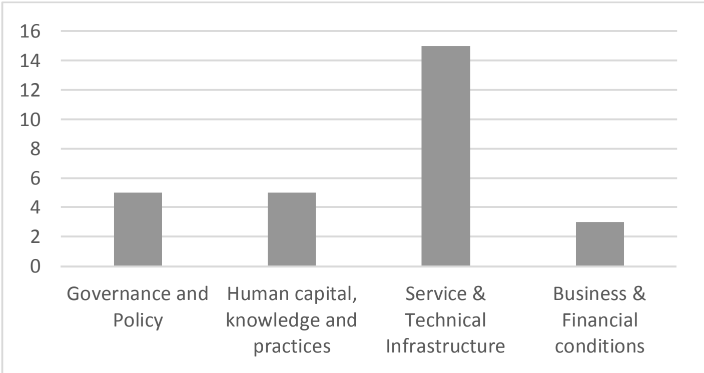

Figure 7: Frequency of ecosystem structure layers in papers

4.2.2 Barriers to ecosystem adoption for SMEs

SMEs have unique characteristics that create barriers for them to adapt to an ecosystem environment. These barriers are important considerations when creating an ecosystem specifically for SMEs. Several of the reviewed publications discuss more than one barrier. Figure 8 breaks down the occurrence of each barrier.

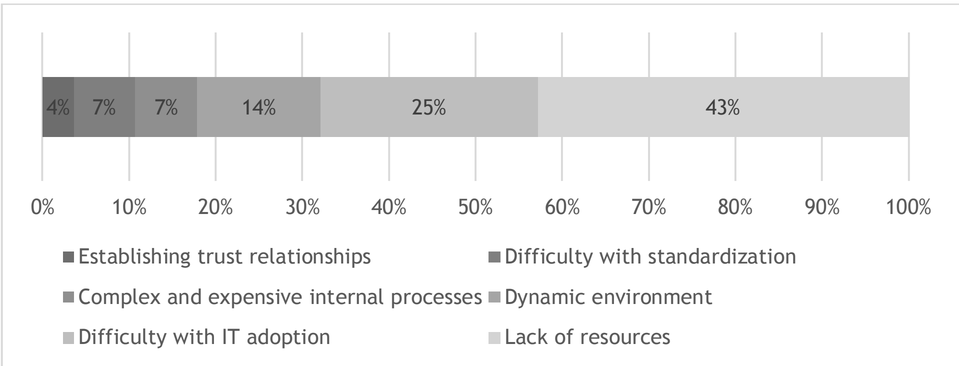

Figure 8: Occurrence of barriers to ecosystem adoption

As can be seen from **Error! Reference source not found.**, the largest barrier for SMEs is their lack of resources. This includes resources such as time, money, workforce, internal expertise and managerial resources [18], [22]. Due to this lack of resources most SMEs find it difficult to Figure 7study and select the right software for their business processes. The use of internal software is further hindered by the lack of IT expertise of employees [29], [37]. Furthermore, SMEs do not have sufficient resources to cope with large amounts of data, information and opportunities that will be required of them in an ecosystem environment [22]. In this environment, they would often have to deal with bigger companies where they would most likely be in an unfavourable position due to lack in negotiation power and legal expertise [35]. Almost as a direct consequence of the lack in resources, SMEs have a difficult time to adjust to new IT systems. Integrated software is mostly designed for large corporations, making it difficult for SMEs to apply [29]. Introducing new software systems also implies high costs at first rollout before cost savings become effective [29].

According to **Error! Reference source not found.** another barrier for SMEs is to survive in a dynamic environment. The small scale and resource strapped nature of SMEs often burden them with the challenge to successfully respond to substantial strategic discontinuities, unpredictable environment changes and uncertainty dynamism [21]. It's important to note that SMEs are practically present in all business sectors and contexts. This means that it would be very difficult to provide a standardised way to cover all the tasks and processes required by SMEs [18], [27]. Internal processes are also often complex and done on small scale, leading to high production costs [28]. The last barrier as indicated by **Error! Reference source not found.**, is the difficulty for SMEs to establish trust relationships in the increasing opportunistic environment created by online commerce [35].

4.2.3 Capabilities of business ecosystems

A business ecosystem supports the networking of interdependent and dynamic entities. This means that the ecosystem has the dual role of facilitating relationships between different SMEs, as well as supporting internal capabilities of the participating SMEs [10]. Table 5 provides the capability requirements of a functional and operable ecosystem while ensuring that value is created for all participating SMEs.

Table 5: Capabilities of business ecosystems

Capability	*Description*
Communication	A business ecosystem is a real-time adaptive knowledge exchange network where all participants share and use resources, applications, services and knowledge [29], [38]. The ecosystem environment strongly depends on the effectiveness of communication between businesses, including both B2B and B2C communication [21], [30]. Effective communication includes the following capabilities [21], [39]: • The ability to create and sustain data relationships; • The transformation of data and data constraints across different platforms; • The ability to handle complex queries across multiple sources; and • The ability to retrieve, store and combine information that accumulates throughout the network.
Knowledge and information management	Organizational information is complex and has complex relationships. This means that advanced mechanisms are required to capture and manage such information [30]. Data shared between members of the ecosystem is likely to contain sensitive information which will require privacy controls [35]. Sensitive information rises issues such as trust, security and consumer protection [28]. The management of sensitive data requires the following [35]: • A defined level of data sharing that will not violate regulations on data protection; • Agreement between partners that ensures data will not be shared with unauthorized third parties; and • A means of generating traceable records to deal with any data breaches.
Integration and interoperability	A business ecosystem facilitates both inter- and intra-enterprise distribution of business processes and information. For the system to be interoperable, two or more components in the system must be able to exchange information as well as use the exchanged information [29]. This is achieved by the cooperation of multiple processes and applications to become one functional unit. This integration is required at the following two levels [29]: • Technological integration, including the processes and applications, as well as the system interface; and • Information integration, including the accumulated data and knowledge within the system.
Dynamics and reconfiguration	Companies in an ecosystem operate in a complex environment and they interact dynamically. This means that the ecosystem should be capable of supporting dynamic entities as well as supporting the entities to handle its dynamic environment [10], [21]. Dynamic capabilities refer to the following [10]: • The ability to re-deploy existing competencies to build new products that better match emerging markets; • The ability to sense the environment to identify market needs and new opportunities; and • The learning capacity to generate new knowledge and enhance existing resources.
Self-organisation and evolution	The aim of the ecosystem infrastructure is to provide a flexible, distributed platform that will imitate the self-organizing and evolutionary behaviour from biological ecosystems [28]. Self-organizing capabilities include the following: • The ability to facilitate the emergence of long-lasting collaborative partnerships [18]; • Intelligent behaviour and the ability to learn and adapt to produced and derived knowledge on a short time scale [30]; • The ability of self-optimization through differentiation and selection of its own components on a long time scale [30]; and

	• The ability to support user decision making by providing optimal solutions ad combinations [33].
Service offerings	The business ecosystem enables SMEs to create, integrate and operate services via inter and intra organizational links [32]. The service architecture will require the following capabilities [20], [36]: • Services must be designed as loosely-coupled independent units of functionality to ensure minimum coordination is required; and • A clearly defined, externally visible interface must provide a unified view for other system members to use their functionality.
Open innovation	Open innovation is a term used to describe the use of external knowledge flow and expanded markets to accelerate internal innovation [40]. A business ecosystem creates an environment with increased possibility for open innovation due to the exchange of knowledge and skills [38]. It does however, remain the responsibility of the SME to scout the environment for valuable inputs and apply it to their own complex and technical innovation processes [22]. SMEs are severely limited in this regard due to their smallness, scale limitations and restricted technological assets. Open innovation for SMEs will require the following [22], [27]: The implementation and execution of boundary spanning activities; and Involving customers with product and service development processes.

5. FINDINGS AND RECCOMENDATIONS

By completing the systematic review, a large gap in literature regarding the conceptual understanding of business ecosystems was identified. Regardless of this gap, several attempts have been made to design the service and technical infrastructure of such a system. This infrastructure is only one of four levels required in a business ecosystem structure (Figure 9). This tendency led to many inadequate structures and contradicting elements within the designed ecosystems.

This paper strived to fill this research gap by extracting and synthesising conceptual elements discussed throughout the papers. As shown in Figure 9, the structural components and core capabilities for the business ecosystem were identified. SMEs, who are a sub-element of the business ecosystem, were recognized as autonomous yet interdependent entities. SMEs have their own set of internal and external barriers (Figure 9) to overcome before successfully participating in an ecosystem.

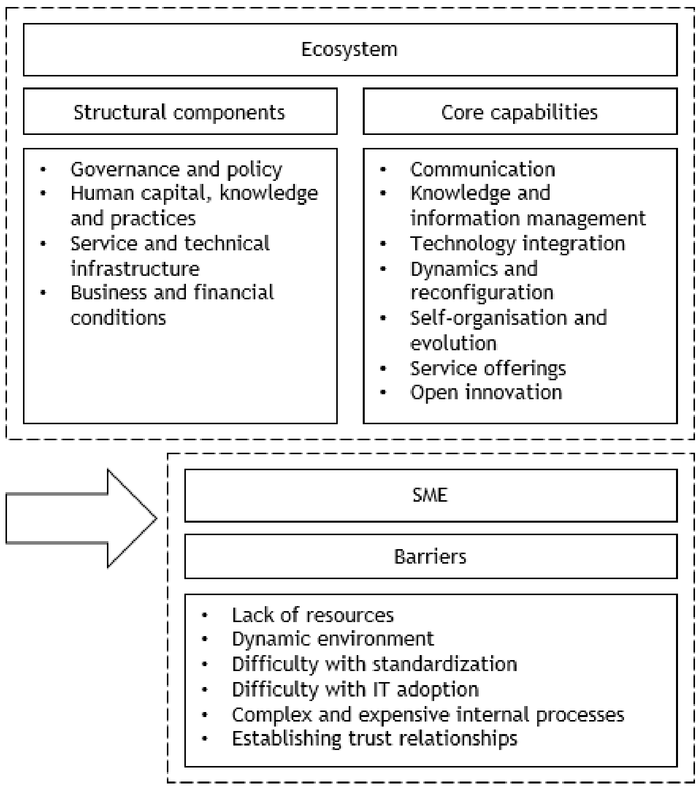

Figure 9: Conceptual framework

The results of this paper serve as a step towards maturing the concept of business ecosystems. Further work needs to be done to determine more detailed conditions and operational requirements. A study is required to determine the evolutionary nature of networks across the organization lifecycle, from start-up through growth to maturity [41]. To determine the contribution of business ecosystems to SME support during the various lifecycle stages, an in-depth effectiveness analysis or feasibility study would be required.

6. CONCLUSION

SMEs are a critical part of the South African economy, contributing significantly to the GDP and employment of the country [1] [2]. Regardless, the failure rate of SMEs is alarmingly high due to the many challenges they face [4] [5]. A digital solution was identified as one of the possible solutions to counteract the challenging environment in which SMEs operate. Business ecosystems have the potential to address many of the challenges that South African SMEs face and ultimately improve the survivability of SMES. The findings of this paper are the first step towards the improvement of SME participation in South African business ecosystems.

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LOCAL CONTENT OF THE ALTERNATIVE ENERGY INDUSTRY IN SOUTH AFRICA

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ABSTRACT

Although there has been a remarkable growth in global renewable energy (RE) consumption, the South African energy system is still highly biased towards fossil fuel sources. Despite its nondepletable renewable sources, particularly solar and wind, there is a wide gap between the potential for RE production and actual generation. This may be attributed to the lower costs (per kilowatt-hour) for municipal electricity supply, gasoline, diesel (all fossil fuel derived), versus that from alternative sources. A direct cost index for alternative energy devices commercially available in South Africa can be the proportion of local content (LC) in respect of materials and technologies in the devices. It is highly probable that higher LC will drive increased productivity in local industries, which based on economy of scale should lead to costs reduction. After a survey of the environmental and economic potentials and prospects of alternative energy sources and technologies, within the South African context, this paper explores the LCs of alternative energy solutions in the industry, against the backdrop of the LC policy. In terms of set goal and reality, the level of stewardship clearly requires more commitment. Identified research and development gap areas include components with improved performance, advanced and mass-production friendly manufacturing techniques for components, reduced materials requirements, and improved methods for integration of RE into buildings, electricity grids, and other distribution systems. Increased attention to these areas will hasten realization of the set goals.

Keywords: Alternative energy, energy security, fuel cell, local content, solar energy

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1. INTRODUCTION

Alternative energy sources in general (apart from nuclear sources) are more widely available, environmentally friendly, and allow the use of energy more efficiently than conventional technologies such that our existing energy supply sources can last longer. With nuclear sources, different issues (such as waste disposal, reactor safety, and nuclear proliferation) has kept the prospect contentious, and greater emphases are now on RE sources [1], and RE generation is the fastest-growing source of electric power globally, rising by an average of 2.9%/year [2]. However, coal, which emits more CO_2 per unit energy than oil and natural gas still constitutes more than 70% of South Africa's primary energy source [2]. Increased deployment of RE technologies is accepted as crucial in redressing this situation.

Towards achieving this, governments tend to link RE deployment strategies with socioeconomic goals, through industrial policies such as the local content requirement (LCR) [3]. The South African Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) establishes LCRs for RE projects in SA to encourage the growth of the local industry. This policy requires investors to incorporate a certain amount of local materials and technologies in their product [4],[5],[6]. A common argument against LCR policy is that it can restrict investors from using the full range of internationally available technologies to their advantage. If locally available technologies are not competitive, investors may face higher costs, which will most likely be passed to the consumers [7]. The RE transformation drive of SA, therefore, is seeking two goals simultaneously – LC and energy sustainability.

To decouple the issues, extensive use of RE sources remains key to sustainable energy system in SA, and this transformation has been shown by several studies [8], [9], [10], [11], [12] to be technically and economically feasible. In this pursuit, several criteria should be considered. These include resource size, resource availability risk, demand matching, technology risk, learning rate, environmental risk, localization and export potentials, and local participation [13]. The commitment of key players to the development of alternative energy industry and the proper coordination of their activities are also important. Within these diverse issues, the available RE resources, localization potential vis-à-vis the current situation in terms of utilization, and local content of RE have been addressed in further details herein, to point towards the prospects going forward.

2. RENEWABLE ENERGY RESOURCES IN SOUTH AFRICA

The location of SA on the globe, its geography, and size provide multiple, abundant and widespread RE resources. Hence, SA's alternative energy industry has been growing, but it is still far from reaching its full potentials. These resources are addressed following.

2.1 Solar power

SA has a perfect climate for solar energy, with average direct solar radiation levels of 4.5-6.5 KWh/m^2 per day and an average sunshine per year of more than 2500 hours, which place it among the top three countries globally in terms of solar energy resource [14]. It is thus a potentially ideal place for solar power generation. However, with the country not being among the first ten countries in terms of cumulative installed solar photovoltaic (PV) capacity and wind power generation [15], [16], there is obviously a wide gap between the potential for RE production and actual generation in SA. For example, SA has almost two times the solar resource of Germany (Figure 1), where solar photovoltaic is in close cost competitiveness with convention energy source. SA's planned PV capacity by 2030 is 8.4 GW while Germany has attained almost 40 GW installed solar PV capacity as at 2015 [17]. Different solar power technologies in use in SA, compared with other nations will give more insight into the situation.

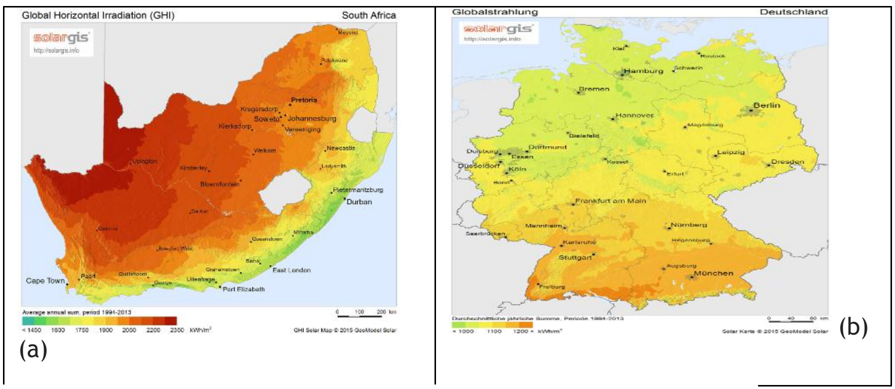

Figure 1: Solar resource in South Africa (a) as compared with Germany (b) [18]

2.1.1 Solar thermal

SA is an energy-intensive economy consuming about 122.4 million tons of oil equivalents annually [19] and at least 1 117 PJ (about 44% of the country's total final energy demand) for heating [20]. Although solar water heaters, process heaters, and space heating systems are all currently being used in SA, and there have been significant signs of maturity and growth potential of the water heater market, utilization of this resource in the country is still behind best practice norms [9]. In spite the country's huge potential for solar power generation, it has far fewer installed solar thermal (ST) systems (1, 055 MWth) than European countries such as Austria with 3.5 times more installed systems (3, 5451 MWth) and Germany with 12 times more systems (12, 281 MWth) than SA [21]. Furthermore, little information about the typical costs, payback, return on investment, and existing successful large-scale installations are made available to potential consumers, installers and decision makers [22].

One of the sectors in which ST can significantly contribute to the energy demand is the industry. The industrial sector uses more delivered energy than any other end-use sector, and in SA, this sector consumes about 43% of the final energy [23]. Process heat and steam are widely used in SA's industrial sector especially in petrochemical plants, base metal refining, and power plants. Therefore, the potential for using ST energy as a primary or supplementary energy exists. However, this market is currently underexplored, and only few studies have been conducted to date on the economic and other benefits of using solar generated heat to replace or support conventional heating methods for large-scale industrial process heat applications [24],[23]. It has been estimated that 30% of the total thermal energy demand in industrial processes is below 100ºC while 57% is below 400ºC [25]. In the agro-processing sector, 79% of the sector's energy demand is for low-temperature heat. As ST provides low-temperature heating most economically, this presents a key opportunity. The potential for ST energy within the agro-processing sector has been estimated to be between 425 000 m^2 and 3 758 000m^2 of collectors, which could result in 111 000 to 943 000 tonnes of CO_2 emissions reduction per annum [21]. Also, taking differing applications into account, a payback period as low as four years can be achieved when replacing electricity with ST, assuming no electricity cost increase while a payback period of less than three years is possible for replacing diesel, petrol and LPG with solar thermal, again assuming no fuel cost increase [21].

Despite the potentials for industry size ST systems, most of ST technologies are currently used in small-scale applications for domestic hot water production in single-family houses. Large-scale applications such as multifamily houses, schools, hospitals, hotels, etc, account for only 9% of the global installed capacity and very large scale applications such as district heating and industrial applications make up only about 1%, despite the advantages of larger ST systems such as reduced losses, more balanced heat demand per m^2 and lower cost [22]. According to an analysis by Joubert *et al.* [22] on a database set up by the Stellenbosch University on large-scale ST systems in SA that have been commissioned between 2007 and 2015, based on data obtained from active ST companies in SA and databases of Blackdot Energy and Soltrain 1 and 2 projects, 89 ST systems with gross collector area >10 m^2 each and a total collector area of 13 894 m^2 were installed. As shown Table 1, there are a number of large-scale ST systems in SA but the number of installations per year decreased drastically between 2014 and 2015. This decline could be due to external factors such as drop in oil price in 2014 which would make the cost of conventional energy sources more attractive than AE sources.

Table 1: ST collector gross area (> 10 m^2) newly installed in SA from 2007 to 2015 [22]

Year	Approximate collector gross area (m^2)	Total no of installations per year
2007	1500	4
2008	750	8
2009	700	6
2010	1500	8
2011	2200	25
2012	2900	14
2013	2600	13
2014	600	6
2015	1000	5

2.1.2 Concentrated solar power

Like PV systems, the concentrated solar power (CSP) also generate electricity from the sun. However, while PV systems could convert diffuse, indirect radiation into electricity, CSP plants rely only on direct irradiation. SA is one of the best located regions for CSP in the world, with the Northern Cape region of the country experiencing levels of more than 2 900 kWh/m^2 [26], which is significantly more than some of the other CSP hot spots such as Spain and Southern California in the USA. Spain, with a significantly poorer solar resource compared to SA, has the lion's share of the world's installed CSP capacity (2.3 of 3.4 GW in 2013) [27]. The boom in Spain's CSP deployment was facilitated by a renewable energy feed-in tariff (REFIT), with the country being the first European country to introduce a REFIT funding system for CSP [28]. A REFIT of ZAR 2.10/KWh (€ 0.18 at the exchange rate of 21st May 2009) was announced in SA in 2009 [29], which, although was lower than that in Spain (€ 0.28/KWh) at that time [26], should still be enough to encourage local implementation of the technology. However, with a total installed capacity of 150 MW in 2015, all of which became operational in the same year [30], the CSP plant technology is still lagging in SA.

According to some reports [31],[9], the deployment of large CSP plants has the potential for significant contribution to greenhouse gas emission reductions in SA, and installed CSP capacity of above 20 GW by 2035 have been envisaged. In a study by Fluri [26] to assess the potential of CSP in SA, out of the nine provinces, Northern Cape (NC), Free State (FS), Eastern Cape (EC) and Western Cape (WC) include areas suitable for large-scale CSP (Table 2). NC shows the best potential with a power generation capacity of 510.3 GW (assuming a land use of 28 Km^2/GW), followed by the FS and the WC having power generation capacities of 25.3 and 10.5 GW corresponding to 886 and 298 Km^2 site areas respectively (Table 3). Assuming all potential sites are utilized and that the plants operate with an average capacity factor of 38.8% [32], a net annual energy generation of 1861 TWh is possible. This is 3.3 to 5.4 times SA's total electricity requirement forecast for 2025 [33].

The REIPPPP has embarked on some CSP projects, all in Northern Cape, and some of which are currently operational (Table 4). However, with an expected total capacity of 600 MW (for all the plants put together), a wide gap still exists between the potential for generation and actual capacity.

Table 2: Suitable areas for large-scale CSP in various provinces of South Africa (km^2) [26]

Proximity to transmission (km)		NC		FS		WC		EC	
		<20	<10	<20	<10	<20	<10	<20	<10
Average DNI	7.0-7.5 KWh/d	2963	1539	694	326	278	132	44	3
	7.5-8.0 KWh/d	7291	4095	14	14	16	0	0	0
	>8.0 KWh/d	4034	2345	0	0	0	0	0	0

Table 3: Power generation potential, net energy generation and water requirements for large-scale CSP plants in various provinces of South Africa [26]

	NC	FS	WC	EC	Total
Suitable land area (Km^2)	14288.0	708.0	294.0	44.0	15334.0
Power generation potential (GW)	510.3	25.3	10.5	1.6	547.6
Net energy generation (TWh/a)	1734.4	85.9	35.7	5.3	1861.4
Water requirement (wet cooling) million m^3/a	5671.5	281.0	116.7	17.5	6086.7

Table 4: Concentrating solar power projects in South Africa [34]

Project name	Technology	Status	Capacity (MW)	Start year
Bokpoort	Parabolic trough	Operational	50	2016
Ilanga I	Parabolic trough	Under development	100	2020
KaXu Solar One	Parabolic trough	Operational	100	2015
Khi Solar One	Power tower	Operational	50	2016
Redstone Solar Thermal Power Plant	Power tower	Under development	100	2018
Kathu Solar Park	Parabolic trough	Under development	100	2018
Xina Solar One	Parabolic trough	Active	100	2017

Apart from climate protection, grid stability and security of supply, other potential benefits of large-scale CSP plants in SA include: (a) increasing demand for local added value as steel, concrete, mirrors and labour, with potentials to be sourced locally, account for nearly 50% of the investment [35]; (b) conflict-neutral technologies, unlike fossil and nuclear-based sources, which are increasingly involved in unstable political environments and military conflicts; and (c) possible side applications and products as in co-generation for production of electricity and heat for operating adsorption cooling and water desalination facilities [36].

2.1.3 Solar photovoltaic

The PV technology was introduced into SA in the 1980s, and until about ten years later, the industry still consisted of small-scale installations that are predominantly off-grid and in rural areas. In 2010, due to the rapidly increasing cost of electricity and awareness about the unsustainability of fossil fuel energy sources, development of larger commercial-scale solar PV projects increased markedly. In 2013, as a result of the Department of Energy's REIPPPP, construction of 18 large, utility-scale projects with a combined capacity of 630 MW commenced. Despite this progress in the SA's solar PV development, and the various recent solar PV industry activities in the country, compared to developed solar PV markets, SA is still at an emerging stage. Nevertheless, the outlook for the country's PV industry is positive.

Depending on the growth trajectory and other market drivers, it is expected that global PV industry capacity could reach 345 GW to 688 GW by 2020, and could be triple that by 2030 [37]. In the medium to long term, the solar market is expected to shift from developed to developing countries, with Africa sharing 4.1% to 5.7% of the global PV installed capacity by 2030 [37]. This presents a potential opportunity for SA to capitalize on its abundant solar resource and become a big player in global solar PV market. Based on the projected PV technology dissemination paths for all market segments (utility scale, commercial/industrial scale, and residential scale), the total PV market in SA could reach 11 946 MW to 20 133 MW by 2035. Figure 2 shows the projected SA's total PV market growth paths.

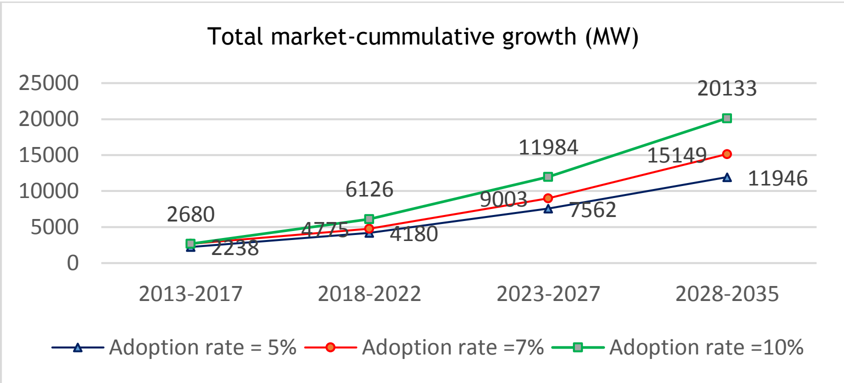

Figure 2: South Africa's total PV market growth paths. Data from EScience Associates et al. [38]

Apart from the environmental and energy security benefits, the development of PV industry in SA also has a significant job creation potential. Between 252 000 and 333 000 Full-Time Equivalent (FTE) jobs were created in the country in 2010, and this could increase to between 1.5 and 2.4 million by 2020 [39]. However, to assess the realistic job creation potential associated with the development of the PV industry, it is important to understand that realization of employment potential associated with the first few stages of the value chain in any given country would be subject to factors such as capabilities of the local industries and regulatory framework that affects the diffusion of the technology among the various market segments [40].

2.2 Wind energy

Power generation through wind has an edge over other renewable energy technologies due to its technological maturity, good infrastructure and relative cost competitiveness [41]. It has been predicted that wind energy could supply about 10% of world's electricity by 2020, and with the improved technology and superior economics, wind power could capture 5% of the world energy market by 2020 [42]. If good information on wind speeds distribution at a site is available, energy production is highly predictable, contributing to the project's future certainty and lowering the investment risk [28]. Also, since the project installation cost, operation and maintenance cost and average wind speed of the site are well known, with no need for fuel or carbon emission cost, lifetime cost of wind power plant can be determined relatively easily [28].

While 40% and 49% of the countries in Africa have been reported to have high and medium wind resources respectively, the continent's wind power is still very limited with an estimated 1.1 GW installed capacity in 2011, which constitutes less than 1% of the continent's total installed electricity generation capacity [38]. The average wind resource potential reported for SA is high, with high average wind speeds (mostly greater than 6 ms^{-1}) along coasts of the KwaZulu-Natal, Eastern Cape, Western Cape, and Northern Cape provinces [43]. In addition to these locations, which are favorable for wind energy projects, SA also boasts of policies and programmes that support the development of a utility-scale wind energy deployments [38]. The integrated total wind potential in SA, considering some constraining factors has been estimated to be between 6 GW for the pessimistic scenario and 56 GW for the optimistic scenario [44]. Details of this are shown in Table 5.

A considerable potential for wind energy generation outside Eskom generation and REIPPPP also exists (Table 6). This market segment includes private utilities of generators (i.e. Independent Power Producers), municipalities, electricity retailers, distributors or aggregators as well as consumers of electricity. Estimates put future potential energy generation from this sector between 458 MW and 6 870 MW [38].

Table 5: Total estimated wind resource potential in SA [44]

Scenario	Max. roads distance	Max. transmission distance	Hub height	Minimum capacity factor	Annual electricity generation		Capacity
Pessimistic	3 km	3 km	60 m	25%	10.0 TWh	8.7%	6 GW
Realistic	4 km	4 km	80 m	30%	80.5 TWh	35.1%	26 GW
Optimistic	5 km	5 km	100 m	35%	157.2 TWh	68.5%	56 GW

Table 6: Wind energy generation potential in SA outside Eskom and REIPPPP generation [38]

Total electricity demand 2030 (GWh)	% of electricity generated by renewables outside Eskom and REIPPPP	Wind energy penetration (MW)		
		5%	10%	15%
401 268	5%	458 (Low)	916	1 374
	10%	916	1 832	2 748
	15%	1 374	2 748 (Medium)	4 123
	20%	1 832	3 664	5 496
	25%	2 290	4 580	6 870 (High)

2.3 Hydrogen economy and fuel cell

The hydrogen economy is an energy system option based on safe, clean and reliable alternative energy sources, in which hydrogen gas is the universal carrier of energy and links all sources of energy production with all points of energy consumption. However, to ensure a no net CO_2 emission advantage for the hydrogen economy, renewable sources must be used to generate the hydrogen gas. In addition to environmental benefits, the hydrogen economy can potentially provide energy security and economic benefits. However, the successful transition from the conventional fossil-based energy system to a hydrogen economy depends on several factors, such as the development of efficient fuel cell (FC) technologies, and development of adequate and efficient hydrogen production and distribution infrastructure.

Central to the hydrogen economy is the FC technology. FC technologies are developing fast, and the efficiency, versatility and scalability benefits that they offer make them a potentially important element of future global energy infrastructure for a broad range of applications, including motive power and both on and off-grid energy generation [45]. The primary fuels that are currently used within FC stacks are hydrogen, carbon monoxide, methanol and methane, depending on the FC type. However, hydrogen is the optimal fuel for all types of FCs [45]. Hydrogen fuel cells (HFCs) use a quiet, efficient process that can be repeated over and over, to convert hydrogen's energy into electricity, with water and heat as the only emissions. Currently, SA has a relatively large CO_2 footprint, being among the twelfth highest in the world in terms of per capita CO_2 footprint. SASOL and Eskom together were responsible for 240, 040, 000 t/a of CO_2 in 2008, and the annual SO_2 emissions in the range of 2, 131, 576 tons were reported in 2010 as a result of combined mining and coal-related operations [46]. Therefore, the hydrogen economy promises huge environmental benefits to the South African energy system.

FCs have been identified as a technology with potentials to play a significant role in SA's future energy infrastructure, industrial policy and economy [45]. The main drivers for promoting the development of HFCs and related technologies are: (a) abundance of Platinum Group Metals (PGMs) in the country (with more than 75% of world's known reserves in SA), which are the key catalytic materials used in most FCs, providing a great potential for socio-economic benefits; (b) potential for job creation through Human Capital Development required to develop the technology; and (c) the capability of the HFC technology to significantly reduce CO_2 and greenhouse gas emissions [47]. The FC markets continue to grow at a steady pace, with 104, 900 FC systems shipped globally in 2014 (Figure 3). This trend contributes towards the potentials of FC technologies to be a promising proposition area for SA, considering its extensive platinum reserves.

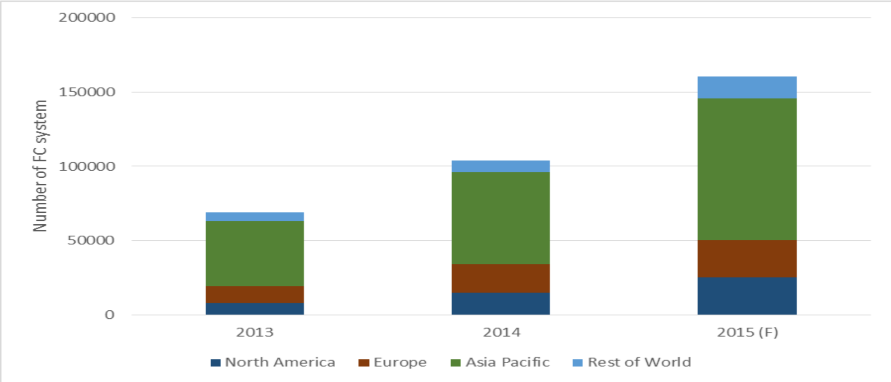

Figure 3: Global fuel cell shipments by region (Forecast for 2015) [48]

The South African Department of Science and Technology (DST), through the National Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy, branded as Hydrogen South Africa (HySA), has been committed to achieving the goal of development and deployment of hydrogen and FC technologies within SA [47]. The DST established three Centres of Competence (CoC) with unique responsibilities (Table 7).

Table 7: Centres of Competence established by the DST [47]

CoC	R & D Focus	Host
HySA Systems	Hydrogen systems integration and technology validation	University of Western Cape
HySA Catalysis	Hydrogen catalysis	University of Cape Town and MINTEK
HySA Infrastructure	Hydrogen generation, storage and distribution	North West University and Council for Scientific and Industrial Research

The unique responsibilities of these CoCs are collectively geared towards attaining the goal of supplying 25% of global PGM based catalysts demand by 2020. Potential products of the R & D activities of these CoCs include a portable back-up power source as a quieter and cleaner alternative to generators, combined heat and power (CHP) source based on FCs, to supply decentralized power and heating for buildings and industries, and FC-powered utility vehicles, using the proton exchange membrane (PEM) technology [47]. Potential benefits of the HySA initiatives include: (a) beneficiation of key South African resources in membranes, catalysts, and other FC-related technologies; (b) improved on-grid energy security and quality, and greater access to energy for off-grid communities; (c) attraction of international FC technology players to SA as well as substantial foreign direct investment; and (d) substantial job creation in knowledge-based industries.

3. LOCAL CONTENT AND COST OF ALTERNATIVE ENERGY IN SOUTH AFRICA

The REIPPPP is the largest and most publicly visible SA government programme for reaching RE targets under the Integrated Resource Plan (IRP). The REIPPPP invites bids from independent producers in a series of bidding windows for the seven major categories of RE i.e. solar PV, solar thermal, onshore wind, small hydro, biogas, biomass solid and landfill gas [49]. The greatest achievement in the REIPPPP is the continuous decrease in tariffs to the country's generation mix, with over 45% and 73% decrease in onshore wind and solar PV tariffs respectively, since round one of bidding [50]. Apart from these decreases in RE prices, 37 out of the projects (consisting of 800 MW_p and 1 GW_p of wind and solar PV respectively) emerging from the REIPPPP, mainly from bid windows 1 and 2, have generated up to R 4 billion in financial benefits more than they cost [51]. It is noteworthy that over subsequent bidding windows, there have been increases in the LCRs in the REIPPPP. It has been reported [50] that for round 1 to 4, the REIPPPP LCRs present a huge investment opportunity of R 65 billion for both local and international players that include original equipment manufacturers, local equipment suppliers, local and international investors, local skill base (in terms of skill transfer) and academic and research institutions (in terms of skills and technology transfer).

Since costs of locally produced components are expected to be higher than costs of imported components, the unit capital costs (R/W) of installed PV systems can be expected to increase with the increase of the local content, for different localization scenario. Projections by EScience Associates [40], using four localization scenarios formulated based on information obtained from status of local industries and time required to increase their capacities or set up new capacities, show that as LCs of solar PV industry increase from imminent scenario (which represents LC scenario based on existing capabilities and capacities in SA that have already been exploited or could be exploited in the immediate future for LC increase) up to the high road scenario (which refers to LC increase that is possible by significant increase in demand for PV installed capacities), expected unit costs of PV systems increase (Table 8).

Table 8: Predicted unit costs of PV systems with increase in local contents [40]

Component	Imminent		Low road		High road	
	LC (%)	Cost (R/W)	LC (%)	Cost (R/W)	LC (%)	Cost (R/W)
Utility scale without trackers	57	23.14	66	23.27	89	24.00
Utility scale with trackers	59	25.19	66	25.32	88	26.05
Commercial/Industrial scale	52	20.72	62	20.81	90	21.69
Residential grid-supported	53	29.03	65	29.21	90	30.13
Residential off-grid	39	48.91	49	49.02	65	50.04

However, in economies with better LCR practices, with their much larger localization capacities and larger RE industries compared to SA, consistent price decreases of RE have been experienced [40]. Also, across the four bidding windows of SA's REIPPPP, with progressive increase in LCs, decrease in tariffs has been recorded (Table 9). The costs of solar PV systems in Europe fell by about 50% from 2005 to 2010, and further decrease by 35-50% has been predicted by 2020[37]. The average global levelised cost for crystalline-silicon PV dropped from $ 315/MWh in the third quarter of 2009 to $ 122/MWh in late 2015 (61% drop), which reflects a decline in PV module prices, balance-of-plant costs and installation expenses [52]. Projects with lower prices have commenced in some countries, such as the ACWA Power International installation in Dubai in 2015 with a $ 58.50/MWh tariff, and further cost reduction has been predicted [52].

These drops in global PV system costs were largely attributed to increased levels of productivity in local manufacturing processes as a result of developed skills and experience, as well as gained economy of scale, which was derived through research and development, innovation and government support [37]. Since increase in LC will be associated with the expansion of local manufacturing capabilities, in addition to greater job creation, it can also be expected to drive RE cost reduction. High cost is one of the major barriers to more widespread adoption of RE technologies. Therefore, by taking advantage of the current global trend in decline of RE costs, rising fossil fuel prices and the abundant RE resources in SA, government support for developing the localization capabilities of RE industry in the country can help in driving down the costs and make products from SA's local industry to be competitive in the global market.

4. SOUTH AFRICA'S RENEWABLE ENERGY LOCALIZATION POTENTIAL

SA is one of the nine emerging economies that account for more than 75% of all green patents granted by the USA to developing countries [53]. This is indicative of the manufacturing and technological innovation potentials of the country to become a competitive manufacturer of frontier green technology. However, in recent years, SA has failed to develop its technology-intensive industries adequately and has consequently fallen behind in innovation and high-technology exports [3]. The impacts of this inadequacy reflect on the country's low rank in global RE markets.

Table 9: Local contents and prices in the all REIPPPP bidding windows [54]

Technology	Round 1			Round 2			Round 3			Round 4		
	MW allocated	Price/MWh	LC (%)	MW allocated	Price/MWh	LC (%)	MW allocated	Price/MWh	LC (%)	MW allocated	Price/MWh	LC (%)
Onshore wind	634	R 1.14	21.7	563	R 0.89	36.7	787	R 0.65	46.9	676	R 0.61	44.6
Solar PV	632	R 2.75	28.5	417	R 1.65	47.5	435	R 0.88	53.8	R 0.78	R 0.78	64.7
Solar CSP	150	R 2.68	21	50	R 2.51	36.5	200	R 1.40	44.3	-	-	-

There is a need to promote the incorporation of locally manufactured or assembled products into the SA's RE value chain. This requires a careful assessment of the current and potential localization capacities for RE technologies within the country.

4.1 Solar PV industry

In a study by EScience Associates [40] to assess the localization potential of SA solar PV industry, it was found that significant increase in LC of key components is possible. One major contributor to the wide gap between SA's RE production potentials and actual consumption is the high initial cost of RE technologies. In deciding and implementing its RE LCRs, SA needs to consider the rapidly changing and highly competitive global RE industry so as to understand better how to best position itself in the market and across the value chain of the various RE technologies. For example, in the solar PV manufacturing industry, manufacturers with large market shares (China, Taiwan, Europe, Japan and the United States) benefit from economies of scale and a vertically integrated manufacturing process to keep costs low [40]. This makes competition from smaller solar PV module manufacturers in SA difficult. Therefore, to propel SA into the global RE market's big stage, concerted and sustained efforts must be put by all relevant stakeholders into developing the capacity for localization of RE technology in the country.

4.2 Concentrated solar power localization

Electricity generation is SA is currently heavily reliant on open cycle gas turbines (OCGTs). If CSP with storage were to be used to supply the same demand as the current OCGT-based plants, the utility would save approximately R 3.6 billion per annum [3]. Recently, there have been promising signs of CSP tariffs reduction through the commercialization of newer CSP technologies operating at greater efficiency (such as the tower), and the achievement of economies of scale linked to larger plant sizes. The CSP tower is a technology with very high localization potential in SA. With respect to tower technology, it has been estimated that at least 50-60% of utility-scale tower plant's value can be produced locally in the near future. Only the power block, storage material, and non-boiler type receiver are beyond the country's current capabilities [3]. Some companies and industries, covering a broad base of the tower componentry and service input requirement, have already been identified [3] as potential suppliers to the South African CSP sector (Table 10).

Table 10: Potential South African suppliers of CSP goods and services [3]

Component Manufacturing		Potential Suppliers
Hellostats	Mirrors	Satchwell (foam injection), Rigifoam (foam), PFG builing glass (silvering, glass)
	Gears/Drivers	Actom
	Steel suppliers for structures	Macsteel, Aveng Trident, Duferco and Arcelormittal SA
	Controls	Hello 100 (intelligence), Wirecon (wiring) and Reutech
	Trackers	Hello 100, Reutech
Receiver		John Thompson, Defence Industry
Tower		Brolaz, Macsteel, Trident, Duferco, Sectional Poles and Graffo
Storage		Intertherm, Steel Companies and EPC (storage container only)
EPC[a] services		Group Five, Aveng and Crowie Concessions

[a]: Engineering, procuring and construction

ACTOM, a major local supplier of electrical equipment, services and balance of plant to the REIPPPP projects, has the potentials to develop into a key supplier along the CSP value chain. The company's capabilities include (a) cooperation agreements with international design and technology leaders; (b) locally dominant and export competitive boiler manufacturing via John Thompson; and (c) provision of elasticized moulding via foam injection to create heliostat facets from flat mirrors [3].

4.3 Wind energy industry

In the case of wind energy, countries such as China, USA, Germany, Spain, Denmark and India that boast the largest wind energy installed capacities are also the countries that account for the largest wind turbine manufacturing market, which was established through creation of significant domestic demand for wind energy. Successful and viable wind energy industries have been built in these countries on local demand through government policies that stimulate the demand for wind power and assist in developing the local manufacturing capabilities [55].

As reflected in REIPPPP Bid Window 3, the capital investment required to design, procure and construct wind energy projects in SA was valued at an average of R 7.9 million/MW in 2013. 55% of this value comprised expenses on wind turbine and its components (tower, blades, nacelle, and hub) while the remaining 45% comprised Balance of Plant (BOP) [38]. The average LC for Bid Window 3 achieved by preferred bidders was 46.9%, three quarter of which was derived through localization of the BOP and the rest from procurement of wind towers from local tower manufacturers (Table 11).

Table 11: Local content for preferred bidders of wind energy projects in Bid Window 1, 2 and 3 [56],[14]

Local content indicators	Bid Window 1	Bid Window 2	Bid Window 3
% of project value	27.4%	48.4%	46.9%
Total Rand value	R 2 727 million	R 4 817 million	R 6 283 million
Components localized	• Balance of Plant	• Towers • Balance of Plant	• Towers • Balance of Plant • Meteorological Masts • Anchor cages

Although, the wind energy industry in SA consists of many wind turbine OEMs with a significant global production footprint, the local manufacturing of key wind turbine components is still in its infancy and remains restricted to a few components. The fact that towers are usually large, expensive and difficult to transport over long distances provides a good basis for the promotion of their localization, and DCD Wind Towers, Gestamp Renewable Industries and Concrete Units currently have local capabilities with respect to wind towers in the country. No blade manufacturing facility currently exists in SA. However, skills, expertise, and capability to manufacture blades for other applications such as helicopters exist in the country. These represent potential resources for the localization of blades manufacturing for wind energy projects. Currently, no local company is engaged in manufacturing or assembling of nacelle components in SA. The potential for the establishment of nacelle manufacturing facilities in SA is limited due to the complexity of the process that requires highly specialized labour and concern about quality and high input cost [38]. Therefore, the greatest potential for the development of local wind turbine manufacturing industry in SA lies in wind tower manufacturing, followed by blade manufacturing.

4.4 Hydrogen and fuel cell technologies development

A very promising way by which SA can use its abundant PGM reserves to drive economic and technological growth is through the development and expansion of local FC industry. The platinum loading in a typical FC passenger vehicle is currently 30 g, which translates into 950 000 oz of platinum, if 1% of the world's current automotive fleet were FC vehicles [57]. Even if the platinum loading is successfully reduced to 10-15 g per vehicle to create a more sustainable platinum market and ensure stable demand, a platinum demand of above 3 000 000 oz could be created, if FC vehicles capture 10% of the global automotive sales [57]. This shows that increased deployment of FC technologies has the potentials to escalate platinum demand. Therefore, FC technology development holds huge opportunities for SA. The Isondo Precious Metals' (IPM's) FC component manufacturing plant, is set to commence the manufacturing of catalyst-coated membranes and membrane electrode assemblies (MEAs), which are key FC components, at volumes required by the growing FC market and at internationally competitive prices. IPM has been licensed by DuPont, through its Chemours spin-off, to manufacture Nafion-based MEA for PEM FC (suited for automotive applications like cars and buses) and direct methanol FC (which finds its niche in materials handling applications such as FC forklifts) [57]. It is expected that due to the plant's modular design, high-volume manufacturing, which can be customized with different components, can be achieved.

Various other FC and hydrogen infrastructure development initiatives are going on in SA. For example, a locomotive which is powered by Ballard PEM FC stacks and Lithium-ion batteries, was developed by Vehicle Projects Inc, in collaboration with Trident South Africa and Battery Electric, Inc. for Anglo American Platinum Limited, and at least 4 000 of this type of locomotive are reportedly operating within the South African mining industry. Also, as a result of the collaborative efforts between the DST, through the University of Western Cape-hosted HySA Systems CoC, and Impala Platinum (Implats), SA's first prototype hydrogen FC forklift at Impala Platinum Refinery in Springs was launched in 2016 [58]. The HySA Catalysis, through a company named HyPlat, has also developed and commercialized platinum-based catalysts targeted at both local and export markets. HyPlat products are two series of platinum-on-carbon catalysts (designated as K-series and V-series) and one series of alloy-based catalysts (using nickel or cobalt as support materials), known as A-series. Using its own technology, HyPlat applies the A-, K- or V- series catalysts to make three-layer, five-layer or seven-layer MEAs.

The above achievements of the R & D activities of HySA are indicative of the huge potentials of these technologies within SA, and the already available local knowledge content. However, the HySA initiatives may be jeopardized by the absence of viable local industries in the areas of hydrogen and FC technologies. Therefore, more knowledge, skills, and infrastructures must be developed not only through sustained funding and direct applied research for product development, but also by identifying and maximizing the localization and commercialization opportunities for the hydrogen and FC technologies within the country. Also, most of the researches on FC technologies have focused on the gas diffusion layers, the electrodes and membrane [59], [60], [61], [62], [63]. However, to fully achieve performance, durability and cost targets for PEM FC, other components such as the bipolar plates (which account for a considerable proportion of the total stack weight, volume, and cost) need to receive more research attention. While capital costs of FC systems are still too high to achieve widespread adoption and commercialization, significant cost reductions can potentially be realized through extensive R & D efforts covering improvement in designs, advanced and mass production-friendly manufacturing processes for the MEA and bipolar plates, and reduced precious metal requirement. Other research areas include development of membranes and bipolar plates with improved performance and durability, and reduced material costs for high-pressure tanks on board FC electric vehicles [64]. As applicable to other forms of alternative energy sources, increase in the LC of hydrogen and FC technologies, nurtured by the development of the local industry and large-scale manufacturing, will help in bringing down the manufacturing costs.

5. CONCLUSION

SA is well endowed with abundant alternative energy sources, notably solar and wind, which can be exploited to derive significant environmental, economic and energy security benefits. Also, by taking advantage of the abundant PGM reserve in the country, SA has the potential to become a big player in global hydrogen and FC technologies development, while meeting its local energy security and emissions reduction targets. However, earning these potential benefits require massive deployment of alternative energy sources and technologies through development of local capacities for alternative energy generation.

The high cost of alternative energy, relative to fossil sources, is the main hindrance to their widespread adoption. There has been decrease in tariffs with progressive increase in LCs across the four bidding windows of the REIPPPP. Also, consistent decreases in RE prices have been experienced in countries with better LCR practices and more developed local industries than SA. Therefore, it can be inferred that increase in the LC of alternative energy in SA, coupled with the development of local alternative energy industry, will lead to increased productivity and economy of scale, which will drive down the costs of alternative energy to levels where they will become competitive or even more favourable compared with fossil fuel sources.

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STRENGTH ENHANCEMENT OF POLYMER COMPOSITE MATERIALS FOR VEHICLE PARTS PRODUCTION

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ABSTRACT

South African government spends billions of rand annually on subsidies for public services. In efforts to reduce these costs, there is need for composite materials with light-weights but similar properties like that of more expensive conventional materials to be designed and used in industries such as road transportation, construction and Air Traffic and Navigation Services (ATNS). In ATNS and road transport, lighter weight but equally functional composite materials have been used extensively for car body, aircraft fuselage and interior furnishings fabrication in place of conventional aluminum and steel. However, there are needs to further explore the possibilities of improving the properties of the composite materials being used. In this study, on applying composite materials techniques, the effect of Aminopropylisobutyl polyhedral oligomeric silsesquioxane- Sodium montmorillonite (POSS)-treated montmorillonite particle inter-separation distances on strengthening a specific automobile engine component is investigated. A model that relates composite material strength to particle inter-separation distances, volume fraction and particle size was proposed and used to make strength predictions. Results reveal critical inter-separation distances and volume fraction which if used can lead to production of lightweight parts with more enhanced strength. This should lead to reduced cost of spare components and less fuel consumption due to lightweight.

Keywords: Public transport vehicle parts, mechanical property enhancement, particle inter-separation distances, composite structure techniques, Aminopropylisobutyl polyhedral oligomeric silsesquioxane- Sodium montmorillonite

OPSOMMING

Die Suid-Afrikaanse regering spandeer jaarliks miljarde rande op subsidies vir openbare dienste. In pogings om hierdie koste te verminder, is daar behoefte aan saamgestelde materiale met liggewigte, maar soortgelyke eienskappe soos dié van duurder konvensionele materiale wat ontwerp en gebruik word in nywerhede soos padvervoer, konstruksie en lugverkeer en navigasie dienste (ATNS) wat veroorsaak dat die algehele koste van voertuie hoër. In ATNS en padvervoer is ligter gewig, maar ewe funksionele samestellende materiale omvattend gebruik vir karre, vliegtuig romp en binne meubels vervaardiging in plaas van konvensionele aluminium en staal. Daar moet egter verder ondersoek word na die moontlikhede om die eienskappe van die saamgestelde materiale wat gebruik word, te verbeter. In hierdie studie word die effek van vermenging van Montmorillonite-deeltjies tussen skeidingsafstande op die versterking van 'n spesifieke motor-enjin komponent ondersoek deur die effek van aminopropylisobutiel polyhedrale oligomere silsesquioxane-Sodium montmorilloniet (POSS) - behandelingsafmetings. 'N Model wat saamgestelde materiaalsterkte aan deeltjie-inter-skeidingsafstande, volume-fraksie en deeltjiegrootte verwoord, word voorgestel en gebruik om sterk voorspellings te maak. Resultate openbaar kritiese tussen-skeidingsafstande en volume-fraksie wat, indien dit gebruik word, kan lei tot die produksie van ligte dele met meer versterkte krag. Dit moet lei tot verminderde koste van spaarkomponente en minder brandstofverbruik weens liggewig.

Sleutelwoorde: voertuigonderdele vir openbare vervoer, meganiese eienskapverbetering, deeltjies tussen skeidingsafstande, saamgestelde struktuur tegnieke, aminopropylisobutiel polyederale

1. INTRODUCTION

The percentage of South Africans who use public transport increased from 75.6% to 81.4% in 2013 [1]. Public transport is clearly of great importance to South African residents. Taxis, buses and trains are the most commonly used modes of public transport. A small percentage is accounted for by airplane travel. A recent survey shows that 2/3 of the country`s lowest income earners used more than 20% of their disposable income on public transport [2]. This therefore shows that public transport is not affordable to the majority of South Africans because, by set statistical standard [3], it is only considered affordable when commuters spend less than 10% of their disposable income on it. This results in increasing cost in other sectors like education and industry. There is therefore a critical need for public transportation fare reduction. Some measures such as government subsidization (grant of up to R6.2 billion for 2017/18) [4] and policy position [2] have been tried to address this problem but have been failing [3].

Composite materials can be defined as materials composed of two or more phases such as the matrix and a reinforcement material (whose particle shapes can be fibres, flakes or platelets of various sizes). The composite materials are often classifications based on their matrix phases such as Metal matrix composites, Ceramic matrix composites and Polymer matrix composites. The combined materials of different physical and chemical properties result in structures with characteristics significantly different from the individual components [5]. The use of a composite material to enhanced strength was therefore done because composite materials offer greater economic advantage because of their high potential of applicability and fabrication of high strength and thermal resistance compared to traditional single phase materials [6]. The strength enhancement was done through composite material techniques, which entailed the use of geometrical locations of particles in the composite to derive their inter-separation distances, the coulomb law to determine the attractive and repulsive energy between the particles and thus derive a model relating strength to inter-separation distances and critical volume fractions to fabricate the composite material. Globally, composite materials have been used to replace conventional and more expensive materials for car bodies and other airplane bodies and furnishing construction materials [7]. This has helped to reduce the cost of travelling with these modes of transport. Notwithstanding the use of composite materials for public transportation vehicles, transport fares are still high [3]. This paper proposes an approach of further reducing this high cost by integrating material science technology and its cost implications to produce a cheaper but still functional automobile parts used in public transportation service. This study establishes a model that relates composite material strength to particle inter-separation distances, volume fraction and particle size using composite material techniques. The results reveal critical inter-separation distances and critical volume fractions which can be used to produce lightweight parts with more enhanced strength, leading to reduced spare part costs and less fuel consumption.

A blown head gasket (made from Multiple Layer Steel coated by a rubber like coating) is considered as one of the most expensive car servicing problems. This paper therefore considers the effect of a chosen material, POSS-treated montmorillonite particle inter-separation distances on strengthening the head gasket of an automobile engine head. Attention can also be given to other important characteristics such as the material`s sizes and structures [8-9] to investigate their effect on the composites mechanical properties but this study focuses on the effect of particle inter-separation distances.

2. APPLYING THE LAW OF CONSERVATION OF ENERGY TO DERIVING THE MODEL RELATING MATERIAL STRENGTH TO VOLUME FRACTION AND PARTICLE SIZE

The schematic in Figure 1 below represents how the reinforcement particles (namely Sodium montmorillonite NaMMT)) is bonded with the matrix material particle (which is namely Aminopropylisobutyl polyhedral oligomeric silsesquioxane (POSS-NH2)). This schematic was derived from the TEM (Figure 2) and XRD (Figure 3) of the prepared composite material. In Figure 3, the presence of a fewer diffraction peaks on the curve for the POSS/Clay composite compared to that of the pristine Clay indicates that the Clay reinforcement was well dispersed in the POSS-NH2 matrix. The different types of inter-separation distances can be clearly observed in correspondence with the schematic. These inter-separation distances are made up of: d- the distance between the matrix particles on the same (single) reinforcement material particle, z- the distance between the matrix particles on different reinforcement material particles, r- the radius of the reinforcement material particle which marks the distance between a matrix material particle and the reinforcement particle on the same reinforcement material particle, and x- the distance between a reinforcement material particle and the matrix particle on different reinforcement material particle, ds -the distance from one reinforcement material particle to another reinforcement material particle.

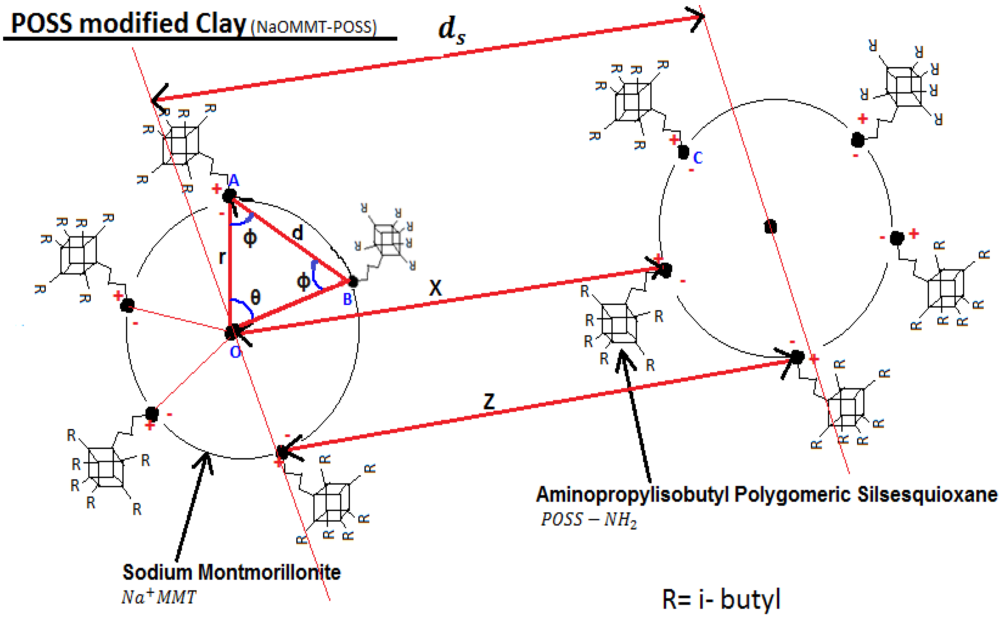

Figure 1: Schematic for POSS modified Clay

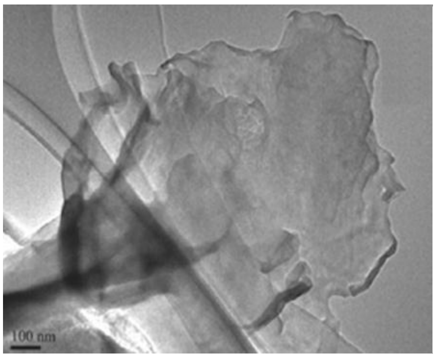

Figure 2: A flake/ almost spherical structure for the clay [10]

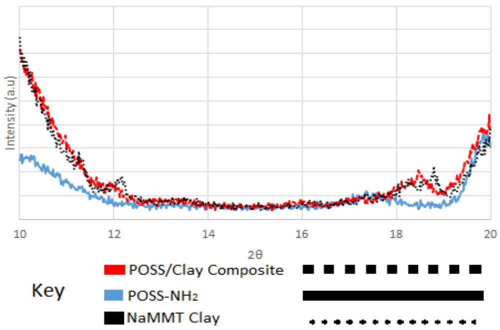

Figure 3: XRD Spectra of the matrix material ($POSS-NH_2$), reinforcement material NaMMT Clay and the Composite material (POSS/Clay)

It should be noted that the reinforcement particle and matrix material particle react with each other in the form of bonding (both attractive and repulsive) forces. Thus the law of nature has to be applied.

Assuming a simple bonding model [11], (with flake-spherical shaped NaMMT particles) the total bonding force results from the sum of its attractive forces F_A and repulsive forces F_R. Therefore the net or resultant force F_N is given by

The net force $F_N = F_A + F_R$ (1)

To find F_A or F_R between any two charged ions in the composite material, the inverse-square coulomb law [12] where like charges repel and unlike charges attract can be used so that, if follows from fig.1 that

$$F_A = \frac{Q_c Q_P}{4\pi\mathcal{E}_0\mathcal{E}r^2} + \frac{Q_c Q_P}{4\pi\mathcal{E}_0\mathcal{E}x^2} \quad (2)$$

$$F_R = \frac{Q_c Q_c}{4\pi\mathcal{E}_0\mathcal{E}{d_s}^2} + \frac{Q_p Q_P}{4\pi\mathcal{E}_0\mathcal{E}d^2} + \frac{Q_p Q_P}{4\pi\mathcal{E}_0\mathcal{E}z^2} \quad (3)$$

Where r, x, d_s, d and z are inter-separation distances and as Shown in Figure 1.

Assuming a closed system at equilibrium [13] (without energy input or output), then $F_N = 0$.

Therefore equation (1) can be written as

$$F_N = 0 = \left(\frac{Q_cQ_P}{4\pi\mathcal{E}_0\mathcal{E}r^2} + \frac{Q_cQ_P}{4\pi\mathcal{E}_0\mathcal{E}x^2}\right) - \left(\frac{Q_cQ_c}{4\pi\mathcal{E}_0\mathcal{E}{d_s}^2} + \frac{Q_pQ_P}{4\pi\mathcal{E}_0\mathcal{E}d^2} + \frac{Q_pQ_P}{4\pi\mathcal{E}_0\mathcal{E}z^2}\right) \quad (4)$$

It then follows form equation (4) that;

$$\left(\frac{Q_cQ_P}{4\pi\mathcal{E}_0\mathcal{E}r^2} + \frac{Q_cQ_P}{4\pi\mathcal{E}_0\mathcal{E}x^2}\right) = \left(\frac{Q_cQ_c}{4\pi\mathcal{E}_0\mathcal{E}{d_s}^2} + \frac{Q_pQ_P}{4\pi\mathcal{E}_0\mathcal{E}d^2} + \frac{Q_pQ_P}{4\pi\mathcal{E}_0\mathcal{E}z^2}\right) \quad (5)$$

The constant 4π and $\mathcal{E}_0\mathcal{E}$ is the dielectric permittivity or constant of the medium, which cancel out on both sides to give:

$$\frac{Q_cQ_P}{r^2} + \frac{Q_cQ_P}{x^2} = \frac{Q_cQ_c}{{d_s}^2} + \frac{Q_pQ_P}{d^2} + \frac{Q_pQ_P}{z^2} \quad (6)$$

Since the free energy for the coulomb interaction between any two charges Q_1 and Q_2 with distance s apart is given by [12];

$$w(s) = \int_\infty^s -F(s)ds = -\int_\infty^s \frac{Q_1Q_2}{4\pi\mathcal{E}_0\mathcal{E}s^2}ds = \left[\frac{Q_1Q_2}{4\pi\mathcal{E}_0\mathcal{E}s}\right]_\infty^s \quad (7)$$

Taking $s = \infty$ as the point where there is zero energy, it follows from equation (7) that

$$\left[\frac{Q_1Q_2}{4\pi\mathcal{E}_0\mathcal{E}s}\right]_\infty^s = \frac{Q_1Q_2}{4\pi\mathcal{E}_0\mathcal{E}s} = \frac{v_1v_2e^2}{4\pi\mathcal{E}_0\mathcal{E}s}\text{ Jouls} \quad (8)$$

Where: V_1 and V_2 are the respective ionic valance's of the ions in attraction or repulsion and e is the elementary electron charge (1.602 X 10^{-19} C). Therefore equation (6) can be written in terms of energy as:

$$\frac{v_cv_pe^2}{r} + \frac{v_cv_pe^2}{x} = \frac{v_cv_ce^2}{d_s} + \frac{v_pv_pe^2}{d} + \frac{v_pv_pe^2}{z} \quad (9)$$

Where V_C is the valence of the (Na) clay particle and V_P is the valence of the $(POSS - NH_2)$ polymer particle. From equation (9), e^2 cancels out on both sides and Inter-separation distance can be modelled as shown in equation (10).

$$\frac{v_cv_p}{r} + \frac{v_cv_p}{x} = \frac{v_cv_c}{d_s} + \frac{v_pv_p}{d} + \frac{v_pv_p}{z} \quad (10)$$

Alternatively, since $Q_1 = v_1e$ and $Q_2 = v_2e$, equation (9) can also be written as

$$\frac{Q_cQ_P}{r} + \frac{Q_cQ_P}{x} = \frac{Q_cQ_c}{d_s} + \frac{Q_pQ_P}{d} + \frac{Q_pQ_P}{z} \quad (11)$$

Where the LHS, $E_A = \frac{Q_cQ_P}{r} + \frac{Q_cQ_P}{x}$ and RHS, $E_R = \frac{Q_cQ_c}{d_s} + \frac{Q_pQ_P}{d} + \frac{Q_pQ_P}{z}$

To maximize the strength of the composite, it follows that E_A should be maximized while E_R is minimized. This can be expressed as equation (12) (derived from equations (1) and (4) where $F_A - F_R \geq 0$)

$$E_A - E_R \geq 0 \quad (12)$$

Substituting for E_A and E_R from equation (11) yields:

$$\frac{Q_cQ_P}{r} + \frac{Q_cQ_P}{x} - \left(\frac{Q_cQ_c}{d_s} + \frac{Q_pQ_P}{d} + \frac{Q_pQ_P}{z}\right) \geq 0 \quad (13)$$

In expression (13), the "repulsive" inter-separation distances d_s, d and z vary inversely with E_R therefore, the greater they are, the more E_R is minimized and this suggests enhancement/ increase in composite strength and vice versa. The "attractive" inter-separation distances r and x vary inversely with E_A, therefore, the greater they are, the more E_A is minimized and this suggests compromise/ reduction in composite strength and vice versa. It is thus imperative to proceed with presenting how these inter-separation distances can be determined.

3. DETERMINATION OF THE INTER-SEPARATION DISTANCES

3.1. Determination of inter-separation distance d_s

d_s (*d*-spacing) is the distance between adjacent planes of the nano-clay particles. This value is obtained experimentally using X-ray Diffraction technology [14]. From the XRD analysis performed (whose results were shown in Figure 2), the d_s value was 1.60nm for the POSS-NH_2/clay.

3.2. Determination of inter-separation distances *r* and *x*

The average diameter of the clay particle/ Sodium Montmorillonite in deionized water was taken as 18 nm from a similar research in which it was calculated using the Statistical Imaging Analysing (STIMAN) technique from Transmission X-ray microscope (TXM) micrographs [15]. The radius *r* of clay particle (Clay particle size) can therefore be written as shown in equation (14).

$$r = 9\text{nm} \quad (14)$$

As shown in Figure 1, x is the inter-separation distance between any polymer particle attached to a clay particle and it's nearest neighbouring clay particle. This can be taken as the distance from the centre of the clay particle at point (0; 0) to the negative half circle surface centred at (d_s;0) with radius *r*. Therefore the distance ***x*** can be expressed as the equation of the surface of the negative half circle as shown in equation (18). Therefore:

$$x = (d_s - \sqrt{r^2 - y^2}) \quad (15)$$

Converting *y* to polar coordinate system for this specific case, y =$rSin\theta$, where:

$$\theta = \frac{2\pi}{n} \quad (16)$$

n is the number of polymer particles around the clay particle surface or POSS-NH_2:NaMMT volume fraction. θ is the angle between the radii connecting two adjacent POSS-NH_2 particles bonded to the clay.

$$x = d_s - r\sqrt{1 - Sin^2\theta} \quad (17)$$

Therefore

$$x = d_s - rCos\theta \text{ ; substituting } \theta \text{ for } \frac{2\pi}{n}; \quad (18)$$

Therefore $x = d_s - rCos\frac{2\pi}{n}$; applying the trigonometric identity $Cos2\theta = 1 - 2sin^2\theta$ will give,

$$x = d_s - (1 - 2sin^2(\frac{\pi}{n}))r \quad (19)$$

From equations (11) and (19), it can be observed that the inter-separation distances r and x vary inversely with E_A. This suggests that the smaller the distances r and x the greater the value E_A and thus strength.

3.3. Determination of inter-separation distance *z*

z is the distance between any two adjacent polymer particles attached to the surfaces of neighboring clay particles or the distance between the two spherical particle surfaces as shown in Figure 1. This can be taken as the distance between the surface of the positive half circle centred at (0;0) with radius *r* and the negative half circle centred at ($\boldsymbol{d_s}$;0) with radius *r*. This also means that the maximum value of z would be d_s.

Distance between the two surfaces ***z*** = Equation of negative half circle - Equation of positive half circle

Equation of the surface of the positive half circle = $\sqrt{r^2 - y^2}$ (20)

And Equation of the surface of the negative half circle = $(d_s - \sqrt{r^2 - y^2})$ (21)

Therefore

(Distance between the two surfaces)

$$z = d_s - \sqrt{r^2 - y^2} - \sqrt{r^2 - y^2} = d_s - 2\sqrt{r^2 - y^2} \quad (22)$$

Converting y to polar coordinate system (where y =$\boldsymbol{rSin\theta}$)

z = $\boldsymbol{d_s} - \boldsymbol{2r\sqrt{1-Sin^2\theta}}$ (23)

Therefore

z = $\boldsymbol{d_s} - \boldsymbol{2rCos\theta}$; since $\boldsymbol{\theta} = \frac{2\pi}{n}$; (24)

Therefore z = $\boldsymbol{d_s} - \boldsymbol{2rCos}\frac{2\pi}{n}$; from the trigonometric identity $\boldsymbol{Cos2\theta}$=1-2$\boldsymbol{sin^2\theta}$

z = $\boldsymbol{d_s} - (\mathbf{2}\text{-}4\boldsymbol{sin^2}(\frac{\pi}{n}))\boldsymbol{r}$ (25)

3.4. Determination of inter-separation distance *d*

From Figure 1, *d* is the distance between 2 neighboring Polymer particles bonded (or attached) to a spherical clay particle. If the angle Θ is dissected to give $\frac{\Theta}{2}$, then using the trigonometrical ratio (*sine* = *opposite side*/ *hypotenuse*), *d* can be determined as follows

Sin $(\frac{\Theta}{2})$ = $\frac{d}{2r}$ (26)

$\boldsymbol{d}$ = 2 r sin $(\frac{\Theta}{2})$ (27)

Substituting for $\boldsymbol{\theta}$ from equation 15 would give

$\boldsymbol{d}$ = 2 r sin $(\frac{2\pi}{2n})$ (28)

Therefore d = 2 r sin $(\frac{\pi}{n})$ When n= 1 d= 0 and n≠ 0 (29)

Therefore, substituting for inter-separation distances $\boldsymbol{r}$, $\boldsymbol{x}$, $\boldsymbol{d}$ and z into equation (13), the inter-separation distances model can be expressed as;

$$\frac{Q_cQ_P}{r} + \frac{Q_cQ_P}{d_s-(1-2sin^2(\frac{\pi}{n}))r} - (\frac{Q_cQ_c}{d_s} + \frac{Q_pQ_P}{2\,r\,sin\,(\frac{\pi}{n})} + \frac{Q_pQ_P}{d_s-(2-4sin^2(\frac{\pi}{n}))r}) \geq 0 \quad (30)$$

$$E_A = \frac{Q_cQ_P}{r} + \frac{Q_cQ_P}{d_s-(1-2sin^2(\frac{\pi}{n}))r} \quad (31)$$

and $$E_R = \frac{Q_cQ_c}{d_s} + \frac{Q_pQ_P}{2\,r\,sin\,(\frac{\pi}{n})} + \frac{Q_pQ_P}{d_s-(2-4sin^2(\frac{\pi}{n}))r} \quad (32)$$

Expression (32) shows that a smaller distance r may not necessarily result in strength enhancement as initially suggested by expression (3). There was therefore need to experimentally determine the critical distance r while holding the other variables constant such that E_A was maximized while E_R was minimized and thus enhancing strength. An attempt to achieve this was done in a controlled experiment where various choices of clay of known particle size and a specific matrix material were mixed at constant volume fractions. Thermal Mechanical Analysis (TMA) and Thermogravimetric Analysis (TGA) were then done on each sample of the various sizes to determine which size or range of sizes was more dimensionally and thermally stable, thus indicating better strength.

Expression (30) in conjunction with TMA and TVA outputs were used to determine the critical volume fractions n and the inter-separation distances *r*, *x*, d_s, *d* and *z*.

3.5 Determination of critical volume fractions *n*

The volume fraction *n* was determined from expressions (31) and (32), such that it informed the volume fraction that was used to make the composite material. The various samples made using the determined ratios for the greatest and weakest strengths were then tested/confirmed using TMA and TGA. The relationship between inter-separation distances *r*, *x* and d_s and volume fraction *n* is shown in expression (19). Expressions (29) and (25) show the relationship between inter-separation distances *d* and *z* with volume fraction *n*. It can therefore be predicted that (for specific materials, where all other variables can be held constant) the critical values of minimal inter-separation distance x, maximal distance d_s, *d* and *z* are required for enhanced strength.

From expression (31), to enhance strength by maximizing $\mathbf{E_A}$; $\boldsymbol{sin}(\frac{\pi}{n})$ has to be minimized and this happens at the critical volume fraction values of $\boldsymbol{n}$ = 1 or $\frac{1}{2}$. It can also be observed that at $\boldsymbol{n}$ = 2 or $\frac{2}{5}$, $\boldsymbol{sin}(\frac{\pi}{n})$ is minimized, $\mathbf{E_A}$ is in turn minimized and this suggests a weakening of the composite material strength.

From expression (32), to enhance strength by minimizing $\mathbf{E_R}$; $\boldsymbol{sin(\frac{\pi}{n})}$ has to be maximized or negative and this happens at the critical volume fraction values of $\boldsymbol{n}$ = 2 or $\frac{2}{3}$. It can also be observed that at $\boldsymbol{n}$ = 1 or $\frac{1}{2}$, $\boldsymbol{sin(\frac{\pi}{n})}$ is minimized, $\mathbf{E_R}$ is in turn maximized and this suggests a weakening of the composite material strength.

4. RESULTS AND DISCUSSION

The model, (expression (30)) relates the strength of the composite (as reflected by how greater the attractive energy is compared to the repulsive) to the various inter-separation distances between all the particles in the composite. The model predicts the optimum inter-separation distances which result in greater strength or weakening the composite through certain critical volume fractions as shown in Table 1.

Table 1: Critical volume fractions and inter-separation distances for strength enhancement

Inter-separation Distances		Predicted Strength (E_A- E_R)	Predicted Critical Volume Fractions POSS-NH_2: NaMMT(P:N)
maximal	minimal		
d_s, d, z	r and x	High	2:1* and 2:3
r and x	d_s, d, z	Low	1:1** and 1:2**

* The ratio 2:1 may not result in higher strength because it also results in maximizing the inter-separation distance x (as shown in expressions (13) and (19)) and hence counteracting and lowering the strength.

**The ratios 1:1 and 1:2 indicate both lowering (for E_A) and increasing strength (for E_R), therefore their overall effect may be confirmed by experiment.

As the model relates energy to strength, the thermal and dimensional stability of the material can also be linked as directly proportional to it. This can be justified through the first Law of thermodynamics, which states that the total heat energy applied to a system is equal to the sum of the total work done by the system and its total internal energy used. Therefore, the rate of loss of mechanical energy is proportional to the rate of increase in heat ($\boldsymbol{E_{mech}} \propto -\boldsymbol{Q}$) [16].

Thermogravimetric Analysis (TGA) was then used to test for thermal stability of the materials with the various volume fractions shown in table 1 and it can further be predicted that the higher strength volume fractions will result in higher thermal stability compared to the rest.

4.1 Application of the results for enhanced strength of vehicle parts

The volume fractions were used to produce the composite material with enhanced strength as predicted. Following the appropriate procedure for combining the POSS-NH_2 and NaMMT [14], a powder composite material was produced, tested for strength using Thermomechanical Analysis (TMA). Using this powder composite material, the fabrication of the head gasket can be achieved through three alternative methods, which include emulsion polymerization, In-situ polymerization or melt blending of the composite powder (produced using the critical inter-separation and volume fractions) with an appropriate polymer or rubber-modified polymer. A successful practical application of this study may lead to further possibilities of replacing other expensive engine parts such as cam shafts, pistons and connecting rods where higher mechanical strengths are required.

5. CONCLUSION

In equation (33), a model was derived using the free energy for the Coulomb interaction between two charges. The model enabled the prediction of the critical inter-separation distances using volume fractions shown in table 1. These inter-separation distances and volume fractions can inform how much of the POSS-NH_2 and NaMMT need to be combined for greater strength. The volume ratio 2:3 was shown to be the most strength enhancing. In addition, the use of these predicted ratios would likely result in improved thermal and dimensional stability of the material too. The production of cheaper automobile parts (such as the head gasket) will lead to a more profitable and sustainable auto-mobile transport business. The polymer composite also has lighter weight compared to conventional steel, this results in lesser fuel consumption (more so when other engine parts can be replaced). This means that the operation, regular service and maintenance of the vehicles will be cheaper and more affordable and hence leading to lowering of public transport fares. This cost assessment is subject to future validation as many vehicles will have to be compared and over a long period of time.

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DESIGNING FOR OPTIMAL SERVICE LEVEL TARGET BASED ON COST WHEN DEMAND AND LEAD TIME ARE STOCHASTIC

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ABSTRACT

In existing hybrid inventory review systems, it is inevitable that shortages take place due to varying lead-time and demand. Such practical situation is often followed by high inventory cost, which is difficult to estimate, because it is related to other important objective to be achieved simultaneously. When a hybrid inventory system is implemented, designing for high service level should result in fewer stock outs. Hence, it is crucial to set down an appropriate safety stock, since it is used to prevent stock-out situations. These two objectives conflict with each other because the approaches to inventory cost minimization incorporate models for the varying factors such as demand and lead-time, which are both not designed to be fully utilized under uncertain conditions. This paper presents an approach to inventory management that balances the conflicting goals of maximizing customer service and minimizing hybrid inventory cost under uncertainties. A constrained optimization approach is used to find the safety stock that matches with desired customer service level in a plant. Results reveal optimal service level path, which when followed, should lead to optimal inventory cost as demand and lead time fluctuate. Furthermore, adjusting re-order point without considering real demand pattern is risky.

Keywords: service level, inventory cost, constrained optimization, critical reorder point path

OPSOMMING

In bestaande hibriede voorraadoorsigstelsel is dit onvermydelik dat tekorte plaasvind as gevolg van verskillende loodtyd en -vraag. So 'n praktiese situasie word dikwels gevolg deur hoë voorraadkoste, wat moeilik is om te skat, aangesien dit verband hou met ander belangrike doelwitte wat gelyktydig bereik moet word. Wanneer 'n hibriede voorraadstelsel geïmplementeer word, moet die ontwerp van hoë diensvlak tot minder voorraaduitslag lei. Daarom is dit noodsaaklik om 'n toepaslike veiligheidsvoorraad neer te lê aangesien dit gebruik word om uit voorraad situasies te voorkom. Hierdie twee doelwitte stryd met mekaar omdat benaderings tot voorraadkoste-minimalisering modelle vir die wisselende faktor insluit soos vraag en loodtyd , Wat albei nie ten volle ontwerp is nie.

Hierdie vraestel bied 'n benadering tot voorraadbestuur wat die teenstrydige doelwitte van die maksimalisering van kliëntediens balanseer en die bbp-voorraadkoste onder onsekerhede verminder. 'N Beperkte optimaliseringsbenadering word gebruik om die veiligheidsvoorraad te vind wat ooreenstem met die gewenste kliëntediensvlak in 'n Aanleg . Resultate toon 'n optimale diensvlakpad wat as gevolg van optimale voorraadkoste moet lei, aangesien vraag en Aanbod wissel. Verder is die aanpassing van herbestellingspunt sonder om die regte vraagpatroon te oorweeg, riskant.

Sleutelwoorde: diensvlak, voorraadkoste, beperkte optimalisering, kritieke reorder-puntpad

1 INTRODUCTION AND BACKGROUND

Safety stock is the stock that is kept to deal with unforeseen events. Safety stock can also be defined as the inventory that is held to prevent stock out and back-order situations. It could just be called variability stock or the stock that is held in order to account for variability such as delivery date variance (lead time), requirement variance (inaccurate forecast), inventory variance and delivery quantity variance in the supply chain. However, the main problem with safety stock level, of course, is that lead-time and demand volume may not be exactly predicted.

Managing inventory, especially safety stock, can be considered as one of the most challenging tasks facing supply chain managers [1]. For instance, decisions related to inventory levels throughout the supply chain has a fundamental impact on the service level, response time, delivery lead-time and the total cost of the supply chain [2]. Unfortunately, some inventory managers use hunches to set safety stock levels, while others base them on a portion of cycle stock level, for example [3]. While easy to execute, such techniques generally result in poor performances [3]. A proposed mathematical approach to safety stock management will not only justify the required inventory levels to business, but will also balance the conflicting goal of simultaneously maximizing customer service level/satisfaction and minimizing inventory cost.

From a mathematical point of view, one should see an inventory review system as the relationship that exist between the quantity of stock on order and the quantity available, as pre-set and determined by the individual manager [4]. Although it is not realistic to examine all the possible relationships between the parameters involved in inventory management, it is important to describe those that are most important in selecting an inventory review system. Thus, the relationship that exists between the consumption rate, which is dependent on the path of demand and the lead-time, is useful in that it can help to deeply understand the cost of implementing a hybrid inventory review systems. The hybrid inventory model here is that combine in some sense the feature of both periodic *(R, S)* and continuous *(r, Q)* inventory review models.

It is because demand and lead-time uncertainties have direct impacts on the inventory level that a need for setting flexible safety stock levels is unavoidable. Calculating the safety stock mean value is of limited usefulness because it provides no information about the real service level to be achieved. Instead of simply calculating the mean value of the safety stock, all the statistical parameters (such as mean value and dispersion) that determine the true nature of random variation should be incorporated.

Note that in inventory theory, the study of service level is as old as the theory of inventory itself [5]. Every text on operations or production management has sections that are devoted to address the problem of estimating service level because it drives the inventory and can be used as a performance indicator [6], but those texts are mostly dealing with average values that do not completely define the statistical nature of service level.Therefore, such approach cannot indicate the true measure of success for every supply chain.

Among the important definitions of service level is the work of Setamanit [7],, where the service level measures the proportion of demand that are met from the stock. The drawback of this measurement is that it does nott incorporate some important factors such as the random path of demand and lead-time . In this research paper, one takes a look at the service level defined as the probability of not having stock out during the reorder lead-time. The reason is that this type of service level is straightforward and indicates the proportion of the inventory cycle that no stock out occurs [8] . Further, service level is regularly assumed in situation whereby the safety stock must be chosen in order to guarantee that the frequency of random stocking out does not exceed some given value within a variable lead time interval [9].

2 METHOD

2.1 Case study company background

A case study company is a manufacturing firm found in the Vaal region, which produces and sells more than 2 chemical products all over the country, and review the inventory periodically after two week interval. For this study, the company would like to further examine other possibilities such as a flexible hybrid *(r,R, Q)* review systems in order to reduce the system cost while increasing the service level required to satisfy customers. Note that **r** is the re-order point, **R** is the review period and **Q** is the lot-size.

Such hybrid inventory system is described as follows. As demand occur in time, the consumption or utilization inventory may either be continuously depleted from the initial inventory or change instantaneously in response to control command or event. Such command may be triggered by marketing strategy such as promotion and equipment downtime, which in turn may cause the inventory system to be out of stock before the review date ***R***. In order to reduce these numbers of stock-out (backorder) that may occur, an order to replenish the system immediately (continuous inventory review system) can be allowed. Here, an order to replenish the system should then be placed if the inventory level drop below a specified level (re-order point) before a particular review date R, if not, the order quantity Q is determined at the next review date R (i.e. in periodic inventory review system.

2.2 Model development

Note that the cost of stock out can be perceived as an altogether different and most complex matter. The most obvious cost of stock out is the lost sales, but this factor, however important it may be, is far from being the only one, nor the most significant. The back-ordering cost is another cost of stock-out that deserves to be taken into consideration. In order to deal with the inventory system effectively, the solution involves meeting global service-level targets, while simultaneously minimizing a hybrid inventory costs and maximizing revenues. This can be achieved by gaining insight into customer demand and the plant capacity, which in turn may help one to determine the optimal safety sock quantities.

For a company to meet the requirement of the service level that it wants to provide, it should focus on the following individual goals: readiness to deliver, delivery time, delivery flexibility, reliability and quality. In this research paper, an emphasis is made on readiness to deliver. Hence it is crucial to define the aforementioned concept in the next section.

Readiness to deliver is the ability to satisfy a requirement on time. Readiness to deliver can be measured in different ways, depending on company's focus. If the company wants to measure readiness to deliver according to the number of units sold, the formula is

$$Service = \frac{\text{Number of acceptable quantity delivered in time}}{\text{Total quantity demanded}} \qquad (1)$$

Most hybrid inventory models are characterized by the re-order point and order quantity. A related issue is that shortage occurs only if demand *D(t)*, during the Protection Demand Interval *MLT(t)* is greater than the re-order point ***r***. An effective replenishment process is the one that addresses this issue through setting up a well-adjustable service level. Note that the relationship that exists between the stock out probability SP(t), demand D(t) and order quantity Q(t) can be given by

$$SP(t) = \frac{f}{D(t)/Q(t)}$$
$$\therefore SP(t) = f * \frac{Q(t)}{D(t)} \qquad (2)$$

where *f* is the proportion or fraction of or number of stock out per period (i.e. (the number of days with stock out) divided by (the total number of days available)) which is also given as the product of (number of back orders *B(t)* and (each back order duration (*t*) divided by (the total number of days available or period (T) given as , $f = j * \frac{1}{T}\int_0^T B(t)\,dt$ where *j* is back ordering cost per unit per time, *D* Known as D(t) is demand per period, *Q known as Q(t)* is the lot-size per period, and *Q*/*D* is the number of stock-holding days. Another expression of the service level according to Rosseti [10], , is described as follows:

$$SP = 1 - Service_{Level} \qquad (3)$$

By equating both equations (2) and (3) that describe the stock out probability, a new relationship can be obtained

$$1 - Service_{Level} = \frac{Q(t)}{D(t)} * j * \frac{1}{T}\int_0^T B(t)dt$$

$$\therefore \frac{j}{T}\int_0^T B(t)\,dt = (1 - Service_{Level}) * \frac{D(t)}{Q(t)} \qquad (4)$$

The backorder inventory then drive the main optimization equation as follows.

$$TC(r,R,Q) = \left[kN(t)_{Hybrid} + h * \frac{1}{T}\int_0^T I(t)_{Hybrid} + j\frac{1}{T}\int_0^T B(t)_{Hybrid}\,dt \right]$$

Subject to $j * \frac{1}{T}\int_0^T B(t)dt = (1 - ServiceLevel) * \frac{D}{Q}$ (5)

Where *TC(r,R,Q)* is the total cost per unit time of implementing a hybrid inventory review policy, *k* is the order preparation cost per order, *j* is the backordering cost for the item in unit per time, *h* is the holding cost for the item in units per time, *t* is the consumption time, *T* is the inventory cycle stock period *D(t)* is the instantaneous demand. Others parameters are described as follows:

$N(t)_{Hybrid} = \frac{D(t)}{Q(t)_{Hybrid} * T}$ is the number of replenishment orders made per time (6)

$I(t)_{Hybrid} = I_A + I_B$ is the maximum instantaneous inventory held per cycle (7)

$I_A = (Cycle_{Stock}) = \frac{1}{T}\int_0^T \left(I_0 - \left(\frac{\partial D}{\partial t}\right) * t \right) dt$ is the instantaneous consumption inventory model (8)

$I_B = \left(r - \left(\frac{\partial D}{\partial t}\right) * (MLT(t)) \right)$ is the safety stock inventory, I_0 is the initial inventory, demand rate or depletion rate is $\frac{\partial D}{\partial t}$ (9)

Such hybrid inventory model, as described above is a dynamical switching inventory model between continuous and discrete. Hybrid inventory review model is highly recommended as found in other research papers [5,7,11] and thesis inventory system [12]

3 DATA COLLECTION

Demand data were collected for two years and are presented in figure 1. The pattern/trend for the data was established by curve fitting and regression analysis.

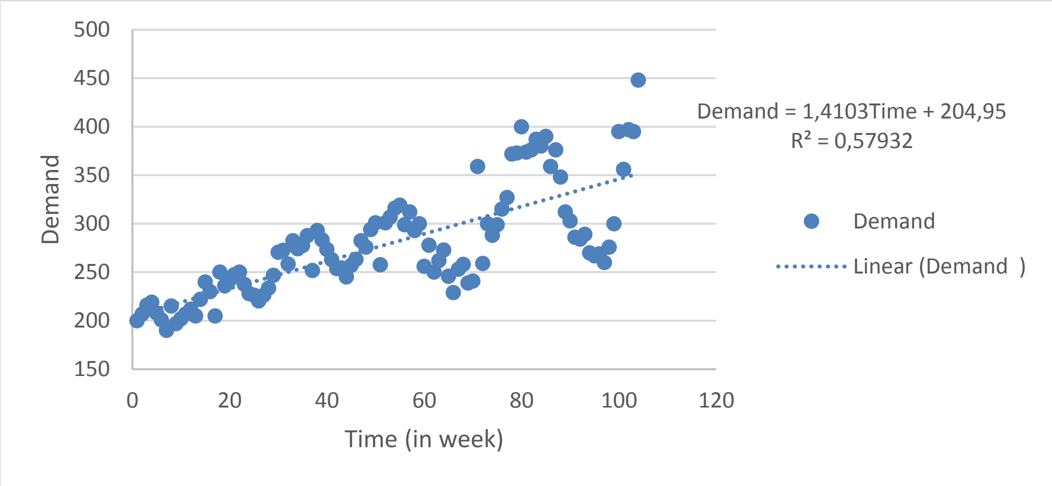

Figure 1: Scatter diagram of demand over 2 years period

The scatter diagram shows an increasing trend of demand with fluctuations with low R^2 value indicating poor fit of data with liner equation. It was clear to assume that the component of the demand function that resulted from the collected data could then be generalized as in the stochastic expression given below:

$$\partial D = D_{rate}dt + f_C dW(t) + f_P dV(t) \qquad (10)$$

Where

- Demand rate is $D_{rate} = \frac{\partial_D}{\partial t}$
- Continuous fluctuation term is f_C
- dW(t) is increment of Wiener process
- Periodic fluctuation term is $f_p = d * (1 - Sin(2 * t))$
- dV(t) is number of stochastic counting process
- Maximum change in demand due to periodic fluctuation *d*=37

Regression analysis was performed to get some of the parameters of the demand fluctuation model..

Weekly data on lead-time were collected for two years. The lead-time data were treated in the same way as with demand data. Figure 2 shows the lead-time pattern over two years. It should be noticed that a regression line on lead-time data was performed.

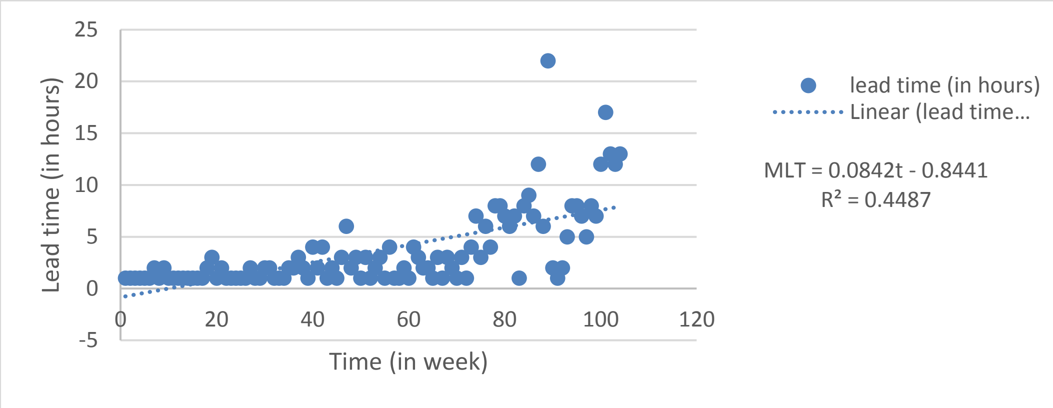

Figure 2: Scatter diagram of the lead-time over 2 years (in week)

The lead-time function or expression was obtained through linear regression analysis with statistical measure R^2 = 0.45 that captures the percentage of error as explained by the regression model. This result implied that the relationship between total lead-time and time was not that much strongly linear. This was a good reason to think of modeling the lead-time in a different way so that it incorporate important parameters that may capture the uncertainty caused by machine downtime.

The time increment of the manufacturing lead-time was then be obtained and results made stochastic by addition of periodic and continuous fluctuation terms given as follows [12,13] .

$$d(MLT(t)) = T_C * \frac{\partial Q}{\partial t} dt + Fluctuation \qquad (11)$$

Where T_C is cycle time which is the time spent to deliver a unit item when all resources are in place and in the case where items are delivered in bulk the cycle time is obtained by dividing the ("time" to deliver the bulk quantity) by (bulk size) and Q the lot-size or bulk size

3.1 Important parameters of the Inventory cost model

Note that in the case study manufacturing plant. The monthly costs for ordering, holding of inventory obtained through rental and preservation, and back order were obtained from the company's record and from instructed data collected. This was then divided by the number of weeks per month to get the weekly costs. The week order cost was further divided by the number of orders per week to get the per order cost. The weekly holding was divided by the total number of units held over the week to get the holding cost per unit per week (or time). The back order cost per week was divided by the number of back order units to get the back order cost per unit per time. The overhead cost was considered from fraction of salary obtained from the fraction of time per cost item. From this, it should be noted that there was no dedicated department responsible for ordering activity nor holding nor backorder activity. They summary of those parameters are represented as follow:

- The ordering cost *k=R125 per order*,
- The holding cost *h=R0.511 per unit per time*,
- The back order cost *j=R201per unit per time*,
- The service level was set to 90%

4 CASE STUDY OUTPUT RESULTS

Engineering Equation Solver (EES) was to solve the system of equations (1) – (11) and the associated condition.

Recall that the main target of this research paper was to establish the effect of implementing simultaneously periodic *(R, S)*, and continuous *(r, Q)* models on cost while considering the service level. Such combination of inventory models could be perceived as hybrid. The EES output results of this study are consolidated in data reports and presented by graphs of Figure 3. This approach is preferred because the usage of graphs can appear more transparent and allow for easy interpretation when comparing with data reports (statistical analysis) [13]. One of the verification techniques suggested by Law [14], such as running the models under simplified assumption and under a variety of input parameters was used to ensure that the models perform correctly.

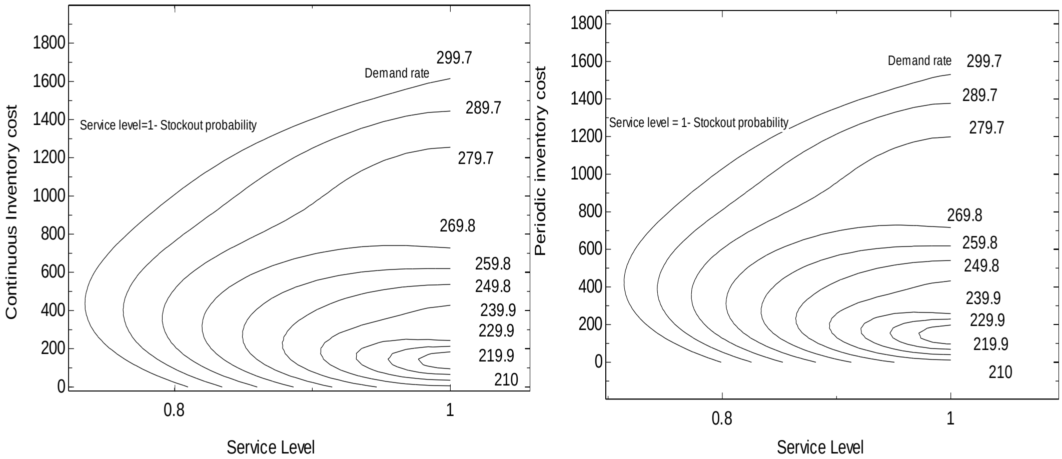

Figure 3: Trend of the demand rate, stock out probability and inventory cost in a stochastic supply chain

As it can be seen from Figure 3 that stock out events are allowed to a certain extent. When demand rate is low, stock-out probability is low with low cost. This implies high service level at low demand rate when the amount of money invested on inventory management is low. At the case study company, this fact was observed and the reason given by the inventory personnel was that it was due to the fact that there was negligent or improper house keeping and less sorting of product into category by volume, leading to poor inventory management although with high service level. It was also observed that at constant demand, the cost increased with decrease in service level reaching a minimum service level, where the cost continues to increase with a increase in service level. This implies that there is a minimal service level that be accompanied by continuous increase in cost, and to further reduce the service level beyond this (critical) minimum value, the cost has to drop, possible through reduced investment on inventory management. This was explained by inventory manager at the case study company that a reduced service level was due to high stock out leading to high reorder cost and back order cost as a result of the periodic review policy that was initially in place, and further investment on hybrid review policy as proposed by this study saw service level improvement

Also, as demand rate gets high, service level decreases with increased cost. It should be noticed that lower service level in response to an increasing demand leads to very high inventory cost. The fact that the stock-out probability increases due to increase demand is probably a reflection of the inventory cost under a backorder case. It should be noticed that the system is likely to be out of stock as demand increase rapidly. This result would suggest that an appropriate amount of inventory must be kept in store if one is to avoid customer dissatisfaction and loss of income. This can also be linked to previous work [5] , where it is stated that in a stochastic supply chain system, the effect of demand on the cost and service level (stock out probability) are stronger.

What this finding also portrays about the trend of the inventory cost and stock out probability in an uncertain supply chain is that implementing a hybrid system would still incur higher cost over time. This finding can be used as performances indicator because it may then be a proof that one should further investigate on the relationship that exist between the inventory cost and safety stock in order to achieve greater profitability.

<u>**Re-order point versus hybrid inventory cost**</u>

Another important result, found useful because it could describe the impact of the re-order point on hybrid inventory cost was portrayed on figure 4.

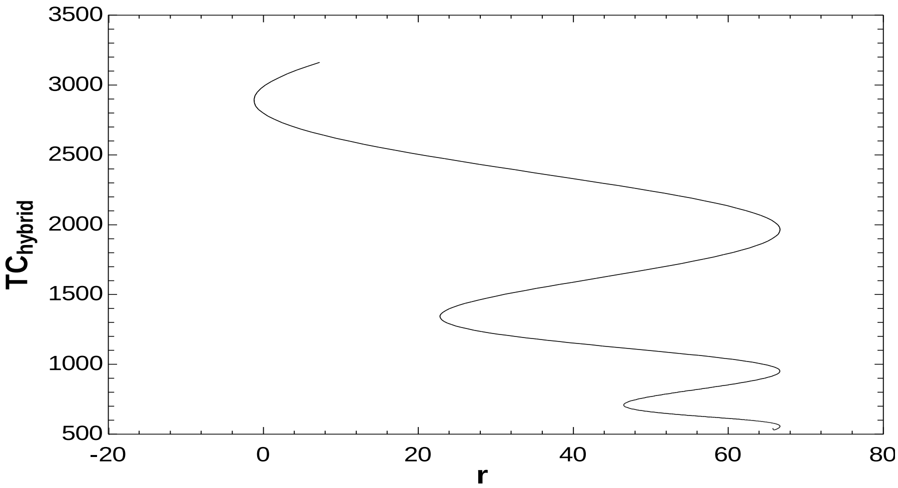

Figure 4: The link between hybrid inventory cost and re-order point

The plot (Figure 4) also reveals the path of the hybrid system cost versus re-order point. In fact, the maximum hybrid inventory cost is reached when the re-order point is equal to zero (when there is not inventory in store). This simply implies that the hybrid system is out of stock. Such event can only occur at the beginning of operation. The high cost incurred at the beginning of operation may be referred to stock-out events. As demand increased, the reorder point had to be increased as well which in turn led to inventory cost mostly being the sum of holding and ordering costs. When demand decreases, the re-order point decrease as well, which in turn impacts the hybrid inventory cost that results from high Back order cost. One can clearly see that the hybrid system cost decreases with increase reorder point because stock-out event are minimised.

5. CONCLUSION

Knowing the characteristic of the sales forecasts compared with actual supply chain conditions can greatly improve your ability to meet customer demand. The key point here is to increase service level without compromising the inventory cost, which in turn is related to profitability. The models show that it is impossible to perfectly balance service level and inventory cost. Trying to establish such balance will cause the inventory to go up. That is why it is crucial to balance the flow of product through the manufacturing plant with demand from the market.

An important point to notice here is the high hybrid inventory cost that occurs as a result of not being able to keep the right safety stock. This simply means that when the re-order point is equal to zero (i.e when the system is out of stock), one seems to observe a high hybrid inventory cost. However, increasing the re-order point with respect to a random increase of demand automatically leads to a noticeable decrease of the hybrid inventory cost. From a practical point of view, the re-order point can be used as an important key performance indicator since it affects the hybrid inventory cost. The result also confirms that, a well-established re-order point will helps one to determine the appropriate order quantity.

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BUSINESS MODEL INNOVATION FOR SEIZING WHITE SPACE OPPORTUNITIES: A DESIGN FRAMEWORK

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Business model innovation is crucial for any business to stay competitively relevant. Yet, few businesses understand its dynamics. Similarly, white space opportunities are often avoided due to a lack of understanding and reliable capturing processes. The potential exists to combine different business-model-innovation frameworks to achieve a well-structured design framework, which supports companies in designing new white space business models. This paper clarifies the definitions for business model innovation, identifies and compares business-model-innovation frameworks - to identify common elements. Finally, the paper proposes a design framework capable of designing appropriate white space business models.

1 INTRODUCTION

Business models and business model innovation (BMI) have been receiving increasing attention in recent years, from both academics and practitioners (Spieth *et al.* [15]; Zott *et al.* [16]). There is agreement that innovation of business models is imperative for companies to compete, especially in the difficult economic conditions as currently experienced by a lot of firms (Johnson [10]; Chesbrough [3]). While BMI has enjoyed an increase in attention in recent years, different perspectives still exist as to what BMI is and how it should be executed (Bonakdar, 2015; Björkdahl & Holmén [1]).

White space opportunities present unfamiliar territory that businesses either fail to identify, too hesitant to capture, or fail in the capturing process due to a lack of understanding. This refers to businesses not understanding their own old and stagnant business models, the BMI and generation process, or the coupled risks associated with such a venture (Johnson [10]). Additional difficulty is added when, according to Gaglio and Katz [7], the process and dynamics of opportunity identification remains mysterious. White space opportunities can bring about exceptional transformational business growth and unlock new revenue streams. Thus, it should be viewed as an opportunity for business expansion and be captured, rather than be an unknown and misunderstood entity that is always avoided (Johnson [10]).

A concrete understanding of present capabilities, along with methodological tactics to assess the requirements of a business model from new opportunities, results in the tough job of mapping a white space sensibly and making it practicably manageable. Although various business model frameworks exist such as Johnson's [10] repeatable BMI process, Osterwalder and Pigneur's [14] five stage BMI process, Lindgardt and Reeves's [12] circular BMI process and Geterud and Tegern's [18] BMI tool framework, there is still a need to gain a better understanding of current BMI frameworks and their associated similarities and shortcomings. Bonakdar [2] supports this idea by stating: *"Pathways or solutions that support incumbents to innovate their business models continuously, similar to products and technologies, are rare."* There is a gap in terms of BMI frameworks for supporting BMI for white space opportunities.

The purpose of this paper is to conduct a thorough and critical examination, in the form of a conceptual review and synthesis, to compare existing BMI frameworks and then indicate what their associated similarities, differences and shortcomings are. Therefore, the aim is to identify good practice from literature and to integrate it into a conceptual design framework, which will guide practitioners through the BMI innovation process for white space opportunities.

This paper clarifies definitions for innovation, BMI and white space opportunities. Additionally, it identifies existing innovation, BMI and business model frameworks, compares these frameworks to identify common elements using a structured approach and then, finally identifies common stages, considerations and structural elements to include in a white space business model design framework. Core concepts such as innovation models, BMI frameworks and business models were identified using various data bases such as EBSCO and by investigating leading authors, key terms and dates in the related fields of study. The first four sections form part of the literature review and describe white space opportunities, business model design frameworks, BMI frameworks and finally innovation frameworks. A synthesis is then generated in Section 6 from the literature review content. Section 7 introduces, creates and describes the solution followed by the conclusion in Section 8.

2 WHITE SPACE OPPORTUNITIES

Often business opportunities become known to serve a completely new customer or market sector in using original means that are not defined within a company's current core structure. Although it may not be apparent at first, these opportunities can slot into a company's current business model smoothly and are therefore called *adjacencies* (Johnson [10]).

However, some of these opportunities will require a company to function in a different manner. Consequently, the company will have to develop a new plan to obtain revenue, resources, expertise and management of activities. If a company in question must deliver new and original value to a market, due to one of these opportunities becoming known, this will require fundamental changes to its core structure and this opportunity lies within the business's white space (Johnson [10]). These core, adjacency and white space opportunities are illustrated at the top of the following page in Figure 1.

The term 'white space' is defined by Johnson [10] as: *"the range of potential activities not defined or addressed by the company's current business model, that is, the opportunities outside its core and beyond its adjacencies that require a different business model to exploit."*

According to Johnson [10], a white space is where goods, and even services, are not presently centred on the current understanding of the company's values, definition or present capabilities. He goes on to state that white spaces can be identified through the analyses of industries.

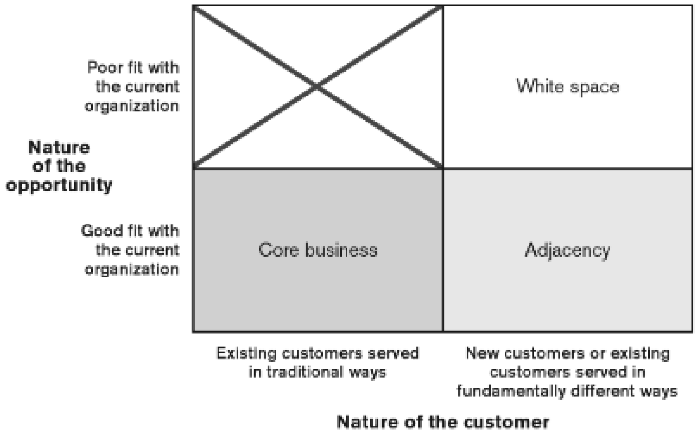

Figure 1 - Block diagram showing the different opportunities in relation to the nature of the customer
(Source: Johnson [10])

3 DEFINING BUSINESS MODELS

Various definitions for business models can be found in the literature. A common definition for a business model used by many authors is the one provided by Osterwalder and Pigneur [14] and supported by Johnson [10]. They define a business model as describing: *"the rationale of how an organisation creates, delivers, and captures value."*

Zott *et al.* [16] studied various definitions and concepts of business models, as described in the literature. A cross-sectional tactic was executed by them in order to derive four important themes on the notion of a business model, i.e. "*the business model as a new unit of analysis, offering a systemic perspective on how to do business, encompassing boundary-spanning activities (performed by a focal firm or others), and focusing on value creation as well as on value capture.*" (Zott *et al.* [16]).

Additionally, the business model entails (Zott *et al.* [16]):

- An original method of examination among firms and system levels
- An all-inclusive and complete view on how companies perform business activities
- A focus on value generation.

3.1 Business model structural elements

Currently there exists various kinds of business model frameworks in literature. This study briefly describes four different structural business model frameworks to describe the various structural components found within a business model. The four frameworks include the business model canvas, four-box business model, value-business model and finally, the triangular business model.

According to Johnson [10], the four-box business model provides suitable structure to disclose and classify all issues which must be confronted before a white space opportunity can be pursued. This structural business model is described due to its direct connection to exploiting white space opportunities. The four-box business model is like the business model canvas yet more compact. It consists of four components, namely the Customer Value Proposition, Profit Formula, Key Resources and Key Activities (Johnson [10]). The Customer Value Proposition describes how a solution generates value for a given customer at a set price. The Profit Formula entails how the firm will capture value for itself from its customers in the form of profit. The Key Resources and Key Activities describe how a firm conveys the value within itself and to its customers.

The business model canvas, which is the most popular model in literature (De Reuver [4]),describes a business model by using nine building blocks that encompass four sectors of any company, namely clients, offer, structure and financial feasibility. The nine building blocks include Customer Segments, Value Proposition, Customer Relationships, Distribution Channels, Key Resources, Key Activities, Key Partnerships, Cost Structure and Revenue Streams.

Additionally, Richardson [23] suggests a business model framework consisting of a value proposition, value creation, value delivery as well as final a value capture component. The *value proposition* defines the value that is generated and for whom. The *value creation* and value delivery describes how the value will be provided. Finally, the *value capture* entails how the firm will make money and capture value.

Frankenberger *et al.* [6] suggested a triangular business model consisting of four components, namely who, what, how and why. The *who* describes the customer group which is influenced by the other three components, the *what* defines the offering the customer values, the *how* entails the processes and resources needed to generate and distribute the offering, and finally, the *why* describes what makes the business model financially feasible.

3.2 Business model archetypes

Bonakdar [2] as well as Osterwalder and Pigneur [14] make use of business model patterns or archetypes to assist their business model design processes.

Osterwalder and Pigneur [14] created five categories in which business models can be categorised into, namely unbundling, long tail, multi-sided platforms, free business models and open business models. They go on to describe that these pattern categories will lead to a better understanding of the dynamics of a business model and will therefore act as a source of inspiration when designing a business model concept.

Alternatively, Bonakder (2015) states that patterns act as source of ideas and inspiration when various business models are considered and can be directly applied to the business being designed. He uses fifty-five business model patterns that were identified by Gassman *et al.* (2013) as a central design tool. Innovative solutions can be generated by comparing how the business model being designed can make use of different business model patterns.

4 Business model innovation (BMI)

A definition for the term BMI is generated in Section 4.1 followed by the description of various BMI frameworks in Section 4.2.

4.1 Defining BMI

BMI remains an unclear concept throughout literature (Geterud & Tegern [18]). Santos *et al.* (2009) defines BMI as: *"a reconfiguration of activities in the existing business model of a firm that is new to the product/service market in which the firm competes."* This definition stresses the transformation of changing from an old business model, to a new one that is suited to a specific industry.

By elaborating on the business model canvas, the definition for BMI can stem from this concept and is thus innovation within one or more of the nine building blocks of the business model canvas (Breiby & Wanberg [17]).

By focusing on corporations and partnerships Giesen *et al.* [20] found that enterprise model innovation seems to be the most common type of innovation in most successful companies. Enterprise model innovation can be defined as: *"Innovating the role we play in the value chain by changing our extended enterprise and networks with employees, suppliers, customers and other including capability /asset configuration."* (Giesen *et al.* [20]).

Johnson [10] states that BMI is not a fixed and stationary process, but rather a methodical, dynamic, recurring and dependable capability that is systematic in nature. Moreover, entrepreneurs, organisations and managers must construct, shape, reinforce and periodically transform to obtain a maintainable competitive advantage in the end. This definition was generated with the four-box model framework in mind.

From the analysis of the above definitions, this study generated its own chosen definition for BMI as the following: *A methodical, dynamic, recurring and dependable capability, possessing enterprise innovation. BMI is systematic in nature and entrepreneurs, organisations and managers must construct, shape, reinforce and periodically transform it to obtain a maintainable competitive advantage within new product/service markets in which the firm competes.*

4.2 BMI Frameworks/Processes

There are currently various frameworks in literature which describe the process of BMI. This section describes some of the most popular BMI frameworks or processes in order describe the different BMI components and their dynamics.

4.2.1 Osterwalder and Pigneur's [14] Five Stage BMI Process

Osterwalder and Pigneur [14] state that BMI is a disordered and unpredictable process, and that it requires the user to be able to handle ambiguity and uncertainty within the initial stages. They suggest a generic BMI process that consists of five linear stages. These five stages rarely progress in a linear manner and are sequentially described at the top of the following page in Table 1.

Table 1 – Stage Descriptions of Osterwalder & Pigneur's [14] Five Stage BMI Process

BMI Stage	Description
1. Mobilisation	Sets the base and prepares for a successful BMI; States the BMI project objectives, plans the BMI project, gathers a cross-functional team; Obtains executive approval.
2. Understand	Investigates and assesses elements that are required for the business model design process; Understanding is gained of the customers, technological developments and business models of industry competitors and look past present market and customer boundaries.
3. Design	Transforms the information from the Understanding stage into business model prototypes which can be assessed and selected.
4. Implement	Implement the designed and selected business model into the market environment.
5. Manage	Adjust and refine the business model accordingly to the reacting market by scanning the external environment and constantly assessing the business model.

4.2.2 Lindgardt and Reeves's [12] Circular BMI Process

Lindgardt and Reeves [12] used a business model design procedure as suggested by the Boston Consulting Group. Their BMI process consists of five separate stages in a circular loop which is described below in Table 2.

Table 2 - Stage Descriptions of Lindgardt and Reeves's [12] Circular BMI Process

BMI Stage	Description
1. Uncover opportunities	Discovers business opportunities by understanding the limitations of the company's current business model, forcing successful business model patterns into industries, identifying undeserved customer needs and re-establishing market boundaries.
2. Convert into business models	Translates the discovered opportunities into appropriate business models; Suitable and rigorous evaluation criteria is used to assist the selection of the correct business model.
3. Prepare and test	Prioritises and prepares for broader implementation; Tests business model within its environment.
4. Scale and iterate	The chosen business model(s) are enlarged in scale and iterated for refinement purposes.
5. Manage the business model portfolio	Concentrates on handling the business model portfolio successfully. Feeds back into stage one.

The circular BMI process concentrates on the preparation and testing phase, due to the unknown feasibility of the newly generated business models within a market segment.

4.2.3 Geterud and Tegern's [18] BMI Tool Framework

Geterud and Tegern [18] proposed an extensive BMI process based on a case study of the worldwide component manufacturing company SKF. Each one of the four stages are completed using various practical tools. Each stage is sequentially described in Table 3 below.

Table 3 – Stage Descriptions of Geterud and Tegern's [18] BMI Tool Framework

BMI Stage	Description
1. Business background	Obtains information on the current/parent business model. This stage obtains a better understanding on the goal, scope, product characteristics, product applications, competitive environment, customer insight and current trends and drivers.
2. Innovating the business model	Generates and assesses innovative business model concepts/ideas by assessing the current/parent company in terms of its business model, value proposition performance and possible opportunities/ideas.
3. Business model concept	Broadens and assesses the generated business model concepts in terms of their returns, implementation barriers and commercialisation viability so that a suitable final solution can be chosen.
4. Reinvented business model	Bridges the gap between having the new business model as a project and implementing the model itself; Assesses the newly innovated business model.

4.2.4 Johnson's [10] Repeatable BMI Process

According to Johnson [10], BMI should not be a fluke and rely on intuition, but rather be a process that is iterative, systematic and flexible in nature to ensure repeatability and optimisation. Centric to Johnson's [10] BMI process is his four-box business model framework and the operation of each component with one another. The goal of his BMI process is to generate a completely new business model, which is suitable to capture a white space opportunity (Johnson [10]). His business model generation process is described in Table 4 below.

Table 4 - Stage Descriptions of Johnson's [10] Repeatable BMI Process

BMI Stage	Description
1. Identify customers JTBD	Identify opportunities by identifying a customer's real JTBD by asking is "*what functional, emotional or social job is the customer trying to get done*?" instead of "*what does the customer need*?"
2. Design the Customer Value Proposition	Establish the offering, the offering's access and its payment scheme; Ensure the offering addresses the JTBD.
3. Devise the Profit Formula	Establish reasonable assumptions; Generate income statement and define revenue model, cost structure, target unit margin and resource velocity.
4. Identify Key Resources and Key Processes	Identify Key Resources and Key Processes from assumed income statement; Compare current business model blueprint to current/parent company.
5. Implementation	Test, learn, iterate and refine business model blueprint; Establish rules, norms and metrics; Scale-up.

4.2.5 Cambridge BMI Process

Geissdoerfer *et al*. [8] proposed a BMI process consisting of eight sequential and linear, yet, iterative stages. Their process is flexible in nature - allowing the user to go back and forth as well as allowing the repetition and skipping of stages. The Cambridge BMI process is summarised below in Table 6.

Table 6 – Stage Descriptions of the Cambridge BMI Process

Phase	BMI Stage	Description
Concept Design	1. Ideation	State the BMI project vision/purpose and identify and assess opportunities/ideas.
	2. Concept Design	Develop the components of the business model by integrating the opportunities/ideas and performing a technology trend analysis.
	3. Virtual Prototyping	Generate, assess and select a prototype. Compare the prototype against other business models and benchmark it against the industry.
Detail Design	4. Experimenting	Test the business model prototype in the environment, after which an analysis is performed and lessons are learnt.
	5. Detail Design	In depth definition and design of each business model component.
	6. Piloting	The entire final concept is implemented, tested, analysed and refined in a section of the target market.
Implementation	7. Launch	The whole business model is scaled up and implemented in the target market.
	8. Adjustment & Diversification	The business model is monitored, iterated and refined.

4.2.6 4I BMI Framework

Frankenberger *et al.* [6] developed a BMI framework that describes the general assembly of a BMI process. Iteration processes exist between every stage - except between the integration and initiation stages. Additionally, an external fit is created between the initiation and ideation stage, while an internal fit is generated between the ideation and integration stage. The 4I BMI framework is summarised in Table 5 at the top of the following page.

Table 5 - Stage Descriptions of the 4I BMI Framework

Phase	BMI Stage	Description
Design	1. Initiation	Identifies opportunities by understanding external environment such as customers, competitors and other firm influences.
	2. Ideation	Converts the identified opportunities into concrete business model ideas.
	3. Integration	Develops the business model ideas into complete and viable business models.
Realisation	4. Implementation	Implement the business model by taking risks, making substantial investments and testing the concept.

5 INNOVATION

Section 5 defines the concept of innovation followed by the description of three different innovation frameworks/processes.

5.1 Definition

Innovation as a term can be widely perceived, used and understood in the business world. According to the Oxford Dictionary [23], innovation can involve the execution or progression of innovation, or it can be a new, fresh and different introduction of a good or service. Marais & Schutte [13] stated that innovation is frequently mistreated within the marketing world to introduce new inventions.

Thomke [20] separated innovation from invention by suggesting that innovation is novel and has value. Similarly, to distinguish invention and innovation, Tidd *et al.* [19] defined innovation as, "*a process of turning opportunity into new ideas and putting these into widely used practice*". Additionally, Tidd *et al.* [19] suggested that innovation consists of four main stages: Search, Select, Implement and Learn, described in Table 7 below.

Table 7 – Stage Descriptions of the Generic Innovation Process

Stage	Description
1. Search	Identifies successfully new opportunities/ideas which can lead to potential innovations in the form of a good, service, process or business concept resulting in an increased competitive advantage.
2. Select	Precisely screens and selects innovative solutions.
3. Implement	Develops the chosen solutions into exploitable goods to execute, launch and sustain it in the external environment.
Learn	Situated externally, it receives input from each of the other three linear stages and gives an output back to the Search Stage.

Therefore, innovation entails the complete process, from the generation of an opportunity, to its successful exploitation in the marketplace (Marais & Schutte [13]).

5.2 Innovation Frameworks/Processes

5.2.1 The Fugle model

Du Preez and Louw [5] designed a generic process, which combines a convergent innovative funnel process and divergent innovative bugle process. The result is dubbed the Fugle model and it serves as a reference architecture for innovation, which comprises of all the activities addressed in defining innovation as well as being commercially implementable (Marais & Schutte, 2009).The Fugle model's phases and stages are summarised at the top of the following page in Table 8.

The goal of the Fugle process is to assist companies to recognise, assess, advance, apply and take advantage of fresh goods and services in a more resourceful and operational way (Du Preez & Louw [5]). According to Marais and Schutte [13], the Fugle model must be an innovative flexible process, which allows for overlapping activities between stages as well as containing iterative loops within specific cycle iterations. Filters and gates exist between the Fugle model stages, which act as points where a decision-making process takes place. During the funnel phase the filter points act more loosely - due to the uncertainty involved in the beginning. Additionally, any non-promising opportunities and concepts are filtered and prevented from proceeding further. However, these rejected opportunities must be stored because they could become valuable at a different time due changing circumstances (Du Preez & Louw [5]).

Table 8 - Phase/Stage Descriptions of the Fugle Model

Phase	Stages Name	Description
Phase 1	Opportunity Identification and Understanding Stage	Generates, discovers and understands opportunities.
Phase 2	Business Model Design Concept Stage	Converts opportunities into a business model concept through an initial design process.
Phase 3	Feasibility Stage	Tests the viability of the business model concept through a prototyping feasibility assessment.
Portfolio Stage	Portfolio Stage	Manages the solution received from phase 3 and launches it once the time is correct to deploy it.
Phase 4	Deployment Stage	Detailed design and implementation of the newly designed business model.
Phase 5	Refinement Stage	The business model is operated within the market opportunity and accordingly refined.
Phase 6	Exploitation Stage	Final business model is exploited in terms of capturing new opportunities and generating new business models to obtain more value.

5.2.2 Innovation Value Chain

Hansen and Birkinshaw [9] proposed an innovation process consisting of three linear high-level phases: Idea Generation, Idea Conversion and Idea Diffusion. Their process assesses innovation, presents managers with an end-to-end understanding of innovation and assists executives to identify opportunities. The innovation chain is described below in Table 9.

Table 9 - Phase Descriptions of the Innovation Value Chain

Phase	Description
1. Idea Generation	Identify ideas by analysing the internal and external business environment. This includes obtaining insight from the industry, customers, competitors, scientists, investors and universities.
2. Idea Diffusion	Identified ideas are assessed, funded and generated into goods, services or processes.
3. Idea Diffusion	The generated solution is diffused into chosen distribution channels, customers and geographic locations.

5.2.3 Ten Types of Innovation Framework

According to Keeley *et al*. [11], the Ten Types of Innovation framework is a tool that can be used to analyse and advance innovation within business models, identify opportunities, reveal innovation voids within an opportunity and assess competition. Furthermore they state that by understanding the framework it results in innovation being easier as well as more effective, complex and resistant. The Ten Types framework, described below in Table 10, is divided into three main categories, namely configuration, offering and experience (Keeley *et al.* [11]). Configuration defines the kinds of innovation that concentrates on the internal mechanisms of a firm and its corporate dynamics. Offering focuses on a firm's central goods, service or collection thereof. Finally, experience concentrates on the customer aspects of a firm and it enterprise system.

Table 10 - Ten Types of Innovation Framework Description

Category	Innovation Type	Description
Configuration	Profit Model	How the business generates money
	Network	Generating value with others through networks
	Structure	Asset and talent alignment
	Process	Methods to execute the required work
Offering	Product Performance	Unique features and functionality
	Product System	Complementary goods and services
Experience	Service	Surrounding offering support and enhancements
	Channel	Defines how the offering will be delivered
	Brand	Business and offering representations
	Customer Engagement	Customer interactions the business fosters

6 SYNTHESIS

The previous sections briefly described some of the innovation as well as business model design/innovation frameworks found in the literature. This section presents a synthesis of all the frameworks explored in the literature review conducted as part of the overall study. The aim was to extract all the key business model structural elements, design process steps, as well as key considerations described in these frameworks and literature sources to develop a comprehensive BMI framework, specifically targeted at white space opportunities. The synthesis was conducted by performing an extensive identification process of relevant, prominent and popular work associated with the problem of this study - after which its evidence was assessed, summarised and interpreted.

6.1 Key Considerations Analysis

The key considerations consist of critical factors that should be considered when executing a white space BMI framework. These considerations are summarised below in Table 11 along with their corresponding and supporting authors.

Table 11 – Key Considerations and the corresponding authors.

Key Considerations	**Author**
Consider Conditions for BMI	Giesen *et al*. [20]
State goal/purpose/objective.	Geissdoerfer *et al*. [8]; Geterud & Tegern [18]; Osterwalder & Pigneur [14].
Understand the organisation's current business model	Lindgardt & Reeves [12]; Osterwalder & Pigneur [14]; Geterud & Tegern [18]; Johnson [10]; Hansen & Birkinshaw [9]; Geissdoerfer *et al*. [8].
Perform an industry analysis	Johnson [10]; Hansen & Birkinshaw [9]; Osterwalder & Pigneur [14].
Identify opportunities by identifying the customers JTBD	Osterwalder & Pigneur [14]; Johnson [10].
Identify opportunities/ideas through gaining an understanding	Hansen & Birkinshaw [9]; Frankenberger *et al*. [6]; Lindgardt & Reeves [12]; Osterwalder & Pigneur [14].
Understand/Analyse Customers	Osterwalder & Pigneur [14]; Lindgardt & Reeves [12]; Geterud & Tegern [18]; Johnson [10]; Frankenberger *et al*. [6].
Understand/Analyse Competitors	Osterwalder & Pigneur [14]; Geterud & Tegern [18]; Frankenberger *et al*. [6]; Hansen & Birkinshaw [9]; Keeley *et al*. [11].
Understand/Analyse Technological trends	Geissdoerfer *et al*. [8]; Osterwalder & Pigneur [14].
Understand/Analyse present market and customer boundaries	Osterwalder & Pigneur [14]; Lindgardt & Reeves [12].
Assess opportunity/idea	Du Preez & Louw [5]; Geissdoerfer *et al*. [8]; Hansen & Birkinshaw [9]; Geterud & Tegern [18]; Tidd *et al*. [19].
Store Opportunity	Du Preez & Louw [5].
Classify opportunity as an adjacent, white space or core opportunity.	Johnson [10].
Generate a business model prototype to be assessed	Geissdoerfer *et al*. [8]; Osterwalder & Pigneur [14]; Du Preez & Louw [5]
Use Business Model Archetypes/patterns to assist the design process	Bonakdar [2]; Osterwalder & Pigneur [14]; Geissdoerfer *et al*. [8].
Ensure a flexible process	Johnson [10]; Osterwalder & Pigneur [14]; Du Preez & Louw [5]; Geissdoerfer *et al*. [8].

6.2 Business Model Structural Components Analysis

The structural elements of a business model were identified by assessing the similarities between the components found within the structural business models presented in Section 2, as well as the Ten Types of Innovation framework. Although the Ten Innovation Types is not strictly defined as a business model framework, but a model describing the different types of innovation, it can still be considered different elements of a business model structure. This structural comparison is illustrated at the top of the following page in Table 12.

Table 12 – Business model canvas and four-box business model component comparison

Four Box Business Model	Business Model Canvas	Value Business Model	Triangular Business Model	Ten types of Innovation
Customer Value Proposition	Customer Segments; Value Proposition; Customer Relationships.	Value Proposition	Who; What.	Product Performance; Product System; Service; Customer Engagement.
Profit Formula	Cost Structure; Revenue Streams.	Value Capture	Why	Profit Model
Key Resources	Key Resources; Key Partnerships; Distribution Channels.	Value Creation; Value Delivery.	How	Network; Structure; Brand; Channel
Key Processes	Key Activities	Value Creation; Value Delivery.	How	Process.

6.1 Process Analysis

In order to identify the key sequential process stages to include in the proposed design framework, the six BMI processes and Innovation Value Chain framework were analysed in terms of their similar steps or stages. Moreover, descriptive names were given for the stages that reflect the different frameworks' descriptions. A comparison of their stages can be seen below in Table 13.

The Cambridge BMI model design by Geissdoerfer *et al.* [8] represents all the BMI stages. While Lindgardt and Reeves [12] and Osterwalder and Pigneur's [14] BMI frameworks contained seven out of the eight BMI stages. Frankenberger *et al.* [6] represents six BMI stages, while Geterud and Tegern's [18] and Johnson's [10] framework only represent five out of the eight stages.

Storbacka (2010) stresses the use of concrete practical tools for the generation of BMI. Osterwalder and Pigneur's [14] as well as Geterud and Tegern's [18] frameworks are the only two that contain a vast amount of substantial practical tools to assist in each BMI stage. The other four BMI frameworks contain very little to no tools that are extremely basic in nature. In total, it can be seen that Johnson's [10] repeatable white space BMI process is the most simplistic and contains the most potential for improvement due to its lack of BMI stage representation and tool content. Therefore, Johnson's [10] framework can be substantially advanced using the synthesis to generate a comprehensive white space BMI framework which will assist the user to capture a white space opportunity and design an appropriate white space business model.

Table 13 - A comparison of the various BMI stages identified from the BMI and innovation frameworks explored in the literature.

BMI Stage	Lindgardt & Reeves [12]	Osterwalder & Pigneur [14]	Geterud & Tegern [18]	Johnson [10]	Frankenberger *et al.* [6]	Geissdoerfer *et al.* [8]	Hansen & Birkinshaw [9]
Mobilise		X	X			X	
Identify	X			X	X	X	X
Understand	X	X	X		X	X	X
Design	X	X	X	X	X	X	X
Assess	X	X	X			X	X
Implement	X	X	X	X	X	X	X
Test	X	X		X	X	X	
Iterate, Scale, Manage & Apply Lessons Learnt	X	X		X	X	X	

7 FRAMEWORK DESIGN

There is uncertainty surrounding the decisions that need to be made in order to capture a white space opportunity and it is considered unfamiliar territory. Thus, managers and firms require a guided process to assist them as to which decisions to make in which order. The proposed framework therefore focuses on the actual decision-making process. The main objective of this research study is to develop a design framework that will assist and guide companies to make a better-informed decision on how to capture a white space opportunity. Additionally, the purpose is to design an appropriate white space business model by following a reliable BMI process. The entire proposed framework can be seen on the following page in Figure 2.

The design framework was developed directly from the synthesis in Section 6. The BMI process steps, key considerations, as well as structural elements of a business model was combined in one integrated business model design framework. The framework was further augmented with different BMI tools identified from the literature that can be useful in each of the different stages of the framework (the description of these tools however is outside the scope for this paper). The result is a proposed BMI design framework that is more comprehensive than the current frameworks found in literature, as well as specifically tailored for supporting business model design for white space opportunities. Additionally, the Fugle model serves as a high-level guide for the solution, illustrated by the striped outlining surrounding certain parts of the design framework in Figure 2. The Fugle model was chosen due to its comprehensive coverage of the innovation process from the opportunity to the exploitation phase. Phases 1 to 4 of the Fugle model each contain individual parts of the proposed framework, while Phase 5 and Phase 6 serve as extensions of the proposed framework that are not within the scope of this study.

The design framework is essentially a flow chart with numbered blocks that are connected by arrows. The arrows guide and lead the direction of the design process resulting in a bound sequence. The numbering system acts as a reference to each framework block for explanatory purposes, as well as serving and acting as a rational chronological guideline in assisting the user. Although it is important to realise that the framework only indicates a logical sequence - it contains a strong flexible nature and its steps do not have to be followed in a strict linear or rigid fashion.

Before the design framework can be executed, a mobilisation step must take place. This involves obtaining the necessary team, money, resources, time and executive backing, as well as stating the project goal and creating a separate business unit. The design framework in Figure 2 is sequentially described step by step in the following list:

- **Step1**: According to Giesen *et al*. [20] there are very little companies that know when a change to their business model is required. It is therefore important for every company to constantly assess when the correct time is to alter their business model when trying to capture new opportunities or react to competitive forces. Step one, which acts as a starting trigger, contains BMI conditions listing whether it is necessary to execute and use the BMI design framework.
- **Step 2**: Understand the current/parent business model of the business executing the framework.
- **Step 3**: Analyses a potential industry before identifying opportunities.
- **Step 4**: If Step 3 produced an unsuitable industry, Step 4 identifies and selects a new industry to be analysed again in Step 3.
- **Step 5**: Identifies market opportunities by identifying the customers JTBD and by performing Step 10: Understanding. If no opportunities were identified a new industry is chosen in Step 4 and the process is repeated.
- **Step 6**: Pools together all the identified market opportunities for storage.
- **Step 7**: Assesses the identified market opportunities through an internal, external and financial analysis. If no opportunities pass the assessment, a new industry is chosen in Step 4 and the process is repeated.
- **Step 8**: Pools together all the viable market opportunities that passes the assessment in Step 7 for storage.
- **Step 9**: Classifies and ranks the opportunities as either a core opportunity, white space opportunity or adjacent opportunity by following conditions stipulated in Figure 2.
- **Step 10**: Selects the top ranked white space opportunity and develops a deeper understanding through a customer analysis, competitor analysis, technological development analysis and finally by looking past present customer and market boundaries.

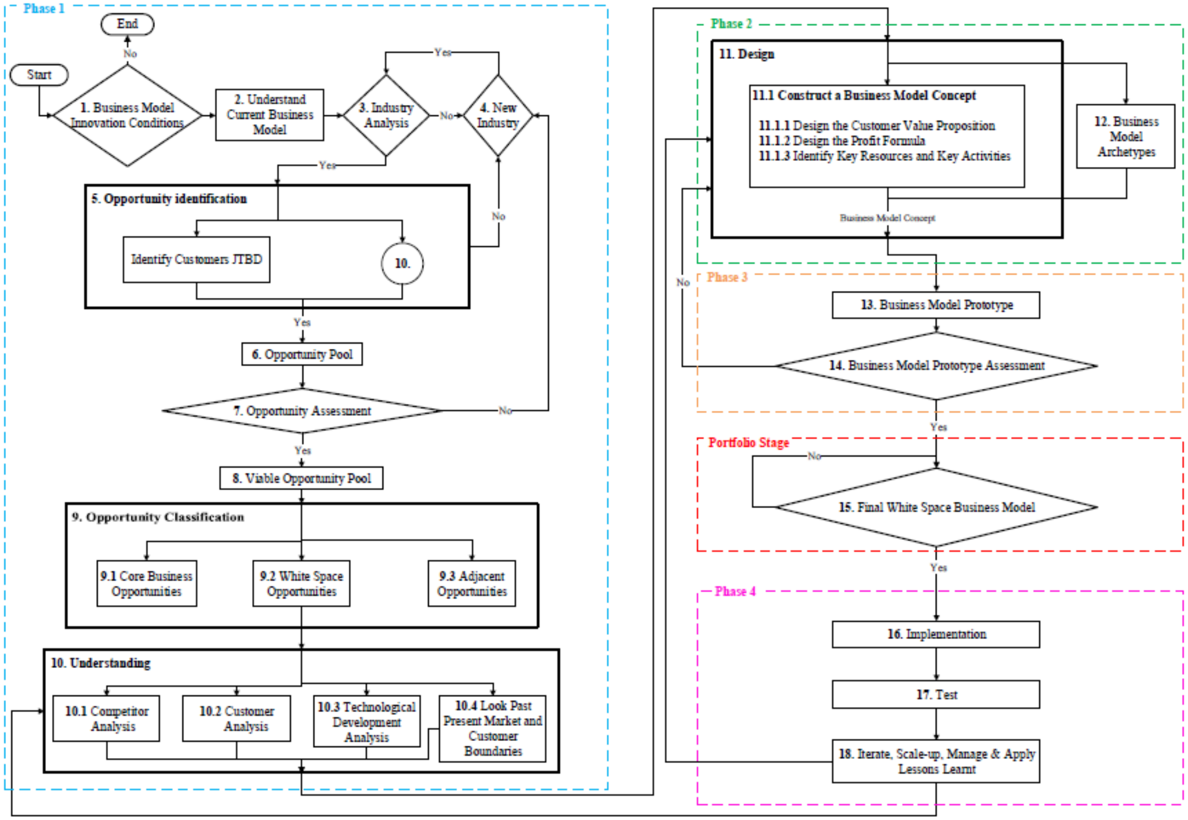

Figure 2 – BMI Framework

3365-13

- **Step 11**: Designs a new and appropriate business model concept for the white space opportunity by following the high level phases of Johnson's [10] repeatable white space business model design process. The categorisation of the Business Model Canvas into the four-box business model in Table 12 is focused on due to the high popularity of the Business Model Canvas in literature (De Reuver [4]). Finally, the Ten Types of Innovation in Table 12 contributes to the generation of innovation on a building block level.
- **Step 12**: Contains Osterwalder and Pigneur's [14] five patterns into which the designed business model concepts can be classified into as well as Bonakder's [2] 55 different business model patterns that act as a source of ideas and inspiration for the design of the business model prototype in Step 11.
- **Step 13**: Classifies all the designed business model concepts into prototypes. Step 13 additionally highlights the output from Step 11 for reference and storage purposes.
- **Step 14**: Assesses the business model prototypes using various tools in order to evaluate whether it is feasible or not. If the assessment highlights any weaknesses, the business model is accordingly adjusted in Step 11 through iteration. The strongest business model is chosen based on the assessment results.
- **Step 15**: This step contains the final white space business model design for reference, highlight and storage purposes. If the time is appropriate it is launched into Phase 4 to Step 16, otherwise it stays dormant within Step 15.
- **Step 16**: Implements the designed business model within the physical white space opportunity environment.
- **Step 17**: The final business model is physically operated and therefore tested within a section of the target market.
- **Step 18**: Learns lessons from Step 17 and then makes the necessary adjustments to Step 10 and 11, as well as manage and enlarge the scale of the business model concept with each iterative process.

Step 2 and Step 11 results in the design framework catering more for users already having a settled business model. However, due to its flexible nature, the framework can still be used with no current business model, i.e. looking to start a novel entrepreneurial mission. The design framework's decision-making nature combined with the applied tools within each framework step results in a BMI process which is extracted out of the theoretical and into the practical world. Therefore, the design framework contains the additional ability to assist users in individual framework aspects only if required in a hands-on manner.

8 SUMMARY, CONCLUSION AND FURTHER RESEARCH

BMI has recently become a popular research topic, yet businesses fail to fully comprehend and understand it. Similarly, white spaces are often considered as risky and unfamiliar due to the company not having a reliable guiding process to go about capturing and exploiting them. This research study assessed four literature areas, namely white spaces, business models, BMI and innovation. They were assessed through good practice within a synthesis to integrate them into a conceptually dependable, practicable, holistic and well-structured decision-making business model design framework, which will guide practitioners through the BMI innovation process for white space opportunities.

The core elements received from literature were the different business model structural components as well as the various BMI and innovation stages and key considerations. These core elements were compared and categorised in terms of their similarities and supporting authors within a synthesis. This synthesis was used to generate a design framework, which will remove user uncertainty. The user is assisted in capturing, designing and deploying a suitable white space business model - by following an organised and reliable process containing practical tools.

This research contributed to current literature by clarifying the concept of BMI, advancing the knowledge on the dynamics of BMI frameworks and linking related fields of study to the field of BMI in a practical and structured manner. The design framework extracts opportunity identification from its mysterious realm by illustrating a dynamical process of how to go about identifying and assessing opportunities. Additionally, the design framework advanced Johnson's [10] current white space BMI process by adding business model, BMI and innovation structures, stages and tools. Thus, clarifying the concept of pursuing white space opportunities.

As was shown, BMI frameworks currently exist in the form of a basic linear or repeatable structure consisting of only a few steps. The proposed BMI framework in Figure 2 is unique due to its solid macro to micro assembly, coupled with its detailed and extensive process flow structure consisting of 18 steps.

The current shortcoming is that the design framework has not yet been validated to date. Therefore, areas for further research include going through a reliable validation process in the form of a Delphi technique - to validate the design framework's phases, stages, considerations, tools and features.

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DETERIORATION OF COMMUTER RAIL SYSTEM EFFICIENCY DUE TO VARYING EXPECTATIONS FROM COMMUTER AND VARYING REWARDS FOR EACH EXPECTATION: A PROPOSED REMEDY

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ABSTRACT

A Commuter Rail Station is an example of a facilities layout. Each layout should be designed to be more effective in the ways that its offers services to its customers. To effectively design layouts, customers' expectations should normally be considered. More often the individuals' specific needs are not considered since the rule of the majority is mostly applied. Those designed commuter train stations soon become obsolete if additional constraints of giving variable priorities to various customer specific expectations are required. The situation is even worsened if variables rewards are required to render those services to customers with variables needs. The present paper proposes the use of an improved flow-pattern measure techniques, specifically improved FROM-TO-CHART techniques, to assess the efficiency of the current layout while considering the constraints of variables expectations from customers and variable rewards for rendering services to different types of customers. The efficiency of the proposed new layout is compared with that of previous layout to improve on stakeholders' confidence

Results reveal the use of a flexible Train Station layout whose flow pattern should be regularly adjusted to accommodate the ever-increasing expectations. It is hoped that station managers who use such guides will improve on customer's expectations.

Keywords: facility layout, flow pattern, from- to- chart, varying customer's expectation

OPSOMMING

'N Pendelaarstasie is 'n voorbeeld van 'n fasilieitsuitleg.Elke uitleg moet ontwerp word om meer doeltreffend te wees ten opsigte van die dienste wat dit aan sy kliente bied. Om die uitlegte effektief te ontwerp, moet kliënte se verwagtinge oorweeg word. Meer dikwels word die individue se spesifieke behoeftes nie oorweeg nie, aangesien die meerderheidsregering meestal toegepas word. Die Pendelaarstasie wat ontwerp word, sal spoedig verouder word as daar addisionele beperkinge benodig word,om verskillende kliente se spesifieke verwagtinge en veranderlike prioriteite te dien. . Die situasie word selfs vererger indien veranderlikes se belonings vereis word om daardie dienste aan kliënte te lewer met veranderlikes se behoeftes. Die huidige referaat stel die gebruik van 'n verbeterde vloeipatroon meet tegnieke toe. spesifiek verbeter VAN-TO-CHART tegnieke en om die doeltreffendheid van die huidige uitleg te evalueer, terwyl die beperkinge van veranderlikes verwagtinge en veranderlike belonings ten opsigte van diens lewering in ag geneem word. Die doeltreffendheid van die voorgestelde nuwe uitleg word vergelyk met dié vorige uitleg om die belanghebbendes se vertroue te verbeter

Resultate onthul die gebruik van 'n buigsame treinstasie-uitleg waarvan die vloeipatroon gereeld aangepas moet word om die toenemende verwagtinge te akkommodeer. Daar word gehoop dat stasiebestuurders wat sulke gidse gebruik, op die verwagtinge van die kliënt sal verbeter.

Sleutelwoorde: fasiliteit uitleg, vloeipatroon, van-tot-grafiek, wisselende kliënt se verwagting

1. INTRODUCTION

Deterioration of train stations can be caused by various Passengers needs. The Johannesburg park station is the central railway station in the city of Johannesburg and serves as a major transport interchange hub. It is therefore crucial for the train station to cater for the varying needs of the passengers. As reported by PRASA [1], disruptions of the current system that uses outdated technology has negative impacts on the quality of rail services, reliability of operations and financial performance.

When planning for passenger flow, it is important to take commuter conditions, evacuations, special events, off peak conditions and the types of passenger-flow into consideration [2]. The types of passengers referred to in this paper are children, the elderly, physical, cognitive, linguistic, auditory, visual, temporary limited, pregnant women, inebriated persons and people using wheelchairs [3]. As reported by Anastasia L.S. et.al [4], the differentiating factors to these conditions are passenger density, passenger attitude and route familiarity. At peak conditions, which are from 6:00am to 9:00am and from 4:00pm to 7:00pm, passenger volumes increase at train stations [5]. During this time what is noticeable with passenger flow is that passengers use the same train station to reach the same destination day after day and therefore are familiar with their habitual routes. This type of passengers may not pay attention to their surroundings as they rely on their travelling experience.

During the morning peak, commuters move with more urgency in order to arrive at work, school etc. in time. During this time, due to crowding, the following may occur: passengers may experience service delays, "deterioration" of facilities may occur due to vandalism, over load of machinery and equipment used for transportation e.g. elevators.

At off-peak conditions, particularly at night, the passenger's safety especially in unmonitored spaces may be regarded as important and the efficient movement of passengers may not be considered. Research done in some areas then proves that train stations that have improved security and visibility have an effect on efficient passengers flow [4].

Rail transit is suited to serve heavy time based, directional and spatial peaking which characterizes special events. Bottlenecks may be experienced during special events e.g. major sporting events [6]. Parking congestions are often burdensome during these events that passengers may opt for alternative mode of transports, which may be trains. Therefore these types of high passenger volumes can cause train station deterioration.

This paper proposes remedy that will improve passenger flow in a commuter rail system by using the Muther's Systematic Layout Planning Procedure and applying FROM-TO CHARTS to determine effective flow and provide alternatives facility layout. By using FROM-TO-CHART, the efficiency of the proposed new layout is compared with that of previous layout to improve on stakeholders confidence.

2. METHODOLOGY

<u>Muther's systematic layout planning procedure</u>

Tompkins et.al [7] points out that to obtain knowledge so as to improve an existing layout, to develop layout alternatives and to determine the required space, the Muther's Systematic Layout Planning Procedure can be followed. In this paper this procedure is used to analyse input data, to understand the roles and relationship between activities. The Muther's Systematic Layout Planning Procedure is used to sequentially develop a block layout and detailed layout for each department as prescribed by Tompkins et.al [7]. To obtain information on flow effectiveness and activity relationship, the technique that is used is FROM-TO-CHARTS and activity charts respectively. The FROM-TO-CHART approach is used to measure the effectiveness of a sequence of flow, intensity of flow and the amount of backtracking.

In order to applying the FROM-TO-CHART technique, all processes or departments are listed in the order that is identical to the required flow route across the column and down the row on the left hand side of the chart. The listing should be in the direction of the overall flow layout from beginning to end. Required next is a compilation of process sequence for a group of representative passengers using information from process chart. This may have to consider flow volume, distances travelled, costs etc. The flow of passengers through each process sequence is tracked and the chart should be completed for each passenger type.

Muther's Systematic Layout Planning procedure that has been employed in this articles is summarised below

The layout procedure

- Obtain information about the passengers with special needs and record the data systematically.
- Collect data on the travelled distance, passenger quantity, and cost per kilometre for each type of passenger.
- Develop a From-To-Chart based on the distance, quantity and cost per kilometre for each type of passenger.
- Determine the flow between departments using the flow-between-chart technique
- Rank the flow values obtained from the flow-between-chart in ascending order and develop an activity chart.
- Construct a relationship diagram from the information obtained on the activity chart.
- Design the block diagram to visualize layout of the station should look like for effective flow.

The general methodology that is presented in section 2 above was applied in collecting the data in the case study company. The case study Company is the Johannesburg Park Station

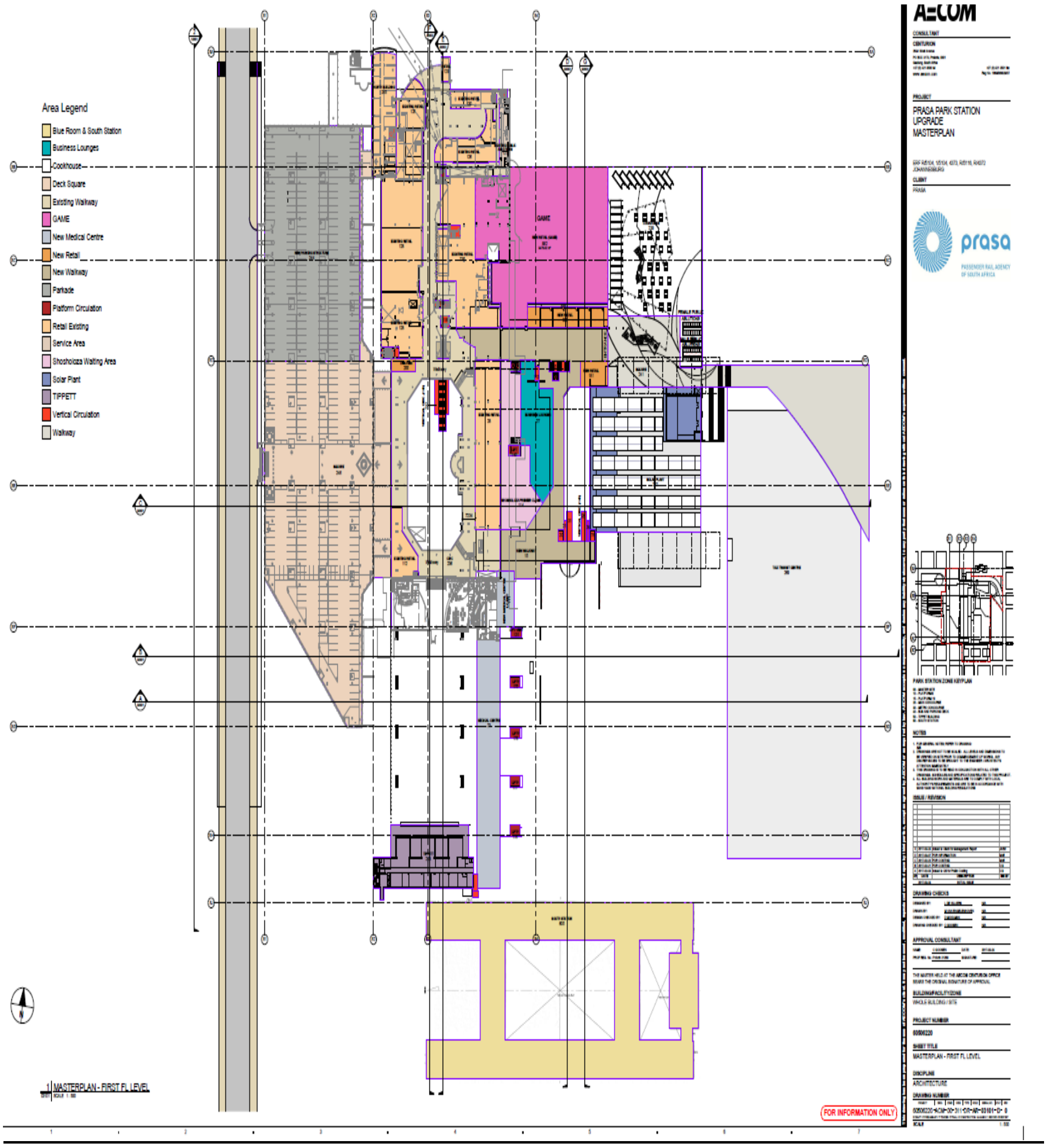
3. CASE STUDY ANALYSIS AND RESULTS

The following passengers were observed entering the Johannesburg Parkstation: children under the age of twelve years, the elderly, physical limited passengers, cognitive limited, linguistic limited, auditory limited, visually impaired, temporary limited, pregnant women, inebriated and people on wheelchairs.

Table 1: Identification and description of passengers with special needs

Passenger Type	Description	Method used to Identify passengers
Children	People under the age of 12	Informed by train station personnel
Elderly	People at the age of 60 and above	Informed by train station personnel
Physically Limited	Physically defective e.g. People with one limb	Direct Observation
Auditory Limited	Impaired hearing, , Defective speech and use of hearing aid	Informed by train station personnel and direct observation
Inebriated Limited	Defective motion and speech	Direct observation
Cognitive Limited	Mentally Defective and speech defective	Direct observation
Linguistic Limited	Foreigner	Direct observation
Pregnant women	Protruded stomach	Direct observation
Temporary limited	Restricted daily activities e.g. walking with crutches	Direct observation
Visually Limited	Defective eye sight and use of walking aid	Direct Observation
Paraplegic (people on wheelchairs)	Impaired sensory of lower extremities	Direct observation

These passengers were observed from the taxi rank through travel points labelled as follows A entrance to the taxi rank, B ablutions which cater for normal passengers and the disabled passengers, C retail (Game shopping store), D business lounges, E Shosholoza premier classes, F medical centre and G which is the exit to train station platform from which passenger catch a train to various destinations [8] .



Picture1: Layout of the park station Kwesiga.M 2017[8]

<u>Assumptions and Constraints used in the analyses are:</u>

- Changes of the new proposed layout will not affect normal passenger and other people employed to work at the train station facilities i.e. Johannesburg Park station employees.
- This paper only discusses the route from the taxi transit area unto the train station entrance: to new retail departments, the shosholoza premier class, continuing to the medical centre and finally the exit into the train. It does not focus on the whole Johannesburg Park Station layout.
- The costs considered per passenger type were for the lighting of the facility as per SANS universal access standard, ablutions required for all people including people with disabilities, accessories and directional signage posts, use of elevators, bench seating and tactile for the blind. The cost per person was determined by dividing the total cost of facility over the number of use before replacement or maintenance.

- Fixed costs were not considered since they cannot be reduced.
- Only of 3422 passengers were used to determine the type of passengers requiring special attention.
- This paper focuses on two scenarios: a first scenario where cost per passenger was not taken into consideration and a second scenario where cost per passenger (identifying various needs) was considered.

Scenario 1:

In this layout scenario the cost was not taken into consideration and the following data and results were obtained using the from-to-chart technique

Table 2: Passengers with special needs information

	ROUTE	QUANTITY	DISTANCE	TOTAL DISTANCE	REL. DIST
CHILDREN	A-B-C-F-G	300	1.5	450	2.25
ELDERLY	A-B-C-F-D-G	500	4	2000	10
PHYSYCAL PHYISICAL LIMITED	A-F-D-G	480	1.5	720	3.6
COGNITVE COGNITIVELIMITED	A-B-C-F-G	350	3.5	1225	6.125
LANGUAGELINGUISTIC LIMITED	A-C-E-G	200	1	200	1
AUDITORY LIMITED	A-B-C-F-G	100	2.5	250	1.25
VISUALLY LIMITED	A-F-E-D-G	150	2.5	375	1.875
TEMPORARY LIMITED	A-C-D-F-G	189	3	567	2.835
PREGNANT	A-B-C-E-F-D-G	488	9.6	4684.8	23.424
INDEB INEBRIATEDPERSON	A-B-E-G	400	1	400	2
WHEELCHAIR	A-B-C-E-G	265	3.5	927.5	4.6375

With ABCDEFG (i.e. a greater major of the customer is expected to enter the train station from the taxi rank at A, and then move B which are ablutions that cater for normal passengers and the disabled passengers, then to C (Game shopping store), then to D (i.e. business lounges), then to E (Shosholoza premier class), then to F (medical centre) and then to G which is the exit to train station platform from where passengers catch trains to various destinations) being the prescribed route that passengers have to follow in the train station, we had to calculate the efficiency of the prescribed routed using FROM-TO-CHART techniques, which involves finding the total point and penalty point. The outputs are given in table 2 above and table 3 below. In this table and subsequent ones, the entries in black colours are used to calculate (i.e. by summing up to obtain) the Total Points and the entries in red are used to obtain the Penalty Point. These Total Points and Penalty Points are then summed and used to calculate the efficiency of the prescribed flow pattern.

Table 3: Current layout and flow pattern From-to-chart for scenario one

	A	B	C	D	E	F	G	Total point	Penalty Point
A	XXX	115.3: 115.3	6.1:12.2	0	0	7.2: 88.2	0	128.6	215.7
B	0	XXX	108.1: 108.1	0	9.8: 21.7	0	0	117.8	129.7
C	0	0	XXX	3.6: 3.6	69.7: 144.5	38.4: 33.3	0	111.6	181.3
D	0	0	0	XXX	0	3.6: 7.1	71.2: 244.9	74.7	252.0
E	0	0	0	0	XXX	46.9:46.0	40.7: 81.4	86.7	127.4
F	0	0	0	25.2: 326.5	7.2: 14.4	XXX	16.7: 16.7	49.1	357.6
G	0	0	0	0	0	0	XXX	0	0
							SUM	568.6	1263.7

This gives the efficiency of this prescribed flow pattern under *scenario 1* as (sum of Total point) divided by (sum of penalty point)=568.6/1263.7= 50%

An efficiency of 50% for prescribed flow pattern is not good enough. So a revised flow pattern or route has to be proposed. According to the knowledge enshrined in FROM-TO-CHART Technique, those departments with high Penalty entries (which signifies high impact of back tracking) have to be placed closer to each other. Upon applying this principle, the newly proposed flow pattern or route or layout from this project should be ABDECFG. This improved routing should also indicate how the various departments should be placed with respect to each other.

Using the proposed new routing of ABDECFG, the principle of FROM-TO-CHART was used again to determine the efficiency. The results in Table 4 below were obtained. It should be noticed that the efficiency of the proposed layout or route shows significant improvement from 50% to 83%. This indicates a service delivery satisfaction improvement from 50% to 83%. Thus, exists enormous potential to improve on service delivery by employing the FROM-TO-CHART techniques when service has to be rendered to individuals who have to move from department to another.

Table 4: Improved layout From-to-chart for scenario one

	A	B	D	E	C	F	G	Total point	Penalty Point
A	0	115.3: 122.51	6.1: 12.14	0	17.6: 31.3	0	0	139.0	166
B	0	0	108.1: 108.1	7.2: 14.5	0	0	0	115.3	122.6
D	0	0	0	72.2: 69.7	38.3: 81.7:	3.6: 10.7	0	114.1	162.1
E	0	0	0	0	46:46	7.2: 14.4	33.5 : 45.4	86.7	106
C	0	0	0	7.2: 14.4	0	81.6: 81.6	16.7 : 38.5	105.5	134.5
F	0	0	0	0	3.6: 7.1	0	89: 88.8 9:	92.4	96
G	0	0	0	0	0	0	0	0	0
							SUM	653.1	787

Efficiency of current layout scenario one is 653/787= 83%.

Scenario 2

Under this scenario both distance travelled and cost incurred to facilitate commuters to travel those distances within the commuter train station were considered. It is expected that commuters with different needs will require different amount of care, which translates into variable costs. Thus, these variations were considered under this scenario, and the data in table 5 below was obtained.

Table 5: Information on passenger's with special needs with cost values

	ROUTE	QUANTITY	DISTANCE km	COST/km	TOTAL COST	RELATIVE COST
CHILDREN	A-B-C-F-G	300	1.5	230	103500	1
ELDERLY	A-B-C-F-D-G	500	4	1304.02	2608040	25.19845
PHYSYCAL LIMITED	A-F-D-G	480	1.5	1500	1080000	10.43478
COGNITVE LIMITED	A-B-C-F-G	350	3.5	849.9	1041128	10.0592
LANGUAGE	A-C-E-G	200	1	1299.6	259920	2.511304
AUDITORY	A-B-C-F-G	100	2.5	866.4	216600	2.092754
VISUAL	A-F-E-D-G	150	2.5	1990	746250	7.210145
TEMPORARY LIMITED	A-C-D-F-G	189	3	650	368550	3.56087
PREGNANT	A-B-C-E-F-D-G	488	9.6	1016	4759757	45.98799
INDEB PERSON	A-B-E-G	400	1	1869	747600	7.223188
WHEELCHAIR	A-B-C-E-G	265	3.5	2649	2456948	23.73862

The efficiency of the prescribed route (of ABCEDFG) was established again under this scenario using the FROM-To-CHART technique. This time, the total costs over the variable distances and variable number of commuters of each type were considered. The results are found in Table 6.

Table 6: current layout from-to-chart for second scenario

	A	B	C	D	E	F	G	Total point	Penalty Point
A	XX	115.: 115.3	6.1: 12.1	0	0	7.2: 88.2	0	129	215.7
B	0	XXX	108.1: 108.1	0	9.7: 21.7	0	0	118	129.7
C	0	0	XXX	3.6: 3.6	69.7: 144.5	38.4: 33.3	0	111.6	181.3
D	0	0	0	XXX	0	3.6: 7.1	71.2: 245	74.8	252
E	0	0	0	0	XXX	46: 46	41: 81.4	86.7	127.4
F	0	0	0	25.2: 326.5	7.2: 14.4	XXX	17:17	49.1	357.7
G	0	0	0	0	0	0	XXX	0	0
							SUM	568.6	1263.7

The Efficiency of the prescribed routing (ABCDEFG) is 568.6/1263.7 = 45%. It can be seen that due to this new dispensation of giving different attentions to commuters of different types, the efficiency of the prescribed route has dropped from 50% to 45%. This shows that the layout or facility is fast becoming obsolete under the prescribed routing.

Using the proposed new routing of ABDECFG, the principle of FROM-TO-CHART was used again to determine the efficiency. The results in Table 7 below were obtained. It should be noticed that the efficiency of the proposed layout or route shows significant improvement from 45% to 64%. This indicates a service delivery satisfaction and costs improvement. Thus this indicates an enormous potential to improve on service delivery by the employing the FROM-TO-CHART techniques when service has to be rendered to individuals who move from department to another.

Table 7: Improved layout From-to-chart for scenario two

	A	B	C	D	E	F	G	Total Point	Penalty Point
A	XXX	104.2: 104.2	14.6: 29,2	10.4: 31.3	2.5: 10.1	7.2: 48.6	10.4: 62.6	149.4	286.045
B	0	XXX	95: 95	0	7.2: 21.7	2.1: 8.4	0	104.2	125
C	0	0	XXX	50: 50	24: 47.5	35.2: 105.8	1: 4	109.5	206.8
D	0	0	0	XXX	0	14: 28	0	14	28
E	0	0	0	0	XXX	46: 46	41: 81.4	87	127.4
F	0	0	0	0	7.2: 14.4	XXX	97.3: 97.3	104.5	111.8
G	0	0	0	0	0	0	XXX	0	0
							SUM	568,6	885

This gives the efficiency of this prescribed flow pattern under *scenario 2* as (sum of Total point) divided by (sum of penalty point)=568.6/885= 64%

The next thing to do is to propose how the Park Station should be laid out by establishing its block diagram under the two scenarios. This was achieved in the following steps

Table 8: Representation of flow between activities scenario one

	A	B	C	D	E	F	G
A	XXX	115,3	6.0722	0	0	0	0
B		XXX	109.08	0	9.7345	0	0
C			XXX	3,5609	69.727	38,35	0
D				XXX	0	0	71.186
E					XXX	53.198	40.683
F						XXX	16.713
G							XXX

Table 9: Representation of flow between activities scenario two

	A	B	C	D	E	F	G
A	XX	104.2	14.6	10.4	2.5	7.2	10.4
B	0	XXX	95	0	7.2	2.1	0
C	0	0	XXX	49.5	24	35.2	1
D	0	0	0	XXX	0	14	0
E	0	0	0	0	XXX	53,2	40.7
F	0	0	0	0		XXX	97.3
G	0	0	0	0	0	0	XXX

Table 10: Activity relationship chart scenario one

DPT	A	B	C	D	E	F	G
A	XXXX	A	O	U	U	U	U
B		XXXX	A	O	O	U	U
C			XXXX	U	E	I	U
D				XXXX	U	U	A
E					XXXXX	E	E
F						XXXX	I
G							XXXXX

Table 11: Activity relationship chart scenario two

	A	B	C	D	E	F	G
A	XX	A	I	I	E	A	I
B		XXX	O	0	E	I	U
C			XXX	O	I	E	1
D				XXX	0	I	0
E					XXX	O	I
F						XXX	A
G							XXX

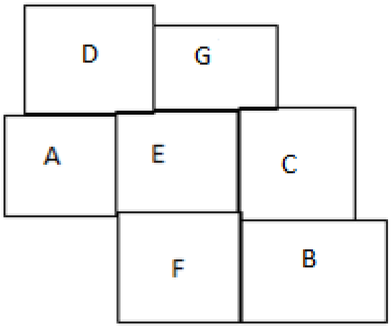


Diagram 1: Block diagram for a proposed layout scenario one

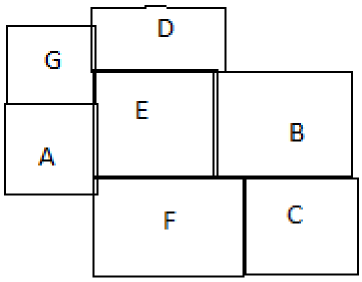


Diagram 2: Block diagram for a proposed layout scenario two

The following paragraph is repeated so as to refresh the mind. . This passengers were observed from the taxi rank with a travel route labelled as follows A entrance to the taxi rank, B ablutions which cater for normal passengers and the disabled passengers, C retail (Game shopping store), D business lounges, E Shosholoza premier classes, F medical centre and G which is the exit to train station platform on which passenger catch a train to various destinations.

In the first scenario where cost was not taken into consideration it is seen that distance travelled could be used to indicate the efficiency of flow in a facility. The current layout's efficiency is 50%, which by rearranging the flow layout so that the distance travelled between departments is decreased has the efficiency now increased to 83%. If people have to travel long distance between facilities this could impact the deterioration of the facility as people are being kept in the facility longer.

In the second scenario where cost has been taken into consideration; it is observed that the current layout's efficiency is 45%. This gives an indication that the train station is losing money to cater for passenger in their facilities. The facility is not being used effectively. In this paper a remedy has been established were a new layout is being proposed. The new layout gives an efficiency of 64%. In the second scenario it is seen that an improved layout will decrease unnecessary costs and an increase on return on capital expenditures. It also promotes ease of facility maintenance. Importantly the passengers will be satisfied since their needs will be met.

4. CONCLUSION

Flow systems, space requirements and flow relationships are essential elements as they provide the foundation for a facility plan Tompkins *et.al* [7]. To provide high quality service and maintain a facility which caters for various people who have different requirements is a challenge. Companies need to meet national imperatives however company do not always have money to their disposal. The results obtained in this paper serve as a recommendation for train station managers to improve efficiencies in the train station through use of facility planning techniques, and also alternatives are given which can assist train station decision makers to choose an efficient layout for the commuter rail system. This paper has provided a remedy to minimize deterioration of train station and increase efficiencies by applying from-to-chart technique.

Layout alternatives are given in which can assist train station decision makers to choose an efficient layout for the commuter rail system.

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CREATING MANUFACTURING SHARED VALUE IN BASE OF THE PYRAMID COMMUNITIES

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ABSTRACT

In the current competitive economic environment, start-up companies struggle to accomplish entrepreneurial value creation tasks alone. The manufacturing industry possess many opportunities for local suppliers to exploit although many of them struggle to capitalise on these opportunities as they may lack certain skills or infrastructure. The Base of the Pyramid (BoP) is regarded as the socio-economic group that consists of more than four billion people who live on less than two dollars a day. Therefore, it is critical to study innovative manufacturing systems to create sustainable manufacturing shared value in these communities. Manufacturing shared value finds synergy amongst various stakeholders in order to mobilise developing BoP communities to create both a profit potential for investors and social impact on the local communities. These type of systems allow local products to be manufactured economically in smaller, more flexible quantities for the customised demand. As part of the Building Blocks Initiative this study was to understand the income levels, sources of energy, consumption patterns and to test the appetite for containerised factories in BoP communities. This case study of the Epworth community in Zimbabwe revealed that community members appreciate and support local initiatives. In combination with the standard of social skills, supporting infrastructure and abundance of entrepreneurial energy enabling manufacturing shared value in the base of the pyramid seems worthwhile to explore in detail with future research.

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1 INTRODUCTION

Poverty remains an issue of the modern world. More than half of the working population belongs to the so called base of the pyramid (BoP). In order to comply with tighter legislation, Broad-Based Black Economic Empowerment policies and to receive tax benefits, several stakeholders attempt to address this issue with passive social responsibility programs [1]. Organisations are increasingly faced with pressures from communities in which they intend to invest, while contributing to the sustainable development of their investment destinations.

Poverty can not only be addressed by programs that adhere to and support sustainable business conduct, growth plans and the Millennium Development Goals. Therefore, it is critical to find a synergy amongst various stakeholders and that actions are orchestrated to support the development goals. The call for systems and strategies to mobilize the target population and to ensure distributed value creation even in isolated regions remains unanswered [2].

In addition to this, billions of people are believed to comprise the BoP market, which comes as a great opportunity to invest in. This potential market is difficult to access with the products and services offered to high income earners. This is because social and cultural dynamics at the two ends differ and also products offered for the high-income customers may be packed in larger amounts, which are not affordable to customers at the BoP. Hence the market at the BoP will fundamentally require different approaches [3]. At the same time from a marketing perspective the poor are believed not to have the same needs, desires, or preferences as those living in more developed economies.

Since the industrial revolution manufacturing has been considered to be the main engine of economic growth and development. It contributes to the quality of life of individuals, to growth of wealth in a nation as well as power and position of a state. Having a strong manufacturing base is important to any society or community, because it stimulates all the other sectors of the economy. The concept of shared value was defined as the policies and operating practices that enhance the competitiveness of a manufacturing company, while simultaneously advancing the economic and social conditions in communities it operates in [4]. Value creation is referred to as the performance of actions that increase the worth of goods, products, services or even a business. Mini containerised factories for micro entrepreneurship can be a tool to realise shared value creation at the BoP using a systematic approach based on the following points [5]:

- the ability for reconfigurability, mobility and reusability of the modules in the factory
- a mini factory that can be integrated in different communities
- customisable product and material cycles
- promotion of skills

Producing directly at the customer's location has become attractive as the production can be adapted to locally varying feedstocks and products requirements in chemical and food production industries [6]. Small scale factories can be much more economical to be invested in as the availability of raw materials in large quantities is not necessary, hence helping to speed up innovation better than large scale processes. Since the capital cost are also lower the entry barrier even for developing countries will be enable rural areas with little infrastructure to benefit from small scale factories [6]. According to [7], there is need for manufacturing to be carried out locally, by local people within their respective ethnic groups.

This calls for the need for containerised factories in communities at the base of the pyramid to adapt to changing external requirements whilst aiming for sustainability. The local communities will employ shared value creation through sustainable production of tangible and intangible products using raw materials, information and energy, processes, equipment, organization and human labor systematically. A localised production and consumption arrangement supported by global flow of non-material resources links local economic benefit with local environmental or societal benefit [8]. Products with potential for profitable production can be made with moveable factories and lack of manufacturing skills and infrastructure are not fundamental barriers [7].

2 MANUFACTURING SHARED VALUE AS INNOVATION DRIVER

Manufacturing shared value finds synergy amongst various stakeholders in order to mobilise developing BoP communities to develop local manufacturing suppliers. Manufacturing shared value strategies enable both a profit potential for investors and social impact on the local communities as shown in figure 1. The concept of shared value can be defined as *policies and operating practices that enhance the competitiveness of a company, whilst simultaneously achieving the economic and social conditions in the communities they are operating in* [4].

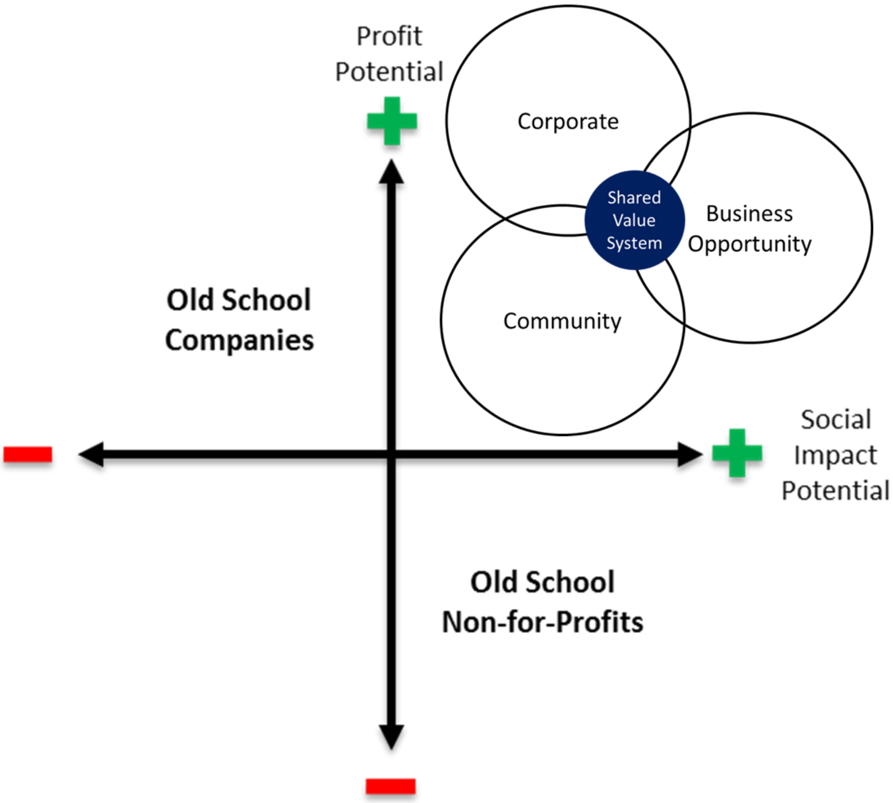

Figure 1: Manufacturing shared value to create both a profit potential for investors and social impact on the local communities

Through shared value the needs and challenges faced by a society are met in the process of creating economic value. Considering that sustainable development entails meeting the needs of the present without compromising the ability of future generations to meet their own needs - this concept has become a real innovation driver to grow the formal economy.

2.1 Base of the pyramid (BoP) value creation

The base of the pyramid represents the largest (4 billion), but poorest (live on less than US$ 2.50 per day) socio-economic group [9]. These are the people that should receive basic needs and basic services to survive. The BoP was first introduced in the work by Prahalad et al. [10] attempting to raise awareness of the world economic pyramid and the vastly untapped market. Since then, there have been considerable attempts toward developing economically viable initiatives to serve the BoP.

In theory, organizations targeting this segment operate under the proposition of mutual value creation, which suggests that creating more value for the BoP creates more value for the venture [9]. In other words, in order to grow the formal economy, stakeholders need to help create value inside the informal economy by investing in education, infrastructure, skill-, supplier- and enterprise development programs. In order to address the BoP issues, a more in-depth understanding of this environment is needed. One must keep in mind that the BoP significantly differs from formal business environments as follows:

- customers have a low and irregular income
- markets can be located in extreme geographic locations (e.g. poor physical and informational infrastructure)
- competition is weak or may be too strong for start-up entrepreneurs to enter the market
- lack of support system (e.g. suppliers, distributors)
- corruption is embedded in the society
- formal institutional (e.g. legal enforcement) environment is usually weak
- the informal institutional environment has strong ties within the community and;
- the informal economy is often in conflict with formal institutions

These are just a few, but noteworthy characteristics of the BoP which require significantly different approaches and business models as we know them from the developed (formal) world. Among other, one has to consider the following principles [11]:

- products are to be produced in small sizes with strong local adaptation (flexibility)
- distribution must take into account frequent, small purchases and hard-to-reach areas
- transactions must consider little reliance on contractors
- transactions have strong reliance on informal tie and;
- important to obtain local recognition and legitimacy

Knowing that sustainable manufacturing deserves a strong and continuous endeavour to ensure sustainable development, the BoP must be considered not only as a potential market, but also as a producer. According to London et al. [12] BoP producers, which are operating in the informal sector, generate goods for sale (e.g. agricultural products and handcrafts). The challenge is that it is sold almost exclusively in local, informal markets. Also, due to the lack of an industrial culture, one must be aware that there is no adequate knowledge, skills, and resources for manufacturing in the BoP.

Still, there is evidence of undergoing activities related to BoP development. Some case studies [13] show what types of innovation are best to reinforce the value propositions to address low-income consumers´ problems. Other work [14] proposes community desired products to meet the needs of the BoP. Khan [15] proposes a new learning method for BoP people. Therefore, there exists opportunities for introducing the manufacturing of low-tech products in BoP communities.

An actively designed and independent life for humans in developing countries can be achieved through value creation by higher teaching productivity and new perspectives of income generation even in socially and geographically isolated regions [5]. Some systems use open design platforms to create value at the BoP by empowering incubators through distributed manufacturing systems as well as embracing new ways of technology transfer, ideas and risks, to create the most collaborative environment possible [1].

2.2 Developing local manufacturing suppliers

The Department of Trade and Industry (DTI) in South Africa re-established its Broad Based Black Economic Empowerment (BBBEE) ratings in 2013. The new ratings have a higher weighting linked to local supplier development (changed from 15% to 40%) in order to encourage larger companies to support local businesses [16]. The new Preferential Procurement Policy Framework Agreement, instituted for all state owned entities (SOE), calls for further stringent adjudication processes, during tender stages to ensure tenders 'utilise a large local supplier base. The challenge however comes from the perceived lack of capability and competence of local suppliers to conform to the necessary quality [17, 18] and technical requirements of larger companies' specifications.

Kaizer Economic Development Partners conducted a study, for the World Bank, in the mining industry across Western and Southern Africa [19]. Their study found that there are three elements constituting local suppliers namely; (1) the level of participation of the supplier in its local vicinity or country (whether the goods or services are supplied or manufactured locally), (2) The level of participation of local citizens in the company (3) and the geographical location of the company.

Local supplier constitutes a company that is majority owned by local participants, manufactures goods locally, procures goods locally and supplies goods locally. Locally therefore, remains a geographical spaced distance although the constituents of the company determine whether it is local or not.

Organisations further struggle to clearly identify the current maturity levels of suppliers in order to determine where to focus their development initiatives. Therefore, a holistic framework for developing local manufacturing suppliers (LMS) was developed for companies and communities to identify shared value opportunities [20] as shown in figure 2.

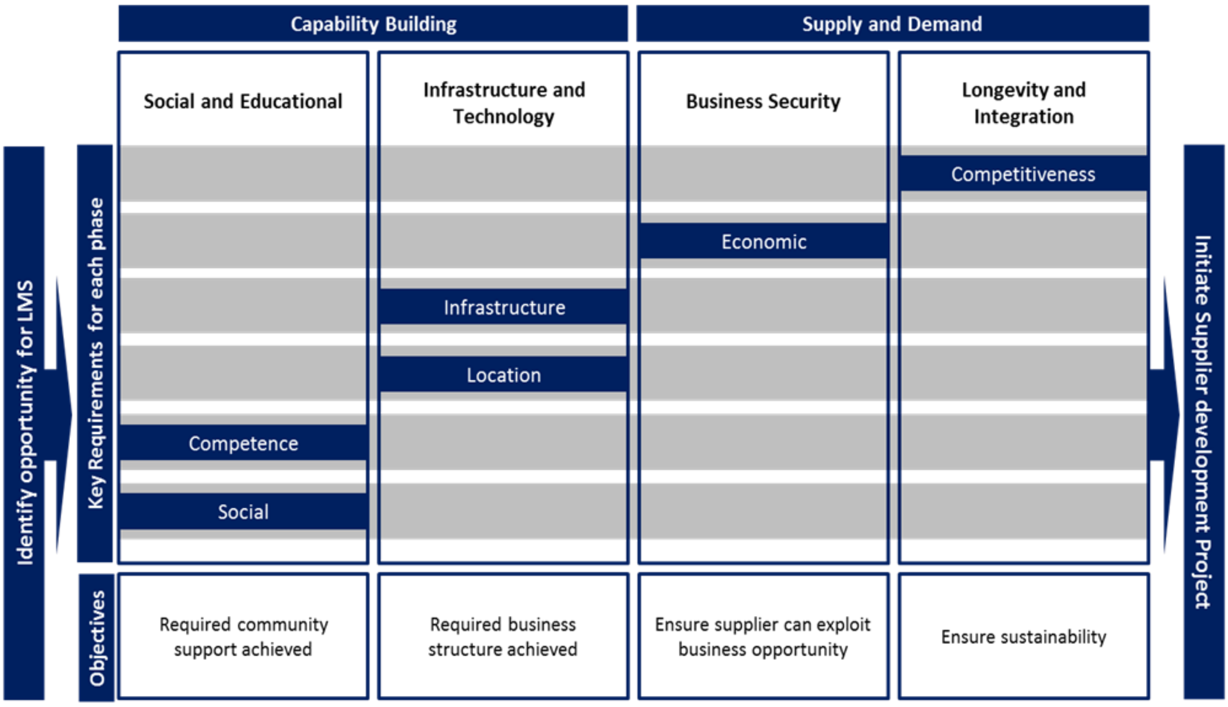

Figure 2: Holistic Local Manufacturing Supplier Development Framework (adapted from [20])

The social and educational phase [21] ensures the required skills and social well-being of the local manufacturing supplier are present to be able to achieve the basic level of support. The objective of the infrastructure and technology phase ensures that the supplier achieves all necessary business structure to support it in complying with the end users requirements. The business security phase involves making sure that the supplier is at the correct manufacturing readiness level and can comply with the necessary requirements. The longevity and integration phase ensures that the supplier can maintain its competitiveness by implementing the necessary performance measurement systems and being integrated into the end users values stream to ensure its sustainability.

2.3 Manufacturing shared value chains

Manufacturing companies are not only transforming and adapting to the technology waves of change, but also making a significant paradigm shift in their procurement strategies and social responsibility toward manufacturing shared value as illustrated in figure 3.

Figure 3: Corporate paradigm shift journey toward manufacturing shared value (adapted from [4])

Open Community Manufacturing (OCM) [1, 22] is a manufacturing shared value chain based on (1) continuous technology transfer based on the Open 'X' principles [23], (2) mobilization of communities belonging to the base of the pyramid (BoP), (3) co-creation of value through development of low-tech products and educational services desired in communities, (4) transfer of technology and knowledge to spin-out micro enterprises based on shared value concepts, (5) interconnection of stakeholders and other interested parties in an industrial cluster, and (6) achieving synergies among individual supporting initiatives provided by the government and public agencies. This value chain is divided into five core phases - community needs analysis, open design, advanced manufacturing, assembly processes and the incubation of future entrepreneurs [1, 22].

In this cluster designers transform their social developing ideas into physical products, by virtually collaborating with the volunteers and manufacturing specialists. These products can include value creating brick-, briquette- or charcoal making machines, recycling and water filtration technologies or; mini-modular factories in containers as examples. The OCM development challenges also ensures that social investments are made with a sustainable impact in people, partnerships, infrastructure and technology to ensure shared value [22].

3 RESEARCH METHODOOGY

A case study was conducted in one urban community in Zimbabwe called Epworth. This community was a Methodist Church farm which was handed over to the government of Zimbabwe and then distributed to the poor people. Epworth was chosen based on it being an urban community where many poor people are living with most not having access basic needs or basic services. Three questionnaires were designed to be administered to community members constituting householders, informal traders and manufacturing enterprises.

The first questionnaire was administered through conducting one on one interviews with householders to establish their income levels, their sources of energy used for cooking and lighting, their consumption patterns, the appreciation for local manufacturing and typical products needed to be manufactured in their communities, the available resources. The questionnaire was administered to randomly selected householders who use various sources of energy for cooking.

The second questionnaire was administered to the dealers who operated in the community to establish their source of products for resale, the types of products they sold, and their appreciation of local manufacturing factories.

The third questionnaire was administered to the producers in the community to establish the products that were being locally produced, if they had local support, procedures to be followed to start manufacturing factories in the communities, number of people employed from local community and challenges being faced.

4 RESULTS AND DISCUSSION

As part of the Building Blocks Initiative this study was to understand the income levels, sources of energy, consumption patterns and to test the appetite for containerised factories as shared value creation systems in BoP communities.

4.1 First Questionnaire

The results revealed that 85% of the respondents do not have access to electricity and those who have no access to electricity would prefer to use electricity or gas for cooking meaning that introducing technology that captures biogas from pit latrines used by the majority would be a welcome initiative. Figure 4 illustrates results from the questionnaire administered to the households relating to the source of energy that is used for cooking purposes.

LPG gas is an option, but however it is more expensive than biogas. None of the interviewees had biogas technology at their households. For those who used wood most of them were burning wood on open fires with a few who used cook stoves. Introducing cooking stoves which burn wood efficiently and economically would be a viable opportunity, which also has the advantage of preventing health issues associated with open fire cooking.

This creates a shared value opportunity to assemble gasifier stoves in containerised factories that could be designed and pre-manufactured with an open community manufacturing development challenge value chain. These gasifier stoves can sold at a very affordable price, while the risk-taking investors find their value by selling the biomass feedstock to the gasifier stoves users in the community.

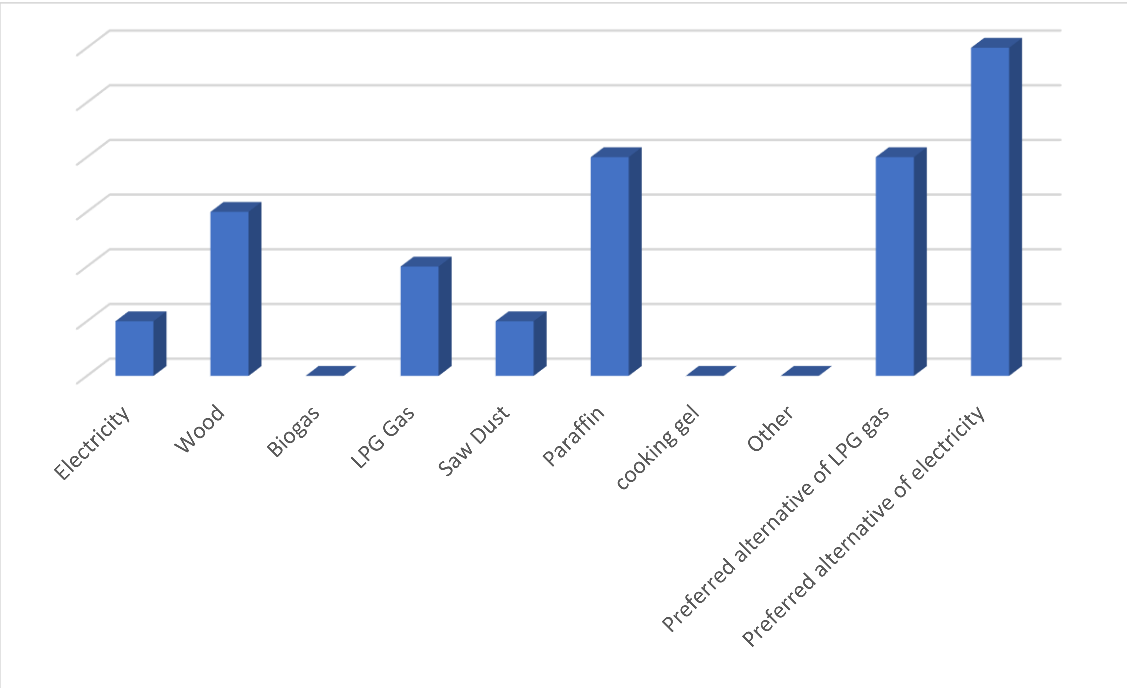

Figure 4: Summary of source of energy used for cooking in the Epworth community, Zimbabwe

Figure 5 illustrates results from the questionnaire administered to the households relating to the source of energy that is used for lighting purposes. 57% of the respondents indicated that they used candles for lighting representing the majority and this situation can be a viable business opportunity of producing candles. Some use solar panels connected to batteries and solar lambs for lighting.

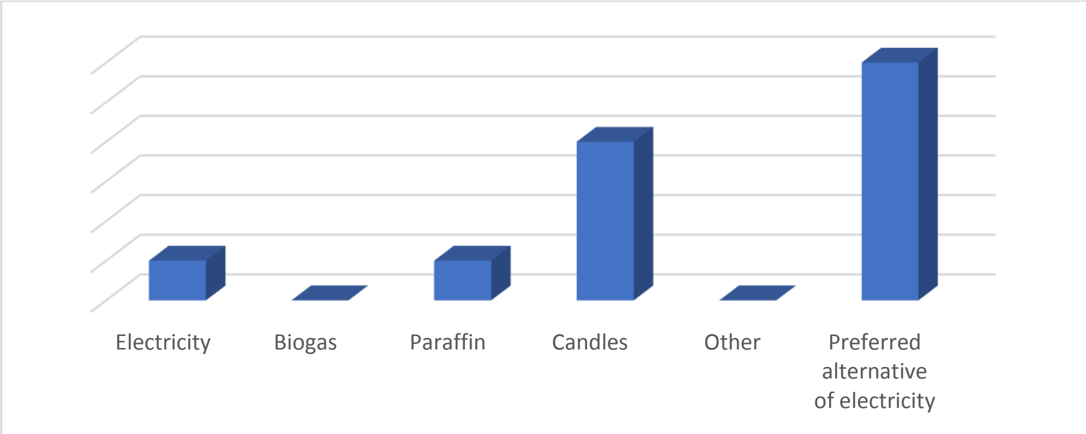

Figure 5: Summary of source of energy used for lighting in the Epworth community, Zimbabwe

Paraffin is used by a few and they indicated that its availability is not reliable. Biogas technology can also be an option for lighting. This creates a shared value opportunity to assemble solar lighting systems in containerised factories that could be designed and pre-manufactured with an open community manufacturing development challenge value chain. The tooling clusters can assist with the design of the solar systems casing, while the stainless steel industry can use their social investment to make the steel affordable. These stainless steel solar lighting system can be sold in local Spaza shops. The system also allows the opportunity to sell energy in the community. Investors find their economic value by capturing the traditional, fire causing candle market in base of pyramid communities.

Figure 6 illustrates that most of the interviewed households earned less than $300. Exact figures were not asked for to avoid intimidating the respondents by asking them personal information hence the use of ranges.

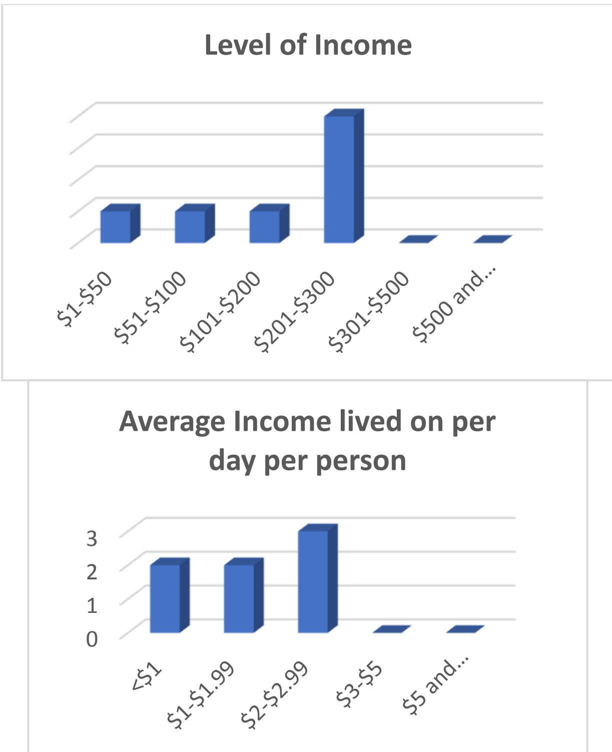

Figure 6: Level of income and average income lived on per person per day in the Epworth community, Zimbabwe

The results show that on average most households live on less than $3.00 per day per person. These results qualify Epworth to be part of the socio-economic group termed the BoP. This shows a need for value creation and employment opportunities. Most respondents were aware of some few production enterprises who operated in the community producing products such as maputi (popped maize), cooking oil, a bakery, and furniture as illustrated in figure 7.

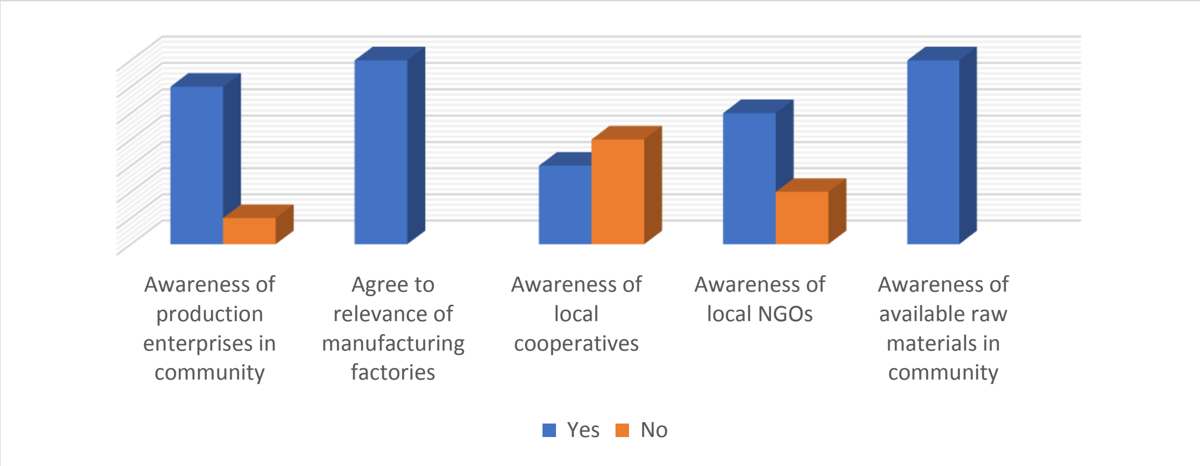

Figure 7: Relevance of the Manufacturing Industry

All the respondents applauded the initiative of small factories in their community as it would create employment opportunities for then and give them access to basic needs such food products e.g. mealie meal, cooking oil, soap, sugar, energy products such as solar lamps, biogas and sanitary products such as pampers, tissues, sanitary pads, as well as other products such as hair weaves, braids etc.

4.2 Second Questionnaire

All the respondents interviewed indicated that there are a lot of avocado trees. The avocados can be packaged for resale or be converted with agro-processing technologies to produce various oil-based products such as hair products and cosmetics. Some respondents indicated they were aware of a few local cooperatives who operated in the community by providing teaching self-help life skills and a few NGOs who are mostly present to give food aid. All the respondents indicated that the most influential leaders were political. Hence all activities that happen in the community are first addressed through the political leaders.

Products that were sold in these tuckshops were basic commodities such us bread, rice, cooking oil, snacks, pampers, drinks, maputi etc. and; meat for some who had either electricity or LPG gas fridges. The sentiments were that residents purchase few items at a time as they receive monet, which confirms what was said by Reiner et al. [3]. The tuckshops are registered with the local board and pay levies and taxes monthly. Most of the products sold in tuckshops are purchased from external (not local) manufacturing companies who delivered their products to them directly.

Challenges faced by many tuckshop owners were that people did not have purchasing power, because many in the community were unemployed and living in poverty. Another challenge were criminal activities, since some unemployed people in the community resort to stealing. The community are also faced with corrupt local board officials who demanded bribes irrespective of levy's having been paid.

4.3 Third Questionnaire

A survey was conducted with the local producers who produced maputi, furniture, animal feed using cotton seed also having cooking oil as a by-product, garment tailoring, and bakery products. All manufacturers indicated that they had support from the local community. However, the issue raised by all was that local people could not afford highly priced goods. The manufacturers have been operating in the community from between 2yrs to 15yrs, which reveals viability. Most of the manufactures used electricity for their operations however some used alternatives such as generators, solar or LPG gas. Raw materials were sourced externally.

Most of the manufacturers had to adjust their pricing to suit their market. The bakery was selling bread at 35c. Yet other bakeries in the Harare region sell their bread between at a cost ranging from 50c to $1. The bakery also sold doughnuts at 10c. Yet the average cost of doughnuts in the Harare region is between 25c to 50c. The garment tailoring company had to bring down their cost of producing garments by around 30-50%. These strategies seek penetrate the BoP with affordable goods. The company that produced cotton cake used for animal feeds also produced cooking oil as a by-product. As waste-to-resource strategy, this by-product is sold to most snacks producers in the Harare region and to the local community.

It is important to note that relatively low rentals and local board levies were incurred operating in Epworth and; other operational costs such as relatively low labour made it easy for most of the producers to also lower their selling prices to be affordable for their customers from the community.

Challenges faced by most of the ventures were the unavailability of raw materials, lack of resources to purchase raw materials or build proper factories to operate in; as well as lack of access to electricity and water. Thus, an opportunity to develop local suppliers according to the holistic development framework exist in this BoP community.

5 CONCLUSION

This contribution introduced the concept of manufacturing shared value. The holistic local manufacturing supplier development framework and open community manufacturing development challenge value chain were discussed in the context of creating shared value in base of pyramid communities. As part of the Building Blocks Initiative this study was to understand the income levels, sources of energy, consumption patterns and to test the appetite for containerised factories in BoP communities. The case study of the Epworth community in Zimbabwe revealed that shared value opportunities to assemble gasifier stoves, solar lighting systems and house bakeries in containerised factories exist. The standard of social skills, supporting infrastructure and abundance of entrepreneurial energy, makes it worthwhile to explore manufacturing shared value opportunities in the base of the pyramid with future research activities.

6 ACKNOWLEDGEMENT

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THE NEED FOR INFORMATION SYSTEM DATA MAINTENANCE

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ABSTRACT

The dawn of the big data era has placed increased emphasis on software information systems. The use of information systems ranges from basic data warehouses to office automation, making software information systems indispensable in modern businesses. Personnel in different fields use information systems to automate their work tasks. In the energy services industry, these systems are used to automatically create reports from data warehouses. Maintenance of information systems is vital to sustain performance and ensure reliability. Normally, maintenance deals with software and hardware aspects with very little effort expended on the maintenance of the information system's data. These systems process many different data points per day and so, to process unnecessary data slows the system down as well as increases the hardware cost of the system. The need to perform data maintenance was investigated within the context of a case study. The strain added to an information system was investigated and it was found that data maintenance is a viable strategy when dealing with traditional information systems.

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1. INTRODUCTION

Global data production is increasing at an exponential rate [1]. During 2013, 90% of the world's data had been generated in the previous two years [2]. In 2014, the International Data Corporation (IDC) estimated that the digital universe doubles in size every two years [3]. Some of the contributing factors of this exponential growth are:

- The increased use of social media such as Twitter, Facebook, and Instagram.
- The ubiquity of Internet of Things (IoT) devices that create and send data unlike ever before.
- Affordable sensors in any type of item which measures various phenomena.

The exponential growth in data has created what is known as, the big data paradigm [4]. An early definition of big data was that of data described in terms of three Vs, Volume, Variety, and Velocity [4, 5]. Volume refers to the physical size of the data and can be measured by the storage capacity required to store it. Typically, the volume of big data can range from terabytes[4] to zettabytes[5]. Variety indicates the different or unique data types included in the data. Variety is classified in terms of structured, partially structured, and unstructured data. For example, data could consist of product information (partially structured), web pages (unstructured), and customer contact information (structured) [5].Finally, velocity is the speed or rate at which data is generated. It, therefore, dictates the speed at which data needs to be ingested into a storage system.

The big data paradigm is placing increased strain on information systems (IS) [4]. ISs need to process and store increasing volumes, varieties, and velocities of data. It is, therefore, in an organization's best interest to maintain the performance of their ISs. Failure to do so could result in the loss of core business functionality [6].

The reasoning behind why this research has been done is as follows: it is clear that if an organisation can simply obtain or develop a big data system, then there would be no need to maintain traditional ISs as posited here. Adoption of big data is, however, still in its infancy. Research by Gartner showed that of 199 companies, 48% invested in big data during 2016 [7]. Furthermore, only 15% of the respondents had deployed their big data project to production. In 2015, the percentage of production big data projects was 14%, meaning there was only a 1% increase in the number of production big data projects. Many companies are, however, experimenting with production big data projects. In a whitepaper by Knowledgent, 25% of 100 respondents indicated that they had implemented a big data solution [8]. A final indication of big data adoption is given in a report by the International Institute for Analytics [9]. Their research conducted on 194 American and international companies showed that 29% have an operational big data system with a further 31% busy implementing one.

LaValle et al. [10], further studied the barriers to big data adoption. They found that most big data obstacles are managerial and cultural in origin. The biggest obstacle was "lack of understanding of how to use analytics to improve the business". One recommendation LaValle et al. provided is to establish an enterprise analytics unit. This unit would centralize analytics and enable resource sharing and streamlined maintenance. Although maintenance is already streamlined, it would be even more important. For if a central enterprise analytics unit deteriorates in performance, all analytics processes would be affected.

This paper proposes data maintenance as a possible strategy to maintain IS performance. The impact of this type of data maintenance was studied empirically with the use of a case study. This strategy would be particularly useful when an organization is unable to, or in the process of, developing a big data system. Such an organization would, consequently, have to maintain and optimise their traditional IS.

The paper is organised as follows. Section 2 will discuss literature on IS maintenance, with an investigation into IS performance discussed in Section 3. There, the results of IS maintenance on a case study are given. The paper concludes with Section 4.

2. INFORMATION SYSTEM MAINTENANCE

The Institute of Electrical and Electronics Engineers (IEEE) [11], defines maintenance on systems as the following:

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[4] 1 terabyte = 10^{12} bytes

[5] 1 zettabyte = 10^{21} bytes

- The process of modifying a software system or component after delivery to correct faults, improve performance or other attributes, or adapt to a changed environment.
- The process of retaining a hardware system or component in, or restoring it to, a state in which it can perform its required functions.
- The effort to keep an application performing according to its specifications, generally without changing its functionality.

According to Nelson et al. [12], reliability is the largest factor in determining the usage of an IS. Robey [13], however, showed that there is a strong correlation between user attitude and system use. Systems can experience resource exhaustion [14]. Here, failure occurs due to a system's use beyond its current capabilities, causing unavailability.

A hardware failure of the system can cause the system to perform at reduced capabilities. When resource exhaustion occurs, users can no longer fully utilise the system by having to wait for the system. Under heavy resource exhaustion, users might even stop using the system entirely. Resource exhaustion can be addressed in two ways, through either hardware or software.

Early computer systems were built on vacuum tube technology which was very unreliable. This caused such systems to only have an availability of 60% [15], however, with the advances in modern electronics, such as the transistor, availability has been increased to 99%. This roughly translates to about 100 minutes of unavailability per week.

Ensuring high availability on the hardware side can be divided into two sections, namely, design and maintenance. These two link together by ensuring hardware can detect a fault and still run, albeit with a reduced capacity. This, in turn, allows time for maintenance and the replacement of faulty components, returning once again, to full capacity.

Although operators are big contributors to failures in modern computer systems, the main contributor is software [16]. However, in high-performance computing systems, the opposite is true. Here, hardware is the main cause for failure, with software and operators only contributing a fair amount [16]. The reason for this discrepancy can be explained as follows: high-performance computing systems use specialized hardware, the software of such systems does not change often, and thus operators tend to be highly skilled with the tasks having a high workload.

This all indicates that, for computer systems, the hardware will unlikely cause a failure. To combat resource exhaustion, hardware can be upgraded, for example, by upgrading the amount of system memory. The problem with hardware upgrading is it can only be performed a limited number of times, with upgrades eventually becoming too expensive or one reaching the physical limits of a system.

Software maintenance is responsible for about 90% [17] of all costs incurred over the lifespan of a software project. It is estimated, however, that most of the maintenance done on software is due to enhancements rather than the reparation of issues. Enhancing the performance of an IS falls under maintenance especially if the system has grown outside of its original designed use.

Mens [18] did empirical research in which problems relating to software maintenance were highlighted. Two of the issues discussed are worth mentioning here. Firstly, the dependencies on certain libraries that are uncontrollable to the developers, and secondly, how to limit the impact of a change when and if a major change is made to the system. If these two issues are not resolved, the system could be abandoned.

Jackson [19] coined two rules regarding code optimization:

1. Don't do it.
2. For experts, only, don't do it yet.

These two rules summarize a core problem with code optimization. Software engineers will spend a lot of time optimizing code that does not require optimization. Code optimization takes a lot of time and effort and almost always sacrifices code readability. Thus, it can be said that code optimizations should only be done after profiling. Furthermore, it should only be performed on sections where it is required, to minimize the sacrifices to code readability.

Data maintenance is often overlooked when maintaining ISs. De Souza described the importance of database maintenance in the biological society, along with the increase in data creation without corresponding maintenance [21]. Without financial support for database maintenance, molecular biology databases could be shut down. The irony is that the finances needed for database maintenance, comprise less than a percent of the budgets allocated for data generation.

Haug et al. [20], evaluated the implications of poor data quality. They referred to the improvement of data quality as data maintenance. Their discussion focused on the costs that an organization incurs for low-quality data. Data quality was defined to be the fitness of the data for a specific use, with data fitness consisting of many dimensions, such as accuracy, reliability, timeliness, and relevance. The main result was that there is an optimal point where the costs incurred by low data quality are minimized and the data quality is maximized. Furthermore, Haug et al. stated that it was infeasible to achieve perfect data quality. The reason being that the costs to achieve perfect data quality, would exceed the costs saved from avoiding low data quality.

Other studies, such as the one by Urhuogo et al. [21], focused on other aspects of maintenance, such as control, reliability, user participation, and training (CRUT). Their focus was the preservation of IS quality. They stated that ignoring IS maintenance, decreases an organization's service quality resulting in employees and customers distrusting an organization's IS. Customers would then seek other, more trustworthy, organizations to do business with, as well as employees reducing their involvement in anything related to the IS.

Early work by Swanson and Dans [22], illustrated the relationship between an IS's life expectancy and maintenance. Their equilibration theory showed that IS managers moderate the level of maintenance. For an IS with a relatively long life expectancy, the maintenance effort will be sustained. As life expectancy decreases, the maintenance effort is balanced accordingly. This makes sense, as managers would rather focus development efforts on the IS's replacement. Swanson and Dans also found that larger ISs tend to have not only a greater maintenance effort but also a greater life expectancy. Therefore, considering the importance of ISs, low effort high impact, maintenance would be beneficial. The data maintenance we propose in this paper strives to do just this. In the case of large information systems, our data maintenance strategy would be even more valuable. Swanson and Dans found that older systems are not significantly linked to greater maintenance. Thus, the data maintenance strategy of this paper would be equally applicable to older ISs, with, the data maintenance strategy aiming to extend the life expectancy of old systems without a greater maintenance effort.

3. INVESTIGATION RESULTS

3.1 Introduction

The IS tested in the case study, is a system used by a consulting company to process data as well as create client feedback reports. The system runs on a Hyper-V virtual machine, while the host machine is an Intel Xeon E5-2630 with 32GB of RAM and a Raid-5 hard disk drive (HDD) setup. Currently, there are three virtual machines (VMs) running on the host: an IS, website testing VM and data retrieval VM. The website testing machine is used to host a website used for testing changes that should be made to a production website. The data retrieval VM makes remote database queries to extract data for the IS.

The IS was designed for use by project engineers who do not necessarily have excellent computer literacy skills. Because of this, the main steps are performed independently and open to view. The system uses C# as the core programming language, MySQL for configuration data, data files (CSV) for data storage and MS Excel for data processing and reporting.

The IS leverages Excel due to its support for users without excellent computer literacy skills. The system will link certain data to an Excel workbook, and when data processing or reporting is required, the data will be added to the workbook and the workbook calculated. Excel allows personnel to use their basic computer literacy skills to define what calculations should be performed on the data. It also allows the visuals of a report to be created as well as the definition of which data it should contain.

The system stores data as tags, where a tag is a collection of related data. An example of a tag is a pump's power usage. Currently, the IS contains 262 Excel workbooks, processes 10000 tags daily and stores 8 GB of historical data for the tags. The IS was designed to create a few reports per day on a temporary basis, only to be replaced by a code created report if the reports were to be used on a permanent basis.

More reports are continuously being added by personnel who require additional unique data calculations or reports, causing the system to grow to its current 262 unique reports. Currently, the performance of the IS has degraded to such an extent that usability of the system is being influenced. Therefore, this investigation will be largely theoretical in nature and look at what can be done to increase performance.

3.2 Hardware

3.2.1 Testing procedure

Microsoft specifies certain parameters [23] to measure when ensuring the health of a Hyper-V host machine and its VMs. These parameter values should fall within certain boundaries to ensure that the performance of the VMs is acceptable. In cases where the software does not run on a VM, the tests are still valid, with some values differing slightly. This is, however, not of relevance here, as the IS in the case study runs on a VM.

Microsoft specifies the four parameters to measure as input/output (I/O), memory, network and processor. These were all measured by logging the values from the Windows performance monitor program.

3.2.2 I/O

Microsoft specifies the following disc latencies for a normal 7200 rpm HDD:

- Below 15 ms = Healthy
- 15 ms-25 ms = Warning or Monitor
- 26 ms or greater = Critical, performance will be adversely affected

According to Microsoft, non-VMs can sustain larger latencies because of the direct access to the HDDs. Measuring I/O on the IS's host machine, Figure 1 below highlights the latencies observed during a full day. A small snapshot of a 25-minute window is shown in Figure 2 for a more detailed graph.

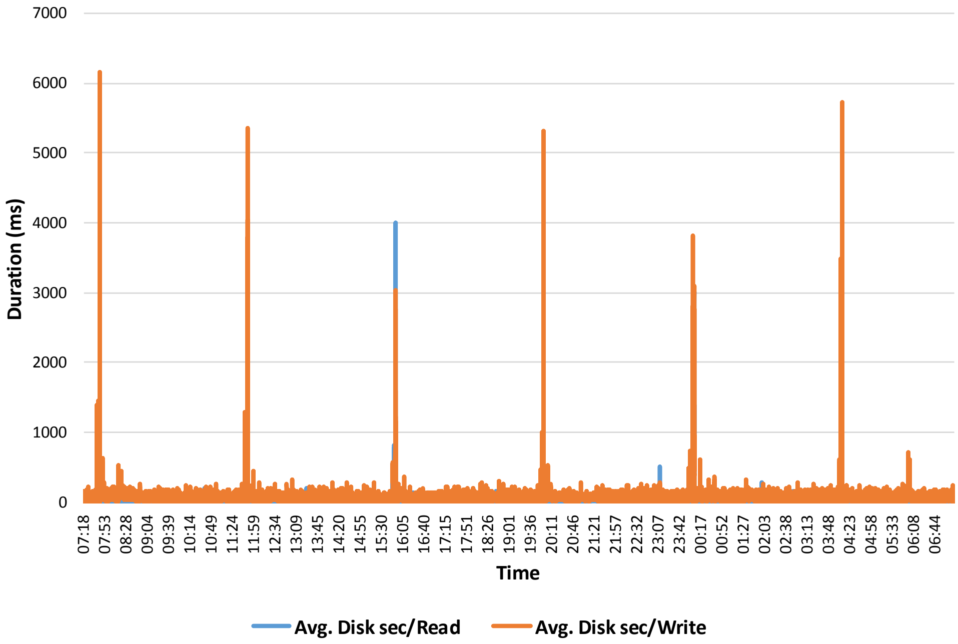

Figure 1: I/O latency observed over a full day

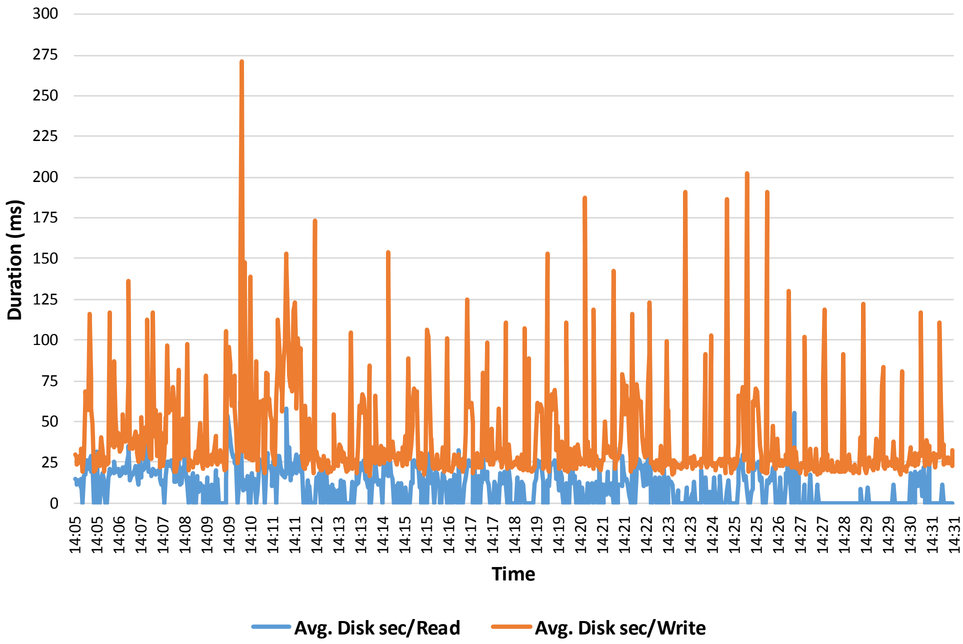

Figure 2: Snapshot of I/O latency

From Figure 1, it can be seen that both the read and write latencies have very high spikes throughout a day. Figure 2 shows the read latency was continuously hovering in the warning area of between 15 ms and 26 ms, occasionally moving above 25 ms into the critical section. The write latency continuously remained in the critical section.

3.2.3 Memory

Memory performance can be checked with two criteria: available memory and pages per second.

Microsoft specifies the regions for the available memory as follows:

- 50% or more of memory available = Healthy.
- 25% of memory available = Monitor.
- 10% of memory available = Warning.
- Less than 5% of memory available = Critical, performance will be adversely affected.

The pages per second bound is defined as follows:

- Less than 500 = Healthy
- 500-1000 = Monitor or Caution
- Greater than 1000 = Critical, performance will be adversely affected

Figure 3 below provides an overview of the day's memory performance.

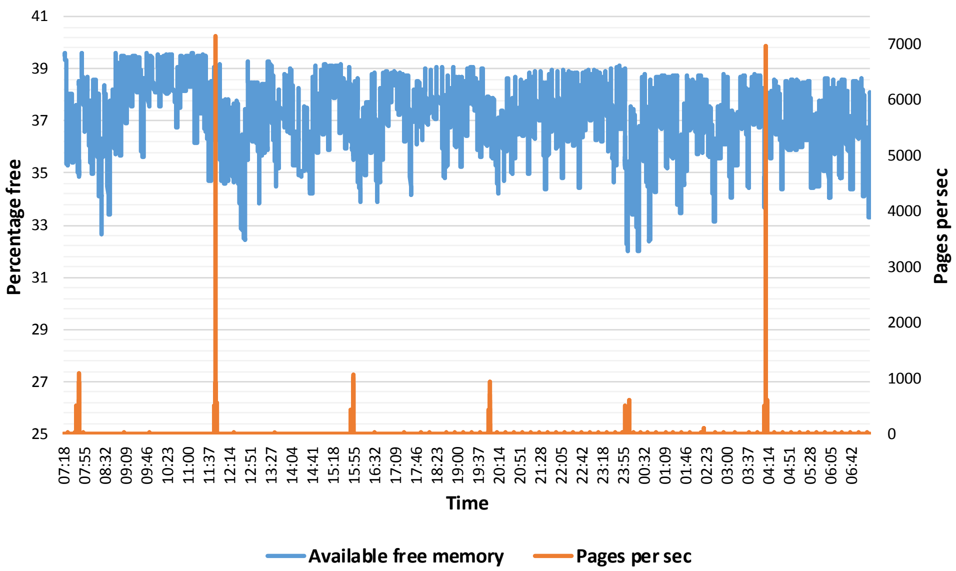

Figure 3: Memory performance

From the graph, it can be seen that throughout the day, available memory was between the healthy and warning sections. The pages per second mostly fell within the healthy section with a total of four spikes in critical and two in caution. Due to this, it can be concluded that the memory is not currently a cause for concern.

3.2.4 Networking

The networking performance was benchmarked by the total network interface utilisation and the output queue length. Network utilisation is calculated by looking at total bytes per second and converting this to bits. The bits are then divided by the network adapter rating to calculate utilisation.

Microsoft specifies the utilisation as follows:

- Less than 40% of the interface consumed = Healthy
- 41%-64% of the interface consumed = Monitor or Caution
- 65%-100% of the interface consumed = Critical, performance will be adversely affected

The output queue length is specified as follows:

- 0 = Healthy
- 1-2 = Monitor or Caution
- Greater than 2 = Critical, performance will be adversely affected.

Figure 4

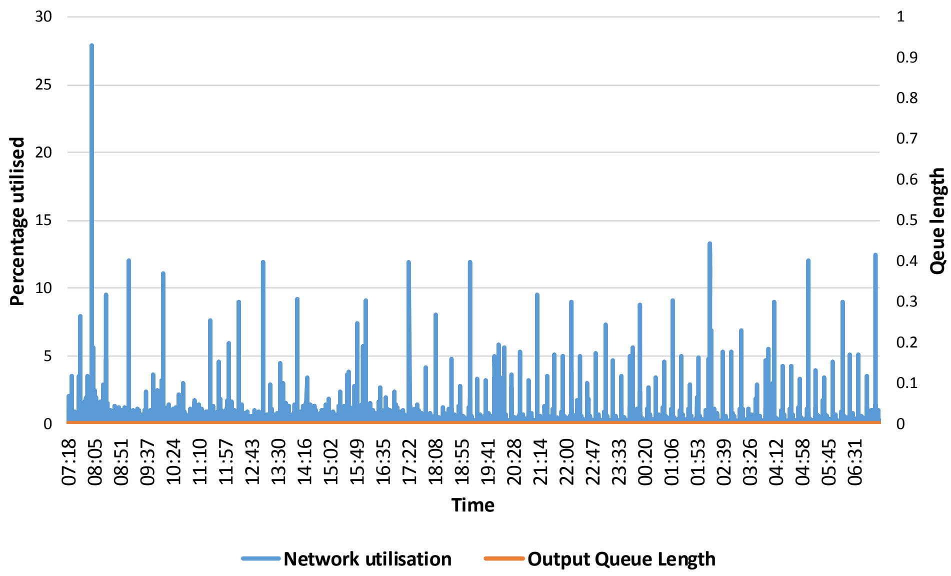

Figure 4 below shows both the network utilization and the output queue length for a day. Both remain firmly in the healthy section. It can, therefore, be concluded that networking is currently not of concern.

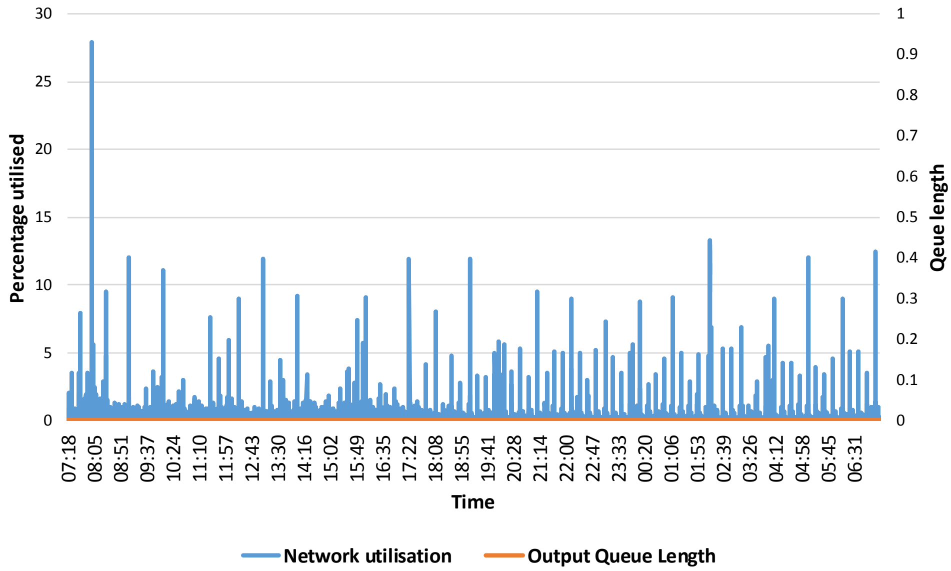

Figure 4: Network performance

3.2.5 Processor

The processor performance was checked by measuring the utilisation of the central processing unit (CPU). Microsoft specifies the following limits for the utilisation:

- Less than 60% consumed = Healthy
- 60%-89% consumed = Monitor or Caution
- 90%-100% consumed = Critical, performance will be adversely affected

Figure 5 shows a full day of the processor performance. It shows that, besides a brief spike above 60%, the processor remained within the healthy section meaning it too is of no concern.

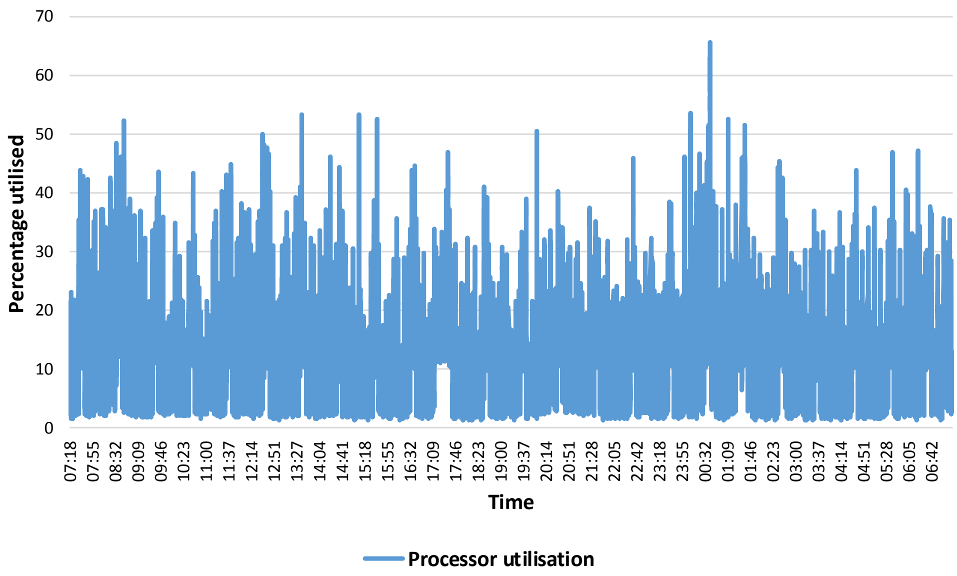

Figure 5: Processor performance

3.2.6 Hardware testing closure

From all the tests done, it can clearly be seen that the main performance issue is the access to the HDD. Raid-5 setups have high redundancy and good utilization of disc space but suffer from poor HDD write speeds. These poor write speeds can be seen in the write latencies of the I/O tests. Addressing this can be done in two ways, namely, improving the HDD speeds or changing the RAID setup.

Although changing the RAID setup is an option, there are concerns regarding it. Is it only possible to convert RAID-5 to RAID-0, which will increase the performance but reduce redundancy, however, redundancy is required for the IS. If RAID-1 is desired, then the whole RAID setup needs to be recreated, which entails formatting the whole of the IS. This shows that changing the RAID setup is not a viable option.

The remaining option is to replace the HDDs with faster drives, however, this is an expensive option as an IS typically has large HDDs. Before interchanging HDDs, it needs to be investigated if the specific RAID controller supports different disc technologies simultaneously, many of which do not. If this is the case, the whole IS needs to be formatted as with changing the RAID setup.

3.3 Software

As the hardware investigation only pointed to a source of the performance problem and not a solution, the next step would be to look at improving the software.

Maintenance on the IS software was done at a previous time to improve the performance of the file handling. Tracing was done on all the aspects of the software to determine where the problems were. Performance gains were considerable but not recorded at the time, with all new tests conducted after the improvements. If more gains are desired from the software, it needs to be changed at the core, which would be a large operation. Currently, the system is being adapted to make use of a big data storage system, but this has not yet been completed.

3.4 Data

The impact of data maintenance was the next step to be investigated in the case study. Data maintenance would, therefore, be accomplished through the reduction of superfluous tags. Tags could not be deleted during the tests, to protect the organization from accidental data loss. Careful consideration should be made before data is deleted. The impact of reducing tags was, therefore, simulated with the use of Python scripts.

To protect confidentiality, the IS divides the data files by clients. These files differ in size ranging from a few hundred tags to over 3200 tags on the largest client. The tag reduction impact was measured on two operations. The first was, searching a file for a given tag. The second operation was the updating of a data file when tag data changed.

To determine the impact of a search operation, a file was created with 2000 tags. An assumption was made that the search time would increase linearly, and to reduce the testing time, tag 1001 to tag 2000 was searched for respectively. This was done so that larger numbers could be worked with. The time taken to find each tag respectively was logged for analysis. The second test was used to determine the impact of updating tag data. This was done by continuously adding an individual tag till a thousand tags were added. As with the first test, the time taken to add a tag was logged for analysis.

Each of the individual search and updating test cases was performed one hundred times. The minimum execution time was taken to determine the relationship between the time taken and the number of tags. By using the minimum value, one can provide a lower bound on the execution time. The importance of this is due to the fact that execution time is influenced by various factors on a computer. The maximum execution time could, therefore, be very large but not meaningful.

The results of the tests are given in Figure 6.

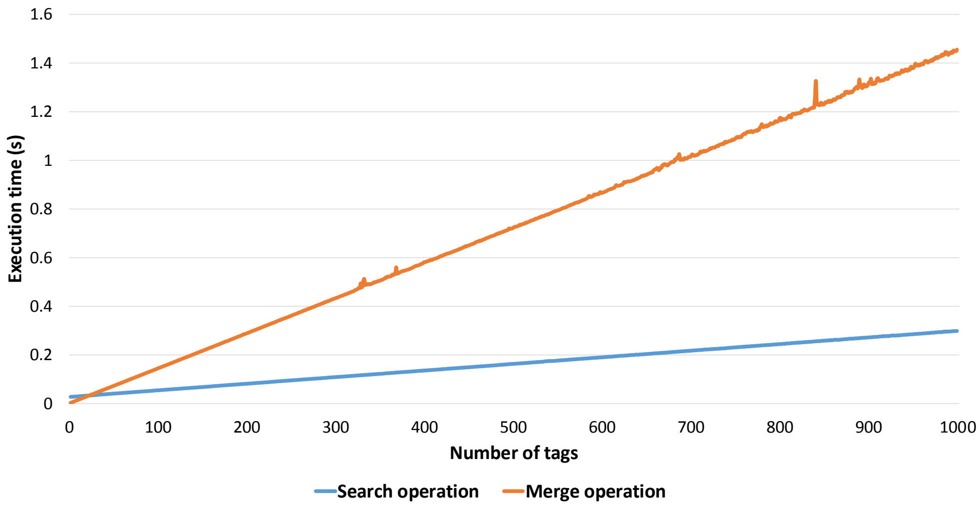

Figure 6: Execution times of the search and merge operations for a different number of tags

Figure 6 shows that the search and update operation execution times are directly related to the number of tags and that their relationship is linear. The update operation is more sensitive to changes in the number of tags compared to that of the search operation.

An analysis of the search and update times was done to obtain mathematical models. A model was sought to represent the linear relationships illustrated in Figure 6. To determine the relationship, Python was used to fit a linear polynomial to the data. The polynomial for the search operation is given by:

$$f(Tx) = 0.2713\,Tx + 26.56 \text{ ms} \quad (1)$$

where:

- The calculated answer is in milliseconds; and
- Tx is the number of the tag.

The polynomial for the merge operation is given by:

$$f(Rt) = 1.458\,Rt - 2.913 \text{ ms} \quad (2)$$

where:

- The value calculated is in milliseconds; and
- Rt represents the number of tags.

It is clear from these two mathematical models that each superfluous tag removed from the IS will speed up each operation. It is also clear that the updating operation is more sensitive to removals than that of the searching operation. The time gained from each tag removed might seem insignificantly small, but it will result in a cumulative saving from each operation performed on the tags.

During the testing period, 103 of the 262 reports had not been generated in the last 60 days. The reason for this, in most cases, is that some of the tags do not have data for the period required by the report. The IS will then not automatically generate a report as all the data is not included. Using the average number of tags per report as 38 and removing those 103 reports, 3931 tags can be removed.

Equation (3) was created for calculating the total time in milliseconds gained by removing a tag for a client, it was created by combining (1) and (2). Using (1), (2) and (3), while assuming that the tags were divided equally among 80 clients and that the bottom tags were removed, the time saved by removing the tags can be calculated as 6.5 seconds from (3):

$$f(Rt) = [(0.2713Tt + 26.56) - (0.2713(Tt - Rt) + 26.56)] + (1.458Rt - 2.913)\, ms \quad (3)$$

where:

- Rt is the total number of tags removed, and
- Tt is the total number of tags in the system.

The IS tries to create a report each time a change is made to the system, by determining if the data required for the report was added. By removing the 103 reports, that 6.5 seconds will be saved each time a change is made to the system.

Most of the tags come in daily, and by making a crude assumption that 10 tags are used per file, this translates to 1000 changes daily. This can then be extrapolated to 1.8 hours of saved server time. For each additional report that can be removed more time is saved by the removal of tags, while also additionally saving 80 seconds as this is the average time required to create a report. By reducing the amount of data the IS has to process, the HDD latencies should improve as the load is reduced, and thus improving the system response time.

4. CONCLUSION

Maintenance of ISs is fundamental to ensure adequate performance and an increased life expectancy. IS maintenance can be classified into hardware, software, and data. The big data era has decreased the emphasis on data maintenance with the reason being that big data systems are created to support large data volumes, varieties, and velocities. However, big data adoption is still in its infancy, therefore, making data maintenance a viable option for traditional ISs as was shown through the case study. The case study was also used to show the effect of data maintenance on a consulting company's IS. All three maintenance strategies were investigated, however, data maintenance was identified as the only immediate option to increase the system's performance. Data maintenance was also shown to comprise less effort than other maintenance strategies. This makes it useful in situations where a temporary performance increase was required, which was the situation in the case study. However, before any maintenance is done, it is important to investigate the hardware, software and data aspect as choosing a strategy will always be situational and IS dependent.

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THE ROLE OF POLICY ANALYSIS TO SUPPORT PUBLIC MEDICINE AVAILABILITY INITIATIVES: THE CASE OF VAN

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ABSTRACT

The National Strategy: Visibility and Analytics Network (VAN) aims to improve the public sector's medicine availability. This paper argues that a holistic, systems-based approach, that transcends the operational, tactical, strategic and policy levels, is required to support the implementation of a strategy such as VAN. The VAN strategy is evaluated to determine the type of policies that could have an impact on the success of the VAN implementation. Additionally, it explores the topic of designing systems that facilitate public sector medicine availability from a policy perspective. Furthermore, this paper argues that initiatives to support public healthcare systems on an operational level (such as VAN), should take into account and be informed by, the policy frameworks within which such an initiative will operate.

OPSOMMING

Die Nasionale strategie vir 'n '*Visibility and Analytics Network*' (VAN) het ten doel om die beskikbaarheid van medisyne in die publieke sektor te verbeter. Hierdie verhandeling argumenteer dat 'n holistiese benadering, wat die operasionele, taktiese, strategiese en beleidsvlakke in ag neem, benodig word om die strategie soos die VAN te ondersteun. Die VAN-strategie word geëvalueer om die hand van verskillende beleide te bepaal wat moontlik 'n impak kan hê op die sukses van die VAN-implementering; ondersoek die ontwerp van 'n stelsels wat die beskikbaarheid van openbare sektor medisyne vanuit 'n beleidsoogpunt fasiliteer; en argumenteer dat inisiatiewe ter ondersteuning van publieke gesondheidstelsel op operasionele vlak (soos VAN) ingelig moet word deur en rekening gehou moet word met die beleidsraamwerke waarbinne so 'n inisiatief sal funksioneer.

1. INTRODUCTION

The World Health Organisation (WHO) [1] defines health as, a *"state of complete physical, mental and social well being"*. Unfortunately, for the majority of South Africans, this definition of health is not representative of their current circumstances [2]. South Africa's public health sector reflects the lack of equity amongst the population. One of the contributing factors is the challenge associated with access to essential medicine, which plays a vital role in the improvement of an individual's health. Essential medicines are defined as the required drugs used to treat the majority of the most prevalent conditions and diseases in a country [3].

In 1996, a National Drug Policy was adopted to address the lack of equitable access to essential medicines in the public pharmaceutical sector of South Africa. The aims and objectives of the National Drug Policy are shared amongst three main objectives: health, economic, and national development. In terms of the health development objective, the government clearly states that their aim is to ensure the availability and accessibility of safe, high-quality essential medicines to all citizens [4]. The aim from an economic point, is to lower the cost of drugs for both the private and public sector, and promote a cost-effective and rational use of drugs [3]. However, according to the World Health Organisation [5], the availability of essential medicines at public health facilities in South Africa is still poor, despite the improvements in the past decades. This hardship was in conflict with the goal of the National Health Policy, because rising drug prices, irrational use of drugs, and ineffective procurement and logistics still contributed towards the cause of concern [3].

In 2010, stock management problems were detected at more than half of the provincial medicine warehousing and distribution depots. Investigations showed that on the day of investigation, 29% of the items on the essential medicines list were out of stock, and the stock outs became more prevalent over the following years. Specific examples of such stock outs included antiretroviral and tuberculosis medicine, where in some cases 70% of facilities reported having stock outs lasting longer than a month [6]. After telephonic surveys across all provinces were conducted in 2015 by the 'Stop Stock Outs Project', the findings were worrisome. From the 699 stock outs on the day of contact, 23% resulted in patients leaving primary healthcare facilities with no medicine, 4% were patients leaving with incomplete treatments, 37% were patients with less supply than what was necessary, and 36% were patients who received a suitable alternative treatment, or received borrowed supply from other facilities [6]. It is vital to note that substitution of unavailable medicines and under-treatments poses a risk to a patient's health [7].

The abovementioned problems depend heavily on a facility's supply chain management capabilities [8]. Supply chain describes the interrelationships among organisations, people, processes and resources with the aim of successfully delivering a product or service [8]. Public drug supply chains differ from commercial supply chains due to the extended global pipelines, the uncertainty and fluctuation in demand, and the high product level requirements [8]. Supply chain also refers to all the players involved in the distribution of medicine, from the time it leaves the manufacturer's warehouse, to the time it dispensed to patients in a pharmacy or medical facility [9]. The delivery and distribution of medical drugs is not possible without appropriate procurement and inventory management. Demand and Supply management tools are necessary to support the distribution of drugs from the suppliers to the facilities. In order to distribute the right amount of drugs, forecasting is crucial. Despite the availability of supply chain tools for the procurement of medical drugs, none of the tools are valuable without adequate resources managing these tools [8].

A Visibility & Analytics Network (VAN) reference model was developed in 2015 and subsequently customised for specific contexts and countries. For example, in South Africa the VAN model aims to facilitate and sustain the availability, and equitable access to health commodities in the public health sector. This is achieved through the adaption of private sector operating model approaches [10]. The model was developed with participation from multiple donors (The Global Fund, UNICEF, UNFPA, USAID, Gavi and BMGF) and from various governments (Kenya, Nigeria, Ethiopia and Tanzania) ([10], [11]). In the context of South Africa, the VAN model aims to transform the pharmaceutical supply chain from an 'uninformed pull' system, to an 'informed push' system [11]. In a pull-based supply chain, the ordering and distribution of goods are demand driven. This is dependent on the customers' true demand; however, a push-based supply chain is dependent on the estimated demand calculated by means of forecasting [12]. The pull-based system of South Africa's public sector pharmaceutical supply chain is complex, and a 2010 analysis by the South African Department of Health concluded that some parts of the country's public sector pharmaceutical supply chain are too costly and that others are redundant [13].The transition from a pull-based to a push-based system is achieved through distributing a cadre of supply chain experts that are responsible for analysing the complex links in the supply chain, and subsequently optimising it [11]. The concept of an informed push model was deployed due to the lack of supply chain competence from the current resources at the health facilities [11].

The current public sector pharmaceutical supply chain system demands time-consuming supply chain and medical-related tasks of scarce resources in the public sector [13]. With the present resources, it is challenging to train facility level staff to have the required competence to act as the informed demanders for the VAN informed push model. Therefore, an informed push model would make use of highly skilled supply chain specialists in each province, who are encouraged to make or suggest ordering recommendations based on the forecasted data ([11], [14]). This means that these supply chain specialists will make ordering recommendations for the facilities, rather than facilities doing their own ordering [11]. As a result, this will transfer the highly sophisticated supply chain work away from the ill-equipped facility staff.

The VAN blueprint describes the people that are involved, the processes required for implementation, and the integrated information technology system to ensure end-to-end visibility across the supply chain. However, at an aggregate level there is a lack of understanding in terms of the enabling and limiting effects of country-specific policies on the VAN strategy. These four elements (people, processes, technology and policies), need to be considered in an integrated way - from a national level all the way to a facility level - in order to achieve their vision [14]. To apply the VAN in a system as complex as South Africa's public pharmaceutical supply chain, it is important to understand how a such a supply chain, and its governing policies, operate before identifying the differences in policies that might be impacting the possible operation of the VAN model [14]. These policies typically formalise the organisation of these elements, governing aspects such as interaction between the elements and shared accountability. The objective of this article is thus to evaluate and investigate the VAN initiative, with all its elements, actors, and processes in order to determine the types of policies that govern the VAN model. This article will focus mainly on supply chain management and supply chain related policies, as well as health policies in the context of the public sector pharmaceutical supply chain system within which it operates.

In this article, an overview of the VAN concept is given to create a general understanding of the processes and roles involved. This is achieved through studies of the VAN strategy and roll-out plan documents gathered form the National Department of Health and BroadReach. Conversations with VAN informers and policy documents were reviewed to establish the types of policies that govern a public health sector pharmaceutical supply chain. Furthermore, literature reviews were performed to identify which policies might have an influence on the VAN initiative. Finally, an analytical framework was created to illustrate which policies govern certain VAN functions.

2. ANALYTICAL FRAMEWORK AND RESEARCH APPROACH

Identifying the interconnectedness of activities and actors within a system, will facilitate an understanding of which policies could possibly enable or hamper the VAN processes. Therefore, in this study, a systematic approach is used to breakdown the VAN processes into different supply chain categories, in order to analyse the various components with regards to the relevant policies. The structure of the analytical framework used in this research inquiry will follow similar guidelines as those presented in the 'Energy Market System Assessment Framework' (EMSAF) [15], as shown in Figure 1. The EMSAF is divided into three levels: the value chain; the required inputs and finances; and the enabling environment [15]. For the purpose of this study, the three functional levels are adapted to allow support the VAN processes: (i) the VAN supply chain; (ii) the inputs from the various actors; and (iii) the enabling environment - which represented the policies that influence the VAN operations. Ultimately, these three levels of analysis are combined into an integrated framework to illustrate how each process, actor, and policy interact with one another within the context of VAN.

Given that the objective of this study / research inquiry is focused around the policies that could have an influence on the VAN initiative, the focus will primarily be on the VAN supply chain level, and the enabling environment level of the abovementioned analytical framework.

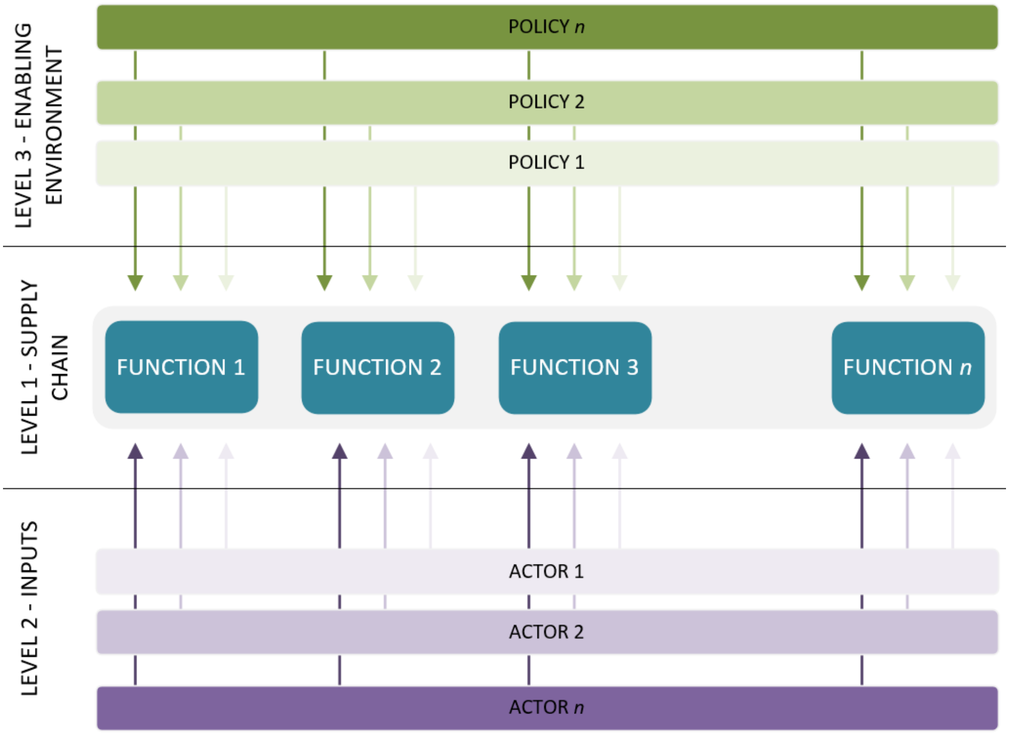

Figure 1: Analytical Framework and Research Approach, adapted from [15].

3. CONTEXTUALISATION: THE VAN INITIATIVE

3.1 The VAN Operating Model

The VAN operating model is a complicated system with various supply chain activities that are inter-linked. Multiple public and private sector actors are involved, and the operating model is designed to be implemented across the three tiers[2] of the South African public sector pharmaceutical organisational structure: national level, provincial level, and the district/facility level. These levels are aligned with the three spheres of South Africa's governmental structure [16]. Each sphere has a set of actors and organisations, and when the public sector pharmaceutical is considered, each of these spheres are concerned with specific roles and responsibilities within the VAN model. In the context of South Africa, the VAN model builds on the existing split of responsibilities between the national and provincial levels; at a provincial level, the responsibility is geared towards administrative supply chain activities, and is referred to as a Provincial Medicines Procurement Unit (PMPU) [11]. As previously mentioned: supply chain specialists in each province are encouraged to make or suggest ordering recommendations for facilities, rather than facilities being responsible for their own ordering. Each PMPU is thus responsible for the ordering quantities in their respective provinces and the Affordable Medicines Directorate (AMD), which is a subset of the Department of Health, is responsible for governing the processes at an aggregate (national) level [11]. Figure 1 illustrates the relationship between the provincial and national levels, as well as the centralisation of the aggregated data regarding the pharmaceutical supply chain at a national level.
The VAN provides an approach to supply chain management within each PMPU, as shown in Figure 2. It has the objective of improving and sustaining the availability of, and equitable access to, health products and medicines [11]. The AMD created a strategic framework (shown in Figure 3) that is derived from evidence-based problems and solutions in order to illustrate the VAN supply chain functions (the core functions are emphasised in the blue

[2] These tiers are referred to as the three level / spheres of the South African government structure (national, provincial and district).

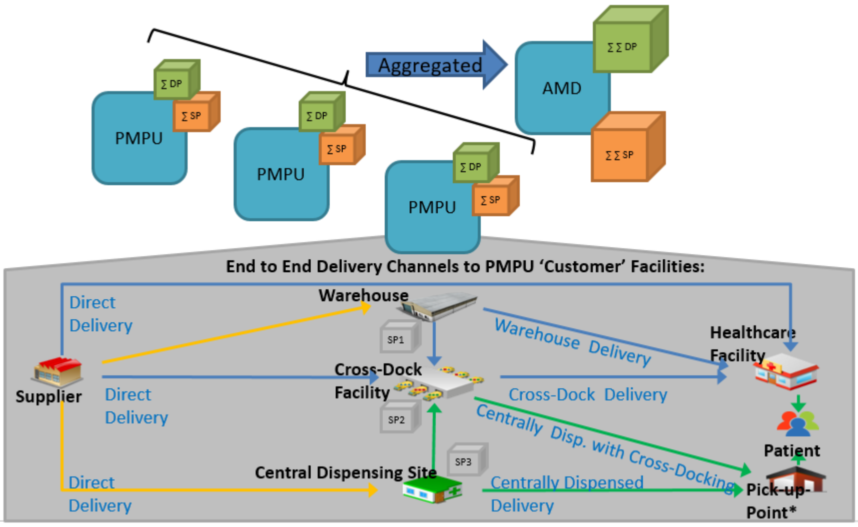

Figure 2: Aggregated role between the PMPU's and the AMD [11].

frame), as well as the supporting bodies that are necessary to achieve accessibility and availability of essential medicine [11]. In literature, a supply chain is described as the interrelationships among organisations, resources, and procedures in getting the commodities to a desired location and customer [8]. To correlate the AMD's strategic framework with the supply chain definition in literature, the organisations and resources refers to the supporting bodies responsible for executing the various functions/procedures within the pharmaceutical supply chain. Healthcare / pharmaceutical supply chains are also referred to as all the activities involved from the time the product leaves the manufacturers or suppliers, to the time a healthcare facility or pharmacy dispenses the product [9], and includes entities from manufacturing, warehousing, transportation, and service delivery [17]. However, the VAN blueprint documentation describes supply chain as many overlapping activities, and defines three supply chain planning categories, namely: demand planning, supply planning and distribution planning; these categories operate within the core supply chain functions of the AMD strategic framework and are discussed below.

3.2 VAN Supply Chain Planning Categories

The three planning categories encompass processes that occur across the 'Supply Chain' function of the AMD strategic framework. The majority of these processes only operate from the selection to the contract management functions; seeing that the VAN model does not include activities that relates to the 'product use' function (refer to Figure 3).

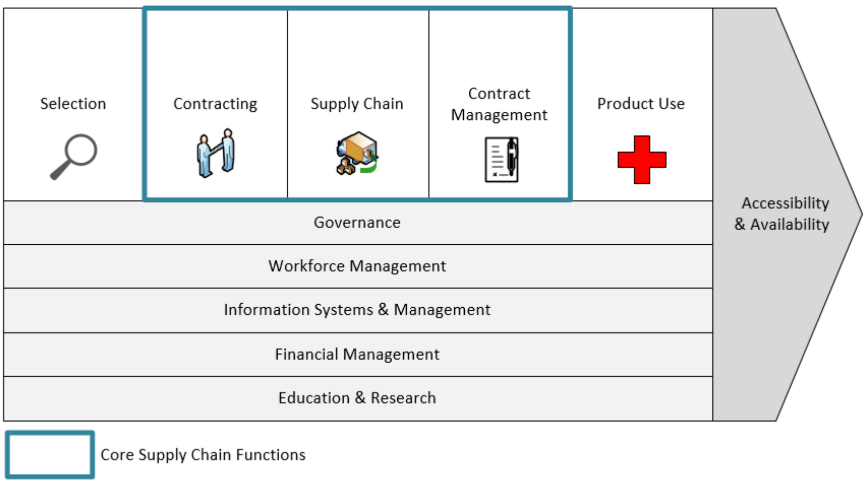

Figure 3: The Affordable Medicine Directorate (AMD) strategic framework to Improve Medicine Availability [11]

In this section, the three supply chain planning categories are discussed and illustrated with process maps showing the various activities that relates to each of these categories. Each planning category is divided into a hierarchy comprising of four levels based on a time dimension; namely: annually, six monthly, quarterly, and monthly. This relates to the frequency at which the various processes and activities occur, as well as the governmental sphere (national, provincial and district/facility) that governs that level. The annual and six monthly updates are governed at a national level by the AMD, and the quarterly and monthly updates are governed at a provincial level by the PMPUs. The process map of each planning category shows the actor(s) that is responsible for, and / or involved in, the different processes and activities. Even though this article does not focus on the actors, it is important to note which actors (i.e. organisations) are responsible for the flow of products to the end-consumer, with support from information systems and financing [8].

3.2.1 Demand Planning

Demand planning activities apply trend analysis to historical data gathered from the various districts and facility, and use statistical modelling to determine the demand plan consensus across all facilities in the respective provinces [11]. The demand planning processes are illustrated in Figure 4, along with the actors and organisations that govern the processes. In addition, Figure 4 shows how these processes integrate with the supply chain planning category. At a national level, long term forecasting processes takes place with inputs from national statistical data, such as demographic trends, disease burdens, and seasonality aggregated from the PMPUs [11]. The annual demand forecast estimate determines tenders and annual budget allocations. It is the National Treasury and Chief Financial Officer (CFO) of the NDoH's responsibility to inform the annual budget allocation to the province level for the procurement of pharmaceuticals [11]. Every six months, the selection and update of the Master Procurement Catalogue (MPC) is reviewed to ensure the best treatments and medicines are selected to improve a patient's outcome. The AMD governs the annual processes and updates of the MPC, which will is then disaggregated down to quarterly and monthly plans for the provincial level.

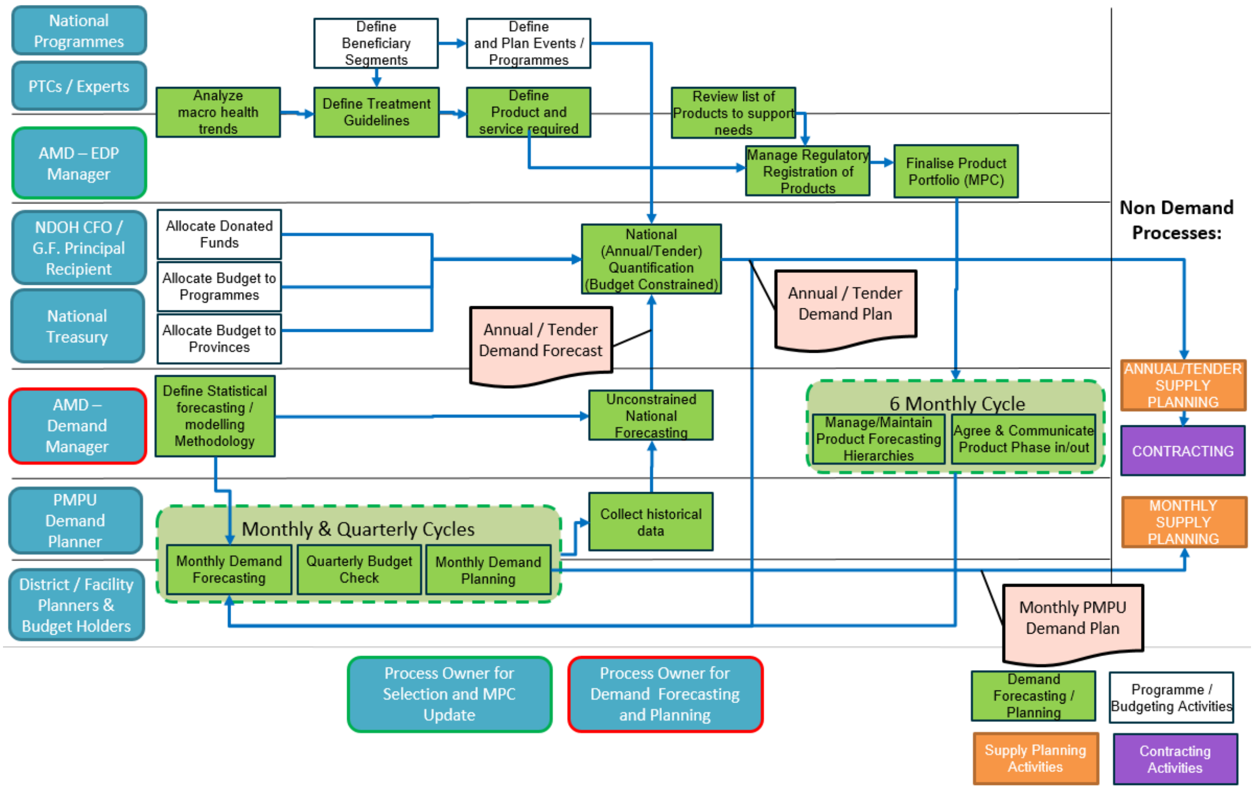

Figure 4: A process map on the integration of Demand Planning and other supply chain activities [11].

PMPUs are responsible for updating the monthly demand forecasts and demand plans in order to track the consumption data that is necessary for the inputs of the monthly supply planning processes. The PMPUs also need to conduct quarterly reviews to ensure that the actual consumption aligns with the demand plan and budget that was agreed to from the national level, and re-adjust the budget where applicable [11]. A change in the updated demand forecasts from the consumption data will have a direct effect on the budget, therefore a budget holder is allocated for the quarterly updates and who also needs to amend the budget allocation for medicine procurement according to the forecasted data [11]. The PMPUs is also responsible for conducting monthly reviews to the demand forecast plans to reflect the actual consumption data received from respective provincial facilities. These updates are used to inform monthly supply planning processes, which in turn are used to calculate supplier orders and replenishments [11]. The consumption data and changes in budget allocation are subsequently aggregated and used at the national level to provide a baseline for annual or tender plans [11].

3.2.2 Supply Planning

Supply planning activities (in Figure 5) aims to optimally coordinate inventory and orders, in order to ensure sufficient stock, and to fulfil the demand plan. The supply planning activities are based on the outputs from the demand planning activities and supplier collaborations [11]. The data, along with multiple planning variables, are used to calculate the number of orders, and the shipment plans for the different depots and facilities, in each province, district and facility [11]. Examples of planning variables include: replenishment frequencies, demand variability, order cycle, lead time stock on hand sample rate, etc. The supply planning activities also include contracting activities like the negotiation of suppliers and tenders, which are governed at a national level. The supply planning hierarchy is similar to the demand planning hierarchy, but has different processes for the annual and monthly frequency updates.

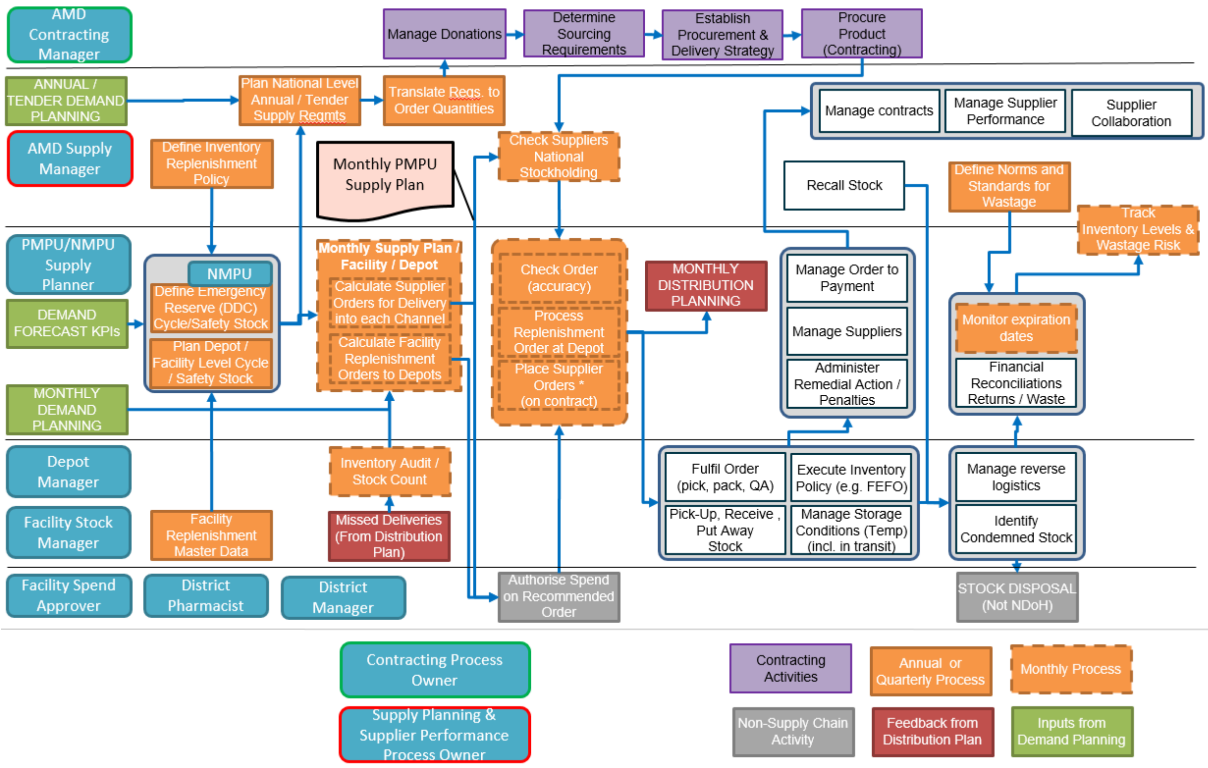

Figure 5: A process map on the integration of Supply Planning and other supply chain activities [11].

Once the long term (annual) demand planning and forecasting activities have taken place, an AMD Supply Manager is responsible for analysing the ordering quantities required to ensure stock availability, and works in collaboration with a contracting team, governed by an AMD Contracting Manager, which is responsible for managing the tenders [11]. The six monthly and quarterly cycles are performed from the demand planning side. The demand planning activities must inform the timing of implementation of the Standard Treatment Guidelines (STG) and new product selection. The AMD Supply Manager and Essential Drug Program (EDP) Manager collaborate in order to create contracts and orders to achieve the required new product availability [11].

As mentioned, the demand planning division is also responsible for the quarterly review on budget availability [11]. Evidently, this budget has an impact on the supply plan when the monthly process creates order recommendations that need to be authorised by the spend approvers at facility or district level. The PMPUs will be responsible for the monthly supply plan of orders required from the suppliers, as well as the replenishment plan for the movement of stock throughout the depots [11]. These monthly plans will be aggregated to the national level to confirm (by the AMD Supply Manager) whether the suppliers have sufficient stock to meet the current (and expected future) demand [11]. After the orders are placed at the suppliers, the demand / supply data is then used for the distribution planning activities. Figure 5 illustrates that there are multiple “non-supply chain activities.” Even though these activities are not directly involved in getting the commodities from the suppliers to the facilities, they do play an important role in managing the suppliers, payments, storage availability, waste management, and expiry dates, which in the case of a health procurement supply chain is considered crucial in order to achieve medicine availability [11]. These non-supply chain activities, as well as the distribution planning activities provides feedback to the supply plan.

3.2.3 Distribution Planning

Distribution planning (Figure 6) in concerned with the scheduling of shipments and distribution of products between the different warehouses and facilities, in response to the supply planning (discussed in section 3.2.2) [11]. Outputs from the monthly supply planning activities are identified as the relevant information necessary to plan delivery schedules, and the distribution plan subsequently provides feedback to the supply plan given the product delivery information. Operations that are involved in both the supply and distribution planning stages include: the execution of the physical delivery of material flow, the operations from the picking and packing, supplier management, stock logistics and storage management. The distribution plan determines the shipment and loads that are required by the respective depots, sub-depots, and facilities in order to meet the replenishment plan. The distribution plan aims to use storage and available capacity as efficiently as possible, and feeds back information to the supply and replenishment plans respectively in the event that unwanted issues arises.

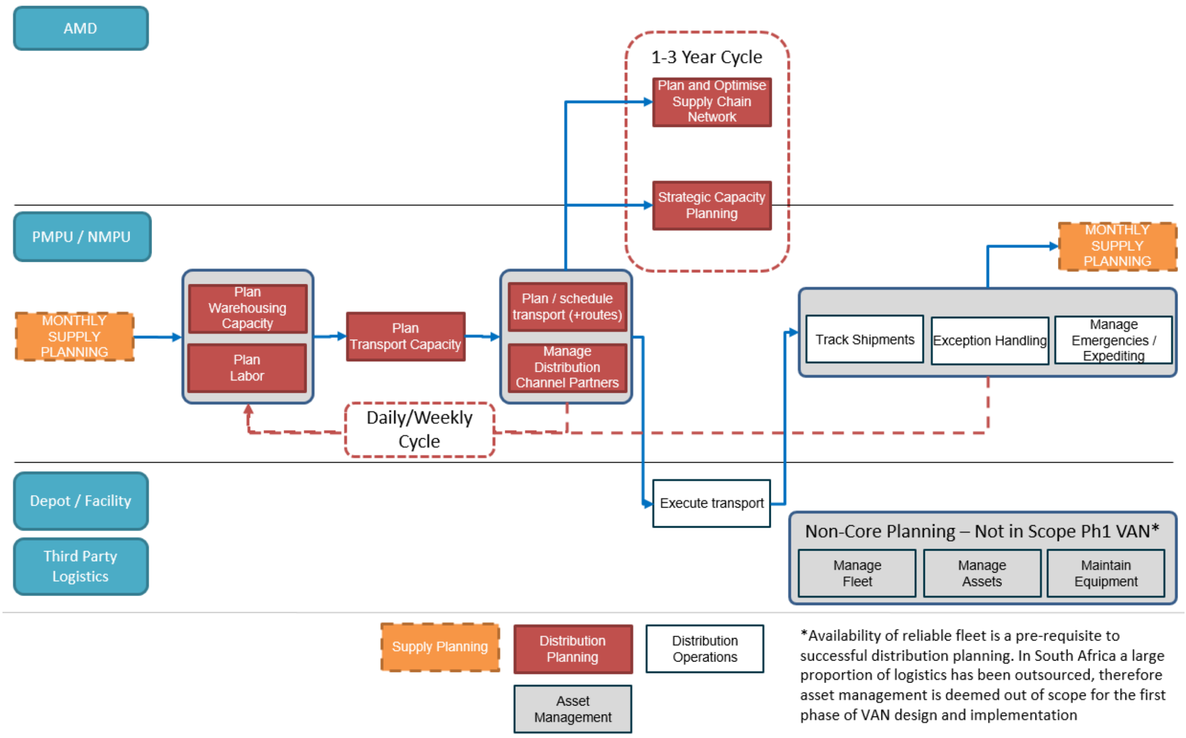

Figure 6: A process map on the integration of Distribution Planning and other supply chain activities [11].

The hierarchy process for the distribution plan is only divided into two levels of frequency updates: Long term (1-3 year cycles, and short term (weekly/ daily cycle) [11]. The long term updates are distribution trend analysis, governed by the AMD, National Treasury, and provincial health managers, to calculate the capacity plans and network optimisations. This process generates data on order deliveries, shipment reliability, and costs of shipments. The short term level consists of creating a distribution plan to schedule replenishment between the various government depots, sub depots, and facilities [11]. The short term updates are done by the depot managers and third party logistics companies. In the VAN operationalisation, the updates is done at a weekly or daily frequency and will provide input on the available capacity, window for dispatch, and information on the delivery and receipt of stocks.

Due to the amount of integrated processes and activities from the VAN model and process maps (Figure 4, 5 and 6), the three different planning categories (demand, supply and distribution) need to be simplified in order to provide a comprehensive illustration of how these categories flow into one another.

3.3 Proposed VAN Supply Chain Analytical Framework - Level 1[3]

Using the approach detailed by the analytical framework discussed in section 2, the activities across the different planning categories (discussed in section 3.2) are illustrated in Figure 7. As mentioned, the supply chain planning activities operates within the core supply chain functions shown in Figure 3. According to the first level (supply chain functions level) of the analytical framework, activities can overlap amongst the different categories [15]. The processes from the process maps in subsection 3.2 are combined to illustrate the key operations within the VAN operating model. The processes are also organised according to the frequency levels: from annual (top) to weekly/daily (bottom). An understanding of how the different categories are measured can provide insight into how these activities flow across the functions of the VAN supply chain.
The schematic representation of the VAN supply chain planning activities within the ADM's strategic framework is used as a foundation to determine how policies govern the public sector's pharmaceutical supply chain. In order to do such an investigation, policies within the context of healthcare and supply chain needs to be identified.

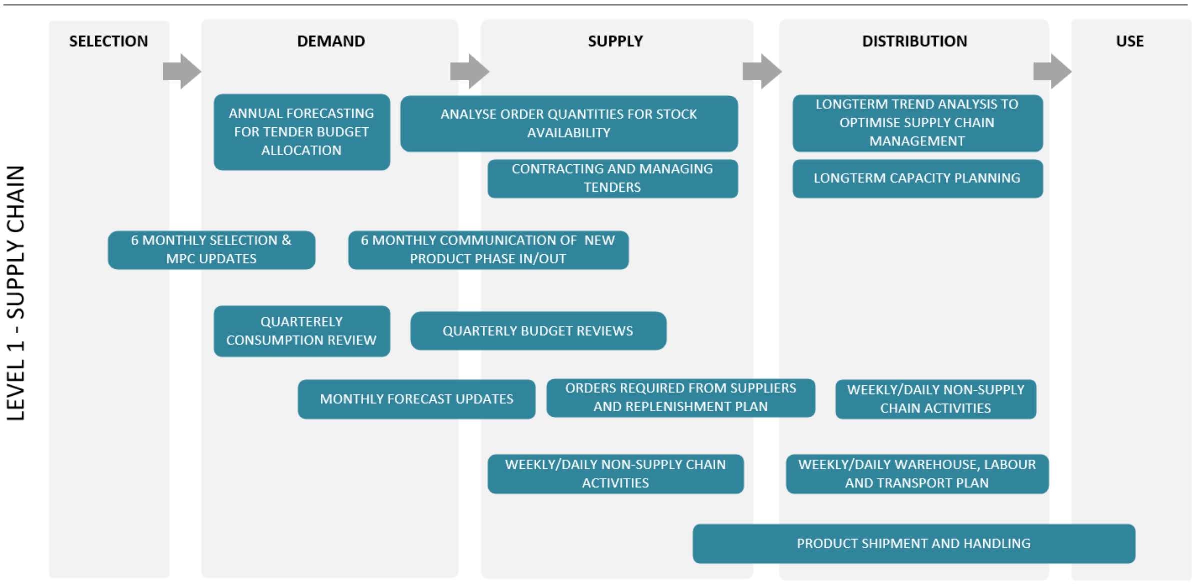

Figure 7: Level 1 - VAN supply chain planning activities within the AMD strategic framework functions

4. POLICY STRATEGIES FOR PUBLIC SECTOR PHARMACEUTICAL SUPPLY CHAINS

4.1 Components of a National Drug Policy

Pharmaceutical policy has a significant impact on health system performance in low- and middle-income countries. It influences, either directly or indirectly, the health of the population, public satisfaction (and dissatisfaction) with the health sector, and the cost-effectiveness of the care provided [18]. A National Drug Policy (NDP) is used to guide the government on how to ensure safe and efficient medicines of quality, affordability, and accessibility. The goals and objectives of a NDP may differ between various countries ([19], [20]), but the components that need to be included in a pharmaceutical policy are similar. In this research, we use the term "pharmaceutical policy" to refer to, the conscious efforts of national governments to influence the

[3] Level 1 refers to the operating level where the supply chain functions / activities of the VAN model is illustrated.

functioning of the pharmaceutical supply chain [18]. In a broader sense, a NDP policy has three general objectives, which is to ensure: access and availability of affordable essential medicines, quality and safety of all medicines, and the rational use by health professionals and consumers [20]. The relationships between the key components of a NDP and the main objectives are illustrated in Table 1, by means of their direct 'X' link or indirect 'O' link.

Table 1: Components of a National Drug Policy, linked to the key policy objectives (adapted from [19] and [20]).

Components:	***Objectives:***		
	Access	***Quality***	***Rational use***
Selection of essential medicines	X	O	X
Affordability	X		
Drug Financing	X		
Supply Systems	X		O
Regulations and Quality Assurance		X	X
Rational use			X
Research	X	X	X
Human Resource development	X	X	X
Monitoring and evaluation	X	X	X

Each of these components consists of multiple sub-components or decision strategies, which are considered necessary when implementing a national drug policy [19]. The sub-components can form part of, or consist of policies that are linked with other governmental departments, as well as cross-linked with other components. The policies within the different sub-components depend on the context of the country. Each of the NDP components listed in Table 1 are briefly described in the remainder of this section, along with short examples of such policies in the South African context.

Selection of Essential Medicines

The selection process of these essential medicines should be based on the relevant patterns of prevalent diseases, the proven safety and efficacy, the evidence-based scientific data in various situations, the quality, cost-benefit ratio, local manufacturing possibility and availability as a single compound [19]. In most cases, generic medicines are the preferred choice, rather than the branded medicines; this is because the active pharmaceutical ingredient is similar and often more cost-effective. Treatment guidelines go hand-in-hand with the selection of essential medicines and should be developed systematically. These guidelines are used to assist prescribers in deciding the appropriate treatment and preferably needs to be updated every two years ([19], [20]). Traditional and herbal medicines are widely distributed and many countries wish to include it in their health policies. The medicines are selected once they have satisfied criteria and evidence-based practices that are carried out by a specified committee, which follow WHO guidelines [20]. **Policy Example:** a National Essential Drugs List Committee is responsible for selecting the drugs used in the public sector. The committee is also responsible for reviewing the selected drugs need to be periodically using generic names. The list needs to be reviewed every three years [3].

Affordability

The competitive level between different price strategies for affordability depends on three different pharmaceutical product categories: new and innovative, generic medicine and branded off-patent medicines. Branded off-patent medicines no longer have patents and the same company produces them alongside a generic version [19]. Affordability of generic medicines can be increased by promoting competition through generic policies and good procurement practices ([20], [21]). **Policy Example:** There needs to be total transparency in the pricing structure of pharmaceutical manufacturers, wholesalers, and dispensers [3]. All drugs at the primary care level will be supplied free of charge [3].

There are a number of other factors throughout the supply chain that have an influence on the pricing of medicine. Essential medicines can follow a long and complex supply chain with many different strategies and pathways, such as manufacturing, transportation, storing, and distribution [9]. The price from the manufacturers are the selling price, which increases with the transportation cost (local or internationally) to the wholesalers. At the wholesaler, additional costs are added for storage, insurance and a profit margin. The cost can differ for private, or public organisation. To distribute the products to the retailers, additional costs are added for the transportation and transit insurance fees. At the retailer, there are additional profit margins added to the dispensing products, as well as a professional service fee [19]. Another addition to the price increase, is imposed by the government in forms of taxes and tariffs. Even though this contributes to the state's revenue, it is in conflict with the public health objective of affordability [9]. There are options for negotiation with regards to essential medicine prices. Tendering is the most common, when different offers are compared between the different pharmaceutical suppliers [19]. **Policy Example:** Price negotiations for the procurement of essential drugs need to be undertaken at the national level, using national and international tendering. After contracts are awarded, provincial authorities has to purchase drugs directly from suppliers [3].

Drug Financing

The quality of healthcare and the availability of medicines rely heavily on financial support. In order to ensure financial sustainability, a balance needs to be established amongst the demand for medicine, the cost of these medicines, as well as the resources procuring these commodities [20]. The links between the different activities of the supply chain have different financing mechanisms. Therefore, the government plays a different role at each link in the financial strategy [19]. The first type of financial strategy is the public funding through governmental budgets. This is useful in the case of limited resources in the public sector, especially for the basic healthcare for the poor and disadvantaged [22]. Another type of financial strategy is funding through health insurance schemes, because the WHO guidelines suggests that countries should include a "prepayment mechanism" as part of their financial strategy [19]. Health insurance can be divided into different categories: social health insurance, private health insurance, community prepaid schemes and health savings account. An additional financial strategy is gathering voluntary funds and donations. These aids are usually provided by foreign and international funding organisations [22] and are considered as grants to ensure the access and availability of essential medicines. Example include, UNICEF, Melinda & Bill Gates Foundation and Global Fund, to mention a few. With regards to drug donation, there are guidelines that need to be followed due to difference in labelling, dosage and Active Pharmaceutical Ingredients [19]. **Policy Example:** Donated drugs are to follow the WHO guidelines for drug donation [3].

Supply Systems

Procurement is a significant factor in ensuring medicine availability, and consists of a large amount of activities. For example, the selection of suppliers through tenders, monitoring orders, payments, distribution of medicines, consumption monitoring and determining funding needs [19]. These activities all influence the inventory management system and the policy should enforce the handling of inventory under the generic name. Additionally, the tender policy should promote competitive procurement methods in the public sector [20]. The supply systems are divided into five different strategies: central medical stores, autonomous supply agencies, direct delivery, prime vendor system and primarily private supply [19]. The direct delivery system, primary vendor system, and in some cases the autonomous supply system, al involve contracting activities. The contracting consists of outsourcing delivery services from the private sector. Outsourcing functions best when competition exists, due to the level of performance that is needed from the distributors [19]. **Policy Example:** Provinces need to manage their own distribution system to ensure that drugs and medical supplies are distributed in the most cost-effective manner, and are allowed to outsource to private sector [3].

For manufacturing, production practice can be divided into three different levels: Primary, Secondary, and Tertiary. The potential for local production, rather than importing, can be considered only if the pharmaceuticals can be produced more cost-effectively [23]. This will promote self-sufficient production in a country, but will create tension between health policies, which strive towards low-cost, quality medicine, and industrial policies that want to optimise growth through local industries ([19], [23]). **Policy Example:** Preference should be given to national/local manufacturers. In the case of lowest available prices, the government reserves the right to consider procurement on the international market, which includes parallel importation and purchasing on the international generic market [3].

Regulations and Quality Assurance

Quality assurance in a pharmaceutical supply chain ensures efficacy, safety of medicines and standard quality [19]. Therefore, there is a need to establish a regulatory authority which governs the principles relating to licensing, controlling, and monitoring [22] of manufacturing, importing, exporting, distribution, supply, marketing, prescribing, labelling, dispensing, and clinical trials ([19], [20]). **Policy Example:** Only practitioners who are registered in terms of the Medicines and Related Substances Control Act (No 101 of 1965) may be used for the manufacture, supply and dispensing of drugs. Medical practitioners and nurses will not be permitted to dispense drugs, except where separate pharmaceutical services are not available [3].

Productions standards are guidelines adopted by the industry to ensure quality production takes place while adhering to specific standards [19]. The quality of the product is one of the major objectives of a national drug policy and needs to be reviewed at registration processes. The quality of the product is further affected by the ongoing activities and services of the pharmaceutical supply chain. Thus, policies are necessary to maintain the quality of the product. Manufacturers are to ensure Good Manufacturing Practices (GMP); the regulatory authority should ensure good storage and distribution practices and that the people responsible for dispensing and distributions, follow the appropriate guidelines for product and package handing [22]. In order to ensure that the medical drugs are safe, information pertaining to drug reactions need to be captured, by means of a pharmacovigilance system. In the case of defective drugs, a policy should be in place describing the recall system for example, tracking information and categorisation by degree of risk, etc. [20]. **Policy Example:** Inspections will be carried out regularly by the inspectorate of the Medicine Control Council in order to ensure compliance with GMP [3].

Rational Use

Policies need to address all the manufacturers, retailers, consumers, prescribers, and dispensers about the rational use of medical drugs [22]. According to the WHO, the policy for the rational use of medicines should state that medicines should be dispensed in the right dosage, for the right amount of time, and at the lowest possible cost [19]. Scheduling decisions of drugs are considered vital as part of the national drug policy. It determines which drugs are 'over-the-counter drugs', and which drugs are only available with prescription, for the purpose of regulating the drug usage [20]. To ensure the safe and rational use of medicine, policies and guidelines should ensure that the following strategies are supported: education through formal and informal training, guided decision-making by therapeutic committees, district health teams, and professional prescribers; regulations by enforcing standards and guidelines and financial incentives. The in-service training should also apply to drug sellers in the rural areas who have little to no formal training [20]. **Policy Examples:** The public should be provided with access to information on drugs and their proper use, written in lay language, and including appropriate self-diagnosis and treatment [3]. Pharmacy technicians should be prepared for certain tasks in hospital and pharmacies under the supervision of pharmacists, and for managing drug supply in primary care clinics under the indirect supervision of a district pharmacist [3].

Research

The two types of research categories that are necessary for a national drug policy, are operational research, and drug research and development. By assessing the impact of the various policies on the health system [22], the operational research approach focuses on the different factors that might have an effect on the drug use. On the other hand, drug research and development focus on factors of the drug itself. These factors include new drugs, new dosage forms, manufacturing, molecular biology and clinical trials. **Policy Example:** The research findings should be used to make the necessary adjustments in strategy and to ensure that policy objectives are achieved [3].

Human Resource Development

Human resources are the central organisations that bind policies, finance, leadership, and education [19]. Policies and strategies are required to ensure that the personnel are trained and motivated on order to implement or adopt a national drug policy. Educational training policies should be implemented for each staff category. Examples of these categories are: medical doctors, nurses, pharmacists, supporting staff and health service managers. All the educational and training should be skilled-based in order for the staff to develop the required competence. **Policy Example:** Training programmes need to be developed and implemented to address on-the-job requirements of the following groups: medical doctors; Nurses; pharmacists and supporting staff; health service managers and pharmaceutical depot managers [3].

Monitoring and evaluation

Monitoring and evaluation policies are an important component that assesses the on-going progress of the national drug policy, by monitoring selected indicators from the WHO guidelines [20]. This policy should also include the periodic evaluation frequency to evaluate the national drug policy. It is recommended that the evaluation should be done periodically every two or three years [20]. **Policy Example**: Indicators (from WHO guidelines) for monitoring the National Drug Policy need be compiled for the information system, and a full evaluation of the National Drug Policy will take place every three years [3].

4.2 Summary of Policy Components.

Policies that govern pharmaceuticals are mostly concerned with ensuring the availability of effective, good quality and safe drugs as well as accurate information about the supply, demand and availability of such medicines. These tasks are covered in drug laws, pharmacy acts and drug regulations. Table 2 provides a summary of the components that are considered necessary for a NDP, and discussed in section 4.1. The sub-components are based on the higher operating level of a pharmaceutical supply chain and can be sub-categorised into further details based on the context of the country. Several departments are involved, each having different components or sub-components that they govern and are responsible for. It is clear that there are many sub-components that overlap between the respective policies components within the NDP.

Table 2: Summary of the necessary components of a National Drug Policy.

National Drug Policy Components	*Sub-Component(s)*	
Selection of essential medicines	Use of National Essential Medicines List	Generic
		Brand-Name
	Standard Treatment Guidelines	
	Selection of Traditional Medicines	
Affordability	Pricing Policy	Equity pricing
		Profit Margins
		Taxes and Tariffs
	Generic Substitution Policy	
	Parallel Importation	
	TRIPS Agreement	
	Tendering (national/international)	
Drug Financing	Public Governmental Funding	
	Health Insurance Schemes	
	Drug Donations	
Supply systems strategies	Procurement	Inventory Management
		Tenders
		Consumption Management
		Payment activities
	Private/Public Distribution	Central Medicine Store
		Autonomous Supply Agency
		Direct Delivery
		Prime Vendor
		Primarily Private
	Manufacturing	Local Production
		Importation
	Contracting	
	Waste Management	
Regulations and Quality Assurance	Regulatory Authority	
	Safety	Pharmacovigilance
		Monitoring
		Recall System
	Quality	Licencing
		Inspection
		Good Manufacturing Practice
Rational use	Education	
	Minimum Required training	
	Drug Scheduling	
	Financial Incentives	
	Therapeutic Committees	
Research	Operational Research	
	Drug Research and Development	
Human Resource development	Training and Motivation	
Monitoring and evaluation	Indicators (WHO Guidelines)	
	Evaluation Frequency	

5. RELATIONSHIP BETWEEN POLICIES AND THE VAN INITIATIVE

5.1 Proposed Analytical Framework of the Policy Relationship - Level 3[4]

The relationship between the VAN model activities (discussed in section 3 and shown in the 'supply chain' level of the analytical framework below / Figure 7) and policy components is illustrated in Figure 8. Level 3, also known as the enabling environment from the analytical framework, shows the NDP components from Table 1 that governs the VAN supply chain activities. In the event that a specific policy component has an association with, or influence on, one or more of the supply chain functions, as stated in literature, it is illustrated by means of an arrow, and labelled accordingly. These connections were identified, and subsequently defined, by reviewing the discussion of the policy components in section 4 and comparing it to the VAN processes discussed in section 3. Due to limited information available of actual policies within the pharmaceutical supply chain of South Africa, the relationship between the policy components and the VAN model can only be illustrated according to their significance in literature. Therefore, as an initial investigation, only a selected number of the available policies are discussed with regards to the VAN.

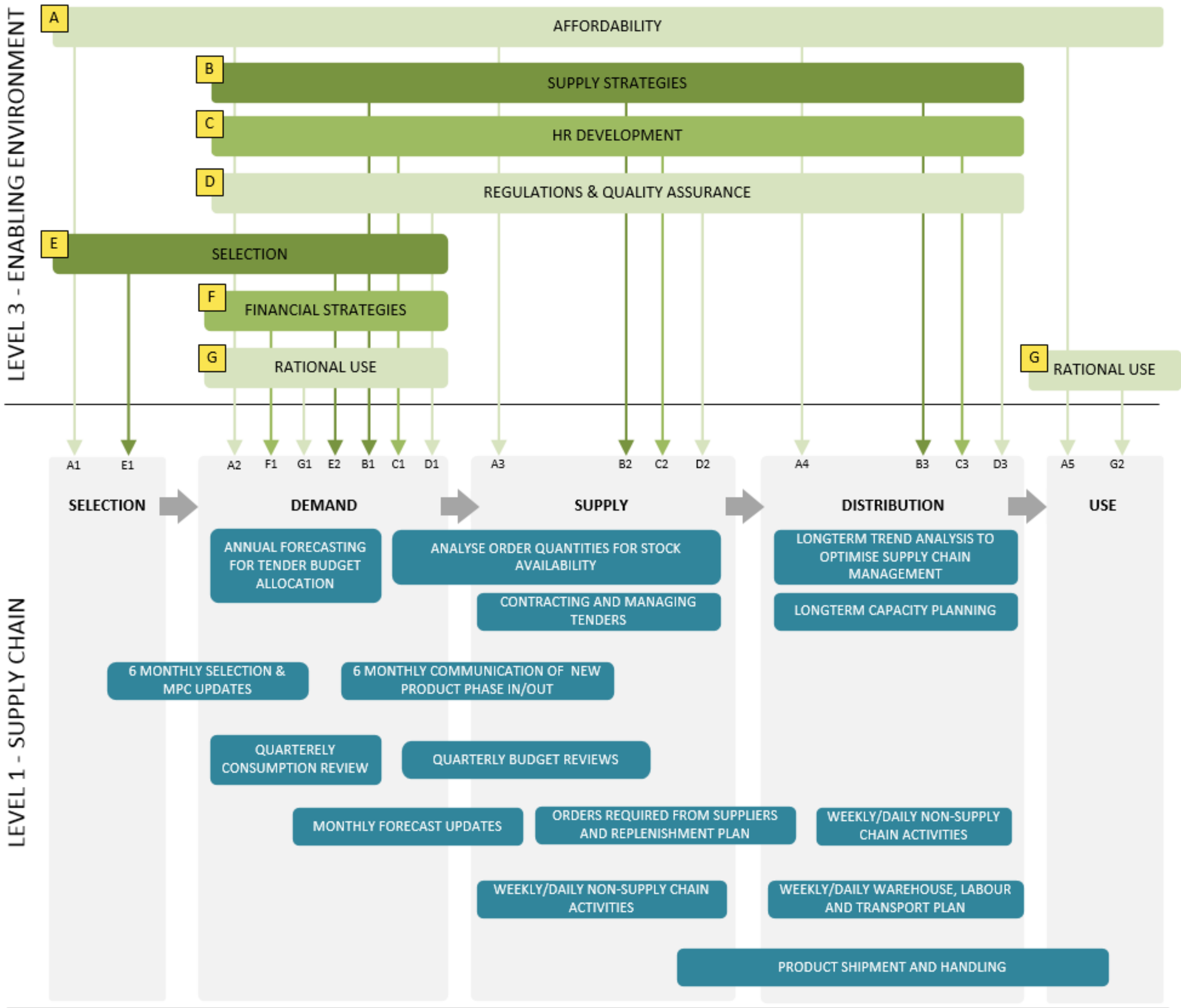

Figure 8: Relationship between the VAN processes and the policy components.

[4] Level 3 refers to the enabling environment (the policies) that governs the VAN supply chain functions within the analytical framework.

Affordability governs the entire VAN supply chain. In the selection process (A1), the NDP aims to promote the selection of generic drugs, because it is more cost effective than branded medicines. The VAN has the objective to select the best treatments, modalities and medicines required to improve patient health outcomes, but do not focus on whether or not the drug has to be generic. Treatment guidelines are closely linked to the selection of the medicines and should ideally be systematically developed. The current policy states that the essential medicine lists and standards treatment guidelines should updated every two years (E1-E2), however, the VAN plans on updating the selection of medicine and reviewing the treatment guidelines every 6 months.

Because there are a number of factors and actors, such as suppliers, wholesalers, distributors and dispenser, that adds their own profit to the cost, the VAN model will be required to ensure that there is a transparency between the pricing structures within the supply chain (A2-A5). The supply system strategies are considered the most relevant to the VAN model, due to all the supply chain characteristics that are recognised from Table 2. Tendering policies state that the price negotiation of drugs (B1, B2) needs to be undertaken at a national level, and after contracts have been awarded (B3), the provincial authorities are allowed to purchase drugs directly from the suppliers. The VAN is in line with national authorities (CFO and National Treasury) to handle the tender with regards to the allocated budgets. However, even though the PMPUs can place orders at the suppliers, they still remain restricted within a budget. Therefore policies need to address the allocation of budgets for the provincial authorities which is agreed upon at a national level. This means that the provincial authorities do not handle their own budget within the VAN model, but with the quarterly reviews and input from the AMD, be able to re-allocate the medicines to for the budget. The VAN plans to allocate the budget for the different provinces at an aggregated level.

Due to the fact that the VAN model is focused on placing supply chain specialists along the supply chain, and changing the organisational structure of the pharmaceutical supply chain with regards to the three governmental spheres: national, provincial and district/facility, it is important that there are training policies (C1-C3) implemented for each staff category in order to fulfil the new accountabilities and responsibilities, especially within the AMD and PMPU categories. With the staff responsibilities are policies based on scheduling of the medicines. It is important to set policies that inform the facility staff of which medicines are prescribed medicine or 'over-the-counter medicines (G1). Although the VAN aims to ensure the availability of medicines, it is possible that stock might be condemned at some facilities (D2), therefore the recall system needs to be managed by the facility level and reported back to the PMPUs for financial reconciliation, as well as the AMD to adjust the inventory levels.

It is apparent that there is insufficient information on actual policies within the South African context to formulate a detailed framework, but that it is important to understand how these policies influence the VAN; Figure 8 clearly illustrates that there are multiple policy components that governs and also influence the VAN model. This concludes that there is a need for further investigation into South-African specific policies that transcends the operational, tactical, and strategic level of the VAN operating model. The fact that policies govern the VAN model across the three governmental spheres, indicates that the level of detail to which a policy needs to be adopted may differ. Therefore, policy analysis should not only be focused on the operational, tactical and strategic level, but should also take into account the level at which a policy need to be reviewed.

6. CONCLUSION AND THE WAY FORWARD

Healthcare challenges related to stock-outs, and how this led to the development of the concept of a Visibility and Analytics Network (VAN) model, which aims to ensure medicine availability in the public sector, is highlighted. The VAN initiative was evaluated and it was found that the model lacked the contextualisation from a policy perspective, therefore, this article's main objective was to understand the types of policy that has an influence on the VAN model. The first section of this article provided an overview on the VAN model and discussed the processes, as well as the authorities responsible for the processes in detail. The second section of this article provided an overview of the National Drug Policy and the policy components that are deemed necessary by the World Health Organisation for a pharmaceutical supply chain. Both of these sections were conducted from a mutually exclusive perspective. The relationship between the VAN supply chain and the governing policies were subsequently illustrated by means of an analytical framework and discussed.

From the analytic framework, it was concluded that there are various policy components that are considered necessary for a national drug policy and that a majority of those components govern the pharmaceutical supply chain in which the VAN model will operate. Although this article have been able to identify which component governs which processes, it is important to understand how the VAN will be influenced by the actual policies of South Africa. This argues that context matters and reasons that the degree of impact a policy would have on the VAN initiative is context-specific. In the context of South Africa, limited information is available on the actual policies within the policy components that govern and influence the VAN model. Therefore, the relevant policy component needs to be identified in the South African context to determine the expected impact these policies would have on the VAN.

It is evident that majority of the activities within the VAN model are affected by one or more policy components. Future research will thus focus on the elements that might enable or hinder the VAN on an operational level and how it can be resolved on a strategic level. This article clearly illustrates that policy plays a vital role in the operation of the VAN initiative and that the designing of systems, to support the healthcare system from a policy perspective, should be taken into account.

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IMPROVED MELTING EFFICIENCY IN RURAL ALUMINIUM FOUNDRIES THROUGH TECHNOLOGY TRANSFER BY THE METAL CASTING TECHNOLOGY STATION AT THE UNIVERSITY OF JOHANNESBURG.

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ABSTRACT

The Metal Casting Technology Station (MCTS) at the University of Johannesburg (UJ) is an initiative of the Department of Science and Technology (DST) launched in 2005 to assist local foundries increase their competitiveness. The MCTS has five focus areas including sand casting, physical metallurgy, casting simulation, rural foundries and training. A coal fired furnace with a blower was designed and commissioned to improve the melting efficiency of the rural foundries. A 75 % improvement in the melting and 77 % reduction in the fuel use was achieved with this furnace. The technology transfer initiative laid a foundation for the production of better quality of castings in rural foundries in a safe and healthy working environment.

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1. INTRODUCTION

Technical support of small and medium enterprises (SMMEs) in order to increase their competitiveness is the key purpose of the Technology Station programme overseen by the Technology Innovation Agency (TIA) of the Department of Science and Technology (DST) [1]. This programme takes advantage of the scientific expertise available in South African Universities of Technologies to assist SMMEs develop and grow to serve as catalysts of job creation in the country. Currently thirteen Technology Stations are operated in the country focusing on diverse engineering manufacturing disciplines [2].

As such, The Technology Station programme is aligned with the National Development Plan (NDP) specifically with regards to its objectives related to economy and employment, economic infrastructure, environmental sustainability and resilience and inclusive rural economy [3]. The NDP is South African blueprint for growth and development whose main goal is to eliminate poverty and reduce inequality by 2030. Activities of Technology Stations include technology transfer, innovation and human capacity development which are key ingredients of the NDP.

The Metal Casting Technology Station (MCTS) is one of the Technology Stations in the country located at the University of Johannesburg (UJ) [4]. This Station established in 2005 operates to assist the local foundry industry which produces metal castings. These components are obtained through a forming process basically consisting of melting of scrap metal, pouring of the liquid metal in sand moulds or dies and solidification of the metal [5]. Castings have various applications including automotive, mining, agriculture, and art and cooking utensils. The latest statistics indicate that South Africa count approximately two hundred small and medium foundries [6].

One of the priority focus areas of the MCTS is the technical assistance to rural foundries. An informal sector of rural foundries producing sand cast aluminium pots for cooking applications is prevalent in the country. The technical assistance is two-folded concentrating on foundry technology skill development and improvement of melting methods. In particular, current melting practices based on coal heating of aluminium scrap in steel drums were found to be slow and not compliant in terms of health and safety regulations.

Figure 1 shows a typical melting practice in a rural foundry in the Limpopo province. The furnace uses coal as combustible. The melting charge consists of scrap aluminium loaded in an old three-legged cast iron pot. The process to produce the molten metal takes six hours and use an average of 75 kg of coal to melt a single heat.

Figure 1: A 200 L steel drum used as the furnace. Melting charge is loaded in the cast iron pot. The rectangular opening at the bottom serves as tuyere. The furnace does not have a lid.

A similar melting practice can be found in Nigeria. A study was done by researchers in Nigeria where evaluation of a charcoal fired furnace was conducted [7]. In their study, they estimated that a furnace fired with charcoal as shown in Figure 2 had a melting efficiency of close to 11 %.

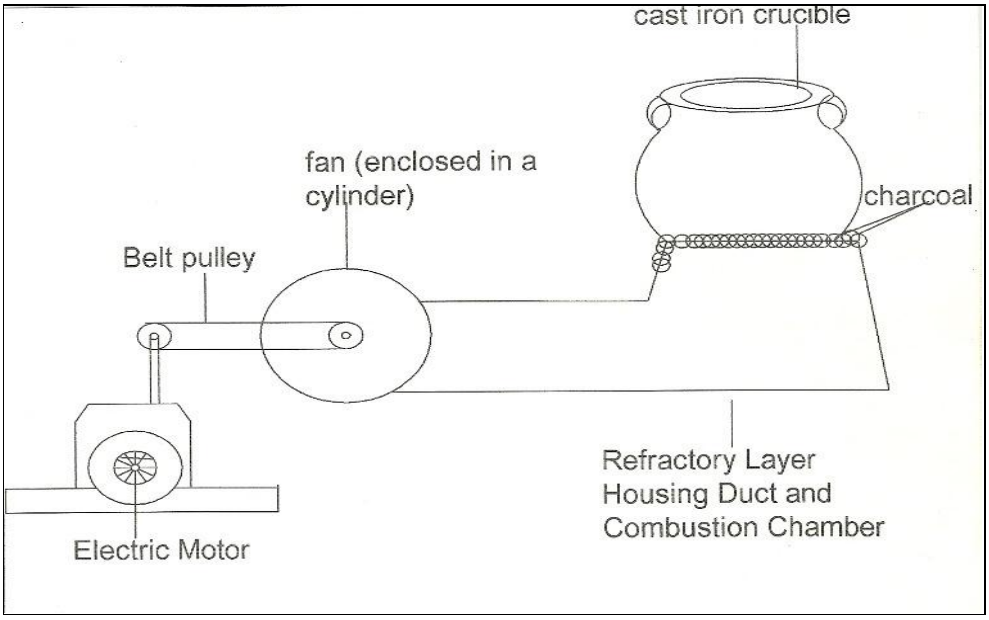

Figure 2: Setup of the local charcoal-fired furnace for melting aluminium [7]

This paper presents a recent intervention case study conducted by the MCTS to upgrade the melting method in rural foundries in order to, improve the molten metal productivity in a sustainable environment. The design of a new melting furnace and the preliminary results from the commissioning of this furnace in a local foundry are presented in the sections below.

2. EXPERIMENTAL PROCEDURES

2.1 Design of melting furnace

The design of an improved furnace was conducted with the following technical considerations:

- Cost of the furnace to be kept as low as possible
- The furnace to use the original concept familiar in foundries so as not to affect the production process.
- The furnace to be robust and withstand harsh conditions of the rural foundries
- The furnace to comply with health and safety regulations

Figure 3 below shows technical drawing of the furnace. The new furnace was designed as a rolled steel drum.

To get the cost of the furnace as low as possible a mild steel sheet was used as the case of the furnace and low cost castable refractory was chosen in this case. 375 kg/furnace of castable refractory were used at a cost of R5.70/kg giving total cost of R 2138. The cost of the mild steel and labour for rolling and welding was R3500.00. The total cost of making the furnace was R5638.00. The blower used costed R700.00.

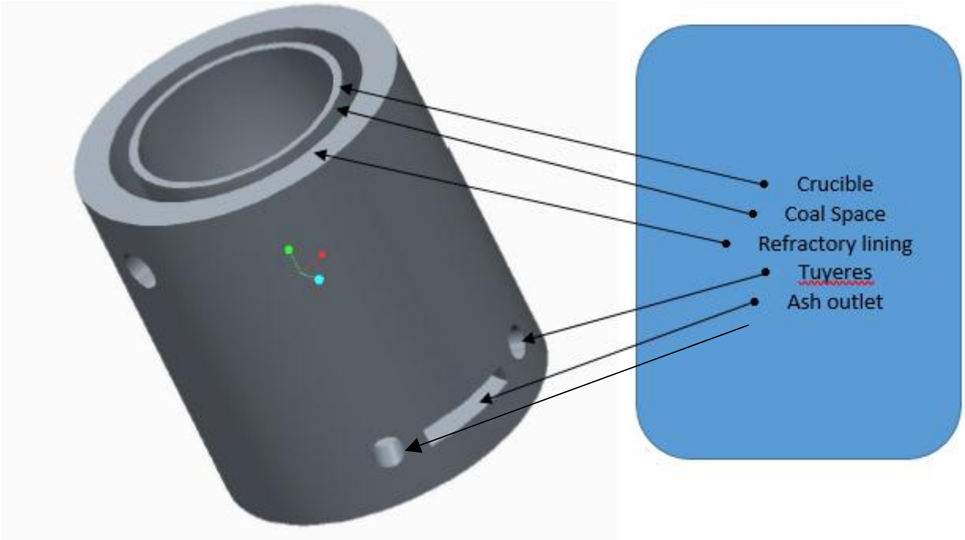

Figure 3. 3D drawing of the new design of the furnace with the SiC crucible placed inside the furnace

2.2 Furnace description

The upgraded features of the melting system consist of a rolled steel drum with a castable refractory cement lining. Two cylindrical holes on each side of a larger rectangular hole were made at the bottom of the furnace. The three holes serve as tuyeres while the larger rectangular opening is used to remove excess ash built up during melting. The crucible sits on refractory bricks, which sit on a metallic grill at the bottom of the furnace. A cylindrical hole is drilled on the top of the furnace to provide for a chimney outlet for emission control that will either be joined to a stack or bag house. The two cylindrical holes at the bottom can be used to insert a gas burner in the event the coal gets wet or there is no supply of coal. The furnace can use coal or natural gas as combustible. To minimize heat loss from the top, a top part of the steel drum is cut and rammed with castable refractory cement and used as a lid.

Scrap metal can be easily fed through a hole provided at the center of the lid. The lid can be taken off by lifting using handles provided on the outside of the lid. The critical element in our new melting system is the integration of forced air at the bottom of the furnace through the tuyeres by use of a blower Figure 4 and the refractory that minimizes heat loss. This will allow high temperatures to be achieved during melting which will improve the quality of the products.

2.3 Commissioning of the new furnace

A prototype furnace was built by the MCTS at the University of Johannesburg according to the technical design described in section 2. Melting trials were conducted in a local foundry. 17 kg local coal and 52 kg scrap Aluminium from the region were used respectively as combustible and charge material. Three leg pots were produced during the trials. Furnace operation was also demonstrated to the foundry workers. Figure 4 shows the final built furnace ready for melting.

Figure 4 Experimental design furnace used in the trials with foundry.

The commissioning was done through measurement of amount of coal used and the time taken to get the first melt out. The operators used the same procedures of loading the scrap metal until the furnace was full.

3. RESULTS AND DISCUSSION

3.1 Melting Efficiency

Table 1 shows a comparison of the old and new melting furnaces in terms of combustible consumption as well as meting rate for the same quantity of charge material. Preliminary results appear to indicate an improved performance of the proposed new melting system.

Table 1: Comparison of the old and new furnace

	Old furnace	New furnace	Difference
Weight of Coal used (kg)	75	17	58
Time taken to melt	360 min	90 min	270
Weight of Al melted (kg)	52	52	0

The melting of 52 kg of aluminium charge was completed in 90 minutes using the updated furnace. This represents a 75 % improvement in melting time compared to 6 hours the foundry usually took to melt the same quantity of metal. 17 kg of coal were consumed compared to the 75 kg the foundry uses with old furnace. This represented a 77 % improved coal usage efficiency. The improved melting efficiency could be possibly attributed to a better insulation due to the refractory lining, the lid cover and air flow generated by the blower.

3.2 Product Quality

Several pots were cast during the trial as seen in figure 5. Much higher temperature was achieved as seen from the quality of pots produced. As this trial was a proof of concept to the foundries no temperature measurements and temperature control equipment were used. This is planned to be used in the industrialisation process where additional technical information will be collected.

Figure 5: A sample of a pot produced during the trials

Figure 5 shows one of the biggest sizes of pots and some lids produced for a local customer by the foundry. The operators were satisfied with the quality of the pots produced from the trial. The pot shows good surface finish with no evidence of cold laps as a direct consequence of higher pouring temperature.

3.3 Environmental and Cost Implications

The improved melting process means that less coal is used during melting and as result there is less pollution generated by the foundries. The cost of design and building the new furnace was estimated at R5600. A similar furnace will cost ~$2000 (R26 000) [8]. In addition, better health and safety working conditions are enabled by the new melting furnace. The Occupational Health and Safety Act No 85 of 1993 as amended also requires compliance by melting entities to use of personal protective equipment (PPE) for all employees working with hot metal [9]. The foundry workers were shown how to use PPE during melting.

4. CONCLUSION

The case study introduces a new approach of melting suitable South African rural foundries. An innovative design of the melting furnace provides better insulation of the charge and rapid melting rate. The preliminary results from the commissioning of a prototype furnace appear to indicate that 77 % improvement in fuel (coal) usage, 75 % reduction of melting time and better environmental management of air quality could be achieved compared to the old furnace. This technology transfer to rural foundries is a practical example of how to implement the objectives of the NDP with regards to environmental sustainability and inclusive rural economy. Future upgrade of the furnace will focus on the use of renewable energy by incorporating solar panels to aliment the blower. Process control and quality of scrap as well as chemical compositions of raw materials and products will be monitored in future studies.

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THE APPLICATION OF DIRECT CLUSTER FOR IMPROVING TRAIN STATION LAYOUT

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ABSTRACT

Facilities Layout Planning is a systematic and functional way of arranging various departments and ensuring delivery of services. A commuter rail station is considered as a Facility Layout. To have an effective train station layout implies that customer requirements are to be met including the requirements of customers with special needs. Flow constrains exist in a train station due to ineffective layout. These constraints may result in bottlenecks and poor service delivery. This paper presents an algorithmic approach that should assist in combining processes to reduce the cost of movement and minimise conflicts or bottlenecks within train stations.

Keywords: Direct Cluster Algorithm, Facility layout, Flow Constraints

1. INTRODUCTION

In the past when the commuter rail system and networks were constructed in Johannesburg, not enough thought was given to the many commuter rail passengers with special needs. As by the quantitative research conducted by Maidin [1], commuter rail passengers with special needs are classified as ambulant disabled, wheel chair bound, sensory disabled and temporarily disabled. In this paper passengers with special needs are classified as Swart[2]

- children,
- the elderly,
- physically limited passengers,
- cognitively impaired passengers,
- auditorily impaired passengers,
- linguistically impaired passengers,
- temporarily limited passengers,
- visually impaired passengers,
- pregnant women and
- people in wheel chairs.

Many constraints and barriers exist in commuter rail facility, which mainly affects people with special needs [3]. A significant amount of research efforts and resources have been invested in improving the layout of commuter rail facilities in Johannesburg e.g. Johannesburg Park Station, Gautrain commuter rail facilities etc. According to the South African Gautrain Benefits Booster [4], Gautrain facilities are designed to allow for simple use, flexibility, equitable use, perceptible information management, tolerance for error, low physical effort and effective space utilisation and accommodates for passengers with special needs.

Flow constrains exists in train stations due to ineffective layout. These constraints may result in bottlenecks and poor service delivery[5][6][6][7][8][9][10]. This research paper applies the Direct Clustering Algorithm technique [11] to improve the layout of a train station. Research was conducted at Johannesburg Park Station. Only flows from the following departments were considered: taxi transit area, entrance, new retail, Shosholoza premier class, business lounges, the medical centre and the South station.

1.1 Reasons to improve a facility layout as reported by Tompkins et.al [11]

1.1.1 To improve customer satisfaction by conforming to the customer's requirements.
1.1.2 Increase return on assets by increasing inventory returns
1.1.3 Continually improving the facility
1.1.4 Decreasing unnecessary costs
1.1.5 Integrating the supply chain through partnership and communication
1.1.6 Support the organisation's vision through improved material handling, material control and good housekeeping.
1.1.7 Utilise people, equipment and space effectively
1.1.8 Increase investments on return on all capital expenditures
1.1.9 Promote ease of maintenance
1.1.10 Give safety, employee satisfaction, job satisfaction, energy efficiency and environmental responsibility.
1.1.11 Assure sustainability and resilience.

2. METHODOLOGY

The Direct Cluster Algorithm [11] is applied which combines processes to reduce the cost of movement and minimise conflicts or bottlenecks within train stations. The Direct Cluster Algorithm consists of the following steps [11]:

2.1 A matrix is set up where one dimension represents departments and other passengers. All intersections that require a passenger are filled with ones; all other intersections are assigned zero values.

2.2 Ordering rows and columns. Sum the ones in each column and in each row of the passenger-department matrix. Order rows in descending order of the number of ones in the rows and order the columns (left to right) in ascending order of the number of ones in the rows. Where ties exist, break the ties in descending numerical order.

2.3 Sort the rows column by column. Start with the left-most column. Shift the rows upward when opportunities exist to form blocks of one.

2.4 Search for opportunities to form cells such that all processing for each passenger type occurs in a single cell.

3. CASE STUDY ANALYSIS AND RESULTS

Upon applying the direct cluster algorithm processes are combined and bottlenecks are minimised in the train station. This has been shown to manage flow during peak hours and during those periods when there are special events i.e. sports events were a lot of people are using the facility.

The movement of these passengers was observed from the taxi rank with a travel route labelled as follows

A. entrance to the taxi rank,

B. ablutions which cater for normal passengers and the disabled passengers,

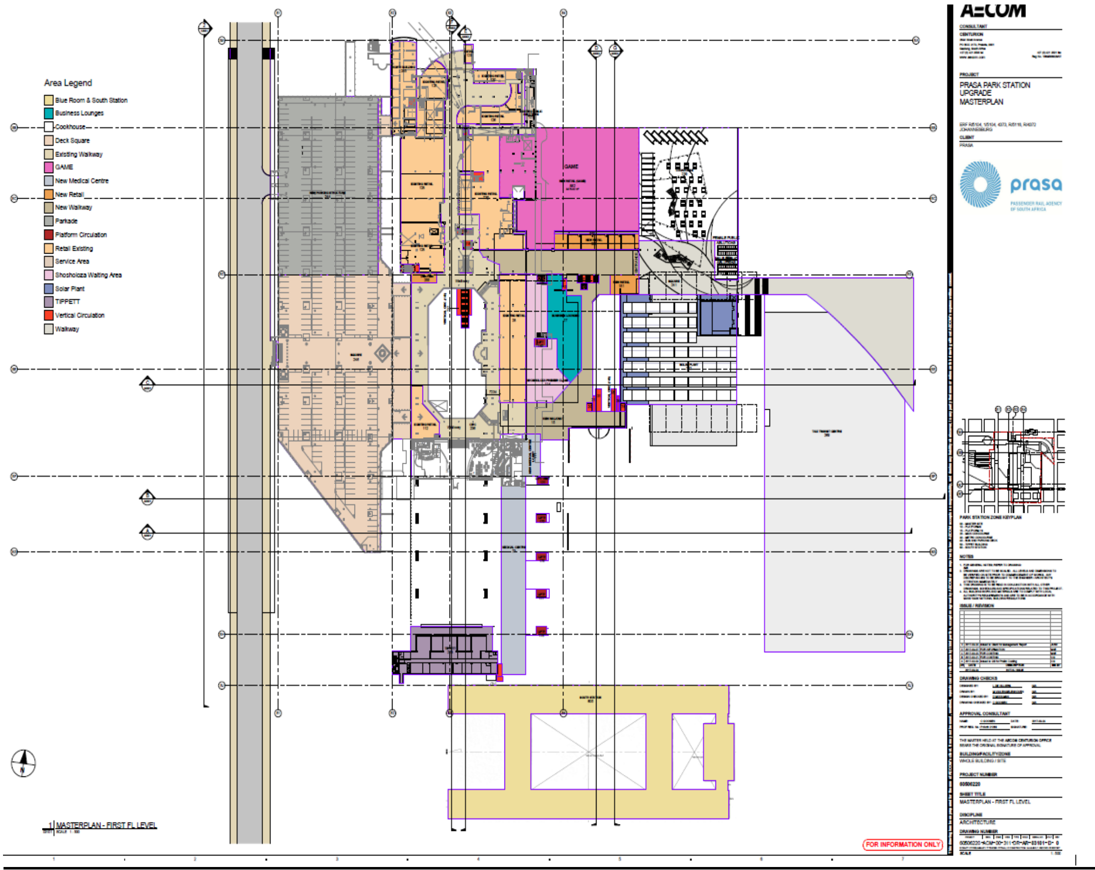
C. retail (Game shopping store),

D. business lounges,

E. Shosholoza premier classes,

F. the medical centre and

G. which is the exit to train station platform on which passenger *catch a train to various destinations*.



Picture1: Layout of the park station Kwesiga.M 2017[12]

<u>A table showing the routes taken by each passenger type has to be included</u>

Table 1: Sum of 1s in each row and each column

	A	B	C	D	E	F	G	Total
CHILDREN	1	1	1			1	1	5
ELDERLY	1	1	1	1		1	1	6
PHYSICALLY LIMITED	1			1		1	1	4
COGNITVE LIMITED	1	1	1			1	1	5
LINGUISTIC LIMITED	1		1		1		1	4
AUDITORY LIMITED	1	1	1			1	1	5
VISUALLY LIMITED	1			1	1	1	1	5
TEMPORARY LIMITED	1		1	1		1	1	5
PREGNANT	1	1	1	1	1	1	1	7
INEBRIATEDPERSON	1	1			1		1	4
PARAPLEGIC (PEOPLE ON WHEELCHAIRS)	1	1	1		1		1	5
	11	7	8	5	5	8	11	55

Table 1 indicates the various passengers with special needs travelling to various departments in the train station. Upon of completion of summing up the cells, it was observed that conflicts or bottlenecks do exist in the facility and that there's an opportunity to apply the second step to try and group processes that have a similar ranking together.

Table 2: Ranking of column in ascending order and rows in descending order

	D	E	F	C	B	A	G	Total
PREGNANT	1	1	1	1	1	1	1	7
ELDERLY	1		1	1	1	1	1	6
COGNITVE LIMITED			1	1	1	1	1	5
AUDITORY LIMITED			1	1	1	1	1	5
VISUALLY LIMITED	1	1	1			1	1	5
TEMPORARY LIMITED	1		1	1		1	1	5
PARAPLEGIC		1		1	1	1	1	5
CHILDREN			1	1	1	1	1	5
LINGUISTIC LIMITED		1		1		1	1	4
PHYSICALLY LIMITED	1		1			1	1	4
INEBRIATED PERSONS		1			1	1	1	4
	5	5	8	8	7	11	11	

In Table 2, rows were ranked in descending order and columns in ascending order. This helped to be able to determine which departments and passenger types should be grouped together in cells. Results from Table 2 indicate that the entrance (A) and exit (G) of the train station can be placed close to each other as this will eliminate bottlenecks or congestion in the train station. It will also allow for passengers not to spend too much time in the facility, as they will be entering and leaving the facility quicker, having to cover a shorter distance.

Table 3: Ordering rows and columns

	D	F	A	C	G	B	E
PREGNANT	1	1	1	1	1	1	1
ELDERLY	1	1	1	1	1	1	1
COGNITVE LIMITED		1	1	1	1	1	
AUDITORY LIMITED		1	1	1	1	1	
VISUALLY LIMITED	1	1	1		1		1
TEMPORARY LIMITED	1	1	1	1	1		
PARAPLEGIC			1	1	1	1	1
CHILDREN		1	1	1	1	1	
LINGUISTIC LIMITED				1	1	1	1
PHYSICALLY LIMITED	1	1	1		1		
INDEBRIATED PERSON			1		1	1	1

In Table 3 rows and columns are ordered to break conflicts that may exist in the facility.

Table 4: Shifting rows upward

	D	F	A	C	G	B	E
PREGNANT	1	1	1	1	1	1	1
ELDERLY	1	1	1	1	1	1	
TEMPORARY LIMITED	1	1	1	1	1	1	
VISUAL	1	1	1		1		1
PHYSICALLY LIMITED	1	1	1		1		
CHILDREN		1	1	1	1	1	
COGNITVE LIMITED		1	1	1	1	1	
AUDITORY LIMITED		1	1	1	1	1	
PARAPLEGIC			1	1	1	1	1
LINGUISTIC LIMTED			1	1	1		1
INEDEBRIATED PERSON			1		1	1	1

Table 5: Cells formed after matrix

	D	F	A	G	C	B	E
PREGNANT	1	1	1	1	1	1	1
ELDERLY	1	1	1	1	1	1	
TEMPORARY LIMITED	1	1	1	1	1	1	
VISUALLY LIMITED	1	1	1	1			1
PHYSICALLY LIMITED	1	1	1	1			
CHILDREN		1	1	1	1	1	
COGNITVE LIMITED		1	1	1	1	1	
AUDITORY LIMITED		1	1	1	1	1	
PARAPLEGIC			1	1	1	1	1
LINGUISTIC LIMITED			1	1	1		1
INEDEBRIATED PERSON			1	1		1	1

In table 5 Department A (which is the entrance) and Department G (which is the exit) has been placed in the centre. This allows for passengers to enter and exit the facility quickly, covering a shorter distance than before. Centralising Department A (entrance) and Department G (exit) makes it easier for passengers travelling through Departments D and F to not conflict with passengers travelling through Departments C, B and E.

Passengers who follow the route A, D, F and G will not require assistance to travel in the facility as the time and distance they travel is shorter. An elevator which allows access to Departments E, B and C can be used for passenger to use the facility without causing any conflicts or bottlenecks. This service can be outsourced to eliminate efficiencies in the train stations. The elevator is recommended as it can allow passengers to travel backwards to the exit e.g. pregnant women can travel from E, B and C. This will utilise people, equipment and space effectively.

Table 6: Suggested routes for passengers with special needs

PREGNANT	A	F	D	E	B	C	G
ELDERLY	A	F	D	B	C	G	
TEMPORARY LIMITED	A	F	D	B	C	G	
VISUALLY LIMITED	A	F	D	E	G		
PHYSICALLY LIMITED	A	F	D	G			
CHILDREN	A	F	G				
COGNITVE LIMITED	A	F	B	C	G		
AUDITORY LIMITED	A	F	B	C	G		
PARAPLEGIC	A	E	B	C	G		
LINGUISTIC LIMITED	A	E	C	G			
INEDEBRIATED PERSON	A	E	B	C	G		

Table 6 gives recommended routes for passengers with special needs. These routes will allow maximum space utilization, eliminates bottlenecks and allows for processes to be combined to have an effective flow. Integration of the supply chain will also be achieved through partnership and communication. The organisation's vision will be supported through improved material handling passenger control. The results obtained also prove that passenger safety, employee satisfaction, job satisfaction, energy efficiency and environmental responsibility can be improved.

4. CONCLUSION

The Direct Cluster Algorithm gives alternatives to train station managers, as it gives them an opportunity to see if services or departments can be outsourced, if processes can be combined or to identify areas where bottlenecks exist and can be eliminated. This research paper has given a recommendation to managers of the train station to be able to maximise space utilisation, improve passenger flow patterns and minimise the time and distance travelled by different special needs passengers when using the train station by. Flow patterns have been suggested as per Table 6 which will allow for an effective train station layout.

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THE NEED FOR EFFECTIVE APPLICATION OF DATA VISUALISATIONS IN MANAGEMENT INFORMATION SYSTEMS

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ABSTRACT

Data visualisation allows for visual data interpretation, thus simplifying the process of identifying patterns in data. Many Management Information Systems (MIS) are limited to using traditional data visualisation methods that could render these visualisations ineffective. This research sets out to establish a need for the effective application of data visualisations in MISs by removing the constraints that limit data visualisations to predefined types. A methodology was developed and implemented on an existing Energy Management Information System (EMIS), which was regarded as a specialised MIS. The incorporation of innovative visualisation methods was applied to firstly improve administrative aspects of the EMIS, including security and data structuring, and secondly, to effectively highlight data patterns relevant for energy management decision making.

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1. INTRODUCTION

Analysis of organisational data can reveal trends or patterns that can give an overall view of an organisation's activities [1], and can directly support decision making at different levels within the organisation. When these decisions lead to meaningful actions, the organisation gains a market advantage. As more data become available, the challenge of making sense of high dimensional data increases. Decades ago, industry faced the problem of having insufficient data or insufficient access to data to support decision making. Today, however, data warehousing and big-data are leading concepts, with data having become a valuable resource for organisations [2]. The problem that industry faces now is collecting, processing, storing and using large amounts of data as efficiently as possible [1].

2. MANAGEMENT INFORMATION SYSTEMS

Business Intelligence (BI) systems can support organisational decision making [3]. BI puts the user in a better position to make decisions, without the user being an expert on data querying [4]. BI systems include the technology or tools that collect, integrate, analyse and make data available for use [3, 5]. Therefore, a BI system provides access to data from multiple sources, allows for data aggregation and analysis, and supports customisable data visualisation and reporting [6]. For all the advantages that BI offers, a trade-off exists between ease of use and customisability. Increased ease of use and reduced reliance on developers or technical personnel, results in less flexibility or customisability, especially when it comes to data visualisation.

Organisations also have the option to structure and interact with data using Information Systems (IS). Different definitions exist for Information Systems, but in essence an Information System is concerned with collecting, processing, storing and distributing information [7]. Information Systems are used by banks [7], hospitals [8], industrial manufacturers [9] and various other organisations. Furthermore, Information Systems are used for improved traffic safety [10], sustainable supply chain management [11], energy management [12] and monitoring electricity transmission grids [13], to list a few.

Organisations use Enterprise Resource Planning (ERP) systems, which are Management Information Systems (MIS) to support decision making by forwarding relevant information to the different levels of management as soon as action is required based on this information [2]. This MIS therefore consolidates data from different departments in an organisation into a single system.

Graph theory and simple representation of historic data provides a concrete visualisation with direct access to the underlying knowledge or data respectively [14]. This type of data can be represented using a 2-dimensional chart with familiar charting types like a line, bar, area, pie or scatter plot. These chart types are familiar to most people who have worked with data before and are regularly used in spreadsheets and reports. It is therefore not surprising that variations and combinations of these chart types are common place in data dashboards and MISs [15–17]. The functionality of these data visualisations are often supplemented by introducing data interactivity through selection, filtering, reorganization, etc. [18].

Modern data visualisation, however, is focused on delivering visualisations that promote visual identification of patterns or trends in data that would not be possible using traditional charting methods, or that would have required complex computations [19]. The need exists to go beyond the borders of traditional visualisation types to improve the effectiveness of data visualisations in MISs. This can only be done by removing the limitations that are imposed on MISs by restrictive options with regards to data visualisations types. Organisations that own a custom developed MIS could benefit from extending its data visualisation capability to allow for less restrictive and more effective application of data visualisations in MISs.

3. EFFECTIVE DATA VISUALISATION

The benefits of data visualisation become more apparent as datasets become larger and more complex. Hegarty [19] reviewed literature on the insights that cognitive science provides into the design of data visualisations. The main concern noted by Hegarty [19] is that data can be visualised in many different ways using different visualisation types. Therefore, the key challenge is to design a data visualisation to be as effective as possible.

A data visualisation could be custom-made to optimally convey specific information with a specific purpose [20]. However, complex datasets contain many variables that can be visualised in different combinations to reveal different patterns [21–23]. Cota et al. [18] believe that three-dimensional data visualisations could be the most effective method of analysing ever-growing data sets in future. The challenge of designing an effective data visualisation, becomes increasingly more difficult when moving from specific-purpose to broad-purpose data visualisation design. Broad-purpose data visualisation supports data exploration, sense making, and reasoning, with no specific outcome in mind [13, 19].

Hohl [14] argues that effective and meaningful data visualisation design requires an interdisciplinary approach where a designer or artist works with content experts like physicists or engineers. In line with this, Moore [24] distinguishes between the roles of the data wrangler, the content expert and the designer. Table 1 elaborates on the responsibility of each of these roles.

Table 1: Roles required for effective data visualisation design

Role	*Responsibility*
Data wrangler	Understanding data sources and how to access data
Content expert	Having domain knowledge to answer questions effectively
Designer	Using the right type of visualisation to convey the data message clearly

Even data visualisations designed by a multi-disciplinary team may be exposed to bias. Intuitions about the effectiveness of data visualisations do not always conform to their actual effectiveness. Therefore, Kali [25] proposed a Design Principles Database (DPD) for building collaborative design knowledge through empirical application and examination of design principles. Hegarty [19] also recommends that empirical methods used in the cognitive sciences are used for the evaluation of design principles. These well-formed design principles can then aid designers to create effective visualisations.

The literature therefore highlights the importance of effective data visualisation and makes recommendations to promote the design of effective data visualisation. A multi-disciplinary approach ensures diversity in the design process to reduce biases that could render data visualisations unusable. Even when following these recommendations, researchers recommend empirical evaluation of data visualisations to improve their effectiveness.

4. METHODOLOGY

From the literature survey, it becomes clear that although data visualisations already form an integral part of a MIS, this does not guarantee that these visualisations are effective. Therefore, this research sets out to establish a premise for developing more effective data visualisations for MISs. The research approach is summarised in Figure 1. The main steps include:

- Choosing an existing MIS
- Determining opportunities to improve data visualisation effectiveness
  - Identifying opportunities to innovate existing/lacking visualisations
  - Establishing where new data visualisations can be incorporated
- Developing new and improved data visualisations
- Conducting empirical testing to increase the cognition and effectiveness of the developed visualisation

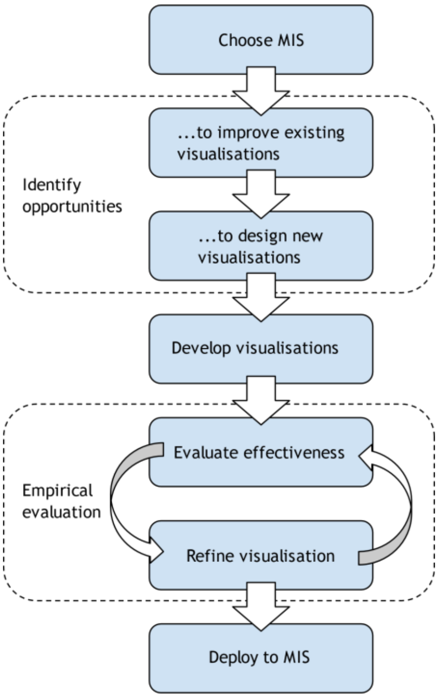


Figure 1: Research approach

The scope of this work is not limited to visualisations that support the core purpose of the MIS, but assesses the need for any data visualisation, with the potential to improve the MIS as a complete system. Figure 2 shows a very simplified architecture of a typical MIS. The main components are the *Database*, *Management platform*, *User interface*, *Administrator interface* and *Data interface*.

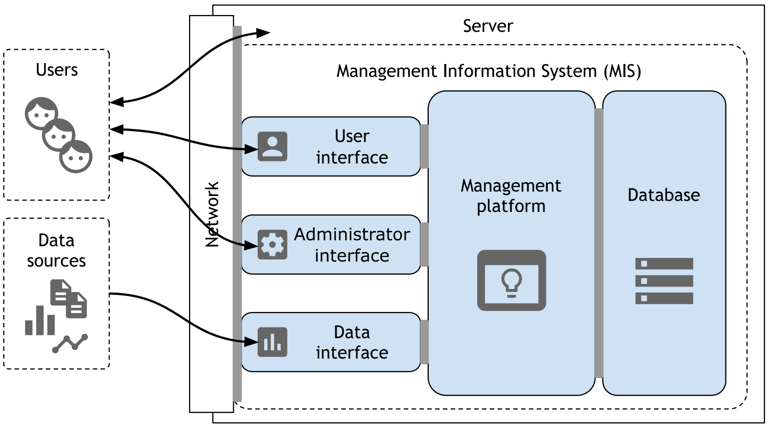


Figure 2: Structural diagram of the chosen EMIS

Data from different data sources reach the *Management platform* through the *Data interface*. Data are then processed, analysed and stored within the *Database*. System *administrators* use a dedicated *Administrator interface* to administrate the MIS. Finally, personnel responsible for decision making use the *User interface* to access dashboards that support decision making, or alert them to exceptions that are identified by the MIS.

The diagram in Figure 2 lays the foundation for the assessment of an MIS to establish where new data visualisations could be incorporated or existing visualisations transformed, to achieve the goals of this research. The main areas identified are:

- Data processing and analysis (*Administrator interface*)
- Security and access control (*Administrator interface*)
- Data structuring (*Administrator interface*)
- Core purpose (*User interface*)

Interestingly, only one of the four areas falls under the *User Interface* which is directly used by the MIS user. The user interface is normally perceived to represent the MIS in its entirety, where in fact the opportunity to incorporate data visualisations extend well into the *Administrative interface*.

When designing a data visualisation, the objectives should be to eliminate irrelevant information [19] and focus on important information or exceptions. In this regard, three questions should be asked: "What information is required from the visualisation?", "What type of data visualisation will convey the information in the best way?" and "Can this information be represented on a single data visualisation?". For less complex data, a single static data visualisation could be sufficient. For more complex data, multiple data visualisations or an interactive data visualisation that allows for data exploration, could be created.

After an improved or new data visualisation has been designed, empirical testing should be done to assess and improve the effectiveness of the visualisations. Hegarty [19] proposes two different methods to assess comprehension of a data visualisation. The first option is to show data visualisations with specific questions, and to then record the accuracy and response times of answers. The second option is to show data visualisations and ask for a description of what the participants take from the visualisation. It might, however, not be necessary to invest time in empirical testing to improve the effectiveness of a visualisation that has a simple objective or merely visualises simple data.

5. CASE STUDY: ENERGY MANAGEMENT INFORMATION SYSTEM

An Energy Management Information System (EMIS) was chosen to assess the need for the improved application of data visualisations to enhance the usability and overall effectiveness of the system, while providing users with actionable information. Examples were chosen from specific areas of the EMIS to illustrate the effect of implementing new or improved data visualisations. Data visualisations were developed using a JavaScript library known as D3 (Data-Driven Documents) [26], which does not place any limitations on the type of data visualisation that can be developed [18].

5.1 Intrusion detection

Security is a growing concern for online Information Systems and ensures that sensitive information is not accessed by unauthorised persons or corporate competitors. Therefore, monitoring network activity to identify any unwanted or malicious activity is critical. The EMIS intrusion detection system monitors all incoming network traffic. Information on suspicious network traffic is stored in the database and displayed in the Administrative interface of the EMIS as shown in Figure 3.

Date-time	Alert description	Event	Type	Port	Source IP	Physical address
2017-05-02 08:04:41	protocol-snmppublicaccessudp	attempted-recon	UDP	161	209.126.136.2	54:E0:32:98:DD:81
2017-05-02 07:55:54	microsoftwindowsgetbulkrequestattempt	attempted-admin	UDP	161	185.94.111.1	54:E0:32:98:DD:81
2017-05-02 07:55:54	protocol-snmprequestudp	attempted-admin	UDP	161	185.94.111.1	54:E0:32:98:DD:81
2017-05-02 07:55:54	indicator-shellcodex86incecxnoop	shellcode-detect	TCP	25	41.74.201.107	54:E0:32:98:DD:81
2017-05-02 07:55:54	protocol-voipsipvicioususer-agentdetected	attempted-recon	UDP	5060	163.172.211.135	54:E0:32:98:DD:81
2017-05-02 07:58:15	hi_server_no_contlen	unknown	TCP	56724	165.255.193.150	54:E0:32:98:DD:81

Figure 3: Intrusion detection log table

Thousands of logs are created by the system per day, hence viewing or filtering these logs using a table can be impractical and time consuming. A "Sankey" visualisation, as shown in Figure 4, was used to represent the logs and to simplify the analysis process. The visualisation is divided into three linked sections, the source IP address, the port of entry and the type of network traffic alert. Much of the information that is logged is repetitive, therefore to simplify the information, repeating parameters or links are grouped together. The size of a group or link represents the relative proportion of occurrences of alerts.

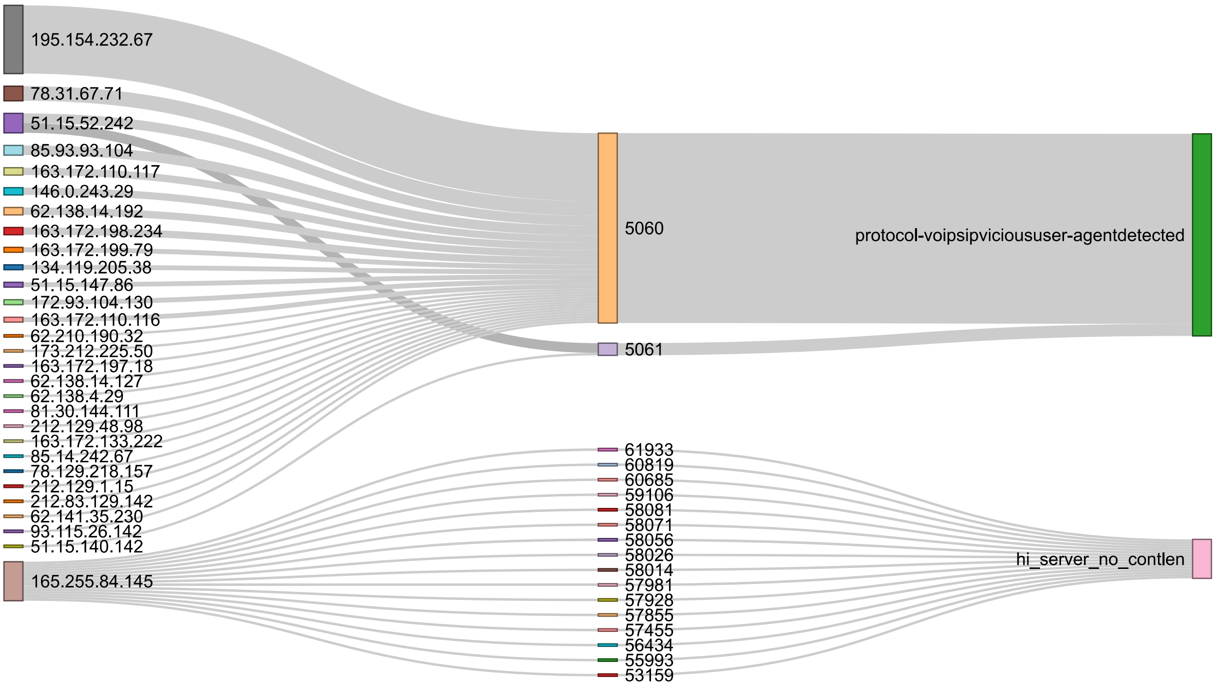


Figure 4: Sankey visualisation of intrusion alerts

Simply looking at the visualisation in Figure 4, a system administrator can see that IP address 165.255.84.145 caused suspicious traffic alerts on different EMIS ports, therefore the origin of the IP address should be investigated. Furthermore, port 5060 produces the most alerts from multiple IP addresses, thus the firewall rules for this port should be reviewed. This visualisation allows system administrators to identify trends, and to act accordingly.

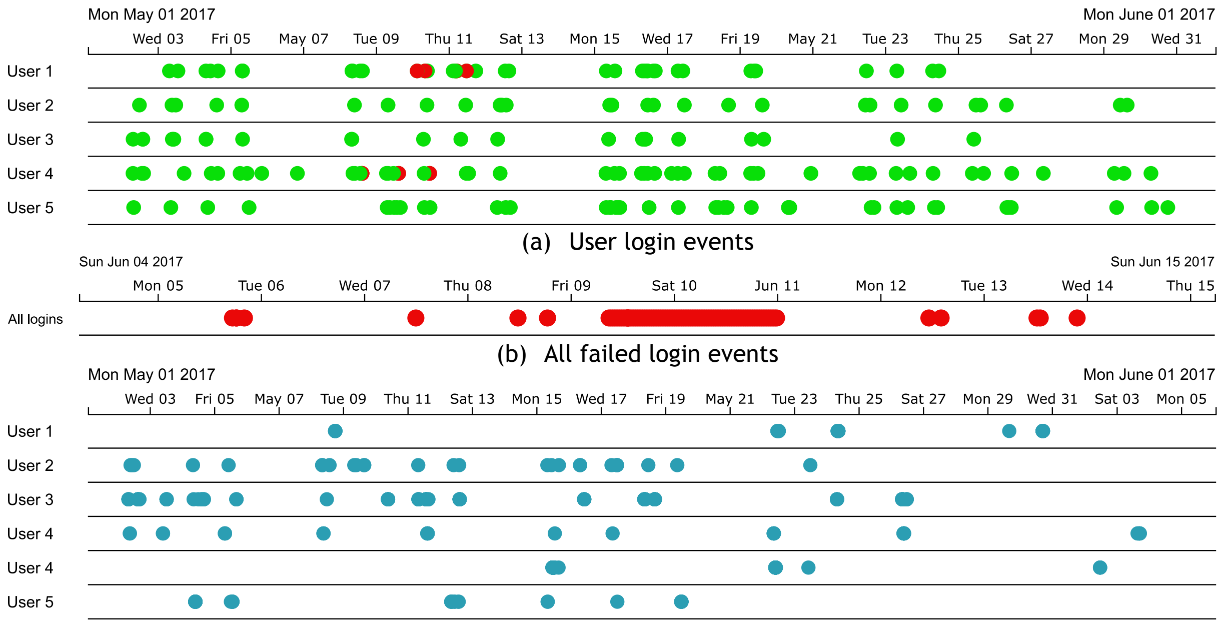
5.2 EMIS user event logs

Another mode of access to the EMIS is through a login portal on the EMIS webpage. It is not only imperative to monitor the activity of authorised users, but also to identify situations where unauthorised users attempt to gain access to the EMIS. Many web systems utilise an event log to store information regarding events that occur. It is important to be able to view the logged events to identify any irregular or unwanted behaviour. The typical way to visualise an event log is using a table as shown in Figure 5.

Date Stamp	User	Username Entered	Success	IP address
2017-05-15 11:29:21	User 1	User1@email.com	Yes	0.0.0.1
2017-05-15 11:06:57	User 2	User2	Yes	0.0.0.2
2017-05-15 10:37:24	User 3	User3@email.com	Yes	0.0.0.3
2017-05-15 10:29:50	User 4	User4@email.com	Yes	0.0.0.4
2017-05-15 10:02:14	User 5	admin.user5	Yes	0.0.0.5
2017-05-15 09:26:20	User X	UserX@email.com	No	0.0.0.10

Figure 5: An example of an event log table

This table provides all the information that is logged. However, it is difficult to identify problem areas or locate patterns in these logs. Figure 6 shows different examples of the “event drop” visualisations that were developed. This visualisation represents each event as a dot on a timeline for a user. A tooltip displays more information for a specific event.



(a) User login events

(b) All failed login events

(c) User access events (for a specific view)

Figure 6: Event drops visualisation

In Figure 6 (a), login successes and failures are indicated using colours. This allows quick identification of users with frequent failed logins as well as other patterns. To further assist with security, Figure 6 (b) shows an example of a filter that was applied to only show failed login attempts. This visualisation can immediately highlight high frequency incorrect logins which could be an indication of an automated system attempting to obtain unauthorised access to the EMIS. Figure 6 (b) is an example of other user events that can also be displayed on the same data visualisation. Figure 6 (c) visually shows the events when users access a specific view of the EMIS. This could improve the understanding of when users access specific EMIS data, or it could highlight views that are not accessed at all.

5.3 EMIS data structure

The EMIS consists of different sections that represent electricity billing, energy intensive systems, energy initiatives and documents. The EMIS has individual node tree structures for each section, and data are linked to the specific node in the tree structure. These tree structures are useful to access data in a structured way, and for authorising user access to specific data by linking the user to specific nodes they are authorised to access. These tree structures mostly have only minor variations. This results in a scenario where data must be linked to similar nodes on different tree structures, increasing administrative responsibility.

A potential solution to this problem is to develop a master structure and to create each individual tree structure as a customised version of the master structure. Therefore, the individual tree structures share the nodes of the master structure and avoid the duplication of nodes. This is the perfect solution, except when considering the master structure of a mining group that consists of different mines and offices in different countries. This requires a master structure that allows for nodes to have multiple parent nodes, effectively moving from a flat tree structure to a much more complex structure.

Therefore, while reducing node duplication, the new solution merely increases the complexity of the administrative user interface. A network visualisation, consisting of sets of nodes connected by edges, was developed to address this problem [27]. To illustrate the concept of basing tree structures on a master structure, Figure 7 shows an example of a simple master structure (left) and different derived tree structures (right). Depending on the requirement of the specific section of the EMIS, the tree structure can be adapted, while inherently preserving the link between tree structures, as the tree structures share the same nodes.

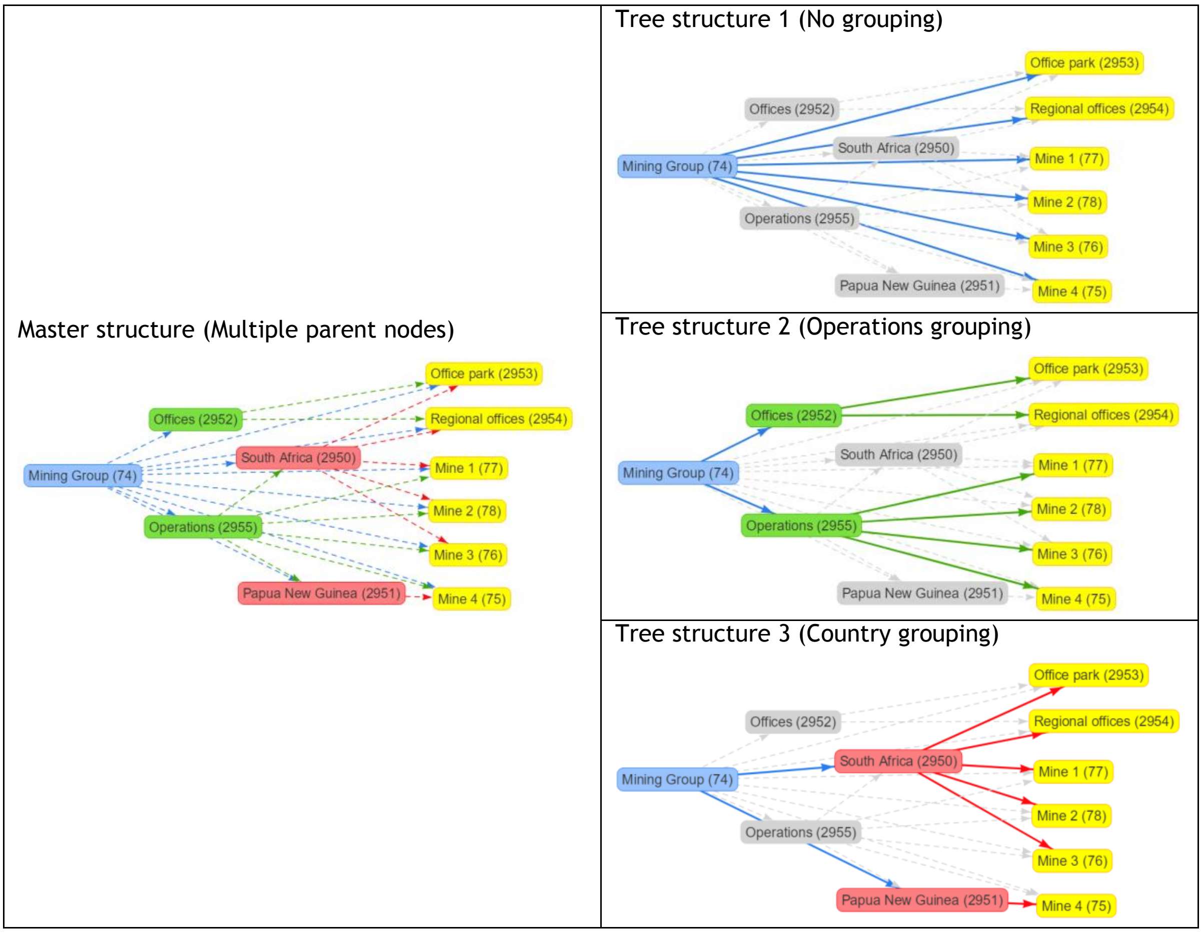


Figure 7: Node builder

As it may not be practical to view a complete master structure with legible details, the visualisation is interactive, allowing the user to zoom in and out, and to pan to navigate the whole data area. A search function was added to allow administrative personnel to search for node names. To decrease user disorientation when jumping to a selected node, a transition effect was used as proposed by Hegarty [19].

5.4 Energy initiative performance monitoring

In an effort to identify the most effective visualisation to represent energy initiative performance metrics, a number of visualisations were developed that would represent the same data set. The ideal visualisation would convey more information than before, whilst not over complicating the view. With this in mind, a process of iterative improvement of visualisation methods was implemented. Each visualisation was developed with the aim of improving on the previous visualisation.

Figure 8 shows the initial visualisation used for the performance assessment of energy initiatives or projects. The main colourised blocks, green and red, indicate days where project targets were met or missed, respectively. Orange indicates days where targets were missed by a margin of less than 10%. Blue represents days where targets may have been missed under unavoidable circumstances. Finally, the grey blocks indicate days where data were unavailable.

	1 Mar	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31 Mar
Project 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Project 2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Project 3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Project 4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

Figure 8: Basic matrix visualisation

The problem with this visualisation is that it is not possible to ascertain to what extent a project may be over/under performing. This makes it difficult to compare projects or to prioritise projects that need the most attention. In a first attempt to present more information visually, additional colours were added to the grid. This "heat map" visualisation allows the viewer to identify the extent of under or over performance. An example of this visualisation is shown in Figure 9.

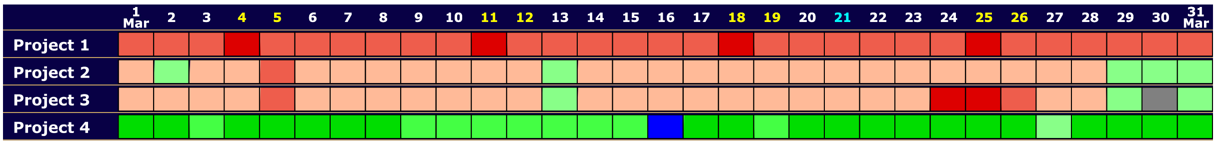
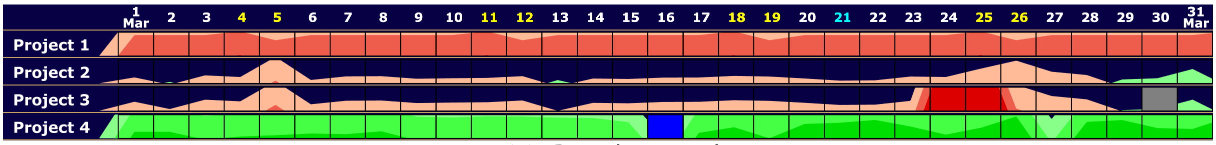
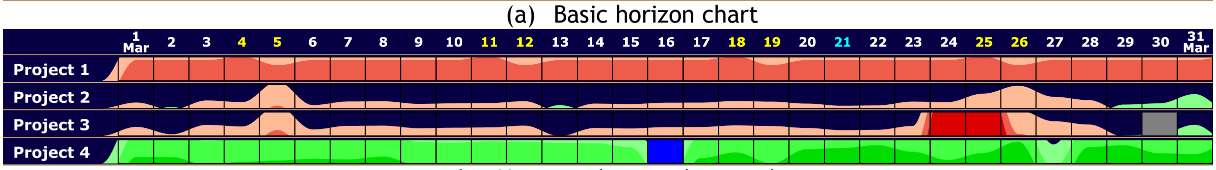


Figure 9: Heat map visualisation

The heat map visualisation remains simple and intuitive whilst adding a bit more information. However, an improvement could be made by providing even more information. To achieve this, the "Horizon" visualisation method was investigated. In this method, data are displayed as an area graph. The graph area is divided into band ranges where each band is given a different colour. To use the horizontal space more effectively, the bands are then overlapped and negative values are mirrored. Smoothing was implemented on the data to remove the sharp edges in the visualisation. An example of the horizon visualisation is shown in Figure 10 (a) and (b).



(a) Basic horizon chart



(b) Horizon chart with smoothing

Figure 10: Horizon chart visualisation

Whilst the horizon chart did provide more information, due to the low resolution of the dataset it is not immediately clear how to interpret the visualisation. As the daily performance is mostly independent of performance on other days, clarity can be increased by removing the interpolation between data points. Figure 11 shows the data represented using vertical bars for each date.

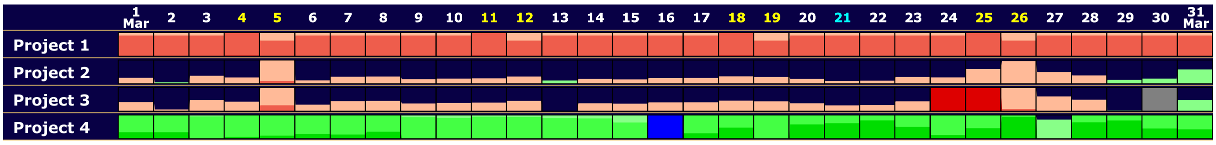


Figure 11: Overlapping bar visualisation

At this point, a new visual type was investigated. In this visualisation, as illustrated in Figure 12, the area of a circle was used to represent the performance metric per day. The same colour scheme as in the initial table, was used to show under or over performance as well asunavailable data. Therefore, more information is added whilst not adding much more complexity. Due to the similarity with the initial visualisation's style, users would not have difficulty making a transition.

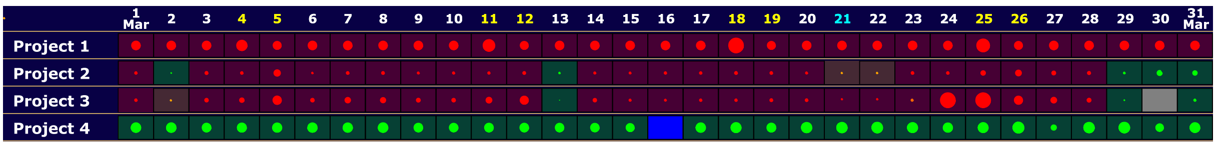


Figure 12: Bubble visualisation

A survey was conducted to assess whether the perceived comprehension of the visualisations matched the actual comprehension from users. This led to the continuous refinement of the visualisations from Figure 8 through Figure 12. The survey results are detailed in the next section.

The developed visualisations provide more visual information without compromising on complexity. However, an alternative visualisation may add additional value. As an alternative approach, an interactive "parallel coordinates" [28, 29] visualisation method was implemented for the dataset. In this visualisation, all the energy initiatives or projects share the y-axis as shown in Figure 13. This makes it easier to compare the performances of projects and identify outliers.

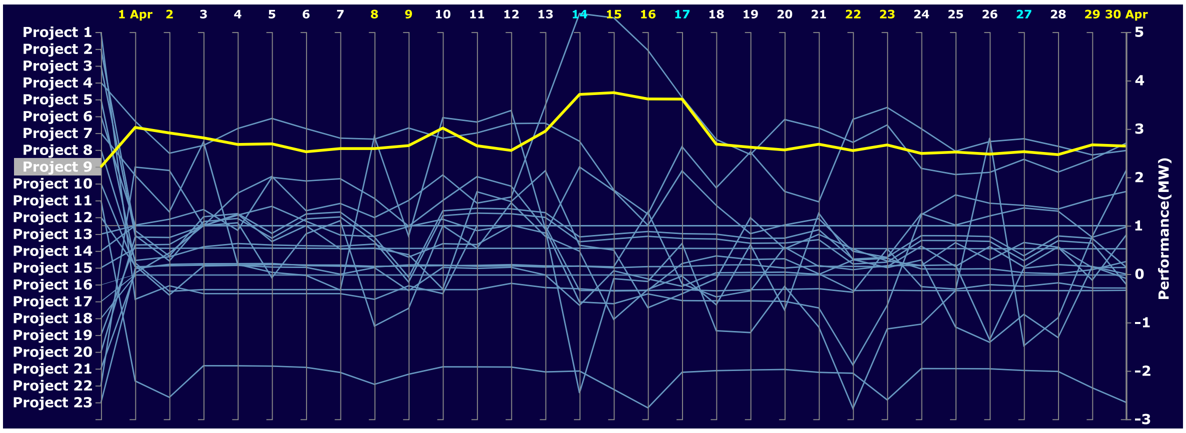


Figure 13: Parallel axis chart

Interactive filters were added to ease the analysis of the data. An example of the use of the filters can be seen in Figure 14. In this example, the projects that have produced an energy impact in excess of 2 Megawatt, for the last 5 working days, are highlighted.

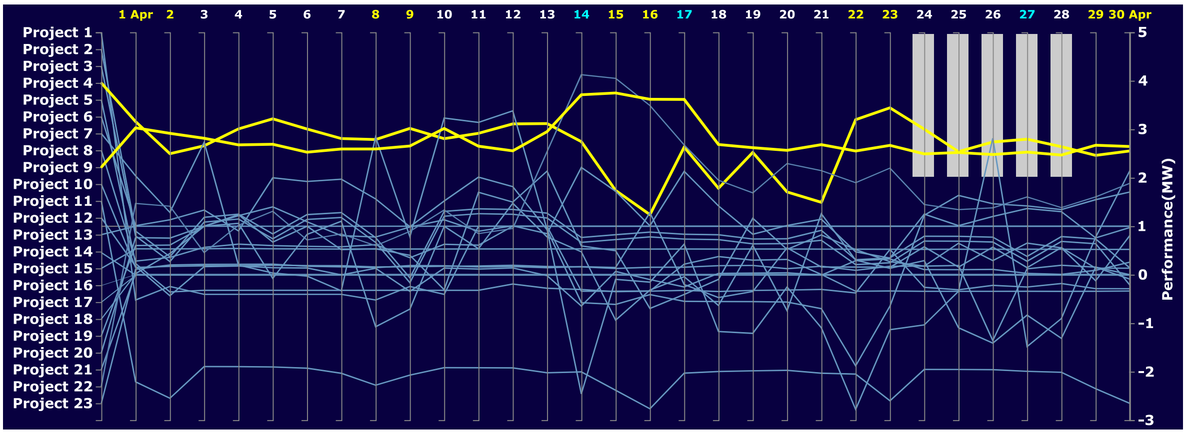


Figure 14: Using parallel axis filters to show over performing projects

This interactive visualisation requires some form of familiarisation and is therefore not intended to provide an intuitive static visualisation. This type of visualisation, however, promotes data exploration and is a suitable alternative view to the matrix visualisations.

5.5 Survey conducted (energy initiative performance monitoring)

Survey questions were asked regarding each visualisation. The participants were asked to solve typical problems using each visualisation. The responses for these questions were timed as more difficult visualisations take more time to analyse. Typical survey questions/problems relating to energy initiative performance include:

- Identify the best performing initiative (overall)
- Identify the worst performing initiative (overall)
- Identify an initiative that shows improving or declining performance

The survey results are presented in Figure 15, showing the response times for each question asked, grouped by the different visualisations. This figure also shows the average response time for each visualisation and the proportion of incorrect responses that were excluded from the figure.

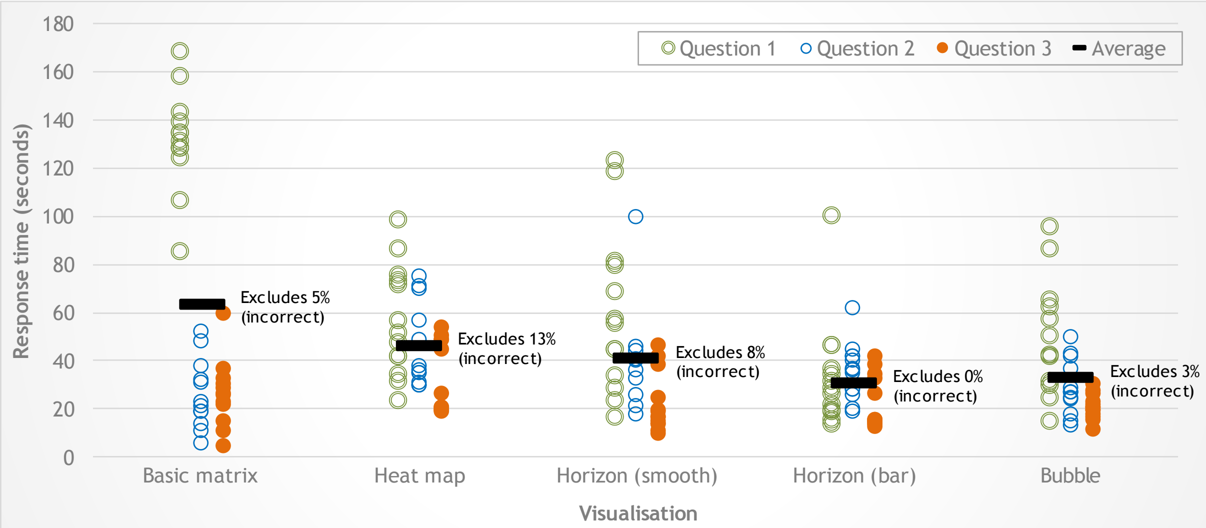


Figure 15: Survey results

From Figure 15 it is clear that the response time and incorrect responses were reduced using the newly developed visualisations. The horizon bar and bubble visualisations produced the shortest response times with the most accurate responses. The purpose of the survey was not to identify visualisations with the shortest response time, but rather to assess the effectiveness and ease of use of visualisations. The spread of response times however, differs from question to question, therefore indicating that the questions need to be relevant to the intended use of the visualisation to provide useful insights.

The surveys were conducted in group sessions with participants being EMIS users. The number of questions was limited to ensure that the total time spent on conducting follow-up surveys would remain time effective. The main purpose of the surveys was not to quantify the effectiveness of newly developed data visualisations. However, the surveys assisted to compare the improvement in effectiveness of the visualisations to the perceived effectiveness for each iteration of the development process.

6. CONCLUSION AND RECOMMENDATIONS

This research sets out to show that there is a need for the effective application of data visualisations in Management Information Systems (MISs). As a case study, an existing Energy Management Information System (EMIS) was assessed to identify opportunities for effective application of data visualisations. The core objective of an EMIS is to provide energy managers with information in a way that supports decision making. However, this research regarded the EMIS as a specialised MIS, thus considering all aspects of a MIS including security, data processing, data structuring and user interfaces.

The assessment that was performed on the existing EMIS was limited to key areas to ascertain the potential for developing more effective data visualisations for MISs in general. The results presented in the previous sections merely provide a glimpse into the benefits of implementing more effective data visualisations on a MIS. It is clear that there is a need for effective application of data visualisations on MISs. This need is rooted in the fact that effective data visualisation has the potential to reduce the burden on system administrators, and to support end-users with quicker and more effective decision making.

It is therefore recommended that a full audit of an existing MIS is done to detail the extent to which the need for more effective data visualisation exists. A detailed list of potential applications of data visualisations is the expected outcome of this audit. It is further recommended that a critical review of the audit findings is done in order to shortlist the most beneficial and cost-effective items on the list. Only after developing and implementing these data visualisations, can an attempt be made to quantitatively or qualitative assess the true benefit and impact of these more effective data visualisations.

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TECHNICAL ASSISTANCE PROGRAMME FOR THE SOUTH AFRICAN FOUNDRY INDUSTRY

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ABSTRACT

The local foundry industry is expected to play an important role to support the infrastructure development advocated by the South African National Development Plan (NDP). To this end, the Department of Trade and Industry (DTI) through its initiative of the National Foundry Technology Network (NFTN), embarked since 2015 on a series of technical programmes to assist the foundry industry to overcome various challenges which are negatively impacting on its competitiveness. This paper presents an account of projects carried out by the Metal Casting Technology station at the University of Johannesburg aimed at improving the performance of selected sand casting foundries with regards to productivity, environmental compliance and technical skills. Lessons from this exercise are drawn to motivate for the continuation, expansion and enhancement of the technical assistance programmes for the South African foundry industry.

Keywords: National Development Plan; Foundry Technology Network; Metal Casting

OPSOMMING

Die plaaslike gieterybedryf sal na verwagting 'n belangrike rol speel om die infrastruktuurontwikkeling wat deur die Suid-Afrikaanse Nasionale Ontwikkelingsplan (NGD) voorgestel word, te ondersteun. Om hierdie rede het die Departement van Handel en Nywerheid (DTI) deur middel van sy inisiatief van die Nasionale Foundry Technology Network (NFTN) sedert 2015 begin met 'n reeks tegniese programme om die gieterybedryf te help om verskeie uitdagings te bowe te kom wat 'n negatiewe impak op sy mededingendheid. Hierdie vraestel bevat 'n verslag van projekte wat deur die Metal Casting Technology-stasie by die Universiteit van Johannesburg uitgevoer word, wat daarop gemik is om die prestasie van geselekteerde sandgieteregies te verbeter ten opsigte van produktiwiteit, omgewingsvereistes en tegniese vaardighede. Lesse uit hierdie oefening word getrek om te motiveer vir die voortsetting, uitbreiding en verbetering van die tegniese bystandsprogramme vir die Suid-Afrikaanse gieterybedryf.

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1 INTRODUCTION

The National Development Plan (NDP) of South Africa was launched in August 2012 [1]. The ultimate goal of this plan is to eliminate poverty and reduce inequality in the country by 2030. Building of capabilities in terms of infrastructure development, sustainable environment and improving quality of education are some of the critical priorities of the plan in order to achieve its goal. Infrastructure development specifically relates to the upgrade and modernisation of telecommunications, water, energy and transport which are essential for faster economic growth of five percent per annum and lower unemployment of six percent by 2030. The plan recommends that the Gross fixed capital formation needs to reach thirty percent of Gross domestic product (GDP) by 2030, with the public sector investment reaching ten percent of GDP. SMART objectives and details associated actions addressing the economic infrastructure are identified and listed in Chapter Four of the plan.

The local foundry industry is one of the manufacturing industries that is expected to play a critical role for the success of the infrastructure development envisaged in the NDP [2]. It is estimated that fifty percent of components used for electrical, water, transport applications are made of castings produced by foundries. Metal casting consists of pouring molten metal in the cavity of a refractory mould or die. The metal flows and solidifies in a controlled manner inside the mould or die. At the end of the solidification process, the mould or die is separated from the casting [3]. Advantages of the casting process include mass production, low cost, complex shape and good mechanical properties of products [4]. Approximately 70 percent of castings are manufactured by the sand casting process with the rest obtained from other processes including die casting, shell casting and investment casting [4].

Recent statistics from the South African Institute of Foundrymen (SAIF) indicate that close to 200 foundries were operating in 2015 in the country [5]. The metal casting industry is known to be experiencing challenges that threaten its long term survival [6]. Major difficulties facing the industry include a cutthroat competitive global market of castings, outdated equipment and scarcity of foundry skilled workforce. This situation forces the country to export castings required for infrastructure development at inflated price and long lead times`. In the case where the non-competitiveness of the local foundry industry is not adequately addressed, an opportunity for job creation is also missed which is inconsistent with the objectives of the NDP to reduce unemployment.

In addition to the peculiarities of problems highlighted above, the local foundry industry is also confronted with global metal manufacturing issues prevailing in any foundries across the world [7]. These challenges include amongst other the stringent demand for quality castings free of defects with continuously reduced wall thickness and weight. Reduction of manufacturing cost and lead design time through technology innovation such as Additive Manufacturing processes [8]. New and strict environmental compliance regulations in terms of waste disposal and gas emission [9]. These issues are also mentioned and considered as part of the NDP scan of the environment and objectives.

Several initiatives and programmes have been established by the South African government through the Department of Science and Technology (DST) and the Department of Trade and Industry (DTI) to assist the local foundry industry [10]. The Metal Casting Technology Station (MCTS) is one of the initiatives of DST started in 2005 to provide technical assistance to local foundries by using the scientific expertise and equipment available at the University of Johannesburg [11]. The National Foundry Technology Network (NFTN) is an example of a programme launched in 2008 by the DTI designed to stimulate the local foundry industry by enabling technology localization, human capacity development and technical assistance [10]. This programme is currently steered by the Centre for Scientific and Industrial Research (CSIR).

This paper presents case studies of technical assistance to four local sand casting foundries. The projects were carried out by the MCTS with the funding of the NFTN during the period of 2015 to 2016 years. The total value of the assistance programme amounted to 1.5 million Rands. The projects addressed a relatively wide spectrum of metal casting manufacturing issues including casting design, scrap reduction and environmental compliance. The project methodology, results and lessons learned are explained in the following sections.

1. EXPERIMENTAL PROCEDURES

Four foundries located in Gauteng and Kwa-Zulu Natal were selected to receive the sand technical assistance of the NFTN on the basis of their potential with regards to job creation, technology localisation and casting export. Two of those foundries were greensand foundries while the other two foundries were resin bonded sand foundries based on poly-urethane no bake (PUNB) system. Table 1 indicates the casting process, type of castings produced by the foundry as well as the problem experienced for which technical assistance was required to eliminate or reduce it. The casting defects were ranked first in terms of associated cost or occurrence in the different foundries. Foundries are presented in a chronological order of assistance intervention. Projects duration was approximately six months.

Table 1. Type of castings and technical problems experienced by the selected foundries for NFTN assistance

Foundry name	Casting Method/Moulding method/ Metal	Casting type	Problem
Foundry 1	Greensand/blowing-Disamatic/ Cast iron	Automotive	Shrinkage on knuckle casting
Foundry 2	PUNB/Hand ramming/ Aluminium	Automotive	Gas defect
Foundry 3	PUNB/ hand ramming/Aluminium	Electrical	High new sand addition
Foundry 4	Greensand/ jolt-squeeze/ Steel	Road/ Water/ Sugar industry	Rough surface finish/ sand inclusion

The shrinkage casting defect experienced by foundry 1 on an automotive knuckle component supplied to international OEM is shown in figure 1. An example of gas defect occurring on casting stick produced at Foundry 2 for automotive application is shown in figure 2. A typical electrical casting manufactured at foundry 3 is illustrated in figure 3. This casting exhibits sand inclusion defect. Rough surface finish and sand burn-on defects are clearly visible in Figure 4 on a high production casting at Foundry 5.

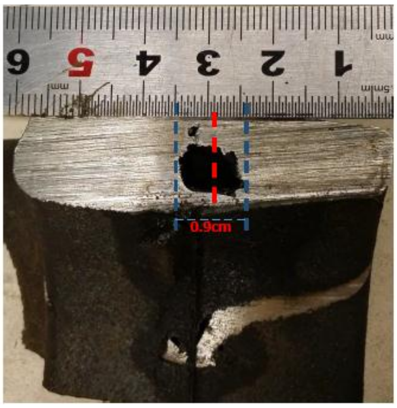

Figure 1: Shrinkage defect at Foundry 1

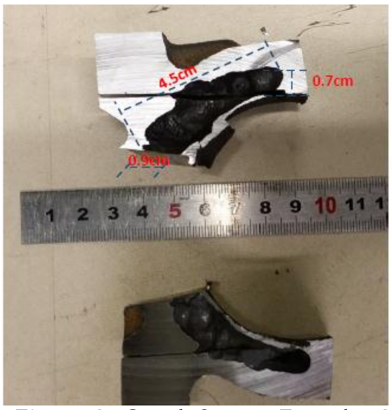

Figure 2: Gas defect at Foundry 2

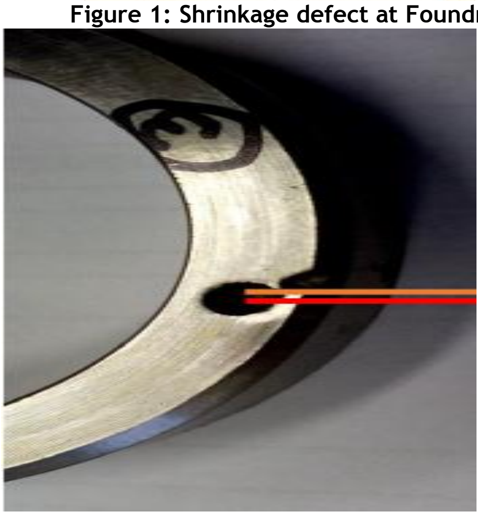

Figure 3: Sand inclusion

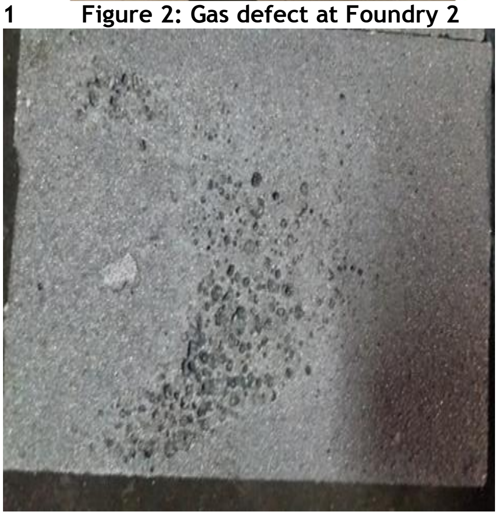

Figure 4: Sand inclusion

Root-cause analysis (RCA) was the methodology adopted for the technical assistance projects to local foundries. Manufacturing factors including raw materials, equipment, process and workmanship was assessed in order to determine the root causes of the problem experienced by the foundry. Table 2 shows the different sand testing techniques used during the RCA

Table 2. Sand testing used during the RCA

RCA factors	Types	Sand Testing
Raw Materials	Silica sand	Sieve analysis Loss on Ignition (LOI)
	Greensand/ Resin bonded sand	Moisture Compactibility Strength Sand density
Equipment	Mulling machine	Mulling efficiency
	Mixing machine	LOI
	Sand shakeout	LOI
	Returned sand storage hopper	LOI
Foundry Process	Moulding	Sand/ iron ratio
	Sand reclamation	LOI
	Sand control system	-

The manufacturing factors were informed by the literature [13, 14] as possible causes for the casting defects experienced by the foundries. These factors were assessed using appropriate sand testing techniques on a daily basis over the duration of the project. The sand testing results and trends were analyzed using descriptive statistics and compared to specifications. Out of specification factors were corrected and the casting production carefully assessed for elimination of the casting defects. This iterative process was stopped as soon as the root cause responsible was found. Casting trials were also conducted to confirm the root cause by switching it on and off.

The technical Assistance Programme also had a human capacity development component. NFTN required that students get involved in the execution of the projects as part of their experiential learning or final year project. In addition, training was organized for foundry employers on sand control to avoid casting defects.
The next section present the root cause identified for the different casting defects at the selected foundries beneficiaries of this technical Assistance Programme.

2. ROOT-CAUSE ANALYSIS RESULTS AND DISCUSSION

2.1. Case study 1: Foundry 1

The non-uniform compaction of the sand mould produced on the Disamatic machine was identified as the root cause for the shrinkage casting defect of the knuckle component. This casting defect can occur when the feeding system designed to prevent the defect does not optimally function due mould wall movement resulting from low compaction of the sand [15]. Figure 5 shows the distribution of mould hardness on the cope and drag pattern profiles. Areas with the lowest sand hardness were found to have low sand density and to be prone to sand casting shrinkage.

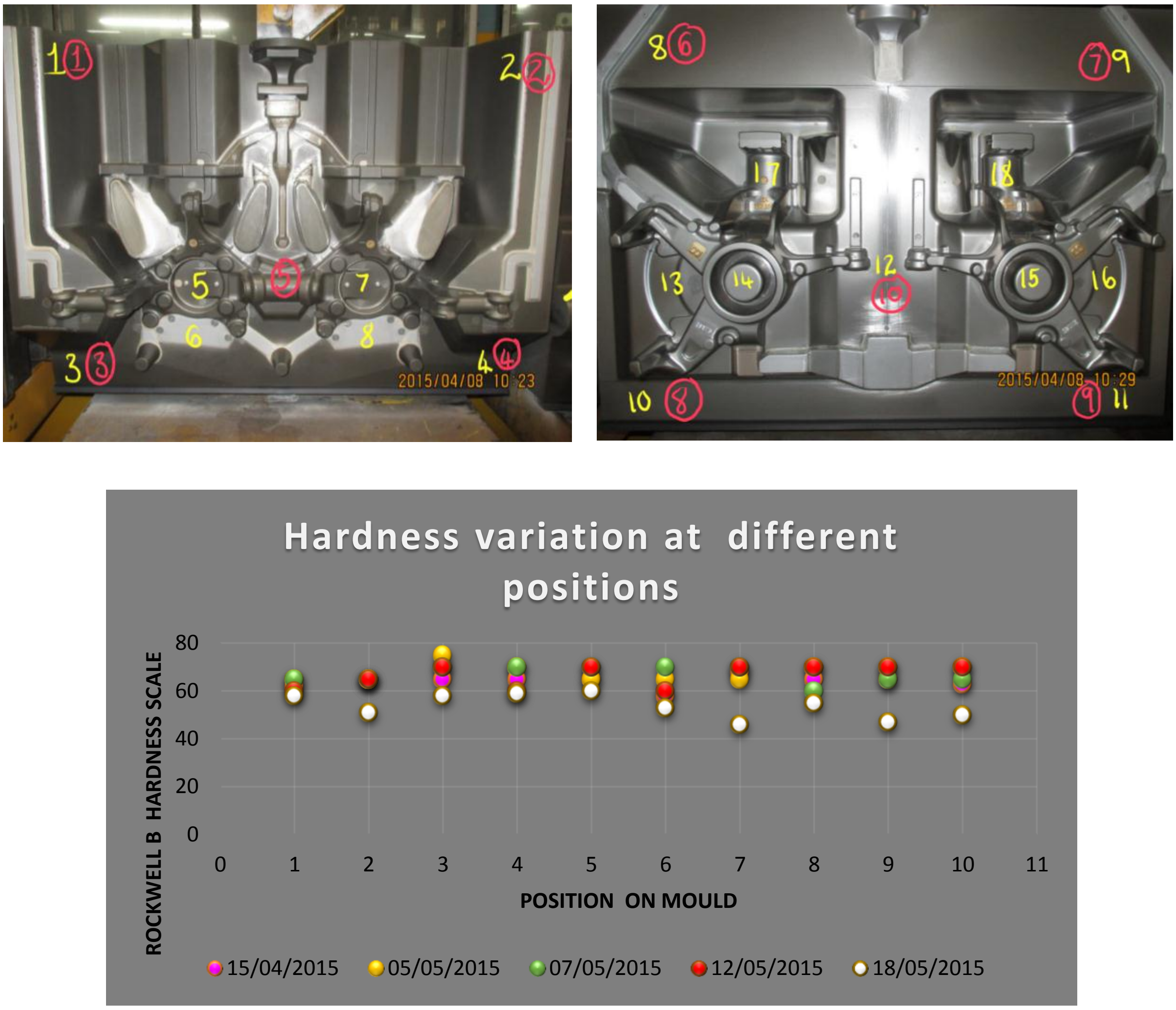

Figure 5: Variation of mould hardness a function of position shown on the cope and drag pattern profiles.

The casting defect problem was alleviated by increasing the moulding pressure of Disamatic machine (values) and avoiding the mulling efficiency to fall below 80%. It was also found that the occurrence of the shrinkage casting defect increased when the mulling efficiency was reduced below 70% due to high addition of clay in the mulling machine. Employers at Foundry 1 were trained on sand control with emphasis on clay addition on the mulling machine to maintain an adequate mulling efficiency.

3.2 Case study 2: Foundry 2

In the case study of the gas casting defect experienced at Foundry 2, a faulty continuous mixer was identified as the root cause. The resin addition during the moulding sand preparation was found to be erratic as illustrated in Figure 6. High loss on ignition (LOI) as shown in figure 6 generated gas that could easily be trapped at the surface of the casting. Other sand issues were also uncovered at Foundry 2 in the course of the project execution including inconsistent silica sand properties and poor reclamation. These factors could occasionally aggravate the gas defect on stick components.

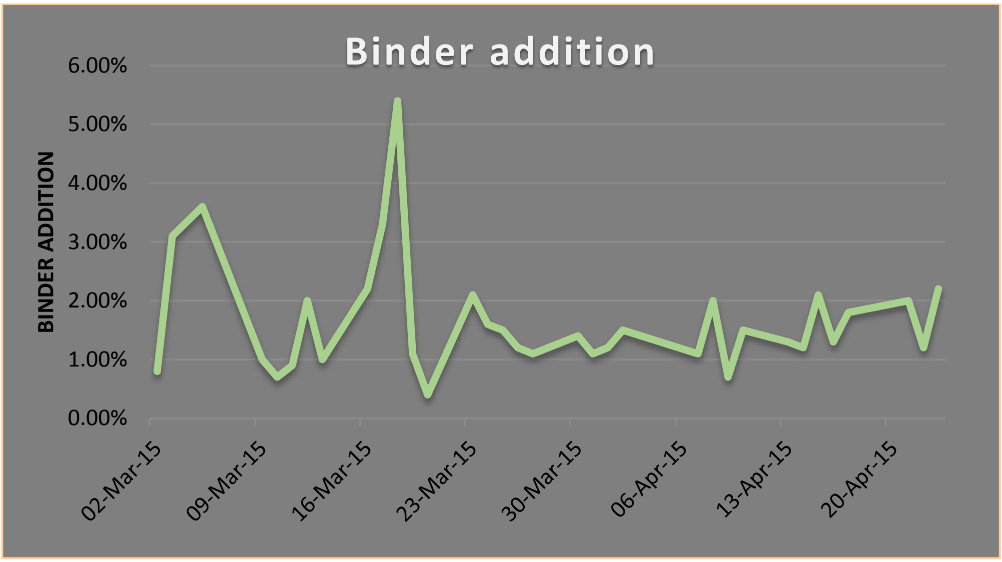

Figure 6: Variation of LOI in the moulding sand at Foundry 2 over a month period. Graph shows High LOI on the 2nd, 16th of March due to excessive addition of resin and catalyst.

Repair of the chemical addition devices on the continuous mixer and proper calibration of this equipment were measures implemented to produce a consistent sand mould and eliminate the gas defect. Importance of mixer maintenance and calibration was the focus of the training offered to the sand plant employers at Foundry 2.

3.3 Case study 3: Foundry 3

The main problem at Foundry 3 was the excessive new silica sand addition to the system resulting in high operating cost of the plant and poor quality casting in terms of surface finish and sand inclusion. The associated discarding and dumping cost of the used sand also contributed to high operating cost as well as environmental non-compliance.

Inexistent sand control in the plant was identified as the root cause of the problem. Because of the lack of sand monitoring and testing, large quantity of new silica sand was added to the system sand in an attempt to prevent casting defects. Figure 7 shows the addition of new sand as a function of LOI.

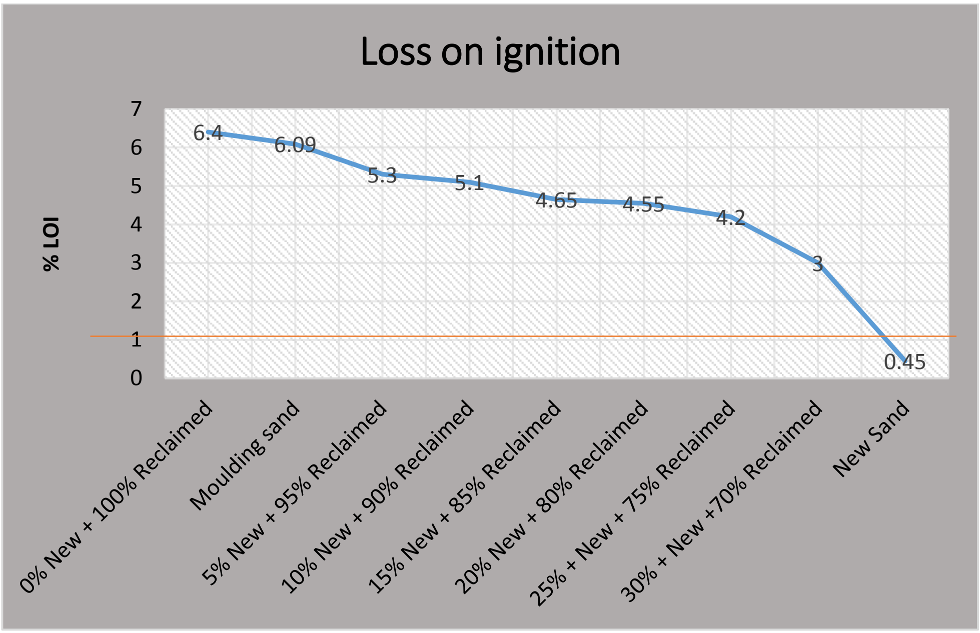

Figure 7: Sand addition to the system sand at Foundry 3

A sand control system based on the monitoring of the LOI of the used sand to determine the addition of the new silica sand to maintain an appropriate size distribution and sand strength was put in place at the foundry in order to eliminate the problem. Figure 8 shows the associated chart of the proposed sand control system. This solution resulted in the decrease of sand addition by 20% compared to the initial quantity.

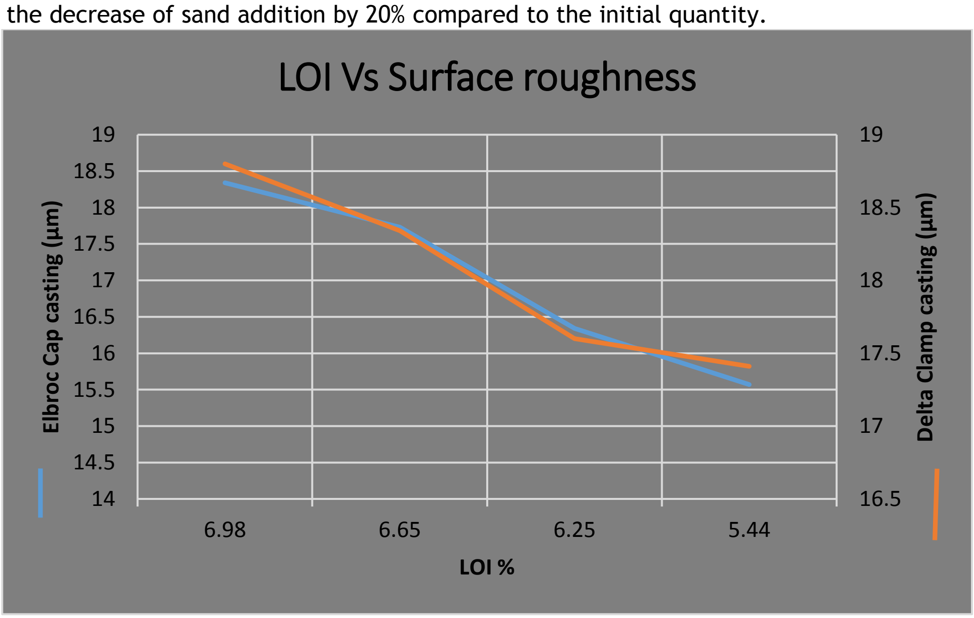

Figure 8: Sand control chart implemented at Foundry 3

3.4 Case study 4: Foundry 4

Rudimentary sand control was identified as the root cause of casting defects at Foundry 4. The foundry was enabled to determine the composition of the prepared and returned sand in terms of silica sand, clay, carbonaceous and inert materials. As a result mill additions were erratic and inappropriate resulting in moulding sand having inadequate properties prone to casting defects such as poor surface finish, sand burn-on, sand inclusion and gas defect. Figure 9 shows the returned sand composition at Foundry 4 obtained by conducting a silica sand programme. The pie chart clearly indicate that the composition of the sand was inadequate in terms of low silica sand, high coal dust and very high inert material explaining the casting defects experienced at the foundry.

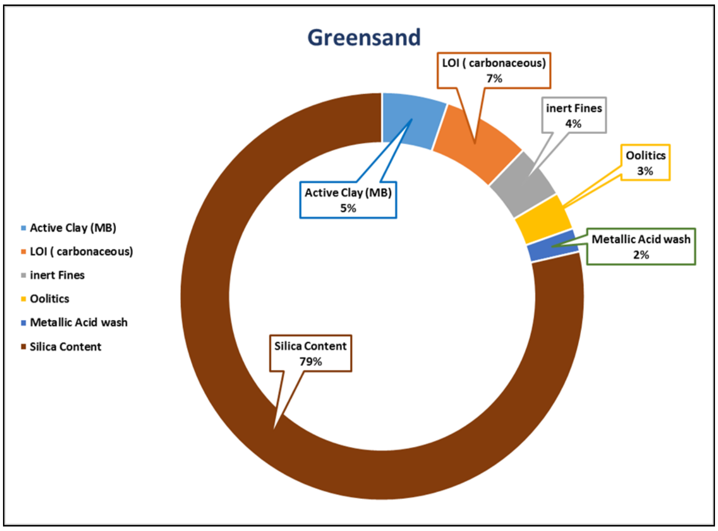

Figure 9: Silica programme test results at Foundry 4

Routine methylene blue testing for active clay, volatile and LOI determination for carbonaceous materials were proposed to Foundry 4 as a mean of eliminating the problem at Foundry 4. The proposed tests complement the physical tests performed at the foundry in providing a better picture of the greensand and determining the correct mill additions. Employers were trained on greensand testing and control.

3. LESSONS FROM THE PROJECTS

The positive and negative lessons drawn from the projects are listed below:

Positive lessons

- Reduction of casting scraps in the foundry beneficiary of technical assistance
- Increase competitiveness of casting due to production of quality castings
- Awareness of local expertise availability in the technical field of sand casting (MCTS, UJ, SAIF, CSIR, Mintek, etc.)
- Human resource capacity development and successful internship programme for University learners.

Negative lessons

- Inferior local raw materials in terms of properties used by foundries
- Elementary sand control system practiced in foundries
- Lack of investment in new technology
- Skill shortage
- Limited funding

4. CONCLUSION

South African foundries are expected to play a critical role for the success of NDP in terms of its infrastructure development priority. This will only be possible if the quality challenges experienced by these foundries are addressed to increase their competitiveness and readiness to supply high integrity castings. The paper showcased governmental interventions in the form of sand technical assistance programme to local foundries to eliminate casting defects, reduce operating cost and comply with environmental laws. This programme also offered opportunity for human capacity development which a key objective of the NDP. The recommendation from this programme is the continuation of the technical intervention with possibility of equipment funding for sustainability of implemented or proposed improvement solutions.

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MECHANISMS INFLUENCING HEALTH CARE OUTCOMES IN SUB-SAHARAN AFRICA: A SYSTEMATIC REVIEW

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ABSTRACT

Health care outcomes in sub-Saharan Africa are found to be the poorest in the world. In order to make motions toward remedying this, mechanisms involved which affect these outcomes must be investigated. This paper systematically reviews academic literature discussing factors which influence health care outcomes in order to identify prominent issues affecting the improvement of health in sub-Saharan Africa. In order to retrieve literature five electronic databases were searched, namely: Academic Search Premier, Emerald, ProQuest, Scopus and Web of Science on the 7 October 2016. The search utilized search terms "Factors affecting OR influencing", "health care outcomes" and "Africa". Results were restricted to fall between 2000 and 2016, papers returned not referring to sub-Saharan Africa were excluded. The initial broad search yielded 1199 papers, of which 363 fit the criteria to be reviewed. Of these papers 180 of the 363 paper had been published over the four-year period 2013-2016, showing the incline in focus of healthcare in sub-Saharan Africa. The review developed a comprehensive understanding of the health research landscape in sub-Saharan Africa in terms of area and diseases covered as well as health service factors identified as enabling factors for the improvement of health outcomes. Factors recognized as barriers can aid in both informing policies and to steer future projects.

1. INTRODUCTION: HEALTH CARE IN SUB-SAHARAN AFRICA

The topic of healthcare is multifaceted, illustrated by the definition of health care as the set of services provided by a country or organization for the treatment of the physically and the mentally ill (Oxford Dictionaries n.d.). When considering healthcare it is therefore necessary to analyse the provision of services in conjunction with the state of the community to be served. It is not possible to accurately understand the level of healthcare provision without analysing the two collectively. Thus, factors which influence health care are multidimensional. Both services, in terms of policy, organization and resources and the state of the community, in terms of demographics and health pandemics must be thoroughly understood and analysed (Andersen 1995).

In order to monitor the health of a region, and thus give an indication of the healthcare systems in place, the World Health Organization (WHO) have selected three overarching indicators to be used to do so, these indicators are: life expectancy; healthy life expectancy (HLE) and number of deaths before age 70. When analysing the standing of sub-Saharan Africa (SSA) for each indicator attention needed in the field of health care becomes clear. When considering life expectancy: 22 of the 48 SSA countries make up the lowest ranking countries worldwide. HLE which considers the number of years from birth one can expect to live in full health, shows, according to the WHO in 2015, that the average world expectancy is 63.1 years. The African Region (AFR) is the only region below this average, coming in almost 10 years behind the South East Asia Region, the next lowest region. The third indicator, the number of deaths before age 70, yields results no differently, with the number of deaths in AFR being significantly higher than any other regions. When considering the health in Africa these results clearly highlight the importance of understanding this sector in order for improvement and development to take place.

2. LITERATURE REVIEW METHODOLOGY

A systematic and comprehensive literature search was carried out on 7 October 2016. The search was completed in accordance with the protocol described in this section. The electronic platforms and search terms used are described in Section 2.1. The restrictions and reasons for inclusion or exclusion of literature is described in Section 2.2. The literature was analysed through the data extraction method described in Section 2.3 in order to accurately sort and synthesize data collected as discussed in Section 2.4.

2.1 Search Strategy

The electronic platforms identified from which to search and retrieve literature were: Academic Search Premier; Emerald; ProQuest; Scopus; and Web of Science. These platforms were selected due to their extensive and well renowned reputations regarding the quality and diversity of articles and databases accessed. On each platform the literature search was restricted to articles, reviews and conference proceedings to ensure that both high quality and a variety of opinions are identified.

The search terms were defined in order to idenitfy a comprehensive array of literature addressing the various factors influencing the health care outcomes in SSA. When searching "*mechanisms*" within five words of "*influencing* OR *affecting*" the volume and relevance of articles returned were found to be poor. Thus the search term "*factors*" was used instead of the term "*mechanisms*". Health care was searched as both one word and two words to make room for spelling differences, enclosing "health care" in inverted commas to return only articles with the words in conjunction. The use of the asterix at the end of Africa was to allow for the return of articles which made reference to the root word africa in any form, to extend the search to articles which may not specify the focus as SSA. The selected keywords of the search defined to retrieve the relevant literature were therefore selected as follows:

(factors influencing OR *factors affecting)* AND
(healthcare OR *"health care")* AND *africa**

2.2 Inclusion and exclusion criteria

Articles published prior to 2000 were excluded from the scope of the literature reviewed. This time period was selected due to the rapid developments and changes in the healthcare field in the new millennium. There are several reasons for the exponential changes, but two specific reasons should be mentioned. Firstly the Millenium Development Goals (MDGs) set by the United Nations (UN) served to focus attention on specific issues. Secondly, the exponential growth of HIV in this period demanded a considerable amount of attention (WHO 2016).

The titles, and where necessary abstracts of literature resulting from the search strategy were analysed in order to eliminate any articles which did not pertain to the field of human health or health care. The number of articles considered was then further reduced by eliminating articles which did not consider SSA either directly or in an indirect manner. The abstracts and keywords of articles were reviewed in order to ascertain the area and scope of the study to establish whether the literature is relatable to SSA.

Citation statistics can be valuable to support the identification of key foundational articles in a field. However, filtering articles based on the number of citations, may lead to the exclusion of more recent articles that have not yet been cited and articles that propose ideas that have not yet been accepted into orthodox thinking. The decision was thus made to not filter on the number of citations to ensure an up-to-date and sample of articles representing a broad spectrum of ideas.

The scope of studies found which met the above criteria were broad. The studies were not further vetted to meet specific quality criteria. This was done to establish a broad spectrum of literature allowing for a comprehensive and diverse array of data to be gathered creating a large library of literature, which touched on an array of factors. The intention behind this was to establish a comprehensive understanding of the different aspects and perspectives on health care in SSA.

2.3 Data Extraction

After completing the study selection process, data was extracted utilising the Atlas.ti platform. Atlas.ti was used to capture text excerpts, where relevant, taken from the full text using coded keywords to capture data and classify themes. For each paper reviewed data was extracted according to a standardized data capturing outline. Not all studies could be classified or contributed to each data field, due to the comprehensive list of fields captured, creating some gaps in the data fields. The data fields comprised of study characteristics, namely:

- Year of publication;
- First author;
- Article title;
- Geographic location and setting;
- Study population subgroup;
- Study type;
- Disease or healthcare outcome of focus; and
- Highlighted factors identified to influence healthcare outcomes.

Highlighted factors were listed according to the categories illustrated in Figure 2.3.1, the choice to utilise the Andersen model is discussed in Section 2.4. The categories are the overarching themes of the model, namely: contextual characteristics; individual characteristics; health behaviors; and outcomes. This was done in order to group the articles in a structured manner. This broad grouping allowed for initial sorting. Each category was then further explored as needed. This data extraction process was repeated to compensate for errors made during the first sweep through the articles.

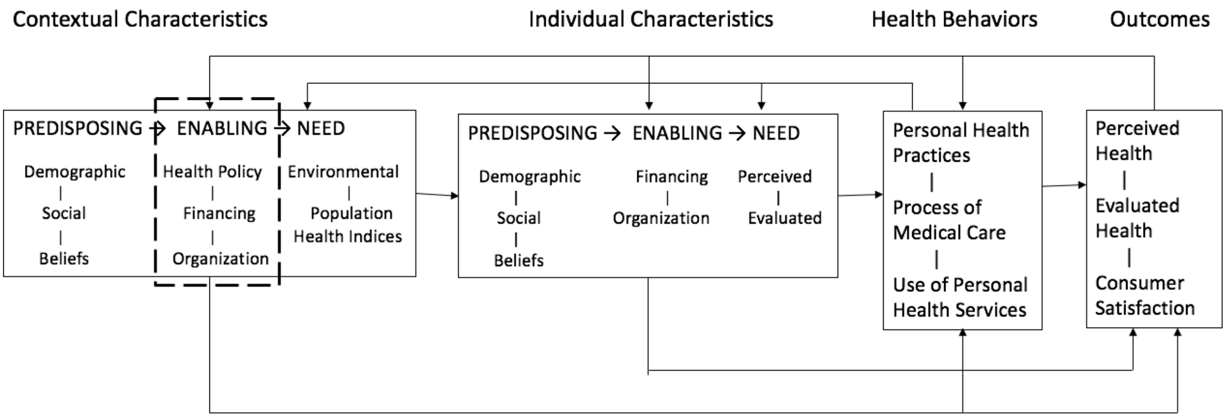

Figure 2.3.1: A behavioural model of health services use including contextual and individual characteristics (Andersen 2008).

2.4 Data Synthesis

In order to synthesize the data captured several methods were applied. Utilising the data table described in Section 2.3, quantifiable data captured such as year of publication, geography, subgroups and health outcome or disease are mapped. This is done in order to create an understanding of the landscape of health care research foci for research focusses on SSA.

The areas selected to be explored were taken from the behavioural model of health services use developed by RM Andersen, as depicted in Figure 2.3.1. With specific focus on the “Enabling contextual characteristics” enclosed by the dashed lines. The choice to pursue enabling factors is made, as Andersen (1995) describes potential access as the presence of enabling resources, indicating the improvement of these can improve health access. Enabling variables are further described as mutable or subject to change through policy with the objective of influencing access to care (Andersen et al. 2002). The realization that areas within the health care system are more mutable than others leads the article to highlight areas within the health system which can be improved upon. This model is selected as it is found to comprehensively encapsulate the health system in SSA and motivates the mutability of factors. This approach was found to be of interest for the given study and was thus pursued.

Data was then synthesized according to the health care definition, in terms of the state of health of the community and the provision of health services. With the provision of health services being the enabling variables identified by Andersen (2008), namely: Health policy; Financing; and Organization. It was found the topic of resources was extensive and aligned both with Financing and Organization thus was established as a stand alone theme within provision of health services. With the intention of highlighting mutable variables which may serve to inform policy makers, and illustrate the areas which receive academic focus when analysing mutable factors found within the health system.

3. RESULTS

A description of the literature found and utilised and the characteristics thereof are discussed in this section of the paper. An understanding of health care in SSA according to the literature is presented, with clarification according to geographic regions.

3.1 Study Selection

The search across the five e-platforms initially yielded 1199 articles, these articles were then screened. Duplicates across platforms were then removed resulting in 793 articles, of these any articles preceding publication in 2000 were removed. The titles, and where necessary abstracts, of the remaining 683 articles were analysed in order to remove any articles which did not relate in any way to healthcare or human health, resulting in 646 articles. Of the final 646 articles any article with a focus that did not consider SSA, or the general population thereof either directly or indirectly was removed resulting in a final 363 articles. This process is summarised in Figure 3.1.1.

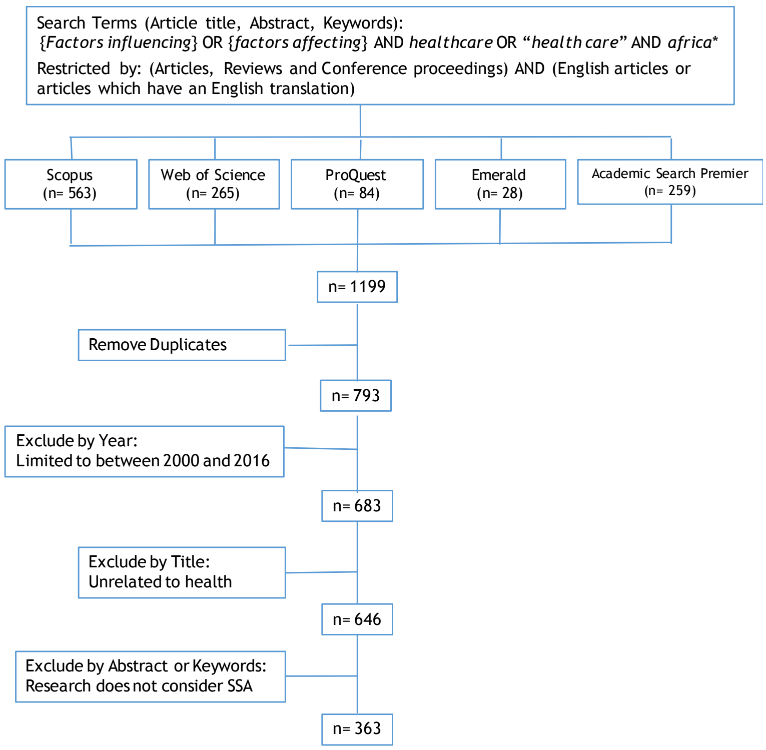

Figure 3.1.1: Flow chart depicting systematic literature review filtering process.

3.2 Study Characteristics

After mapping the 363 articles into Table A.1 in Appendix A, a landscape of health care research focussed on SSA was developed. This table is of interest as it compiles all the literature captured giving indications of which regions and illnesses were captured by literature. The table captures the fields as described in the data extraction section. Figure 3.2.1 shows the distribution of papers published between 2000-2016, it is of interest to note that almost half of the papers were published between 2012 and 2016, with the dip in 2016 attributable to the date of the systematic literature search being before the end of 2016. Whereas less than ten percent of the papers were published in the first four years between 2000-2004, this is an indication of a steady increase in research interest.

By categorising the articles geographically one can get a grasp of where the perspective or information for the literature is coming from as well which areas are unaccounted for and may need to investigate healthcare further. By excluding any articles which do not in any way consider SSA, all articles fell into several geographic categories, namely:

- General: these articles look at an idea without considering the geographic or environmental effects;
- Global: articles use examples from all around the world to derive a globally applicable result;
- Low and middle income: consider developing countries and countries with low or middle incomes, not all countries within these article are based in SSA, yet a country within SSA was mentioned;
- Africa: which made mention of countries both within SSA and the rest of Africa, or referred to Africa as a whole;
- SSA: which considered SSA as a whole or where articles considered several countries which did not fall into the same geographic regions.
- Middle Africa: Angola and Cameroon;
- East Africa: Ethiopia, Kenya, Tanzania, Uganda, Mozambique, Madagascar,Malawi, Rwanda, South Sudan, Zambia and Zimbabwe;
- West Africa: Benin, Burkino Faso, the Gambia, Ghana, Guinea, Mali, Nigeria, Sierra Leone and Togo;
- Southern Africa: Botswana, South Africa and Swaziland.

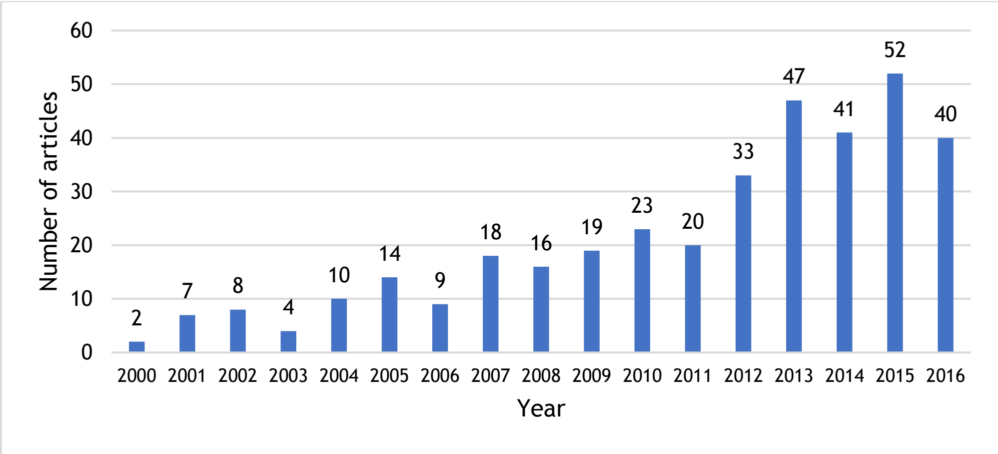

Figure 3.2.1: Number of articles published yearly.

Figure 3.2.2 shows the proportions by which each region contributes to the academic literature reviewed. Geographical sub-regions containing countries as stated above follow the categorisation by the UN. The contribution from East Africa dominates, which can be attributed to the extensive list of countries found in this region. It must be noted that the contribution from Southern Africa follows East Africa and of this 95 of the 101 articles are focussed on South Africa. This is significantly greater than any other country. This result is not unexpected as the review is being carried out in English, so the review may be biased towards Anglophone Africa. Middle Africa contributes three articles, less than 1% of the review articles, due to the likliehood that papers in this region are published in French. This could be attributed to the fact that Cameroon is the only country in this region which lists English as an official language.

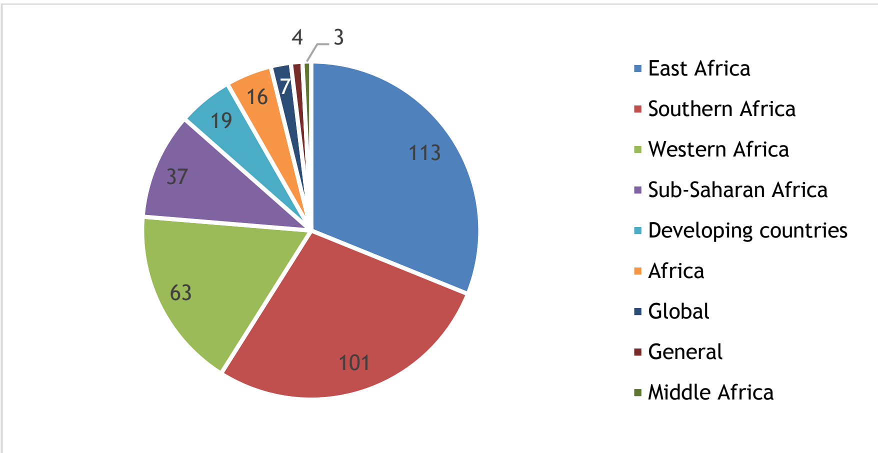

Figure 3.2.2: Proportion of geographic focus according to reviewed articles.

4. FACTORS INFLUENCING HEALTH CARE OUTCOMES IN SSA

The literature reviewed conveys numerous areas of weakness or barriers in SSA which have an impact on health care outcomes. These factors have been categorized as described in Section 2.4. Each area is discussed according to factors identified when reviewing the literature.

4.1 State of the community: Burden of Disease

The burden of disease is investigated in order to understand the state of health of a community. This is done to gain an understanding of the evaluated need in an area, which health services must cater for. SSA is found to have high burdens of disease (Goudge et al. 2009), with the HIV/AIDS outbreak compounding the already high burden. The geographic climate and lack of sanitation has also meant the region has experienced high levels of Malaria and an acceleration of infectious disease pandemics(Zaman et al. 2015)(Buor 2004).

The listed areas of health, in data Table A.1, are extensive thus in order to map it, they are categorised according to Sustainable Development Goals (SDGs). The SDGs contain the following prominent health goals: Universal Health Coverage (UHC); reproductive, maternal, new-born, child and adolescent health; infectious diseases; non-communicable diseases (NCDs); mental health and substance abuse; and injuries and violence. Whist the MDGs focused on: reducing child mortality; improving maternal health; combating HIV/AIDS, malaria and other diseases; as well as health being a component of several other MDGs (nutrition, water and sanitation) (WHO 2015). The choice to look at the SDG categories is due to the broader spectrum thereof. The use of SDGs is of interest as although a portion of the articles are published prior to 2016 during the MDG time period, an understanding of the SDG areas within SSA can be used moving forward. Figure 4.1.1 illustrates the proportion of areas of healthcare of the articles reviewed. It must be noted some articles were categorised in two categories. For example, the treatment of Malaria during pregnancy would be categorised as both an article addressing infectious diseases and maternal health.

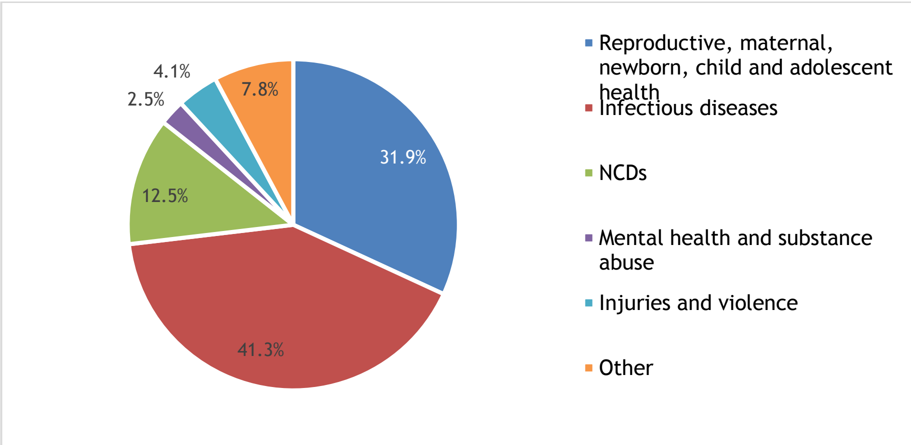

Figure 4.1.1: Proportion of SDG categories addressed by articles.

It is of interest to note 80% of the occurrences of disease discussions in articles relate to 13 specific areas, namely: HIV; Maternal health; Malaria; TB; Child health; Sexual health; Health; Injury; Cervical cancer; Maternal and child health; Mental health; Hypertension; and Epilepsy as illustrated in Figure 4.1.2. This is of interest as it further indicates the areas of focus of research and builds on the understanding of disease focus from Figure 4.1.1. The area of maternal and child health is listed both individually and in conjunction due to the way in which articles addressed these areas. The focus on HIV, Malaria, maternal and child health align directly with Goal 4: Reduce child mortality; Goal 5: Improve Maternal Health and Goal 6: Combat HIV/AIDS, Malaria and other diseases, of the MDG programme over this period (United Nations 2015). It is interesting to note that Diabetes is not found to be topical within the literature, the reason for this is uncertain. It must be noted NCDs for the purpose of this graph are not grouped but listed as distinct health areas such as hypertension and cervical cancer.

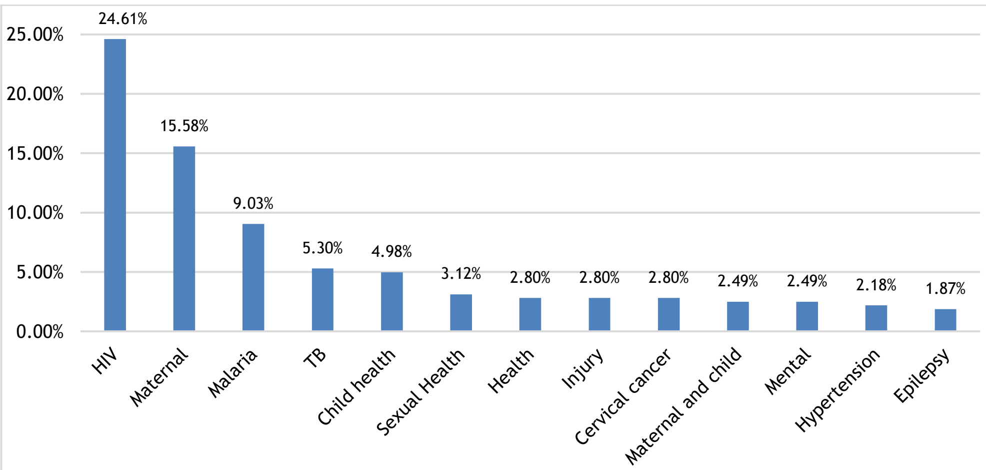

Figure 4.1.2: Proportion of specific diseases discussed contributing to 80% of the literature.

It is of interest to investigate which regions are investigating which SDG category, to gain an understanding of the priorities in health care of the area, according to academic literature. Figure 4.1.3 shows each geographic region and the respective areas of focus. It is of interest to note the area of reproductive, maternal, new-born, child and adolescent health is more frequently found to be carried out over more generalised geographic areas in comparison to that of infectious diseases. This is not found to be surprising as infectious diseases, by nature will affect a specific geographic area and can be studied and combated within this area.

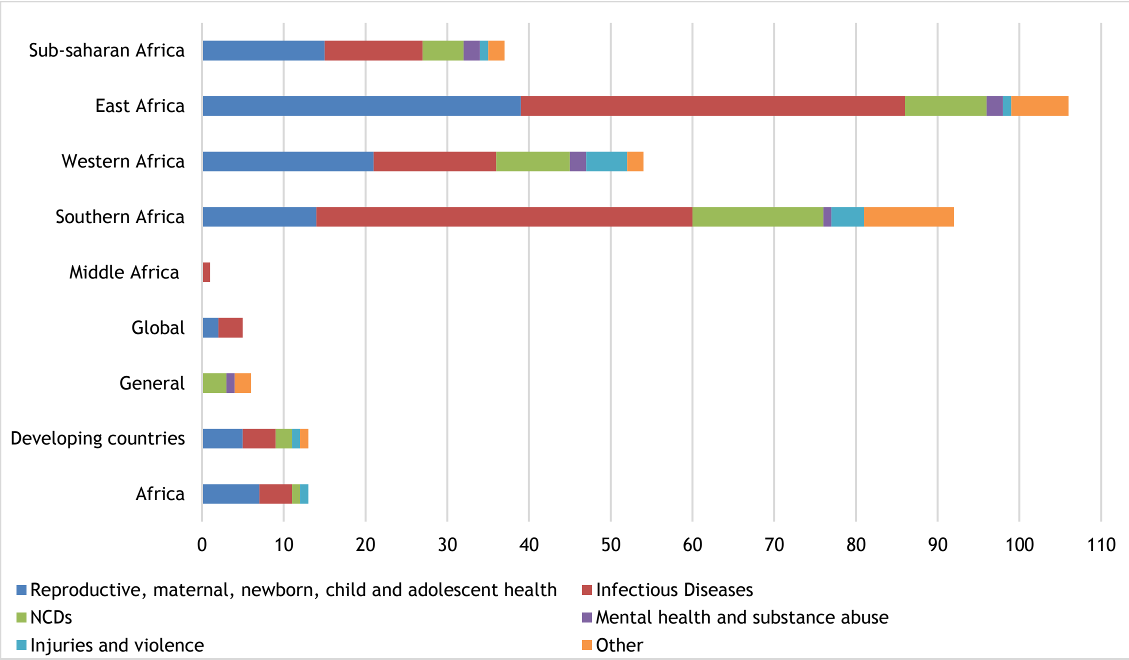

Figure 4.1.3: Healthcare research per geographic region.

The examination of diseases addressed by literature gives an understanding of the perceived need of health care in SSA, however as Figure 4.1.3 illustrates this is not necessarily the actual disease burdens found in an area. For example, the lack of articles found in Middle Africa is not indicative of a lack of disease but academic literature. Therefore, to further quantify burden of disease data is needed.

4.2 Provision of Health Services: Health Policy

Policy both at a national and organization based level is found to have far reaching repercussions and is necessary for system functionality. Health policy is grouped, for the purpose of the review, as clinical practice, governance and policy. These are made reference to by 25% (91) of articles, referring to policy implementation or the barriers presented by a lack of policies, clinical practices and protocols and governance.

From the review it is clear that, at an organization based level, lack of policy brings about functional issues such as mismanaging patients, poor service delivery due to resource mismanagement and issues regarding staff responsibilities and protocols (Kok et al. 2015). On a national level policies or moreover the lack of policy is recognised to hinder health care outcomes, as they are deemed to encourage good practice and project implementation. If there are clear policies laid out projects can be initiated to align with these as well as being a guideline for project goals and protocols. Having a system in place with good policies and protocols has been found to encourage donor and stakeholder investments(Gilson et al. 2012). A lack of policy or protocol is attributed to the lack of knowledge on the respective field, supporting the argument that these articles will be utilised for policy making. It must be noted that policies have limitations, in some cases especially in the SSA climate, rigid policies can be barriers to health care outcomes (Layer et al. 2014). If clinics have rigid policies they may not be able to make compromises when necessary and may push patients away (Welniak et al. 2014). The opposing problem to this is that in some cases good policies may struggle to be received and implemented (Durrheim et al. 2003). A large problem facing policy adherence is lack of communication, there are many policies pertaining to many different spheres, which may undergo changes, it is not uncommon that policies do not reach operational levels resulting in poor adherence of policies (Abekah-Nkrumah et al. 2010)(Sissolak et al. 2011).

The management of diseases and endemics has been strongly aligned with the existence of policies. With policies in place HCWs are able to align the way in which they process patients (Abekah-Nkrumah et al. 2010). The development of policies requires much research therefore the resultant policy is often the most effective solution which, if followed, will have the best results (Aaserud et al. 2005). Articles recognised a lack of policy as a hindrance to systems functioning and disease management.

National health financing projects and insurance programmes are often dictated by policy makers and rely on policies to keep functional and intact(Dror et al. 2016). Having poor policies frequently lead to the demise of such projects, thus it is imperative to set up and communicate these (Twikirize & O'Brien 2012).

On all levels of health care organizations policies dictate operations, resource allocations and influence the populations utilization thereof (Buseh et al. 2002; Twikirize & O'Brien 2012; Fongwa 2002). Whilst not all policies may be adhered to, they make an attempt to influence all health system measures and in return are influenced by the current state.

4.3 Provision of Health Services: Financing

On the reverse to poor service delivery, populations are found to invest in health insurance schemes and seek health care if it is affordable and offers quality service (Dror et al. 2016), it is therefore pivotal to the health of the population to have quality service encouraging health utilisation.

Health care financing in SSA is either done through the government, foreign aid, privately or through health insurance schemes. It is imperative health care is affordable by all and will not be the cause of impoverishment, health care financing provides much needed succour to the majority of the population seeking health care in SSA (Boateng & Awunyor-Vitor 2013).

Health care financing is strongly aligned with policy as these schemes need to be well designed and implemented using policies to function successfully. Seven articles explicitly address community based health insurance programs. Community based health insurance (CBHI) schemes with a variety of designs have been introduced across SSA but with generally disappointing results so far, with two exceptions, Ghana and Rwanda. The success of these both countries can be attributed to introducing the schemes with effective government control and support coupled with intensive implementation programmes (Odeyemi 2014). With four articles addressing National health insurance schemes (NHIS), looking at the readiness of hospitals in South Africa (Dyers et al. 2016), NHIS affecting the informal sector in Kenya (Mathauer et al. 2008) and NHIS in Ghana in terms of the effect of moral hazard (Yawson et al. 2012) and policy (Boateng & Awunyor-Vitor 2013).

Reasons for joining a health insurance system in any form has mixed feedback from the literature, showing there is no one reason. Some prominent reasons, although not consistently found through all the articles discussing insurance are as follows: health service quality, income, education, age, household size, woman as head of the household, elderly family member, recent history of illness and distance to health facilities ((Dong et al. 2009)(Dror et al. 2016)). It is found ambiguity of the benefits, capabilities and services offered by health insurance must be clearly communicated as often enrolees are discouraged, without a comprehensive understanding of the system ((Robyn et al. 2012)(Mathauer et al. 2008)). In 2016 Dorr conducted a systematic literature review looking at factors which influenced the uptake of CBHI in low and middle income countries, of the 54 papers retrieved and reviewed, 36 were based in SSA.

Having health insurance is recognised to reduce the delay in seeking care (Njuguna et al. 2016). If the public health care systems are in a poor state often populations can turn to health insurance or community health insurance schemes. This is done to access health care that would otherwise be unaffordable. It has been found in an article addressing South Africa, Ghana and Tanzania, health insurance is pro-rich and regressive in the informal sector(Macha et al. 2012). Financing systems are urged not only to generate funds, but consider barriers such as affordability, availability and acceptability to improve equitable financing and benefit patterns of health care (Macha et al. 2012).

It is of interest to note no articles investigated the disparities in health care provision between private and public health sectors, (George et al. 2013) acknowledged the large disparity in service levels and HCW workloads but did not pursue the topic. The inequities between the two sectors are large and deserve increased attention.

4.4 Provision of Health Services: Organization

Health care organizations in SSA are comprised of several fields, the health facilities, health clinics and external drivers such as financing systems. For countries with high burdens of disease, such as the prevalence of HIV/AIDS in SSA, it is imperative to strengthen the capacity of public systems as well as improve resource allocation to address immediate needs (Zeng et al. 2012).

17 articles referenced poor health infrastructure as a barrier to health care, eight of which investigated woman and child health, five focussed on HIV/AIDS and the remaining four discussed the health system in terms of HCWs motivation and location, information systems and the public health system. Health care infrastructure in SSA can be found to face three issues, either facilities do not exist, are poorly managed or underfunded. As a result, facilities are frequently found to be overburdened and in a poor state pushing people away from making use thereof (Sipsma et al. 2013)(Sialubanje et al. 2015). In rural areas, it has been found in some cases facilities are in such a poor state women choose not to seek maternity care and deliver babies at home, putting them at greater risk of both maternal mortality and infant mortality (Sipsma et al. 2013).

The lack of infrastructure has led to the development of several other means of health care delivery, such as community health centres, home visitations and initiatives such as m-Health. These may be innovative solutions but cannot be relied on to cater for more dire cases, or larger volumes, for such programs the limited infrastructure poses as a barrier to upscale such programmes (Jordan et al. 2016).

Poor infrastructure, especially facilities which are badly managed, have difficultly implementing improvements or new systems. Often the current system is not strong enough to house the improvements, particularly with regards to introducing computer based systems (Gordon & Hinson 2007). This is unfortunate as these systems are used worldwide to improve functionality. One system was able to be successfully implemented with sufficient training and regular support, however power supply and perceived increased workload were hindrances. This electronic decision support system for antenatal care was found to be successfully implemented regardless of the resource constrained setting in SSA(Sukums et al. 2015).

When looking at the facilities a pivotal area recognised by 42 articles is that of service quality. Service quality is recognised of utmost importance for both satisfying patients, as well as ensuring they return- if service is poor it can result in loss to follow up or non-adherence (Bezabhe et al. 2014). In some cases, it is found poor service quality prevents seeking of care completely. Facilities are grossly wanting in terms of staffing, equipment, essential drugs and supplies. Both quality of care and record keeping are well below acceptable standards (K.O. Rogo et al. 2001).

Poor levels of quality deter HCWs as they need to work in sub-standard environments and must deal with treating patients in these conditions (Adzei & Atinga 2012). These conditions result in challenges for the HCWs as they must aim to serve patients to the best of their ability with very few of the resources needed (Jody R Lori et al. 2012). Shortage of staff increases patient load and as a result it is difficult to deliver the desired quality of care as well as adhering to clinical practice guidelines (Wasunna, Zurovac, Catherine A. Goodman, et al. 2008).

4.5 Provision of Health Services: Resources

One of the greatest issues faced in Africa is that of resource shortages, particularly human resources; however, drug supply, infrastructure, equipment and financial resources also play a large role. The shortage of skilled professionals or HCW in SSA can be accounted for by the lack of those entering the system year on year as well as those leaving the system. Resources are seen to be a function of both organizations and that of financing. Due to the large impact they have on health care in SSA, resources are singled out in this section.

The shortage of HCWs is a global problem, however most acutely felt in countries which need them the most. In SSA the burden of disease is found to be the highest and the workforce to address this the lowest. 53 (14%) of the review articles acknowledge or address the issue of HCW shortages. Majority of the articles described the shortage under the umbrella term of health staff or health care workers; several articles specified the roles of the human resource shortages, this however was erratic across the literature. It is of interest to note the HCW shortages which are specified, namely:

- Physicians;
- Nurses;
- Midwives;
- Specialists;
- Skilled staff;
- Counsellors;
- Obstetricians;
- Psychiatric staff;
- Pharmaceutical staff;
- Supervisors;

- Administrative and technical managers; and
- Health and Human resource officers.

The largest deficit of staff is found in public sectors or rural areas, as these areas are often found to be less appealing than their private or urban counterparts(Jody R. Lori et al. 2012)(Agyepong et al. 2004). The issue of limited human resources may be global, however the 53 articles found discussing human resource constraints covered specific regions. Figure 4.4.1 shows the number of articles addressing HCW shortages per region.

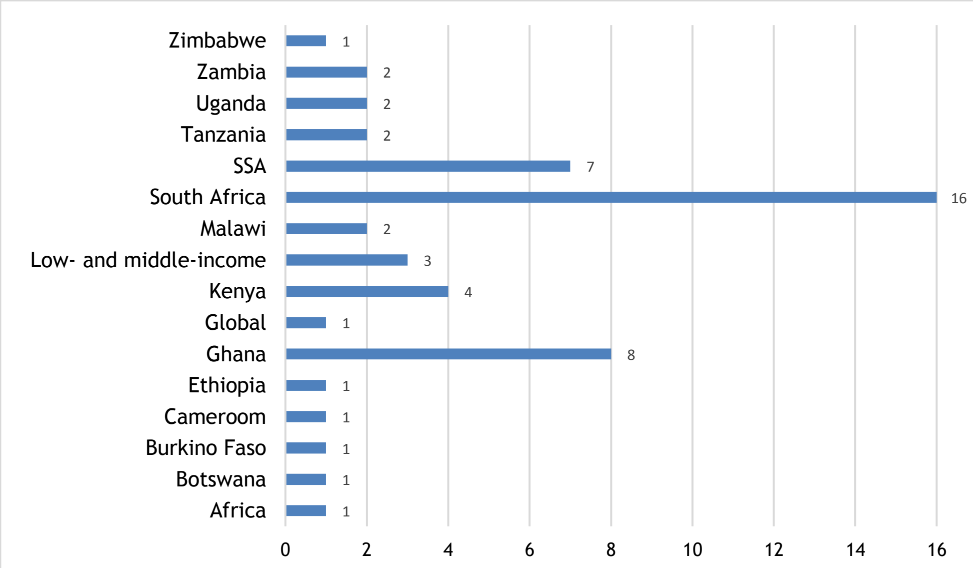

Figure 4.4.1: Regions of articles discussing human resource constraints.

The areas of health care which are affected by the shortage of HCWs is of interest, to understand the fields of health care which may need further attention when it comes to staffing. Figure 4.4.2 illustrates the distribution of health care areas discussed in conjunction with HCW shortages from the articles. The high burden of disease in SSA will also play a role in the HCW shortages as illustrated by the high relation between HIV and Malaria to HCW shortages. The category described as 'Health care system' refers to articles which did not explicitly link to a specific area of health care but to the health system as a whole or areas within the health system such as pharmacies or information technology management.

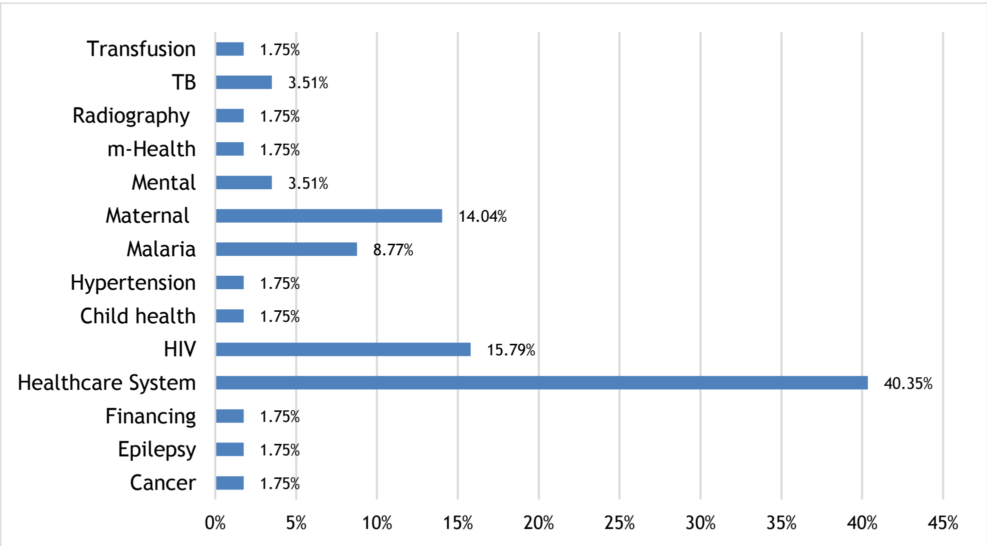

Figure 4.4.2: Distribution of health areas of articles discussing human resource constraints.

Literature revealed HCWs do not receive the compensation (Akintola & Chikoko 2016; Mokoka et al. 2011; Gonzaga et al. 2010; Chandler et al. 2009; Agyepong et al. 2004; Bradley & McAuliffe 2009; Adzei & Sakyi 2014; Osawa et al. 2010a; Dambisya et al. 2007; Paterson et al. 2007) or as many opportunities for skill development and training in SSA (Adzei & Atinga 2012; Agyapong et al. 2015; Mokoka et al. 2011; Akintola & Chikoko 2016; Agyepong et al. 2004; Bradley & McAuliffe 2009; Gonzaga et al. 2010; Jody R. Lori et al. 2012; Paterson et al. 2007; Dambisya et al. 2007; Poppe et al. 2016), their work conditions are often stressful and the under staffing and lack of resources create a difficult working environment (Agyepong et al. 2004; Akintola & Chikoko 2016; Bradley & McAuliffe 2009; Enuameh et al. 2016; George & Reardon 2013; Gonzaga et al. 2010; Mokoka et al. 2011; Osawa et al. 2010a; Paterson et al. 2007). As a result, community, or informal HCWs are being utilized to fulfil needs especially in rural environments (Haile et al. 2014).Community health workers (CHWs) or community home-based programs making use of volunteers or care facilitators are key interventions for combating both the shortage of health professionals and the HIV/AIDS epidemic in many parts of SSA (Osawa et al. 2010b). 15 articles focus on CHWs and the role which they play in health care delivery in SSA. CHWs are members of the community which volunteer to assist in health care management in an area, they do not have medical certification but are trained in some way in the context of the intervention (Kok et al. 2015). CHWs work in community settings and serve as connectors between health care consumers and providers, promoting health among groups that may have traditionally lacked access to care. CHWs are generally found to be women who lived in the area and are able to understand local concerns and constraints (Taylor & Jinabhai 2001) and are able to develop innovative solutions and respond to local needs (Haile et al. 2014).

CHWs array of tasks are primarily promotional, but include preventative and curative health care interventions. They are generally equipped with basic drug kits stocked with over the counter pharmaceuticals such as anti-malarial's, oral rehydration salts, paracetamol, zinc, contraceptives, iron supplements, vitamin A supplements, de-worming tablets, polio and tetanus vaccines and first aid kits for wounds or injuries (Glenton et al. 2013)(Winch et al. 2008). CHWs primarily make home visits and due to their limited range of supplies, which often run out, must refer sick patients to health professionals. These visits are recognized to strengthen the linkage between communities and health facilities, by communities realizing their rights to access of health care (Nzioki et al. 2015).

The responsibilities of CHWs is a topic which needs further research, CHWs are not able to distribute antibiotics due to the concern of health professionals. This opinion is changing as health professionals realize the magnitude of child health issues needing to be addressed at community levels, however policy makers are still concerned about the misuse of antibiotic distributions, leading to antibiotic resistance (Juma et al. 2015).

Resource allocation is one of the most controversial issues found in the health sector. The need for effective resource allocation is a result of scarce resources and the widening inequities in health care access (Asante & Zwi 2009). A Ministry of Health official in Ghana recognized human resources as the main resource constraint. As a result, when allocating resources to an area the human resources available are considered and resources are allocated accordingly. Resource allocators are concerned that without staff to utilize resources effectively, they could go to waste. It must be noted that this allocation decision and reasoning is made by at the regional managers and national policy makers level, a level higher than district health managers. This results in rural or understaffed areas receiving less resources, compounding the problem, as HCWs will be discouraged to join health care systems in these areas. The case study of resource allocation in Ghana by (Asante & Zwi 2009) presented several interesting ideas regarding factors at play which affect resource allocation. For example, politics must be considered- when allocating funds, the development of a big hospital is seen as superior to several smaller clinics, as it is a more recognizable development. Such a development is perceived to reflect positive growth and development of the government, regardless of the fact that smaller clinics in rural settings may be more needed and will cater to more of the poorer populations with a higher burden of disease.

Resource constraints resulting in supply shortages such as drug stock outs or absence of HIV testing kits lead to drop-out, as patients either cannot or will not wait and follow up when supplies are available (Colvin et al. 2014). Drug supply is cited by 20 articles as a barrier to health care. The issue of drug supply shortages results in patients not receiving the medication they need resulting in HCWs having to either deny treatment or switch to a different drug (Iwelunmor et al. 2015). Many patients do not receive treatment as they may not be able to return to collect the necessary medicine, especially in rural areas where transport costs play a role. This is particularly a problem in preventative medicine as the immediate need of the medication is not appreciated, thus is not well followed up.

Of the 20 articles 16 articles sited specific cases of drug stock outs relating to specific health areas, eight (50%) focused on malaria treatment, prevention and diagnosis; four (25%) on HIV diagnosis and treatment; two on maternal treatment; and the final two looking at hypertension and child health treatment respectively. Table 1 summarizes findings from the literature.

Counterfeit drugs are a problem specifically in less developed countries, where is it is estimated 25% of drug supplies are counterfeited according to (Alfadl et al. 2012). This study recognized there is a need for further research in the field and relayed results from Sudan. The strongest influences on counterfeit drug purchases are non-accessibility and unaffordability.

A shortage of drug supply, medical equipment, hospital beds, bedding and consumables such as gloves and stationary are frequent barriers faced by health care workers providing care to patients. The stress which the lack of resources places on a health care worker is a significant push factor. Sipsma et al. (2013) describes mother's delivery at health posts in some areas in Ethiopia as not much different to delivering at home due to the dire shortage of drugs and equipment, saying it is just delivery using gloves.

The supply of resources has an impact on decisions made regarding health insurance enrolment, as if there is a reputation for poor drug supply the motivation behind joining health insurance plans is diminished. The service quality linked with poor resources and the unreliability of the health care system will not promote health financing programs.

Intellectual resources must be utilized, Iwelunmor acknowledged that in South Africa HCWs were not making use of treatment guidelines. By not utilizing intellectual resources patients were not being effectively treated. This aligns closely with the difference between policy existence and policy implementation.

An article by McIntyre acknowledged the lack of data corresponded with a lack of resources, this is a resounding issue in understanding health care outcomes in low resourced areas. This idea must be kept in mind as it indicates areas unaccounted for do not necessarily have sufficient but may perhaps completely lack resources, or data collecting resources at the least (McIntyre 2005).

The health care system measures discussed are presented standing alone, however it is important to recognize the way in which they are interdependent. These components are grouped due to the fact that together they make up the health system and their influence on the success or failure is completely integrated. The state of the health care system must also be recognized to influence the health behaviour and utilization of health services as well as being influenced by the external environment in which it is found.

5. DISCUSSIONS

The provision of health service factors addressed are interlinked and strongly dependant on one another. To best understand the system, it is necessary to evaluate the state of each factor described as well as the way in which they affect one another.

Health policies often dictate the state or success of a system. Policies are developed in order to encourage best practices, however these policies are not or cannot be consistently adhered to, resulting in organizational failures or resource mismanagement. At an organizational level policies need to be both communicated and accepted in order to be effective. Health financing systems rely on good policies to function and grow, which in turn will support health organizations and provide resources. Whilst resources play a major role in the quality of care delivered, organizations need to manage resources effectively. With the poor state of organizations and limited resources found in SSA it is imperative to make efforts toward developing and implementing appropriate policies to begin remedying these issues.

5.1 Strengths and Limitations of the Review

The review is carried out according to predefined protocols in order to remove bias when gathering data. However, it was found that the academic literature was not evenly distributed over the SSA landscape which is recognized to skew information gathered in this review. The review returns only academic literature which gives an idea of areas of research within SSA, not necessarily the state thereof as grey literature or other data is not considered. The exclusion of the e-platform PubMed is regrettable, and due to the date of the search affecting the results returned this exclusion cannot be fairly remedied.

The search terms selected are notably broad, returning a large volume of literature. This was done with the intention of retrieving a wide variety of articles, to explore a vast array of topics, and to get a general understanding of health in SSA. With this in mind it must be acknowledged that the existence of articles which address specific areas of health in SSA, may not have been returned in this search. Thus, themes addressed are not claiming to be comprehensive, but illustrating the contribution when looking at general research within SSA. The vast array of articles returned allows for pre-existing ideas of health in SSA to be challenged as some areas addressed are unexpected and may have been overlooked had more specific terms been utilised.

5.2 Opportunities for further research

Further analysis of the studies gathered during this review can focus on contextual macroeconomic factors and health seeking behaviours which play a role on influencing health care outcomes. The exploration of these areas will further the scope of the review to better understand factors which influence health in SSA. It would be of interest to map the origin of the researchers to understand the perspectives with which articles are written along with the stakeholders interested in health in SSA. In order to further evaluate health in SSA according to the themes discussed, systematic reviews can be carried out utilising more specific terms relating to each individual theme.

5.3 Conclusion

The review developed a comprehensive understanding of the health landscape in SSA in terms of area and burden of disease addressed by literature, as well as the main factors influencing health care service provision. The geographic areas address all regions of SSA, however it was found the majority of articles consider either East or Southern Africa. The health areas discussed by the articles were found to align strongly with the MDGs, attributable to the time restriction criteria placed on the articles but were grouped according to the SDGs, to inform the SDG period. Enabling contextual factors identified as mutable, therefore having the potential for improvement, were addressed giving insights into health service provision according to literature. Policy on both an organizational and governmental level, is found to need careful attention in order to facilitate and ensure implementation. Enrolment in health financing can be improved upon through addressing barriers identified, which in return could improve health service utilization. And finally, the state of health facilities, and resources in SSA are in need of attention. The analysis of the literature in terms of the above-mentioned areas give insight into the state of health systems in SSA, according to academic literature.

Table 5.3.1: Impact and effects of drug supply issues according to literature.

Health Area:	*Drug use:*	*Study Findings:*
Child Health	Treatment	**"Caregivers claimed that as a consequence of inadequate supply or unavailability of drugs at the health facility, they are either given an incomplete dosage of prescribed medicines or are not given at all."** (Lungu et al. 2016)
Child HIV care	Treatment	**"Shortage of cotrimoxazole (provided without charge in the National HIV programme) meant that children were given prescriptions requiring purchase from pharmacies. Many families were unable to afford the drug and either borrowed money or reduced the frequency of dosing."** (Busza et al. 2014) **"Although, this study was not designed to identify the factors associated with drug exhaustion at home (such as caregivers sharing the drugs with other children needing them), missing one's clinic appointment appears to be a major determinant. Therefore, we recommend that caregivers are made aware that a drug refill could be obtained even after the child/caregiver misses a scheduled clinic appointment."** (Iroha et al. 2010)
HIV	Treatment	**"Shortage of drugs was a common challenge at all primary health care facilities. Nurses were faced with having to turn away patients and having them return for their medication on another day. Other patients were given medication for only a week at a time. These patients had to return frequently to collect medication. Some participants travelled to the hospital pharmacy at their own expense to request drugs for their patients."** (Layer et al. 2014)
	Diagnosis and Treatment	**"Persistent stock-outs of HIV test kits, which were common throughout Iringa region for the duration of this study, prevented access to HTC services. Service providers noted that they routinely turned clients away, while clients explained that the stock-out had caused many people to give up on HIV testing completely"** (Mabelane et al. 2016)
Hypertension	Treatment	**"Drugs such as nifedipine, captopril, methyldopa, propranolol, atenolol, prazosin, and digoxin were in available in small quantities or not available during the study period. Hydrochlorothiazide was available throughout the study period at all hospitals."** (Mungati et al. 2014)
Maternal	Treatment	**"All thirty facilities studied, were grossly wanting in terms of staffing, equipment, essential drugs and supplies." " All emergency obstetric drugs were either not in stock or available only in very small quantities."** (K. O. Rogo et al. 2001) **"Drug availability is strongly associated with quality. The implication is that since maternal care in the country is free, mothers prefer that drugs are readily available anytime they report for antenatal care. The absence of prescribed drugs can affect their experience of service quality."** (Atinga & Baku 2013)
Malaria during pregnancy	Preventative	**"A major barrier identified in several studies was periodic stock outs of SP. This results in women either being turned away without being given IPTp or being given a prescription to go and buy the drug from a private drug seller or from a pharmacy at another government facility, and represents a serious missed opportunity, as there is no guarantee that the women will buy and take the drug." "The main barrier at the healthcare system level cited by pregnant women was the "unavailability" of ITNs. These stock outs can exacerbate the issue of cost in many cases, as women often travel to distribution points to collect the ITN."** (Hill et al. 2013)

		"periodic shortages of SP- intermittent preventative treatment (IPT) with sulfadoxine-pyrimethamine" (Launiala & Honkasalo 2007) **"ANC staff may also fail to administer SP not necessarily due to loss of interest, but pregnant women may hate taking SP, or due to drug shortages as noted [in literature]."** (Mubyazi et al. 2011)
Malaria	**Treatment**	**"95 (30.0%) of people who visited public health facilities did not get drugs from the hospital pharmacy and were issued with a prescription to buy drugs elsewhere. Of these, only 31 (32.8%) individuals bought the prescribed drugs." Participants reported that these shortages were more serious during the wet season when the number of malaria cases was high and health facilities could not cope with the increased demand in malaria treatment… Often, public health facilities do not have the recommended anti-malarials in stock. Lack of medicines in the formal sector contributes to people buying drugs, where the quality of drugs is less controlled and information on dosage is not often provided. Health workers and community members reported that public health facilities suffered from chronic drug shortages due to delays in drugs deliveries from the central level and the failure to adjust drug quantities to suit seasonal fluctuations in disease burden"** (Chuma et al. 2010) **"Nearly all health workers indicated that they were rationing the drug because they were not certain of the next supply based on previous stock-outs periods. However, several districts in Kenya are currently moving from the "push" to "pull" drug delivery system where they order AL based on their consumption requirements, which may help to relieve shortages in the long-term."** (Wasunna, Zurovac, Catherine A Goodman, et al. 2008)
	Diagnosis	**"More than half (55%) of the nurses indicated that stock-outs of RDTs occurred. However, they reported that this was rare (one or two times in a season) and contingency plans existed to replace stock from either the nearest clinic or hospital pharmacies. Replacement of stock took place within 24 hours."** (Moonasar et al. 2007)
	Treatment and diagnosis	**"Nine of ten health facilities reported RDT stock-outs at some point since their introduction…running out of ACT for some periods before the next supply is received were also observed in some health facilities, which could be due to overuse of ACT in the treatment of patients with negative RDT results, or health system factors such as delays in procurement or underestimating requirements. This led to the prescription of non-ACT, contrary to national guidelines advocating the use of ACT as first-line anti-malarial drugs."** (Mubi et al. 2013)

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Appendix A

Year of first publication	First author	Title	Country	Setting	Subgroup	Study type	Health outcome	Primary factor
2005	Aaserud, M	Translating research into policy and practice in developing countries: a case study of magnesium sulphate for pre-eclampsia	Low- and middle-income		women	interviews, observational	Eclampsia, Maternal	Contextual Characteristics: Enabling: Health Policy
2011	Abbas, UL	Factors Influencing the Emergence and Spread of HIV Drug Resistance Arising from Rollout of Antiretroviral Pre-Exposure Prophylaxis (PrEP)	South Africa	Public			HIV/AIDS	Individual Characteristics: Need: Evaluated
2014	Abeje, G	Factors associated with Institutional delivery service utilization among mothers in Bahir Dar City administration, Amhara region: a community based cross sectional study	Ethiopia		women	multivariable logistic regression, cross sectional	Maternal	Health Behaviours: Use of Personal Health Services
2010	Abekah-Nkrumah, G	Assessing the implementation of Ghana's Patient Charter	Ghana	District		survey	N/A	Contextual Characteristics: Enabling: Health Policy
2014	Abor, PA	The effects of healthcare governance and ownership structure on the performance of hospitals in Ghana	Ghana			multiple regression	N/A	Contextual Characteristics: Enabling: Health Policy
2011	Abor, PA	The socio-economic determinants of maternal health care utilization in Ghana	Ghana		women	Probit and ordered Probit	Maternal	Contextual Characteristics: Predisposing: Social
2013	Abubakar, A	Socio-Cultural Determinants of Health-Seeking Behaviour on the Kenyan Coast: A Qualitative Study	Kenya				Child Health	Individual Characteristics: Predisposing: Social
2015	Adebayo, E	A systematic review of factors that affect uptake of community-based health insurance in low-income and middle- income countries	Low- and middle-income	Community	households	systematic review	N/A	Contextual Characteristics: Enabling: Financing
2015	Adeniyi, OV	Diabetic patients' perspectives on the challenges of glycaemic control	South Africa	District, rural	patients	thematic content analysis	Diabetes	Health Behaviours: Personal Health Practices
2015	Adjei, KK	A comparative study on the availability of modern contraceptives in public and private health facilities in a peri-urban community in Ghana	Ghana	Peri-urban	women	qualitative, quantitative, cross sectional	Sexual Health	Health Behaviours: Process of Medical Care
2012	Adzei, F	Motivation and retention of health workers in Ghana's district hospitals: Addressing the critical issues	Ghana	District, public	HCWs	systematic review	N/A	Contextual Characteristics: Enabling: Health Policy
2014	Adzei, F	Drivers of return migration of Ghanaian health professionals: perspectives from doctors and nurses in urban Ghana	Ghana	Urban	HCWs	qualitative exploratory, case study	N/A	Contextual Characteristics: Enabling: Health Policy
2009	Afolabi, MO	Determinants of adherence to antiretroviral drugs among people living with HIV/AIDS in the Ife-IJesa zone of Osun State, Nigeria	Nigeria	District	patients	interviews	HIV/AIDS	Health Behaviours: Personal Health Practices

2015	Agyapong, VIO	Factors influencing the career choice and retention of community mental health workers in Ghana	Ghana	Community	CHWs	interviews	Mental health	Contextual Characteristics: Enabling: Health Policy
2004	Agyepong, IA	Health worker (internal customer) satisfaction and motivation in the public sector in Ghana	Ghana	Public	HCWs	interviews	N/A	Contextual Characteristics: Enabling: Health Policy
2008	Ajala, AS	Cultural Determinants of Care and Support for People Living with AIDS in Yoruba Communities of Ibadan and Ilesa, Nigeria	Nigeria		patients	interviews, case study	HIV/AIDS	Contextual Characteristics: Predisposing: Social
2014	Ajuwon, GA	Influence of motivational factors on utilization of Internet health information resources by resident doctors in Nigeria	Nigeria		HCWs	survey	N/A	Contextual Characteristics: Enabling: Organization
2016	Akintola, O	Factors influencing motivation and job satisfaction among supervisors of community health workers in marginalized communities in South Africa	South Africa	District	CHWs	interviews	N/A	Contextual Characteristics: Enabling: Organization
2008	Akinyoola, AL	Factors influencing the outcome of elective paediatric orthopaedic operations in Ile-Ife, Nigeria	Nigeria		children		Surgery	Health Behaviours: Process of Medical Care
2013	Alaba, O	The social determinants of multimorbidity in South Africa	South Africa		adults	multinomial logistic regression	Multimorbidity	Contextual Characteristics: Predisposing: Social
2012	Alfadi, AA	Consumer behaviour toward counterfeit drugs in a developing country	Developing countries			structured equation modelling	N/A	Contextual Characteristics: Enabling: Organization
2002	Anderson, BA	Environment, Access to Health Care, and Other Factors Affecting Infant and Child Survival Among the African and Coloured Populations of South Africa, 1989–94	South Africa		children		Child health	Contextual Characteristics: Need: Environment
2015	Apanga, PA	Factors influencing uptake of voluntary counselling and testing services for HIV/AIDS in the Lower Manya Krobo Municipality (LMKM) in the Eastern Region of Ghana: a cross-sectional household survey	Ghana	District	households	cross sectional survey	HIV/AIDS	Health Behaviours: Use of Personal Health Services
2016	Arba, MA	Institutional Delivery Service Utilization among Women from Rural Districts of Wolaita and Dawro Zones, Southern Ethiopia; a Community Based Cross-Sectional Study	Ethiopia	District, rural	women	cross sectional survey	Maternal	Health Behaviours: Use of Personal Health Services
2007	Aries, MJH	Fracture treatment by bonesetters in central Ghana: patients explain their choices and experiences	Ghana		patients	interviews	Injury	Health Behaviours: Use of Personal Health Services
2015	Asampong, E	Health seeking behaviours among electronic waste workers in Ghana	Ghana		waste workers	interviews	Injury	Health Behaviours: Use of Personal Health Services
2013	Asampong, E	Back to My Roots: A Study of "Returning" Emigrated Health Professionals in the Greater Accra Region of Ghana	Ghana		HCWs		N/A	Contextual Characteristics: Enabling: Organization
2009	Asante, AD	Factors influencing resource allocation decisions and equity in the health system of Ghana	Ghana			qualitative, interviews	N/A	Contextual Characteristics: Enabling: Organization
2016	Ashokcoomar, P	An analysis of inter-healthcare facility transfer of neonates within the eThekwini Health District of KwaZulu-Natal, South Africa	South Africa	District	children	quantitative analysis	Child health	Contextual Characteristics: Enabling: Organization

2013	Asonganyi, E	Factors Affecting Compliance with Clinical Practice Guidelines for Pap Smear Screening among Healthcare Providers in Africa: Systematic Review and Meta-Summary of 2045 Individuals	Africa		women	systematic review, meta-analysis	Cervical cancer	Contextual Characteristics: Enabling: Health Policy
2013	Atinga, R	Determinants of antenatal care quality in Ghana	Ghana		women	interviews	Antenatal	Contextual Characteristics: Enabling: Organization
2014	Aziato, L	Breast Cancer Diagnosis and Factors Influencing Treatment Decisions in Ghana	Ghana		women	qualitative	Breast cancer	Health Behaviours: Process of Medical Care
2013	Azu, OO	Choice of specialty amongst first-year medical students in the Nelson R. Mandela School of Medicine, University of KwaZulu-Natal	South Africa		healthcare students	cross sectional survey	N/A	Contextual Characteristics: Enabling: Organization
2004	Bach, O	Musculo skeletal trauma in an East African public hospital	Malawi	Rural	patients		Injury	Individual Characteristics: Need: Evaluated
2014	Bagonza, J	Performance of community health workers managing malaria, pneumonia and diarrhoea under the community case management programme in central Uganda: a cross sectional study	Uganda	Community	CHWs	interviews, cross sectional	Malaria, pneumonia, diarrhoea	Contextual Characteristics: Enabling: Organization
2006	Banderker	Mobile technology adoption by doctors in public healthcare in South Africa	South Africa		HCWs		N/A	Contextual Characteristics: Enabling: Organization
2013	Barnett, W	Perceived adherence barriers among patients failing second-line antiretroviral therapy in Khayelitsha, South Africa	South Africa	Urban	patients	qualitative, interviews	HIV/AIDS	Health Behaviours: Personal Health Practices
2009	Baume, CA	Factors associated with use and non-use of mosquito nets owned in Oromia and Amhara Regional States, Ethiopia	Ethiopia		households	multivariate analysis, survey	Malaria	Health Behaviours: Personal Health Practices
2016	Bawate, C	Factors affecting adherence to national malaria treatment guidelines in management of malaria among public healthcare workers in Kamuli District, Uganda	Uganda	District, public	HCWs	cross sectional survey	Malaria	Contextual Characteristics: Enabling: Health Policy
2007	Bendech, MA	National Vitamin A Supplementation Coverage Survey among 6-59 Months Old Children in Guinea (West Africa)	Guinea		children	cross sectional survey	Child health	Health Behaviours: Use of Personal Health Services
2001	Berhane, Y	Women's health in a rural setting in societal transition in Ethiopia	Ethiopia	Rural	women	cross sectional survey	Women's health	Contextual Characteristics: Predisposing: Social
2014	Bezabhe, WM	Barriers and Facilitators of Adherence to Antiretroviral Drug Therapy and Retention in Care among Adult HIV-Positive Patients: A Qualitative Study from Ethiopia	Ethiopia		patients	qualitative, interviews	HIV/AIDS	Health Behaviours: Personal Health Practices
2010	Bhat, VG	Factors associated with poor adherence to anti-retroviral therapy in patients attending a rural health centre in South Africa	South Africa	Rural	patients	interviews	HIV/AIDS	Health Behaviours: Personal Health Practices
2014	Bidwell, P	Security and skills: the two key issues in health worker migration	South Africa		HCWs	interviews	N/A	Contextual Characteristics: Enabling: Organization

2003	Bingham, A	Factors affecting utilization of cervical cancer prevention services in low-resource settings	South Africa, Kenya		women		Cervical cancer	Health Behaviours: Use of Personal Health Services
2010	Bird, P	Increasing the priority of mental health in Africa: findings from qualitative research in Ghana, South Africa, Uganda and Zambia	Zambia, Uganda, South Africa, Ghana				Mental health	Contextual Characteristics: Enabling: Health Policy
2004	Bishai, D	Determinants of personal demand for an AIDS vaccine in Uganda: contingent valuation survey	Uganda			multivariate analysis, survey	HIV/AIDS	Health Behaviours: Personal Health Practices
2013	Blacklock, C	Exploring the migration decisions of health workers and trainees from Africa: A meta- ethnographic synthesis	Africa		HCWs	ethnographic, meta-analysis	N/A	Contextual Characteristics: Enabling: Organization
2015	Blanco, AJ	Loss to Follow-Up Among HIV-Exposed Children in an HIV Clinic in Beira, Mozambique	Mozambique	City	children	qualitative, interviews	HIV/AIDS	Health Behaviours: Use of Personal Health Services
2014	Bloomfield, GS	HIV and Non-Communicable Cardiovascular and Pulmonary Diseases in Low- and Middle-Income Countries in the ART Era: What We Know and Best Directions for Future Research	Low- and middle-income			review	HIV/AIDS, Cardiovascular, Pulmonary	Individual Characteristics: Need: Evaluated
2013	Boateng, D	Health insurance in Ghana: evaluation of policy holders' perceptions and factors influencing policy renewal in the Volta region	Ghana	District	households	cross sectional survey	N/A	Contextual Characteristics: Enabling: Financing
2016	Bonenberger, M	Factors influencing the work efficiency of district health managers in low-resource settings: a qualitative study in Ghana	Ghana	District	HCWs	qualitative, interviews	N/A	Contextual Characteristics: Enabling: Organization
2006	Boon, K	Clinical practice guidelines: a critical review	General			review	N/A	Contextual Characteristics: Enabling: Health Policy
2007	Bowman, RJC	Outcomes of Bilateral Cataract Surgery in Tanzanian Children	Tanzania		children	statistical analysis	Optometry	Outcomes: Evaluated Health
2011	Boyles, TH	Factors Influencing Retention in Care after Starting Antiretroviral Therapy in a Rural South African Programme	South Africa	Rural	patients		HIV/AIDS	Health Behaviours: Use of Personal Health Services
2009	Bradley, S	Mid-level providers in emergency obstetric and new born health care: factors affecting their performance and retention within the Malawian health system	Malawi		maternal and child	qualitative, exploratory	Maternal and child health	Health Behaviours: Process of Medical Care
2012	Briand, V	Individual and institutional determinants of caesarean section in referral hospitals in Senegal and Mali: a cross-sectional epidemiological survey	Mali		women	cross sectional survey	Maternal	Health Behaviours: Process of Medical Care
2008	Bronsard, A	Why are Children Brought Late for Cataract Surgery? Qualitative Findings from Tanzania	Tanzania		children	qualitative, interviews	Optometry	Health Behaviours: Use of Personal Health Services
2013	Buckle, GC	Factors influencing time to diagnosis and initiation of treatment of endemic Burkitt Lymphoma among	Kenya, Uganda		children	interviews	Cancer	Health Behaviours: Process of Medical care

		children in Uganda and western Kenya: a cross-sectional survey						
2007	Bunce, A	Factors Affecting Vasectomy Acceptability in Tanzania	Tanzania	District	men	interviews	Vasectomy	Individual Characteristics: Predisposing: Beliefs
2003	Buor, D	Water needs and women's health in the Kumasi metropolitan area, Ghana	Ghana	Urban	women	interviews	Women's health	Contextual Characteristics: Need: Environmental
2012	Burchett, HED	New vaccine adoption: qualitative study of national decision-making processes in seven low- and middle-income countries	Low- and middle-income			qualitative	Child health	Health Behaviours: Personal Health Practices
2002	Buseh, AG	Cultural and gender issues related to HIV/AIDS prevention in rural Swaziland: A focus group analysis	Swaziland	Rural	adults	qualitative, interviews	HIV/AIDS	Individual Characteristics: Predisposing: Demographic
2014	Busza, J	"I don't want financial support but verbal support.'' How do caregivers manage children's access to and retention in HIV care in urban Zimbabwe?	Zimbabwe	Urban	informal caregivers, children	conceptual framework, formative research, interviews	HIV/AIDS	Individual Characteristics: Enabling: Organization
2011	Buthelezi, N	Gift of Life or Cultural Taboo: Effects of an Educational Pamphlet on Young Adults' Knowledge and Attitudes Regarding Organ Donation	South Africa		adolescents	interviews	Organ Donation	Individual Characteristics: Predisposing: Beliefs
2005	Cambanis, A	Rural poverty and delayed presentation to tuberculosis services in Ethiopia	Ethiopia	Rural	patients	interviews	TB	Health Behaviours: Use of Personal Health Services
2005	Carrin, G	Community-based health insurance in developing countries: a study of its contribution to the performance of health financing systems	Developing countries	Community	households		N/A	Contextual Characteristics: Enabling: Financing
2014	Cates, W	Family planning since ICPD — how far have we progressed?	Africa		adults		Sexual Health	Health Behaviours: Personal Health Practices
2016	Caulfield, T	Factors influencing place of delivery for pastoralist women in Kenya: a qualitative study	Kenya		women	qualitative, interviews	Maternal	Contextual Characteristics: Enabling: Health Policy
2013	Chakkalakal, RJ	Implementing clinical guidelines in low-income settings: A review of literature	Low- and middle-income			review	N/A	Contextual Characteristics: Enabling: Health Policy
2004	Chakraborty, R	Infections and other causes of death in HIV-infected children in Africa	Kenya		children		HIV/AIDS	Individual Characteristics: Need: Evaluated
2009	Chandler, CIR	Motivation, money and respect: A mixed-method study of Tanzanian non-physician clinicians	Tanzania		HCWs	interviews	N/A	Contextual Characteristics: Enabling: Organization
2016	Charalambous, S	Clinic-level factors influencing patient outcomes on antiretroviral therapy in primary health clinics in South Africa	South Africa		patients	quantitative analysis	HIV/AIDS	Contextual Characteristics: Enabling: Health Policy
2016	Chauvin, J	A survey of the governance capacity of national public health associations to enhance population health	Global			survey	N/A	Contextual Characteristics: Enabling: Health Policy

2015	Chi, PC	A qualitative study exploring the determinants of maternal health service uptake in post-conflict Burundi and Northern Uganda	Uganda, Burundi		women	interviews	Maternal	Health Behaviours: Use of Personal Health Services
2001	Chirenje, ZM	Situation analysis for cervical cancer diagnosis and treatment in East, Central and Southern African countries	Resource limited countries		women	interviews	Cervical cancer	Health Behaviours: Process of Medical Care
2015	Chitete, L	What Health Service Provider Factors Are Associated with Low Delivery of HIV Testing to Children with Acute Malnutrition in Dowa District of Malawi?	Malawi	District	children	interviews	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2015	Choonara, S	Factors influencing the usage of different types of malaria prevention methods during pregnancy in Kenya	Kenya		women	multivariable logistic regression	Malaria, Maternal	Health Behaviours: Use of Personal Health Practices
2010	Chuma, J	Barriers to prompt and effective malaria treatment among the poorest population in Kenya	Kenya		households	interviews, cross sectional	Malaria	Contextual Characteristics: Predisposing: Demographic
2009	Chuma, J	Reviewing the literature on access to prompt and effective malaria treatment in Kenya: implications for meeting the Abuja targets	Kenya			systematic review	Malaria	Health Behaviours: Process of Medical Care
2009	Claeye, F	Project Delivery in HIV/AIDS and TB in Southern Africa: The Cross-cultural Management Imperative	Southern Africa				HIV HIV/AIDS	Contextual Characteristics: Predisposing: Social
2015	Coetzee, B	Barriers and facilitators to paediatric adherence to antiretroviral therapy in rural South Africa: a multi-stakeholder perspective	South Africa	Rural	children	interviews	HIV/AIDS	Individual Characteristics: Predisposing: Social
2016	Coetzee, B	Video observations of treatment administration to children on antiretroviral therapy in rural KwaZulu-Natal	South Africa	District	children	observational	HIV/AIDS	Health Behaviours: Process of Medical Care
2013	Colombini, M	Factors affecting adherence to short-course ARV prophylaxis for preventing mother-to-child transmission of HIV in sub-Saharan Africa: a review and lessons for future elimination	sub-Saharan Africa		maternal and child	review	Maternal, HIV/AIDS	Health Behaviours: Personal Health Practices
2014	Colvin, CJ	A Systematic Review of Health System Barriers and Enablers for Antiretroviral Therapy (ART) for HIV-Infected Pregnant and Postpartum Women	Global		women	systematic review	Maternal, HIV/AIDS	Contextual Characteristics: Enabling: Organization
2010	Cooke, GS	Population uptake of antiretroviral treatment through primary care in rural South Africa	South Africa	District, rural	patients	multivariable logistic regression	HIV/AIDS	Health Behaviours: Use of Personal Health Services
2011	Cramm, JM	The influence of social capital and socio-economic conditions on self-rated health among residents of an economically and health-deprived South African township	South Africa	Community	households	multivariate analysis, survey	Health	Individual Characteristics: Predisposing: Social
2007	Dambisya, YM	Factors influencing the distribution of pharmacy graduates of the university of the North, South Africa	South Africa		healthcare students	survey	Pharmacy	Contextual Characteristics: Enabling: Organization
2016	Dare, AJ	Prioritizing Surgical Care on National Health Agendas: A Qualitative Case Study of Papua New Guinea, Uganda, and Sierra Leone	Uganda, Sierra Leone			qualitative, interviews, case study	Surgery	Contextual Characteristics: Enabling: Health Policy

2015	De Allegri, M	Factors Affecting the Uptake of HIV Testing among Men: A Mixed-Methods Study in Rural Burkina Faso	Burkina Faso	Rural	men	qualitative, interviews	HIV/AIDS	Health Behaviours: Personal Health Practices
2013	De Meyer, CF	Perceived justice in South African airline and hospital industries: measurement model	South Africa			survey	N/A	Contextual Characteristics: Enabling: Organization
2016	de Vasconcellos, K	Hypoxaemia on arrival in a multidisciplinary intensive care unit	South Africa				Emergency care	Health Behaviours: Process of Medical Care
2016	Delil, RK	Magnitude of Malaria and Factors among Febrile Cases in Low Transmission Areas of Hadiya Zone, Ethiopia: A Facility Based Cross Sectional Study	Ethiopia	Public	patients	cross sectional survey	Malaria	Individual Characteristics: Need: Evaluated
2013	Devanathan, R	Overweight and obesity amongst Black women in Durban, KwaZulu-Natal: A 'disease' of perception in an area of high HIV prevalence	South Africa	Urban	women	interviews	Obesity	Individual Characteristics: Predisposing: Beliefs
2011	Dickson, KE	Voluntary Medical Male Circumcision: A Framework Analysis of Policy and Program Implementation in Eastern and Southern Africa	sub-Saharan Africa		men		Circumcision	Contextual Characteristics: Enabling: Health Policy
2012	Diop, W	From Government Policy to Community-Based Communication Strategies in Africa: Lessons from Senegal and Uganda	Senegal, Uganda				HIV/AIDS	Contextual Characteristics: Enabling: Health Policy
2010	Do, NT	Psychosocial Factors Affecting Medication Adherence Among HIV-1 Infected Adults Receiving Combination Antiretroviral Therapy (cART) in Botswana	Botswana		adults	survey	HIV/AIDS	Health Behaviours: Personal Health Practices
2011	Dodd, PJ	Periodic Active Case Finding for TB: When to Look?	Global				TB	Individual Characteristics: Need: Evaluated
2012	Dodoo, A	Risk Perception and Communication in Sub-Saharan Africa	sub-Saharan Africa		HCWS		N/A	Contextual Characteristics: Enabling: Health Policy
2009	Dong, H	Drop-out analysis of community-based health insurance membership at Nouna, Burkina Faso	Burkina Faso	Community	households	multivariate analysis, survey	N/A	Contextual Characteristics: Enabling: Financing
2016	Dror, DM	What Factors Affect Voluntary Uptake of Community-Based Health Insurance Schemes in Low- and Middle-Income Countries? A Systematic Review and Meta-Analysis	Low- and middle-income		households	systematic review, meta-analysis	N/A	Contextual Characteristics: Enabling: Financing
2003	Durrheim, DN	Beyond evidence: a retrospective study of factors influencing a malaria treatment policy change in two South African Provinces	South Africa	District, public		interviews	Malaria	Contextual Characteristics: Enabling: Health Policy
2005	Duxbury, J	The use of physical restraint in mental health nursing: An examination of principles, practice and implications for training	General		HCWS		Mental health	Contextual Characteristics: Enabling: Health Policy
2013	Duysburgh, E	Counselling on and women's awareness of pregnancy danger signs in selected rural health facilities in Burkina Faso, Ghana and Tanzania	Burkina Faso, Ghana, Tanzania	Rural	women	interviews, cross sectional, observational,	Maternal	Individual Characteristics: Predisposing: Beliefs

						negative binomial regression		
2016	Dyers, RE	Are central hospitals ready for National Health Insurance? ICD coding quality from an electronic patient discharge record for clinicians	South Africa				N/A	Contextual Characteristics: Enabling: Financing
2004	Dzator, J	A study of malaria care provider choice in Ghana	Ghana		households		Malaria	Health Behaviours: Use of Personal Health Services
2014	Echebiri, VC	The factors affecting Nigeria's success toward implementation of global public health priorities	Nigeria	Public			Health	Contextual Characteristics: Enabling: Health Policy
2016	Enuameh, YAK	Factors Influencing Health Facility Delivery in Predominantly Rural Communities across the Three Ecological Zones in Ghana: A Cross- Sectional Study	Ghana	Rural, community	women, children	multivariable logistic regression	Maternal and child health	Contextual Characteristics: Need: Environmental
2007	Ezeome, ER	Use of complementary and alternative medicine by cancer patients at the University of Nigeria Teaching Hospital, Enugu, Nigeria	Nigeria		patients	interviews	Cancer	Health Behaviours: Personal Health Practices
2011	Finnie, RKC	Pilot study to develop a rapid assessment of Tuberculosis care-seeking and adherence practices in rural Limpopo Province, South Africa	South Africa			interviews, pilot study	TB	Health Behaviours: Use of Personal Health Services
2002	Fongwa, MN	International Health Care Perspectives: The Cameroon Example	Cameroon				N/A	Contextual Characteristics: Enabling: Organization
2004	Fylkesnes, K	A randomized trial on acceptability of voluntary HIV counselling and testing	Zambia	Urban	adults	survey	HIV/AIDS	Individual Characteristics: Predisposing: Beliefs
2016	Ganle, JK	Challenges Women with Disability Face in Accessing and Using Maternal Healthcare Services in Ghana: A Qualitative Study	Ghana	District	women	qualitative	Mental, Maternal	Individual Characteristics: Need: Evaluated
2014	Gebremariam, A	Intention to use long acting and permanent contraceptive methods and factors affecting it among married women in Adigrat town, Tigray, Northern Ethiopia	Ethiopia		women	qualitative, interviews, case study, multivariate logistic regression	Sexual Health	Health Behaviours: Personal Health Practices
2010	Gebremariam, MK	Barriers and facilitators of adherence to TB treatment in patients on concomitant TB and HIV treatment: a qualitative study	Ethiopia		patients	qualitative, interviews	TB	Health Behaviours: Personal Health Practices
2015	George, G	Understanding the factors influencing health-worker employment decisions in South Africa	South Africa		HCWs	cross sectional survey	N/A	Contextual Characteristics: Enabling: Organization
2014	George, G	Barriers and facilitators to the uptake of voluntary medical male circumcision (VMMC) among adolescent boys in KwaZulu-Natal, South Africa	South Africa	District	men, adolescents	qualitative, interviews	Circumcision	Individual Characteristics: Predisposing: Beliefs
2012	Georgeu, D	Implementing nurse-initiated and managed antiretroviral treatment (NIMART) in South Africa: a qualitative process evaluation of the STRETCH trial	South Africa	District	patients	interviews	HIV/AIDS	Contextual Characteristics: Enabling: Organization

2013	Gessese, D	The practice of complementary feeding and associated factors among mothers of children 6-23 months of age in Enemay district, Northwest Ethiopia	Ethiopia	District	women, children	cross sectional survey	Maternal and child health	Health Behaviours: Personal Health Practices
2002	Geyer, N	Legislative Issues Impacting on The Practice of The South African Nurse Practitioner	South Africa		healthcare workers		N/A	Contextual Characteristics: Enabling: Health Policy
2015	Gillham, A	Uptake of Genetic Counselling, Knowledge of Bleeding risks and Psychosocial Impact in a South African Cohort of Female Relatives of People with Haemophilia	South Africa		women	interviews	Haemophilia	Individual Characteristics: Predisposing: Beliefs
2012	Gilson, L	Using stakeholder analysis to support moves towards universal coverage: lessons from the SHIELD project	South Africa, Tanzania				N/A	Contextual Characteristics: Enabling: Financing
2010	Glatman-Freedman, A	Factors Affecting the Introduction of New Vaccines to Poor Nations: A Comparative Study of the Haemophilus influenzae Type B and Hepatitis B Vaccines	Africa			qualitative comparative	Hep B, Hib	Contextual Characteristics: Predisposing: Demographic
2013	Glenton, C	Barriers and facilitators to the implementation of lay health worker programmes to improve access to maternal and child health: Qualitative evidence synthesis	Low- and middle-income		maternal and child	review	Maternal and child health	Contextual Characteristics: Enabling: Organization
2009	Gonzaga, MA	Factors influencing students' choices in considering rural radiography careers at Makerere University, Uganda	Uganda		healthcare students	interviews, exploratory	Radiography	Contextual Characteristics: Enabling: Organization
2007	Gordon, AN	Towards a sustainable framework for computer based health information systems (CHIS) for least developed countries (LDCs)	Developing countries			literature survey	N/A	Contextual Characteristics: Enabling: Organization
2009	Goudge, J	Illness-related impoverishment in rural South Africa: Why does social protection work for some households but not others?	South Africa	Rural	households	qualitative, quantitative	N/A	Contextual Characteristics: Enabling: Financing
2006	Grant, H	From the Transvaal to the Prairies: The Migration of South African Physicians to Canada	South Africa		HCWs		N/A	Contextual Characteristics: Enabling: Organization
2008	Gray, J	Intentions and Motivations of Nurses to Migrate: A Review of Empirical Studies	Global		HCWs	review	N/A	Contextual Characteristics: Enabling: Organization
2010	Gray, S	Longitudinal Weight Gain of Immunized Infants and Toddlers in Moroto District, Uganda (Karamoja Sub region)	Uganda	District	children		Child health	Individual Characteristics: Predisposing: Demographic
2002	Green, A	A shared mission? Changing relationships between government and church health services in Africa	Africa				N/A	Contextual Characteristics: Enabling: Organization
2012	Gross, K	Timing of antenatal care for adolescent and adult pregnant women in south-eastern Tanzania	Tanzania		women	qualitative, explorative, interviews	Antenatal	Health Behaviours: Personal Health Practices
2014	Haile, F	Assessment of non-financial incentives for volunteer community health workers – the case of Wukro district, Tigray, Ethiopia	Ethiopia	District	CHWs	quantitative analysis, cross sectional	N/A	Contextual Characteristics: Enabling: Organization

2015	Hapunda, G	Living with type 1 diabetes is challenging for Zambian adolescents: qualitative data on stress, coping with stress and quality of care and life	Zambia		adolescents	interviews	Diabetes	Individual Characteristics: Predisposing: Social
2016	Hasiso, TY	Adherence to Treatment and Factors Affecting Adherence of Epileptic Patients at Yirgalem General Hospital, Southern Ethiopia: A Prospective Cross-Sectional Study	Ethiopia		patients	cross sectional survey	Epilepsy	Health Behaviours: Personal Health Practices
2016	Hategekimana, C	Correlates of Performance of Healthcare Workers in Emergency, Triage, Assessment and Treatment plus Admission Care (ETAT+) Course in Rwanda: Context Matters	Rwanda		HCWs	linear and logistic regression	N/A	Contextual Characteristics: Enabling: Organization
2013	Hattingh, TS	An unlikely suitor: Industrial engineering in health promotion	South Africa				N/A	Contextual Characteristics: Enabling: Organization
2016	Hazemba, AN	Promotion of exclusive breastfeeding among HIV-positive mothers: an exploratory qualitative study	Zambia		maternal and child	qualitative, explorative, interviews	Maternal, HIV/AIDS	Health Behaviours: Personal Health Practices
2011	Heunis, JC	Patient- and delivery-level factors related to acceptance of HIV counselling and testing services among tuberculosis patients in South Africa: a qualitative study with community health workers and program managers	South Africa			interviews	TB	Health Behaviours: Use of Personal Health Services
2013	Hill, J	Factors Affecting the Delivery, Access, and Use of Interventions to Prevent Malaria in Pregnancy in Sub-Saharan Africa: A Systematic Review and Meta- Analysis	sub-Saharan Africa		women	systematic review	Malaria, Maternal	Individual Characteristics: Need: Perceived
2014	Hodgson, I	A Systematic Review of Individual and Contextual Factors Affecting ART Initiation, Adherence, and Retention for HIV-Infected Pregnant and Postpartum Women	sub-Saharan Africa		women	systematic review	Maternal, HIV/AIDS	Health Behaviours: Use of Personal Health Practices
2012	Holt, K	Assessment of Service Availability and Health Care Workers' Opinions about Young Women's Sexual and Reproductive Health in Soweto, South Africa	South Africa	Urban	women	interviews	Sexual Health	Individual Characteristics: Need: Perceived
2015	Honda, A	Analysis of agency relationships in the design and implementation process of the equity fund in Madagascar	Madagascar			case study	N/A	Contextual Characteristics: Enabling: Financing
2015	Hudelson, C	Factors associated with adherence to antiretroviral therapy among adolescents living with HIV/AIDS in low- and middle-income countries: a systematic review	Low- and middle-income		adolescents	systematic review	HIV/AIDS	Health Behaviours: Personal Health Practices
2010	Human, SP	Factors influencing Tuberculosis treatment interruptions	South Africa		patients	quantitative analysis, survey	TB	Health Behaviours: Process of Medical Care
2012	Igira, FT	The dynamics of healthcare work practices: Implications for health management information systems design and implementation	Tanzania			review	N/A	Contextual Characteristics: Enabling: Organization

2010	Iroha, E	Adherence to antiretroviral therapy among HIV-infected children attending a donor-funded clinic at a tertiary hospital in Nigeria	Nigeria		children		HIV/AIDS	Health Behaviours: Use of Personal Health Services
2014	Ishijima, H	Factors influencing national rollout of quality improvement approaches to public hospitals in Tanzania	Tanzania	Public		interviews	N/A	Contextual Characteristics: Enabling: Organization
2011	Issah, K	Maternal and neonatal survival and mortality in the Upper West Region of Ghana	Ghana	District	women, children		Maternal and child health	Contextual Characteristics: Need: Population Health Indices
2015	Iwelunmor, J	A Concept Mapping Study of Physicians' Perceptions of Factors Influencing Management and Control of Hypertension in Sub-Saharan Africa	sub-Saharan Africa				Hypertensi on	Contextual Characteristics: Enabling: Health Policy
2015	Iwelunmor, J	A Narrative Synthesis of the Health Systems Factors Influencing Optimal Hypertension Control in Sub-Saharan Africa	sub-Saharan Africa			narrative synthesis	Hypertensi on	Contextual Characteristics: Enabling: Organization
2014	Izugbara, CO	Research on Women's Health in Africa: Issues, Challenges, and Opportunities	Africa		women	editorial	Women's health	Individual Characteristics: Need: Perceived
2005	Johns, B	Costs of scaling up health interventions: a systematic review	Global			systematic review	N/A	Contextual Characteristics: Enabling: Financing
2012	Johnston, V	Second-Line Antiretroviral Therapy in a Workplace and Community-Based Treatment Programme in South Africa: Determinants of Virological Outcome	South Africa		patients	Poisson regression	HIV/AIDS	Health Behaviours: Use of Personal Health Services
2010	Jombo, GTA	Socio-cultural factors influencing insecticide treated bed net utilization in a malaria endemic city in north-central Nigeria	Nigeria	Urban	Households	Interviews quantitative and qualitative analysis Epi Info 6 statistical software	Malaria	Contextual Characteristics: Predisposing: Social
2016	Jordan, K	Barriers and Facilitators to Scaling Up the Non-Pneumatic Anti-Shock Garment for Treating Obstetric Haemorrhage: A Qualitative Study	Ethiopia, Zimbabwe, Nigeria		women	qualitative	Maternal	Health Behaviours: Process of Medical Care
2013	Joseph, C	Activity limitations and factors influencing functional outcome of patients with stroke following rehabilitation at a specialized facility in the Western Cape	South Africa	District	patients		Stroke	Outcomes: Evaluated Health
2015	Juma, PA	Integrated community case management for childhood illnesses: explaining policy resistance in Kenya	Kenya		children	interviews, review	Child health	Contextual Characteristics: Enabling: Health Policy
2016	Kabatooro, A	Patient satisfaction with medical consultations among adults attending Mulago hospital assessment centre	Uganda		patients	quantitative analysis, cross sectional	N/A	Outcomes: Consumer Satisfaction
2012	Kamau, TM	The effectiveness of social resource intervention to promote adherence to HIV medication in a multidisciplinary care setting in Kenya	Kenya		patients	cross sectional survey	HIV/AIDS	Individual Characteristics: Predisposing: Social

2013	Katz, IT	A Qualitative Analysis of Factors Influencing HPV Vaccine Uptake in Soweto, South Africa among Adolescents and Their Caregivers	South Africa	Urban	adolescents	interviews	Sexual Health, cervical cancer	Health Behaviours: Personal Health Practices
2012	Kawonga, M	Aligning vertical interventions to health systems: a case study of the HIV monitoring and evaluation system in South Africa	South Africa	District, public		interviews	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2007	Kazembe, L	Choice of treatment for fever at household level in Malawi: examining spatial patterns	Malawi		households	multinomial logistic regression	Malaria	Health Behaviours: Personal Health Practices
2016	Keikelame, MJ	'It is always HIV/AIDS and TB'': Home-based carers' perspectives on epilepsy in Cape Town, South Africa	South Africa	Urban	CHWs	interviews	Epilepsy	Individual Characteristics: Need: Perceived
2012	Keikelame, MJ	Lost opportunities to improve health literacy: Observations in a chronic illness clinic providing care for patients with epilepsy in Cape Town South Africa	South Africa		patients		Epilepsy	Individual Characteristics: Enabling: Organization
2016	Keikelame, MJ	"The others look at you as if you are a grave": a qualitative study of subjective experiences of patients with epilepsy regarding their treatment and care in Cape Town, South Africa	South Africa		patients	interviews	Epilepsy	Individual Characteristics: Predisposing: Beliefs
2004	Kinoti, SN	How research can affect policy and programme advocacy: Example from a three-country study on abortion complications in sub-Saharan Africa	sub-Saharan Africa		women	interviews	Abortion	Contextual Characteristics: Enabling: Health Policy
2014	Kisoka, WJ	Factors Influencing Drug Uptake during Mass Drug Administration for Control of Lymphatic Filariasis in Rural and Urban Tanzania	Tanzania	Rural, urban	adults	interviews	Lymphatic Filariasis	Contextual Characteristics: Enabling: Organization
2012	Kizito, J	Improving access to health care for malaria in Africa: a review of literature on what attracts patients	Africa			systematic review	Malaria	Contextual Characteristics: Enabling: Organization
2014	Kohler, PK	Shame, Guilt, and Stress: Community Perceptions of Barriers to Engaging in Prevention of Mother to Child Transmission (PMTCT) Programs in Western Kenya	Kenya	Rural	maternal and child	multivariable logistic regression, cross sectional	HIV/AIDS	Individual Characteristics: Predisposing: Beliefs
2015	Kohler, RE	Developing a discrete choice experiment in Malawi: eliciting preferences for breast cancer early detection services	Malawi		women	review	Breast cancer	Health Behaviours: Personal Health Practices
2015	Kok, MC	How does context influence performance of community health workers in low- and middle-income countries? Evidence from the literature	Low- and middle-income	Community	CHWs	systematic review	N/A	Contextual Characteristics: Enabling: Organization
2009	Kruger, A	Health care seeking behaviour of newly diagnosed HIV infected people from rural and urban communities in the North-West Province of South Africa	south Africa	Community	patients	interviews	HIV/AIDS	Health Behaviours: Use of Personal Health Services
2013	Krumpkamp, R	Health Care Utilization and Symptom Severity in Ghanaian Children – a Cross-Sectional Study	Ghana	Rural	children	Poisson regression, cross sectional	Disease (Diarrhoea, fever)	Health Behaviours: Use of Personal Health Services

2013	Lakew, Y	Geographical variation and factors influencing modern contraceptive use among married women in Ethiopia: evidence from a national population based survey	Ethiopia		women	multivariate analysis, survey	Sexual Health	Individual Characteristics: Predisposing: Demographic
2005	Landau, A	Liver injuries in children: The role of selective non-operative management	South Africa		children		Injury	Health Behaviours: Process of Medical Care
2007	Lara, AM	Laboratory costs of a hospital-based blood transfusion service in Malawi	Malawi	Rural			Transfusion	Contextual Characteristics: Enabling: Financing
2007	Launiala, A	Ethnographic study of factors influencing compliance to intermittent preventive treatment of malaria during pregnancy among Yao women in rural Malawi	Malawi	Rural	women	ethnographic, interviews	Malaria, Maternal	Health Behaviours: Personal Health Practices
2014	Lawani, LO	Dual method use for protection of pregnancy and disease prevention among HIV infected women in South East Nigeria	Nigeria		women	cross sectional survey	HIV/AIDS	Health Behaviours: Personal Health Practices
2014	Layer, EH	Multi-Level Factors Affecting Entry into and Engagement in the HIV Continuum of Care in Iringa, Tanzania	Tanzania			interviews, observational	HIV/AIDS	Health Behaviours: Process of Medical Care
2013	Ledikwe, JH	Evaluation of a Well-Established Task-Shifting Initiative: The Lay Counsellor Cadre in Botswana	Botswana		HCWs	interviews, observational	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2014	Ledikwe, JH	Scaling-up voluntary medical male circumcision – what have we learned?	Africa		men	review	Circumcision	Individual Characteristics: Predisposing: Beliefs
2015	Lewallen, S	Factors affecting cataract surgical coverage and outcomes: a retrospective cross-sectional study of eye health systems in sub-Saharan Africa	sub-Saharan Africa			survey, ANOVA	Optometry, surgery	Individual Characteristics: Need: Evaluated
2012	Lewis-Wall, L	Preventing Obstetric Fistulas in Low-Resource Countries: Insights from a Haddon Matrix	Resource limited countries		women		Maternal	Health Behaviours: Process of Medical Care
2001	Lienhardt, C	Factors affecting time delay to treatment in a tuberculosis control programme in a sub Saharan African country: the experience of The Gambia	Gambia		patients	interviews	TB	Health Behaviours: Use of Personal Health Services
2015	Likwa, RN	Building capacity for public health and population policy-making: perspectives from Zambia	Zambia	Public			N/A	Contextual Characteristics: Enabling: Health Policy
2001	Lishimpi, K	Necropsies in African children: consent dilemmas for parents and guardians	Africa		children		Child health	Individual Characteristics: Predisposing: Beliefs
2013	Liverani, M	Political and Institutional Influences on the Use of Evidence in Public Health Policy. A Systematic Review	Global	Public		systematic review	N/A	Contextual Characteristics: Enabling: Health Policy
2012	Lori, JR	Factors influencing Ghanaian midwifery students' willingness to work in rural areas: A computerized survey	Ghana	Rural	healthcare students	multivariable logistic regression, interviews	N/A	Contextual Characteristics: Enabling: Organization
2012	Lori, JR	Perceived barriers and motivating factors influencing student midwives' acceptance of rural postings in Ghana	Ghana	Rural	healthcare students	qualitative, explorative, interviews	Maternal	Contextual Characteristics: Enabling: Organization

2013	Louw, VJ	Factors affecting the current status of transfusion medicine education in South Africa	South Africa			review	Transfusion	Contextual Characteristics: Enabling: Organization
2016	Lowe, M	Social and Cultural Factors Affecting Maternal Health in Rural Gambia: An Exploratory Qualitative Study	Gambia	Rural	women	interviews	Maternal	Contextual Characteristics: Predisposing: Social
2015	Lund, C	Generating evidence to narrow the treatment gap for mental disorders in sub-Saharan Africa: rationale, overview and methods of AFFIRM	sub-Saharan Africa		patients		Mental health	Individual Characteristics: Need: Perceived
2016	Lungu, EA	Healthcare seeking practices and barriers to accessing under-five child health services in urban slums in Malawi: a qualitative study	Malawi	Urban	children	qualitative, interviews	Child health	Health Behaviours: Personal Health Practices
2013	Lusignani, LS	Factors associated with patient and health care system delay in diagnosis for tuberculosis in the province of Luanda, Angola	Angola		patients	cross sectional survey	TB	Health Behaviours: Process of Medical Care
2013	Lygizos, M	Natural ventilation reduces high TB transmission risk in traditional homes in rural KwaZulu-Natal, South Africa	South Africa	District, rural	households	multivariable logistic regression	TB	Health Behaviours: Personal Health Practices
2015	Mabelane, T	Factors affecting the implementation of nurse- initiated antiretroviral treatment in primary health care clinics of Limpopo Province, South Africa	South Africa	District		quantitative analysis, survey	HIV/AIDS	Contextual Characteristics: Enabling: Health Policy
2012	Macha, J	Factors influencing the burden of health care financing and the distribution of health care benefits in Ghana, Tanzania and South Africa	South Africa, Tanzania, Ghana		adults	interviews	N/A	Contextual Characteristics: Enabling: Financing
2010	Maharaj, P	Missing opportunities for preventing unwanted pregnancy: a qualitative study of emergency contraception	South Africa		women	qualitative, interviews	Maternal	Health Behaviours: Personal Health Practices
2010	Mairiga, AG	Sociocultural factors influencing decision-making related to fertility among the Kanuri tribe of north-eastern Nigeria	Nigeria	Community	women	qualitative	Maternal	Individual Characteristics: Predisposing: Social
2008	Makin, JD	Factors Affecting Disclosure in South African HIV-Positive Pregnant Women	South Africa		women	survey	Maternal, HIV/AIDS	Individual Characteristics: Predisposing: Beliefs
2015	Mannava, P	Attitudes and behaviours of maternal health care providers in interactions with clients: a systematic review	Low- and middle-income	Public	HCWs	systematic review	Maternal	Contextual Characteristics: Enabling: Organization
2010	Maqutu, D	Factors affecting first-month adherence to antiretroviral therapy among HIV-positive adults in South Africa	South Africa		patients		HIV/AIDS	Health Behaviours: Personal Health Practices
2011	Marschall, P	Efficiency of primary care in rural Burkina Faso. A two-stage DEA analysis	Burkina Faso	Rural		data Envelopment Analysis	N/A	Contextual Characteristics: Enabling: Organization
2008	Martin, C	Dietitians' perceptions of the continuing professional development system in South Africa	South Africa		HCWs	qualitative, quantitative	N/A	Contextual Characteristics: Enabling: Organization
2007	Mathauer, I	Extending social health insurance to the informal sector in Kenya. An assessment of factors affecting demand	Kenya		adults	survey	N/A	Contextual Characteristics: Enabling: Financing

2006	Mathews, C	Factors associated with teachers' implementation of HIV/AIDS education in secondary schools in Cape Town, South Africa	South Africa	Urban, city	adolescents	survey	HIV/AIDS	Individual Characteristics: Predisposing: Social
2012	Maticka-Tyndale, E	Condoms in sub-Saharan Africa	sub-Saharan Africa		adults		Sexual Health	Health Behaviours: Personal Health Practices
2010	Mavhu, W	Chronic cough and its association with TB-HIV co-infection: factors affecting help-seeking behaviour in Harare, Zimbabwe	Zimbabwe	Urban, city	patients	cross sectional survey	HIV/AIDS, TB	Health Behaviours: Use of Personal Health Services
2004	Mayeya, J	Zambia mental health country profile	Zambia			interviews	Mental health	Individual Characteristics: Need: Evaluated
2000	Mayhew, SH	Integration of STI Services into FP/MCH Services: Health Service and Social Contexts in Rural Ghana	Ghana	Rural			Sexual Health	Contextual Characteristics: Enabling: Health Policy
2005	Mayhew, SH	Donor agencies' involvement in reproductive health: Saying one thing and doing another?	Zambia, Kenya, South Africa, Ghana				Sexual Health	Contextual Characteristics: Enabling: Organization
2013	Mbulawa, ZZA	The impact of human immunodeficiency virus on human papillomavirus transmission in heterosexually active couples	South Africa		heterosexuals		HIV/AIDS	Health Behaviours: Personal Health Practices
2005	McIntyre, J	Maternal Health and HIV	Resource limited countries		women		Maternal, HIV/AIDS	Individual Characteristics: Need: Evaluated
2012	McMillan, WJ	Recruiting and retaining rural students: evidence from a faculty of dentistry in South Africa	South Africa	Rural	healthcare students	interviews	Dental	Contextual Characteristics: Enabling: Organization
2003	Mensah, OA	Malaria incidence in rural Benin: does economics matter in endemic area?	Benin	Rural	households		Malaria	Contextual Characteristics: Need: Environment
2008	Merlin, T	Factors influencing women's decisions to purchase specific children's multi-nutrient supplements in the Gauteng Province (South Africa)	South Africa	District	women, children	interviews	Child health	Individual Characteristics: Predisposing: Social
2016	Mijovic, H	What does the literature tell us about health workers' experiences of task-shifting projects in sub-Saharan Africa? A systematic, qualitative review	sub-Saharan Africa		HCWs	systematic review, qualitative	N/A	Contextual Characteristics: Enabling: Organization
2016	Mohammed, F	Determinants of Desire for Children among HIV-Positive Women in the Afar Region, Ethiopia: Case Control Study	Ethiopia	District	women	case study	HIV/AIDS	Individual Characteristics: Predisposing: Beliefs
2011	Mokoka, KE	Factors influencing the retention of registered nurses in the Gauteng Province of South Africa	South Africa	District	HCWs	survey	N/A	Contextual Characteristics: Enabling: Organization
2015	Moodley, J	Understanding pathways to breast cancer diagnosis among women in the Western Cape Province, South Africa: a qualitative study	South Africa	District	women	qualitative, interviews	Breast cancer	Individual Characteristics: Need: Evaluated

2007	Moonasar, D	An exploratory study of factors that affect the performance and usage of rapid diagnostic tests for malaria in the Limpopo Province, South Africa	South Africa	District		cross sectional survey	Malaria	Health Behaviours: Use of Personal Health Services
2006	Moore, AR	Stress, social support and depression in informal caregivers to people with HIV/AIDS in Lomé, Togo	Togo		patients	interviews	HIV/AIDS	Individual Characteristics: Predisposing: Social
2013	Morgan, R	Aligning faith-based and national HIV/AIDS prevention responses? Factors influencing the HIV/AIDS prevention policy process and response of faith-based NGOs in Tanzania	Tanzania	Urban		qualitative	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2015	Morton, D	Support for volunteer caregivers and its influence on the quality of community home-based care in the Eastern Cape, South Africa	South Africa	District	CHWs	interviews	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2015	Mponela, MJ	Post exposure prophylaxis following occupational exposure to HIV: a survey of health care workers in Mbeya, Tanzania, 2009-2010	Tanzania	District, public	HCWs	cross sectional survey	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2007	Mrisho, M	Factors affecting home delivery in rural Tanzania	Tanzania	Rural	women	interviews, cross sectional, observational, negative binomial regression	Maternal	Individual Characteristics: Predisposing: Beliefs
2013	Mubi, M	Malaria diagnosis and treatment practices following introduction of rapid diagnostic tests in Kibaha District, Coast Region, Tanzania	Tanzania	District	patients	interviews	Malaria	Health Behaviours: Process of Medical Care
2008	Mubyazi, GM	Implementing Intermittent Preventive Treatment for Malaria in Pregnancy: Review of Prospects, Achievements, Challenges and Agenda for Research	Tanzania		women		Malaria, Maternal	Health Behaviours: Personal Health Practices
2005	Mudokwenuy-Rawdon, C	Factors influencing post abortion outcomes among high-risk patients in Zimbabwe	Zimbabwe		women		Abortion	Outcomes: Evaluated Health
2008	Mulder, AA	Healthcare seeking behaviour for Buruli ulcer in Benin: a model to capture therapy choice of patients and healthy community members	Benin		adults	interviews	Buruli Ulcer	Health Behaviours: Use of Personal Health Services
2014	Mungati, M	Factors affecting diagnosis and management of hypertension in Mazowe District of Mashonaland Central Province in Zimbabwe: 2012	Zimbabwe	District	HCWs	analytic, cross section, interviews	Hypertension	Health Behaviours: Use of Personal Health Services
2013	Musheke, M	A systematic review of qualitative findings on factors enabling and deterring uptake of HIV testing in Sub-Saharan Africa	sub-Saharan Africa			systematic review, ethnographic, meta-analysis	HIV/AIDS	Health Behaviours: Personal Health Practices
2012	Mushi, D	Perceptions, social life, treatment and education gap of Tanzanian children with epilepsy: A community-based study	Tanzania	Community	children	interviews	Epilepsy	Individual Characteristics: Predisposing: Social
2014	Mutasa-Apollo, T	Patient Retention, Clinical Outcomes and Attrition-Associated Factors of HIV-Infected Patients Enrolled in	Zimbabwe		patients	retrospective review	HIV/AIDS	Health Behaviours: Use of Personal Health Services

		Zimbabwe's National Antiretroviral Therapy Programme, 2007-2010						
2014	Mutero, CM	Factors influencing malaria control policy-making in Kenya, Uganda and Tanzania	Kenya, Uganda, Tanzania			interviews	Malaria	Contextual Characteristics: Enabling: Health Policy
2015	Naanyu, V	Barriers Influencing Linkage to Hypertension Care in Kenya: Qualitative Analysis from the LARK Hypertension Study	Kenya	Rural	patients	qualitative, interviews	Hypertension	Contextual Characteristics: Enabling: Organization
2013	Naidoo, K	Survey of ethical dilemmas facing intensivists in South Africa in the admission of patients with HIV infection requiring intensive care	South Africa		HCWs	quantitative analysis, cross sectional, survey	HIV/AIDS	Contextual Characteristics: Enabling: Health Policy
2009	Naidoo, P	Factors influencing HAART adherence among private health care sector patients in a suburb of the Ethekwini Metro	South Africa	Private	patients	cross sectional survey	HIV/AIDS	Health Behaviours: Personal Health Practices
2014	Nakambale, A	Factors Affecting Utilization of Skilled Birth Attendants by Women in Northern Zambia	Zambia	District	women	interviews	Maternal	Contextual Characteristics: Enabling: Organization
2009	Nattabi, B	A Systematic Review of Factors Influencing Fertility Desires and Intentions Among People Living with HIV/AIDS: Implications for Policy and Service Delivery	sub-Saharan Africa		women	systematic review	HIV/AIDS	Contextual Characteristics: Enabling: Health Policy
2015	Ndhlovu, M	Antibiotic prescribing practices for patients with fever in the transition from presumptive treatment of malaria to 'confirm and treat' in Zambia: a cross-sectional study	Zambia		patients	cross sectional survey	Malaria	Health Behaviours: Process of Medical Care
2001	Needham, DM	Socio-economic, gender and health services factors affecting diagnostic delay for tuberculosis patients in urban Zambia	Zambia		adults	interviews	TB	Contextual Characteristics: Predisposing: Social
2014	Ngome, E	The social context of adolescent women's use of modern contraceptives in Zimbabwe: a multilevel analysis	Zimbabwe		women, adolescents	multivariable logistic regression	Sexual Health	Health Behaviours: Personal Health Practices
2008	Ngowu, R	Reducing child mortality in Nigeria: A case study of immunization and systemic factors	Nigeria		children	multivariable logistic regression	Child health	Health Behaviours: Personal Health Practices
2013	Ngxongo, T	Factors influencing successful implementation of the basic antenatal care approach in primary health care facilities in eThekwini district, KwaZulu-Natal	South Africa	District	women	quantitative analysis	Antenatal	Contextual Characteristics: Enabling: Organization
2005	Niba, MBI	Major factors influencing HIV/AIDS project evaluation	South Africa			interviews, case study	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2016	Njuguna, F	Factors influencing time to diagnosis and treatment among paediatric oncology patients in Kenya	Kenya		children	interviews	Cancer	Health Behaviours: Process of Medical Care
2013	Nkosi, D	Factors influencing specialist care referral of multidrug- and extensively drug-resistant tuberculosis patients in Gauteng/South Africa: a descriptive questionnaire-based study	South Africa	District, urban	patients	survey	TB	Health Behaviours: Process of Medical Care
2009	Noble, V	A Medical Education with a Difference: A History of the Training of Black Student Doctors in Social, Preventive	South Africa	District	healthcare students		N/A	Contextual Characteristics: Enabling: Organization

		and Community-Oriented Primary Health Care at the University of Natal Medical School, 1940s–19601						
2015	Nostlinger, C	Factors influencing social self-disclosure among adolescents living with HIV in Eastern Africa	Kenya, Uganda, Kampala		adolescents	multivariable logistic regression, interviews	HIV/AIDS	Individual Characteristics: Predisposing: Social
2014	Ntsepe, Y	Perceptions about the acceptability and prevalence of HIV testing and factors influencing them in different communities in South Africa	South Africa		adults	interviews	HIV/AIDS	Individual Characteristics: Predisposing: Beliefs
2005	Nuwaha, F	Predictors of compliance with community-directed ivermectin treatment in Uganda: quantitative results	Uganda	District		cross sectional survey	Parasitic	Health Behaviours: Process of Medical Care
2000	Nuwaha, F	Psychosocial determinants for sexual partner referral in Uganda: qualitative results	Uganda		adults	interviews	Sexual Health	Individual Characteristics: Predisposing: Social
2008	Nwadiaro, HC	Determinants of Patronage of Traditional Bone Setters in the Middle Belt of Nigeria	Nigeria			interviews	Injury	Individual Characteristics: Predisposing: Beliefs
2015	Nyamunyekung'e, KK	The relative patient costs and availability of dental services, materials and equipment in public oral care facilities in Tanzania	Tanzania	Public		interviews	Dental	Contextual Characteristics: Enabling: Organization
2016	Nyasulu, P	Factors Influencing Delayed Health Care Seeking Among Pulmonary Tuberculosis Suspects in Rural Communities in Ntcheu District, Malawi	Malawi	Rural, community	patients	interviews	TB	Health Behaviours: Use of Personal Health Services
2014	Nyondo, AL	Stakeholders' perceptions on factors influencing male involvement in prevention of mother to child transmission of HIV services in Blantyre, Malawi	Malawi	Urban	maternal and child	qualitative, interviews	HIV/AIDS	Individual Characteristics: Predisposing: Social
2015	Nzioki, JM	Efficiency and factors influencing efficiency of Community Health Strategy in providing Maternal and Child Health services in Mwingi District, Kenya: an expert opinion perspective	Kenya	District		qualitative	Maternal	Contextual Characteristics: Enabling: Health Policy
2005	O'Hare, B	Child health in Africa: 2005 a year of hope?	Africa		children		Child health	Contextual Characteristics: Enabling: Health Policy
2015	Odetola, TD	Health care utilization among rural women of child-bearing age: a Nigerian experience	Nigeria	Rural	women	descriptive study	Maternal	Health Behaviours: Use of Personal Health Services
2014	Odeyemi, IAO	Community-based health insurance programmes and the national health insurance scheme of Nigeria: challenges to uptake and integration	Nigeria			review	N/A	Contextual Characteristics: Enabling: Financing
2014	Oduwo, E	A systematic review of factors affecting children's right to health in cluster randomized trials in Kenya	Kenya		children	systematic review	Child health	Contextual Characteristics: Predisposing: Social
2016	Ogundele, OA	An ontology for factors affecting tuberculosis treatment adherence behaviour in sub-Saharan Africa	sub-Saharan Africa			review	TB	Health Behaviours: Personal Health Practices
2015	Okwaraji, YB	Barriers in physical access to maternal health services in rural Ethiopia	Ethiopia	Rural	women	cross sectional survey	Maternal	Contextual Characteristics: Need: Environment

2007	Olago, D	Climatic, Socio-economic, and Health Factors Affecting Human Vulnerability to Cholera in the Lake Victoria Basin, East Africa	Kenya, Uganda, Tanzania				Cholera	Contextual Characteristics: Need: Environmental
2006	Onah, HE	Factors associated with the use of maternity services in Enugu, south-eastern Nigeria	Nigeria		women	interviews	Maternal	Health Behaviours: Use of Personal Health Services
2013	Onyeonoro, UU	Effect of TB behaviour change communication (BCC) intervention in Enugu state, southeast Nigeria	Nigeria	District	adults	cross sectional survey	TB	Health Behaviours: Personal Health Practices
2010	Osawa, E	Motivation and sustainability of care facilitators engaged in a community home-based HIV/AIDS program in Masvingo Province, Zimbabwe	Zimbabwe	District	CHWs	cross sectional survey	HIV	Contextual Characteristics: Enabling: Organization
2006	Osterholt, DM	Predictors of treatment error for children with uncomplicated malaria seen as outpatients in Blantyre district, Malawi	Malawi	District	children	multivariable logistic regression	Malaria	Health Behaviours: Process of Medical Care
2016	Owusu-Ansah, FE	Access to health in city slum dwellers: The case of Sodom and Gomorrah in Accra, Ghana	Ghana	Urban	slum dwellers	interviews	Health	Contextual Characteristics: Need: Environment
2012	Owusu-Asubonteng, G	Trend, client profile and surgical features of vasectomy in Ghana	Ghana		men		Vasectomy	Individual Characteristics: Need: Perceived
2014	Oyekale, AS	Maternal Factors Influencing Timeliness of Seeking Treatment for Fever in Children under Five and Healthcare Preferences in Malawi	Malawi		children	Poisson regression, Logit regression	Malaria	Health Behaviours: Use of Personal Health Services
2015	Papali, A	A “three delays” model for severe sepsis in resource-limited countries	Low- and middle-income		adults	review	Sepsis	Health Behaviours: Use of Personal Health Services
2005	Parkhurst, JO	Health systems factors influencing maternal health services: a four-country comparison	South Africa, Uganda			comparison	Maternal	Contextual Characteristics: Enabling: Organization
2002	Paterson, M	Probability of assertive behaviour, interpersonal anxiety and self-efficacy of South African registered dietitians	South Africa		HCWs	interviews	N/A	Contextual Characteristics: Enabling: Organization
2007	Paterson, M	Running before we walk: How can we maximize the benefits from community service dietitians in KwaZulu-Natal, South Africa?	South Africa	District	HCWs	interviews	N/A	Contextual Characteristics: Enabling: Organization
2014	Paul, B	Influence of HIV Testing on Knowledge of HIV/AIDS Prevention Practices and Transmission among Undergraduate Youths in North-West University, Mafikeng	South Africa	District	adolescents		HIV	Individual Characteristics: Predisposing: Beliefs
2011	Pell, C	Social and Cultural Factors Affecting Uptake of Interventions for Malaria in Pregnancy in Africa: A Systematic Review of the Qualitative Research	Africa		women	systematic review, qualitative	Malaria, Maternal	Individual Characteristics: Predisposing: Social
2013	Pell, C	Factors Affecting Antenatal Care Attendance: Results from Qualitative Studies in Ghana, Kenya and Malawi	Ghana, Kenya, Malawi		women	qualitative, interviews, observational	Antenatal	Health Behaviours: Use of Personal Health Services

2011	Peltzer, K	Sexual dissatisfaction and associated factors in a sample of patients on antiretroviral treatment in KwaZulu-Natal, South Africa	South Africa	District	patients	survey	HIV	Health Behaviours: Personal Health Practices
2014	Petersen, M	Observational Research on NCDs in HIV-Positive Populations: Conceptual and Methodological Considerations	sub-Saharan Africa				HIV, Cardiovascular, Pulmonary, NCD	Individual Characteristics: Need: Evaluated
2016	Pillay, V	How Do Patients Choose Their Spectacles in the Public Sector of South Africa?	South Africa	District, public	patients	interviews	Optometry	Individual Characteristics: Predisposing: Social
2016	Poppe, A	The views of migrant health workers living in Austria and Belgium on return migration to sub-Saharan Africa	sub-Saharan Africa		HCWs	interviews, case study	N/A	Contextual Characteristics: Enabling: Organization
2015	Ports, KA	Integrating cervical cancer prevention initiatives with HIV care in resource-constrained settings: A formative study in Durban, South Africa	South Africa	District	women	interviews	HIV/AIDS, Cervical cancer	Contextual Characteristics: Enabling: Organization
2016	Rachilis, B	Facility-Level Factors Influencing Retention of Patients in HIV Care in East Africa	Kenya, Uganda, Tanzania		patients		HIV/AIDS	Contextual Characteristics: Enabling: Organization
2010	Rahlenbeck, S	Female genital cutting starts to decline among women in Oromia, Ethiopia	Ethiopia		women		Female genital cutting	Individual Characteristics: Predisposing: Beliefs
2007	Rampanjato, RM	Factors influencing pain management by nurses in emergency departments in Central Africa	Africa		HCWs	survey	Injury	Health Behaviours: Process of Medical Care
2002	Raviola, G	HIV, disease plague, demoralization and "burnout": Resident experience of the medical profession in Nairobi, Kenya	Kenya	City	HCWs	interviews	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2016	Rees, CP	Factors Affecting Access to Healthcare: An Observational Study of Children under 5 Years of Age Presenting to a Rural Gambian Primary Healthcare Centre	Gambia	Rural	children	observational	Child health	Contextual Characteristics: Need: Environment
2013	Rehfuess, EA	Diagram-based Analysis of Causal Systems (DACS): elucidating inter-relationships between determinants of acute lower respiratory infections among children in sub-Saharan Africa	sub-Saharan Africa		children	Diagram-based analysis	Respiratory	Individual Characteristics: Need: Evaluated
2006	Rennie, S	AIDS Care and Treatment in Sub-Saharan Africa	sub-Saharan Africa				HIV	Health Behaviours: Use of Personal Health Services
2014	Rispel, LC	Factors influencing agency nursing and moonlighting among nurses in South Africa	South Africa		HCWs	survey	N/A	Contextual Characteristics: Enabling: Organization
2012	Robyn, PJ	Health insurance and health-seeking behaviour: Evidence from a randomized community-based insurance rollout in rural Burkina Faso	Burkina Faso	Rural	households		N/A	Contextual Characteristics: Enabling: Financing

2001	Rogo, KO	Maternal Mortality in Kenya: The state of health facilities in a rural district	Kenya	District, rural	women	qualitative, interviews	Maternal	Contextual Characteristics: Enabling: Organization
2007	Rowe, AK	Evaluating the impact of malaria control efforts on mortality in sub-Saharan Africa	sub-Saharan Africa		children		Malaria	Individual Characteristics: Need: Evaluated
2015	Rukundo, GZ	Antenatal services for pregnant teenagers in Mbarara Municipality, Southwestern Uganda: health workers and community leaders' views	Uganda	District	women, adolescents	cross sectional survey	Antenatal	Individual Characteristics: Need: Perceived
2010	Rutherford, ME	How access to health care relates to under-five mortality in sub-Saharan Africa: systematic review	sub-Saharan Africa		children	systematic review	Child health	Contextual Characteristics: Need: Environment
2013	Rutto, JJ	Socio-Economic and Cultural Determinants of Human African Trypanosomiasis at the Kenya - Uganda Transboundary	Uganda			cross sectional survey	Sleeping sickness	Contextual Characteristics: Predisposing: Social
2015	Sacks, E	Factors influencing modes of transport and travel time for obstetric care: a mixed methods study in Zambia and Uganda	Zambia, Uganda	Rural	women	quantitative analysis, survey	Obstetric	Contextual Characteristics: Need: Environmental
2014	Sariah, AE	Risk and protective factors for relapse among individuals with schizophrenia: a qualitative study in Dar es Salaam, Tanzania	Tanzania	Urban	patients	qualitative	Mental	Outcomes: Perceived Health
2010	Sarna, A	Access to Antiretroviral Therapy for Adults and Children with HIV Infection in Developing Countries: Horizons Studies, 2002-2008	sub-Saharan Africa		patients		HIV/AIDS	Health Behaviours: Use of Personal Health Services
2016	Saso, A	Vaccination against respiratory syncytial virus in pregnancy: a suitable tool to combat global infant morbidity and mortality?	Global		women	review	Maternal, Respiratory	Health Behaviours: Personal Health Practices
2015	Schoevers, J	Factors influencing specialist outreach and support services to rural populations in the Eden and Central Karoo districts of the Western Cape	South Africa	District	HCWs	Delphi	Health	Contextual Characteristics: Enabling: Organization
2011	Scott, V	Constraints to implementing an equity-promoting staff allocation policy: understanding mid-level managers' and nurses' perspectives affecting implementation in South Africa	South Africa		HCWs		N/A	Contextual Characteristics: Enabling: Health Policy
2008	Seedat, M	The Use of Public Health Research in Stimulating Violence and Injury Prevention Practices and Policies	South Africa			case study	Injury	Contextual Characteristics: Enabling: Health Policy
2006	Seljeskog, L	Factors Influencing Women's Choice of Place of Delivery in Rural Malawi-An explorative study	Malawi	District, rural	women	explorative, interviews	Maternal	Individual Characteristics: Predisposing: Beliefs
2015	Shah, K	Factors Affecting the Academic Performance of Optometry Students in Mozambique	Mozambique		Healthcare students	interviews	Optometry	Contextual Characteristics: Enabling: Organization
2014	Shattuck, D	Who chooses vasectomy in Rwanda? Survey data from couples who chose vasectomy, 2010-2012	Rwanda		men	cross sectional survey	Vasectomy	Individual Characteristics: Predisposing: Beliefs
2015	Sialubanje, C	Improving access to skilled facility-based delivery services: Women's beliefs on facilitators and barriers to	Zambia	Rural	women	interviews	Maternal	Contextual Characteristics: Need: Environment

		the utilization of maternity waiting homes in rural Zambia						
2009	Simba, DO	Factors influencing adherence to referral advice following pre-referral treatment with artesunate suppositories in children in rural Tanzania	Tanzania	Rural	children	interviews	Malaria	Health Behaviours: Personal Health Practices
2007	Simmonds, S	Institutional factors and HIV/AIDS, TB and Malaria	Africa				Malaria, HIV/AIDS, TB	Contextual Characteristics: Enabling: Health Policy
2011	Singer, M	Toward a critical biosocial model of ecohealth in Southern Africa: The HIV/AIDS and nutrition insecurity syndemic	Southern Africa				HIV/AIDS	Contextual Characteristics: Need: Population Health Indices
2013	Sipsma, H	Preferences for home delivery in Ethiopia: Provider perspectives	Ethiopia		women	qualitative, interviews	Maternal	Individual Characteristics: Predisposing: Beliefs
2011	Sissolak, D	TB infection prevention and control experiences of South African nurses - a phenomenological study	South Africa		HCWs	qualitative, interviews	TB	Health Behaviours: Process of Medical Care
2014	Slingers, N	Evaluation of the effect of the introduction of a hypertension club on the management of hypertension at a community health centre in the Cape Town Metropole	South Africa	Urban	adults	systematic review	Hypertension	Contextual Characteristics: Enabling: Health Policy
2004	Smakman, N	Factors affecting outcome in penetrating oesophageal trauma	South Africa		patients		Injury	Outcomes: Evaluated Health
2012	Smith-Hall, C	People, plants and health: a conceptual framework for assessing changes in medicinal plant consumption	General			systematic review	Health	Individual Characteristics: Predisposing: Beliefs
2013	Sofolahan, YA	Cultural Expectations and Reproductive Desires: Experiences of South African Women Living With HIV/AIDS (WLHA)	South Africa		women	interviews	HIV/AIDS	Individual Characteristics: Predisposing: Social
2009	Sowden, M	Factors influencing high socio-economic class mothers' decision regarding formula-feeding practices in the Cape Metropole	South Africa	District	women, children		Child health	Individual Characteristics: Predisposing: Social
2013	Stanford, J	Conversations Worth Having: The Perceived Relevance of Advance Care Planning among Teachers, Hospice Staff, and Pastors in Knysna, South Africa	South Africa				Advanced care	Contextual Characteristics: Enabling: Organization
2015	Stellenberg, EL	Prevalence of and factors influencing postnatal depression in a rural community in South Africa	South Africa	Rural, community	women	cross sectional survey	Maternal, Mental	Individual Characteristics: Need: Evaluated
2016	Stellenberg, EL	Knowledge of midwives about hypertension disorders during pregnancy in primary healthcare	South Africa	District	women	survey	Maternal, Hypertension	Contextual Characteristics: Enabling: Organization
2013	Stewart, KA	Traumatic Injuries in Developing Countries: Report from a Nationwide Cross-Sectional Survey of Sierra Leone	Sierra Leone		households	cross sectional survey	Injury	Individual Characteristics: Need: Evaluated

2015	Strauss, M	A qualitative analysis of the barriers and facilitators of HIV counselling and testing perceived by adolescents in South Africa	South Africa	District, rural	adolescents	interviews	HIV/AIDS	Health Behaviours: Process of Medical Care
2013	Sudenga, SL	Knowledge, Attitudes, Practices, and Perceived Risk of Cervical Cancer Among Kenyan Women	Kenya		women	cross sectional survey	Cervical cancer	Individual Characteristics: Need: Perceived
2012	Sukums, F	Promising adoption of an electronic clinical decision support system for antenatal and intrapartum care in rural primary healthcare facilities in sub-Saharan Africa: The QUALMAT experience	sub-Saharan Africa	Rural			Antenatal	Contextual Characteristics: Enabling: Organization
2009	Talmage, G	An exploratory mixed-method study to determine factors that may affect satisfaction levels of athletes receiving chiropractic care in a nonclinical setting	South Africa		athletes	explorative, interviews	Chiropractic care	Contextual Characteristics: Enabling: Organization
2012	Taylor, KD	Explanatory models of hypertension among Nigerian patients at a University Teaching Hospital	Nigeria		patients	interviews	Hypertension	Individual Characteristics: Need: Evaluated
2001	Taylor, M	Working with community health workers to improve nutrition in rural KwaZulu-Natal	South Africa	Rural	CHWs	survey	Health	Individual Characteristics: Predisposing: Social
2015	Tebekaw, Y	Factors Influencing Women's Preferences for Places to Give Birth in Addis Ababa, Ethiopia	Ethiopia	Urban	women	quantitative analysis, cross sectional	Maternal	Individual Characteristics: Predisposing: Beliefs
2015	Titilayo, A	Knowledge of Causes of Maternal Health Seeking Behaviour in Nigeria	Nigeria		women	multivariable logistic regression	Maternal	Health Behaviours: Use of Personal Health Services
2009	Trapido, EJ	Critical factors influencing the establishment, maintenance and sustainability of population- based cancer control programs	Resource limited countries				Cancer	Contextual Characteristics: Enabling: Organization
2015	Tsawe, M	Factors influencing the use of maternal healthcare services and childhood immunization in Swaziland	Swaziland		women, children	explorative and descriptive	Maternal and child health	Health Behaviours: Use of Personal Health Services
2010	Twikirize, JM	Why Ugandan rural households are opting to pay community health insurance rather than use the free healthcare services	Uganda	Rural	households	survey	N/A	Contextual Characteristics: Enabling: Financing
2013	Uebel, K	Integrating HIV care into nurse-led primary health care services in South Africa: a synthesis of three linked qualitative studies	South Africa		HCWs	qualitative	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2012	Ugiagbe, EE	Post-mortem Examinations on Deceased Neonates: A Rarely Utilized Procedure in an African Referral Centre	sub-Saharan Africa		children		Child health	Individual Characteristics: Predisposing: Beliefs
2011	Ukegbu, AU	Determinants of breastfeeding patterns among mothers in Anambra State, Nigeria	Nigeria	District	women, children	interviews	Maternal and child health	Individual Characteristics: Predisposing: Social
2013	Upadhyay, RP	Need to Focus Beyond the Medical Causes: A Systematic Review of the Social Factors Affecting Neonatal Deaths	Africa		children	systematic review, meta-analysis	Child health	Individual Characteristics: Predisposing: Social

2005	van Kooten Niekerk, NKM	The First 5 Years of the Family Clinic for HIV at Tygerberg Hospital: Family Demographics, Survival of Children and Early Impact of Antiretroviral Therapy	South Africa		children	retrospective review	HIV/AIDS	Individual Characteristics Predisposing: Demographics
2002	Vardas, E	Viral hepatitis in South African healthcare workers at increased risk of occupational exposure to blood-borne viruses	South Africa		HCWs		Hep B	Contextual Characteristics: Enabling: Organization
2008	Varga, C	Factors Influencing Teen Mothers' Enrolment and Participation in Prevention of Mother-to-Child HIV Transmission Services in Limpopo Province, South Africa	South Africa	District	women, adolescents	interviews	Maternal, HIV/AIDS	Health Behaviours: Health Behaviours
2015	Verusia, C	Satisfaction and adherence of patients with amputations to physiotherapy service at public hospitals in KwaZulu-Natal, South Africa	South Africa	District, public	patients	cross sectional survey	Amputatio ns	Outcomes: Satisfaction
2015	Vogel, JP	How women are treated during facility-based childbirth: development and validation of measurement tools in four countries - phase 1 formative research study protocol	Ghana, Nigeria, Guinea		women	qualitative, interviews	Maternal	Contextual Characteristics: Enabling: Organization
2016	Vonasek, BJ	Do maternal knowledge and attitudes towards childhood immunizations in rural Uganda correlate with complete childhood vaccination?	Uganda	Rural	children		Maternal and Child health	Individual Characteristics: Predisposing: Beliefs
2004	Vujicic, M	The role of wages in the migration of health care professionals from developing countries	Africa		HCWs		N/A	Contextual Characteristics: Enabling: Organization
2012	Wamai, RG	Assessing the Effectiveness of a Community-Based Sensitization Strategy in Creating Awareness About HPV, Cervical Cancer and HPV Vaccine Among Parents in North West Cameroon	Cameroon			multivariable logistic regression, cross sectional	Cervical cancer	Individual Characteristics: Predisposing: Beliefs
2011	Wambura, M	Acceptability of medical male circumcision in the traditionally circumcising communities in Northern Tanzania	Tanzania		men	cross sectional survey	Circumcisio n	Individual Characteristics: Predisposing: Beliefs
2008	Wasunna, B	Why don't health workers prescribe ACT? A qualitative study of factors affecting the prescription of artemether-lumefantrine	Kenya	District, rural	HCWs	interviews	Malaria	Contextual Characteristics: Enabling: Organization
2012	Watson-Jones, D	Reasons for Receiving or Not Receiving HPV Vaccination in Primary Schoolgirls in Tanzania: A Case Control Study	Tanzania		women, adolescents	interviews, case study	Cervical cancer	Health Behaviours: Use of Personal Health Services
2014	Welniak, TJ	Chronic obstructive pulmonary disease: Emergency care in acute exacerbation	Africa				Pulmonary, Respiratory	Individual Characteristics: Need: Evaluated
2016	Wilhelm, DJ	A qualitative study assessing the acceptability and adoption of implementing a results based financing intervention to improve maternal and neonatal health in Malawi	Malawi			cross sectional survey	Maternal	Contextual Characteristics: Enabling: Financing
2008	Winch, PJ	Operational Issues and Trend Pilot Introduction of Zinc for Childhood Diarrhoea in Bougouni District, Mali	Mali	District	children	quantitative analysis, survey	Diarrhoea	Health Behaviours: Process of Medical Care

2010	Winkler, AS	Attitudes towards African traditional medicine and Christian spiritual healing regarding treatment of Epilepsy in a rural community of Northern Tanzania	Tanzania	Rural		interviews	Epilepsy	Individual Characteristics: Predisposing: Beliefs
2009	Woelk, G	Translating research into policy: lessons learned from eclampsia treatment and malaria control in three southern African countries	Zimbabwe, South Africa, Mozambique			qualitative, interviews, case study	Malaria, Maternal	Contextual Characteristics: Enabling: Health Policy
2015	Woldesenbet, SA	Missed Opportunities for Early Infant HIV Diagnosis: Results of A National Study in South Africa	South Africa		children	cross sectional survey	HIV/AIDS	Health Behaviours: Process of Medical Care
2012	Yawson, AE	Effects of consumer and provider moral hazard at a municipal hospital out-patient department on Ghana's National Health Insurance Scheme	Ghana			survey	N/A	Contextual Characteristics: Enabling: Financing
2010	Yeap, AD	Factors influencing uptake of HIV care and treatment among children in South Africa a qualitative study of caregivers and clinic staff	South Africa		children	qualitative	HIV/AIDS	Health Behaviours: Use of Personal Health Services
2011	Zain, ME	Impact of mycotoxins on humans and animals	General				Mycotoxins	Individual Characteristics: Predisposing: Demographics
2016	Zaman, K	Environmental Factors Affecting Health Indicators in Sub-Saharan African Countries: Health is Wealth	sub-Saharan Africa				Health	Contextual Characteristics: Need: Environmental
2012	Zeng, W	How much can we gain from improved efficiency? An examination of performance of national HIV/AIDS programs and its determinants in low- and middle-income countries	Low- and middle-income			Data Envelopment Analysis	HIV/AIDS	Contextual Characteristics: Enabling: Organization
2013	Zurovac, D	Ownership and use of mobile phones among health workers, caregivers of sick children and adult patients in Kenya: cross-sectional national survey	Kenya	Public	HCWs	cross sectional survey	N/A	Contextual Characteristics: Enabling: Organization
2008	Zurovac, D	Translation of artemether-lumefantrine treatment policy into paediatric clinical practice: an early experience from Kenya	Kenya	District	children	cross sectional survey	Malaria	Contextual Characteristics: Enabling: Health Policy

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DEVELOPMENT OF AN ENERGY CONSUMPTION BASELINE AND PERFORMANCE INDICES FOR A GALVANISING PLANT

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ABSTRACT

Galvanising plants are characterised by excessive consumption of electricity, driven by several relevant variables such as production, temperature and wind speed. This paper is aimed to identify the relevant electricity consumption drivers for a galvanising line. The methodology entailed defining the boundaries, identifying energy sources, outlining the baseline period, definition of relevant consumption drivers, computing energy performance indicators and addressing baseline adjustments. An energy baseline selection approach involving a single facility, clear boundaries, single energy source, consistent operation during the baseline period, with a single product group influencing energy use, was adopted. There was no need to change the energy baseline period since there were no operational changes nor energy source changes. Regression analysis was used to develop a model for baseline consumption and performance indicators for the galvanising plant.

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1. INTRODUCTION

Many industrial facilities face challenges concerning the development of methodologies for establishing and documenting energy baselines (EnBs) for energy performance improvements [1]. It is critical for organisations to deploy appropriate energy performance indicators as a foundation for monitoring and measuring their energy-related performance. The energy performance indicators are crucial in energy management and should be checked and compared to the initial energy baseline. Galvanising plants are characterised by excessive consumption of electricity, driven by several relevant variables such as production, temperature and wind speed. This paper is aimed at identifying the relevant electricity consumption drivers for a galvanising line and then developing of an energy consumption baseline and performance indices for the galvanising plant.

2. LITERATURE REVIEW

2.1 Energy Consumption Baselines and Performance Indices

The energy consumption that occurs before making improvements is referred to as the baseline energy consumption. The baseline establishes the "before" scenario by capturing a system's total energy use prior to initiating improvements. It serves as a good preliminary point for setting improvement goals for energy efficiency, and it is a comparison point for trending overall performance and appraising future efforts [2]. According to ISO 50001:2011, An Energy Baseline (EnB) is a quantitative reference that can be used to compare Energy Performance Indicator (EnPI) values over time and to quantify changes in energy performance [3]. Determination of baseline consumption can be achieved through artificial neural networks and one can recreate the post-retrofit energy consumption and production of the system in case it would be operating in its past configuration that before energy-saving measures [4].

Energy Performance Indicators (EnPIs) are used to quantify the energy performance of the whole business or its various parts [3]. EnPls are a measure of energy intensity used to gauge effectiveness of your energy management efforts. The basic types of EnPIs include measured energy value, ratio, and Cumulative Sum (CUSUM). A typical example of measured energy value is annualised consumption, and typical problems that characterise the EnPI include misleading results, non-capture of relevant variables and does not measure energy efficiency. A typical example of ratio EnPI is kWh per unit but this EnPI is generally characterised by misleading results and it does not account for baseload and non-linear effects. Specific energy consumption (SEC) is also another ratio EnPI in energy consumption benchmarking, and it is an indicator of the amount of primary energy consumed by a process to produce one physical unit of product [5]. Equations can be used for comparing furnaces of different designs and fuel types in an objective manner, and in order to emphasise the need for energy optimisation, Blake and Beck (2004) presented a set of equations that describe the energy efficiency of a galvanising furnace [6].

Regression analysis is a statistical technique that estimates the dependence of a variable on one or more independent variables, while concurrently controlling for the influence of other variables [7]. It has proven to be reliable when the input data covers the full annual variation in operating conditions and is normally used for approximating energy savings through the measurement and verification of energy programs. Regression modelling use the relevant variables and baseload. They may be more complex if the scenario is non-linear and the other problem that regression models may clouded by uncertainty if multiple relevant drivers are considered, and may need to be adjusted if there is an operational change. Multivariate regression is a technique that estimates a single regression model with more than one outcome variable [7].

A good example of engineering models is energy simulation. eQUEST energy simulation tool has become popular in simulating energy consumption for facilities and verifying the results with actual electricity data. The crucial input data for eQUEST would include building footprint, climate data, space allocation (zoning), heat load and occupancy (equipment, lighting, and people), material property of windows and doors, HVAC system design, indoor temperature and operating schedule. Building footprint can be collected from original CAD drawings of architectural and HVAC designs while a paper survey can be used to investigate occupancy schedule [8].

2.2 Energy Consumption Benchmarking

Comparison of global best practice benchmarks with local companies' performance baselines is crucial for energy management since the developed benchmarks can be used to judge against the performance of individual users. Energy consumption benchmarking a process by which one collects and analyses energy performance data of comparable activities with the purpose of evaluating and comparing performance between or within entities [9]. Energy consumption benchmarking is an energy consumption indicator that takes consideration of the raw materials, product and process output [10]. With the view to improve energy performance, benchmarking can be used to compare of the energy performance of plants within the same industry or for comparison of the dynamics in energy performance of an individual plant at different periods of time [11]. It increases general awareness of energy efficiency among facility owners and occupiers which in turn may effect a change in behaviour provides objective, reliable information on energy use and the benefits of improvements. Energy consumption benchmarking focuses on poorly performing facilities and necessitates the identification of best practices that can be replicated within a facility or across facilities. Within a particular sector, the results of energy consumption benchmarking can be compared against best practice technology currently in operation and it can be quite handy for estimating the energy-efficiency improvement potentials [12].

2.3 Measurement and Verification

There are many approaches that have been developed by different organizations to determine savings and some of these approaches are described by the International Performance Measurement and Verification Protocol (IPMVP) [13]. When considering projects aimed at improving energy efficiency and reducing energy costs, international organisations and governments are considering IPMVP as the international reference text on measurement and verification (M&V) of energy savings. The protocol highlights the criticality of the selection of the method that aims to solve the problem of determining the baseline consumption, as a key factor during the planning phase of a program that embraces M&V of savings [14]. It is worth mentioning that South Africa has also adapted the IPMVP for the Energy Efficiency and Demand-Side Management, and is referred to as the SA M&V guideline [15]. There is need to clearly formalise the baseline development process and the most easily applicable approach for determining the baseline consumption is the engineering method, based on the use of standard formulae and assumptions for calculating the energy use before energy retrofit initiatives [16].

3. CASE STUDY BACKGROUND

Hot dip galvanizing process is a complex metallurgical process in which steel material is rapidly immersed zinc alloy bath whose temperature is normally between 450°C and 480°C [17]. The case-in-point galvaniser provides hot dip galvanising solutions in a functional jobbing production mode. Figure 1 shows the flow diagram for the hot dip galvanising process for the case-in-point galvaniser.

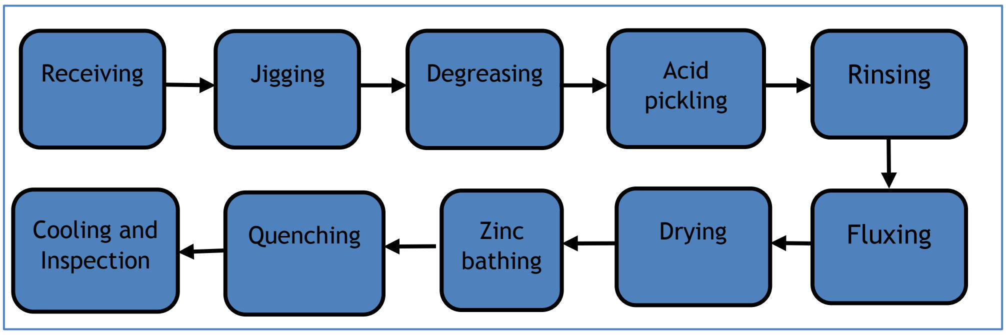

Figure 1: Flow diagram for hot dip galvanising process [18]

The initial preparation step is receiving the materials and subsequently jigging the ungalvanised work. The job is then sent to the first surface preparation process tank in the galvanizing plant, which is the degreasing tank, usually containing a caustic soda solution used to get rid of organic contaminants such as oils and dirt from the surface of steel. The tank is heated to a temperature of about 80° C and can be agitated to hasten the cleaning process. The second surface preparation step is pickling where the degreased steel is immersed into a tank containing acid solution. This tank contains sulphuric acid solution, which is used to remove any mill scale or other oxides that may have developed on the surface of the steel. In order to increase the cleaning action, sulphuric acid must be heated to a temperature of about 60°C.

The third surface preparation step is fluxing which involves the application of a fluxing chemical coating, zinc ammonium chloride, onto the surface of the steel part. The dimensions of the tank are 14 m x 1.3 m x 2.5 m and this 30 000-litre tank has no insulation on the side walls and no covers at the top. The galvanising kettle is powered by 24 rows of chromium heating elements sectioned into 4 zones and furnace temperature is generally set at 600^{0}C. An average of 733 kg of metal was galvanised per dip from an average of 45 dips per day. Total monthly tonnage sat at around 725 tonnes of steel material using about 49 tonnes of zinc.

4. METHODOLOGY

The methodology which was adopted for EnB development process entails defining the boundaries, identifying energy sources, outlining the baseline period, definition of relevant consumption drivers, computing energy performance indicators and addressing baseline adjustments. The first step in the methodology was defining the boundaries. The galvaniser's energy management plan should outline the operations and facilities within the boundaries and it is crucial to note that baseline results would be undermined if the boundary conditions are not properly outlined. Physical, system-related, and organizational are the three primary boundary types that characterise many organisations. Physical is the most common boundary type which pertains to a facility fence line or building within which the energy study is based on. System-related boundaries is whereby an organization focuses on a particular single system that constitutes a significant portion of a facility's energy consumption and the performance of that particular system is seen as a proxy for the facility's performance. System-related boundaries can be required if metering or other data are limited. In this case, phyiscal and organisational-type boundaries are the same and were used in the study.

The second step in the methodology was identifying the energy sources whereby all energy flowing across the defined boundaries were identified, categorized, measured, and collected. Energy sources vary from electricity to on-site renewable generation sources such as solar or wind, as well as from combined heat and power (CHP) systems. In this case, electrical energy that comes from Eskom, an electric generator was used and the electricity is measured in kilowatt hours. The process of creating an energy map of the facility that shows its boundary and the energy flows across the boundary is generally used for identifying energy sources and associated EnPIs. Coal, petroleum products, natural gas, and biomass are the potential fuel sources that exist, but in this case, focus was placed on the electricity from Eskom since it is the key energy source for the galvanizer.

The third step in the EnB development process addressed the measurement and collection of energy consumption data. Meters and utility billing records were used to identify the quantity of electrical energy consumed over the billing period. Knowledge of the billing period is vital for facilitating pairing of energy consumption with other baseline calculation factors. Shorter time intervals are generally considered to be desirable since they enable better analysis and assure reasonable degree of confidence.

The fourth step in the methodology was defining the baseline period duration and the specific historical time frame since these two factors generally affect the tracking results of performance improvement. A duration of less than one year for the EnB can be appropriate in operations where energy consumption is steady throughout the year. Short baseline durations may also be necessary for situations with insufficient reliable or available historical data, or when changes occur to the company's culture, policies, or processes. The one-year EnB duration is common since it aligns with the business's energy management objectives such as reducing energy consumption from a previous year. Availability of data can often limit the baseline period and in this case a twelve-month period was selected. Three potential EnB time frames that characterize the baseline time frame include immediately preceding, prior event, and fixed time frame. The immediately preceding timeframe is used by facilities already making changes that will improve energy performance since it would ease identification and quantification of improvements. Tying up the time frame of an EnB to a prior event would be appropriate for companies that are undergoing a significant change such as a facility enlargement or major acquisition. When demonstrating improvements across a group such as for multi-site corporations, industry organizations or government programs, using a fixed reference year for the EnB time frame becomes more applicable. Given the case-in-point scenario where no major changes on the facility were effected, the best option was the immediately preceding timeframe.

The fifth step in the EnB development process was definition of the relevant variables. The relevant variables are typically quantifiable factors such as production, weather conditions, and hours of operation, which would influence a plant's energy consumption. In this case, production data on number of dips per day, amount of zinc used and product tonnage was collected from the company database. It was envisaged that the galvaniser's energy consumption could be influenced by temperature, of which the monthly temperature data was retrived from an online database. Statistical analysis can be used to establish if the relevant variables would influence energy consumption. Regression analysis was used to determine the relevant variables and to validate the strength of statistical relationships between the variables.

The sixth step in the methodology was determining and calculating Energy Performance Indicators. The EnPIs were crucial for providing the relevant information on energy performance that would enable the galvaniser to appreciate its energy performance and develop interventions to save energy. Using a precise EnPI is crucial for one to accurately connect operational improvements to energy performance improvements, and in this case, two EnPIs which include Energy Intensity Index and cumulative savings (CUSUM) are adopted.

The seventh step in the EnB development process was ascertaining if there was need for baseline adjustments. Changes are common in many organisations and these could include energy source changes, operational change, business change, energy management system change (changes to calculation methodology or improvements to data collection by an organisation). Although there was no need to address baseline adjustments, it was crucial for the galvanizer to define intervals at which it would review the key characteristics of its operations that determine energy performance, regardless of whether there were changes to the operations.

5. RESULTS AND DISCUSSION

5.1 Multivariate Regression Analysis

Since it was anticipated that there could be more than one predictor variable for electricity consumption by the galvaniser, multivariate regression was initially adopted for the study. The four relevant variables that were considered include number dips per day, amount of zinc used, galvanised product tonnage, and the ambient temperature conditions. Table shows the electricity consumption data as well as the relevant variables.

Table 1: Data for relevant variables and electricity consumption

Month	Dips per month	Zinc used (Tons)	Product tonnage (tons)	Ambient Temperature (°C)	Total Electricity (kWh)
Jan	870	52124	691571	25	270236
Feb	813	47434	691571	25	250718
Mar	932	52259	691571	25	270935
Apr	870	51242	691571	23	264703
May	1045	56523	691571	20	291350
Jun	831	49836	691571	18	257878
July	967	54154	691571	18	282982
Aug	894	54477	691571	19	282981
Sept	907	49757	715047	20	262942
Oct	1114	56880	715047	21	286594
Nov	1284	62021	817006	22	294731
Dec	816	48980	623543	24	233301

The initial regression analysis yielded a good R^2 value with p-values (probability that X and Y not related) greater than 0.05 at 95 confidence level, as shown in Table 2.

Table 2: Regression Statistics and ANOVA

Regression Statistics						
Multiple R	R Square	Adjusted R Square	Standard Error	Observations		
0,921548	0,84925	0,763108	8825,768	12		
ANOVA						
	df	***SS***	***MS***	***F***	***Significance F***	
Regression	4	3,07E+09	7,68E+08	9,858651	0,005284	
Residual	7	5,45E+08	77894178			
Total	11	3,62E+09				
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***
Intercept	84337,76	70307,43	1,199557	0,269333	-81912,9	250588,4
Dips per day	-23,368	58,94876	-0,39641	0,703607	-162,76	116,0236
Zinc used	1,897754	3,134276	0,605484	0,563965	-5,51363	9,309138

Product tonnage	0,189619	0,157043	1,20743	0,266476	-0,18173	0,560968
Ambient Temperature	-1081,65	1042,061	-1,03799	0,333793	-3545,74	1382,429

Further analysis was then executed using different combinations using 3 relevant variables, then subsequently combinations for 2 relevant variables and the results for R^2 was improving but the p- values were yet above 0.05. One would have expected temperature variation to have an influence on electricity consumption by the galvanizer, but the effect could be negligible given that the significant energy user, which is the galvanising kettle operates at around 400ºC, yet maximum ambient temperature has a range of 18ºc to 25ºC, which is smaller than 10% of the operating temperature of the kettle. Table 3 shows the regression statistics, significance and P-values for relevant the relevant variables that were considered as drivers for electricity consumption by the galvanizer. The best results were noted from using only one variable, and these results show that zinc used (production) is the main driver for electricity consumption, with R^2 value of 0,780634, Significance F of 0,000138, and p- value of 0,018098. R-squared is a statistical measure of how closely the data are to the fitted regression line and a high R^2, which was noted for the zinc used shows that the model will fits the data much better.

Table 3: Regression Statistics, Significance and P-values for relevant variables

	Dips per day	**Zinc used**	**Product tonnage**	**Ambient Temperature**
Regression Statistics				
Multiple R	0,79502601	0,883535	0,665826	0,402604
R Square	0,63206636	**0,780634**	0,443325	0,16209
Adjusted R Square	0,59527299	0,758697	0,387657	0,078299
Standard Error	11536,0766	8907,543	14189,74	17408,93
Observations	12	12	12	12
	Significance F			
	0,00199671	**0,000138**	0,018098	0,194443
	P-value			
Intercept	2,4927E-05	0,098333	0,304162	1,5E-05
X Variable 1	0,00199671	**0,000138**	0,018098	0,194443

At 95% confidence level, Significance F for amount of zinc used is statistical significant, meaning that the results did not likely happen by chance. The p value is determined by the F statistic and is the probability that the results could have happened by chance. A small p-value (typically ≤ 0.05) indicates strong evidence against the null hypothesis, so we reject the null hypothesis and accept the alternative that the results could not have happened by chance. The above satisfactory results were then used to develop a regression model.

5.2 Scatter Plot and Regression model

The above satisfactory results from Table 3 were then used to develop a regression model, of which the equation is shown in Figure 2. The scatter plot shows some strong correlation between the amount of zinc used and the electricity consumption by the galvanising plant.

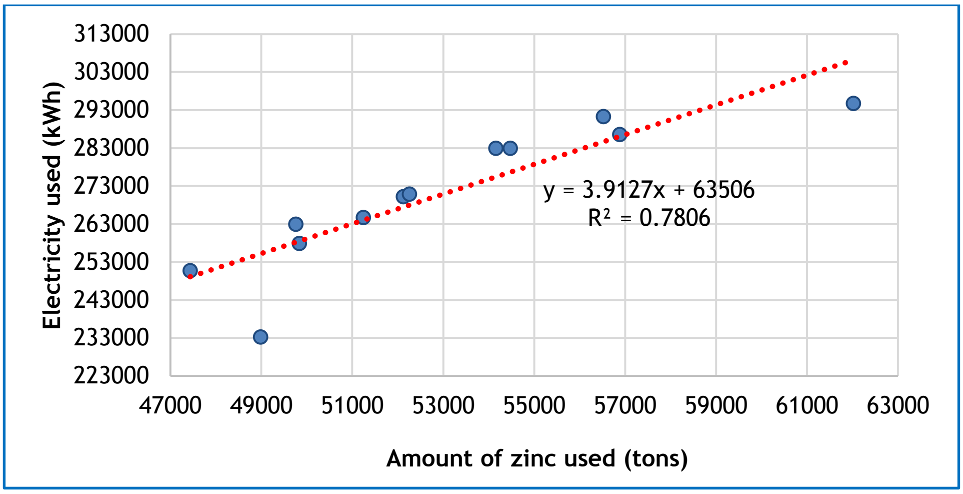

Figure 2: Scatter plot for electricity consumption and zinc used

The dotted line shows the baseline equation. It is worth mentioning that when one is investigating wasted energy, a good starting point is scrutiny of the base loads. In theory, one would expect a low base loads of below 10% from a plant since the facility is not in use, energy should only be required for items such as security lighting and equipment such as refrigerators that needs to operate continuously. However, in this case, the galvanising plant has a substantially higher baseload of 63506 kWh, which is equivalent to 23% of the average monthly consumption of electricity. This is largely attributed to the fact the zinc in the galvanising furnace has to be kept molten even during non-working hours and over the weekend.

5.3 Baselines and Performance Indices

Baseline energy consumption is the consumption that occurs before any energy-saving interventions are effected. Figure 3 shows a comparison of actual consumption and expected consumption during the baseline period.

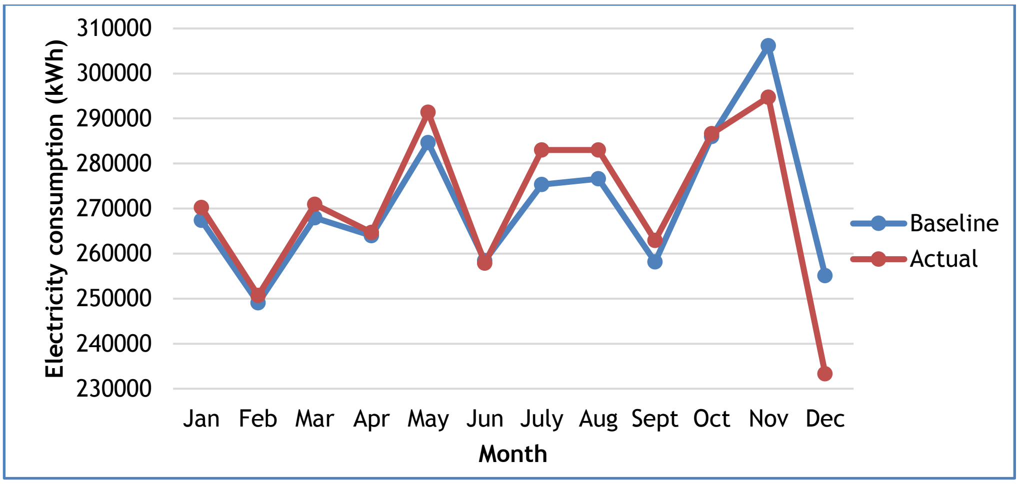

Figure 3: Actual consumption and expected consumption during baseline period

Energy Intensity is measured by the quantity of energy required per unit output or activity, so that using less energy to produce a product reduces the intensity. Figure 4 shows the Energy Intensity Index in kWh per tonne of zinc for the galvaniser. The galvaniser has been failing to achieve its set target of 5 kWh per tonne for the months from January to October, but in achieved in November and December where there was less production due to annual shutdown and festive season holiday.

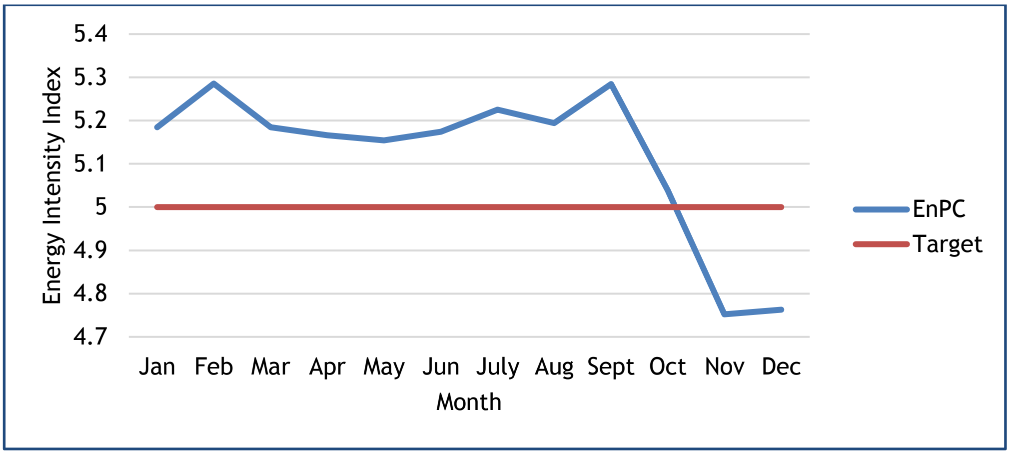

Figure 4: Energy Intensity Index

Cumulative Sum (CUSUM) represents the difference between the base line (expected or standard consumption) and the actual consumption points over the base line period. We calculated the expected energy consumption basing on the trendline equation shown in Figure 2. We then calculate the difference between actual and calculated electricity consumption and then compute CUSUM.

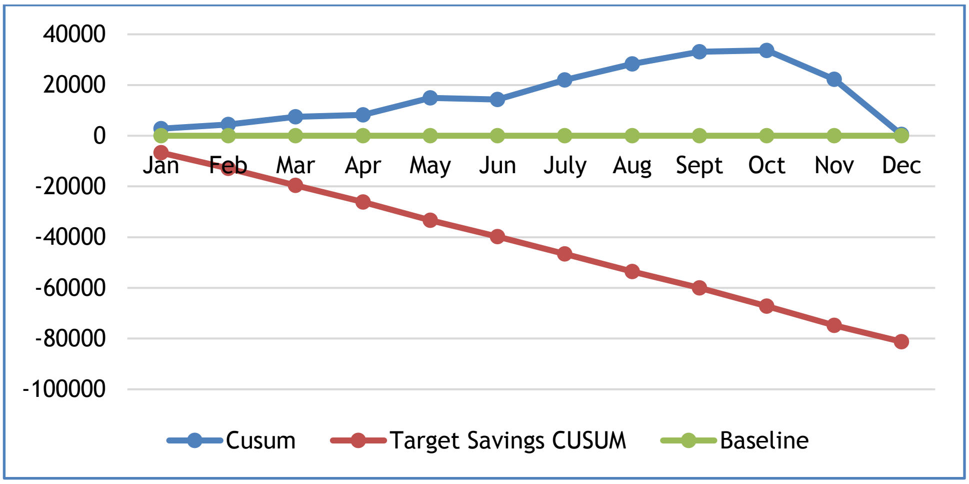

Figure 5: CUSUM and targeted savings CUSUM

Figure 5 shows that during the baseline period, energy performance is deteriorating (line going up) from January to May, improves slightly from May to June and deteriorates again from June to October. Performance then improved (line going down) from November to Decemeber. It is crucial to note that when analyzing a CUSUM graph, the changes in direction of the line point out crucial events that are relevant to the energy consumption pattern. Since we know that during the baseline period, the case-in-point galvaniser had no changes in the energy system, the change in performance can be attributed to poor housekeeping, poor control, or maintenance. Considering the baseline period under study, a targeted reduction in energy consumption to 97.5 % (2.5% savings), would yield cumulative savings shown in Figure 5.

6. CONCLUSION

The aim of this paper was to identify the relevant electricity consumption drivers for a galvanising line. The boundaries conditions were defined and electricity was identified as the energy source and one year as the baseline period. The number dips per month, amount of zinc used, galvanised product tonnage, and the ambient temperature conditions were initially identified as the relevant consumption drivers. Regression analysis was then used for the analysis of the relevant variables and the results demonstrated that the amount of zinc for the galvanising process was driver for electricity consumption by the galvaniser. The regression model then developed using the driver and EnBs and EnPIs were established for the baseline period that was under study. Future work in this area will embrace development of algorithms to derive optimal schedules that would yield energy in batch galvanising plants. The established baseline consumption and EnPIs are crucial for the measurement and verification of savings.

7. REFERENCES

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PRINTED CIRCUIT BOARDS AS AN URBAN MINING COMMODITY IN SOUTH AFRICA

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ABSTRACT

The printed circuit board (PCB) is a highly valuable polymetallic resource, containing base and precious metals. It assay's higher than what is obtained in mines. It transforms into a secondary source of base and precious metal when removed from waste electrical appliances. With about 322 000 tons of electronic appliances, all containing PCBs reaching the end of their service lives in South Africa annually, this is a huge material resource stream. It is a mine with very high potential hiding in plain view. This work highlights these issues by quantifying PCBs from end-of-life appliance as a commodity stream in monetary terms. A conservative estimate of ZAR 5.7 billion per annum was obtained as the worth for the base and precious metal contents. Currently, a small fraction of this value is retained in the country when the eol PCBs are exported with the raw metals content. Increasing aggressive mining for precious metals while ignoring and exporting this secondary resources does not present a good stewardship of South Africa's mineral resources management. Towards harnessing this potential, PCB processing operations were reviewed, with local and global perspectives.

Keywords: recycling, printed circuit boards, precious metals, base metals, commodity

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1. INTRODUCTION

The production, commercialization, use and disposal of electronics have increased exponentially in the last decades since the creation of the first computer. The rapid availability of new technologies makes electronic appliances obsolete within a very short time of purchase. What is most concerning is the amount of electronics that have accumulated as waste worldwide, often called e-waste. It was estimated that the total amount of e-waste generated worldwide in 2014 was 41.8 million metric tons [1]. E-waste may include electronic appliances such as keyboards, screens, computers, mobile phones, household appliances such as televisions; office equipment such as printers, lamps; personal items such as cameras; and miscellaneous items such as photovoltaic panels.

In many countries around the globe, this huge tonnage of material is really not considered as waste, but processed as raw materials to recover the various material contents. The metal content is extracted, refined, and returned to the material use cycle. In essence, the e-waste stream now serve as ores obtained from one-time industrial products, and are therefore better described as urban ores mined via the various recycling and collection routes.

In the centre of all the electronic waste are printed circuit boards (PCB). With smarter appliances, the electronic circuitry in appliances has increased, implying more PCB content in products. The type of PCB in electronic appliances depends on the purpose for which it is made to serve, design and material make up. Figure 1 depicts typical PCB proportions in e-waste streams to be about 12 wt. %.

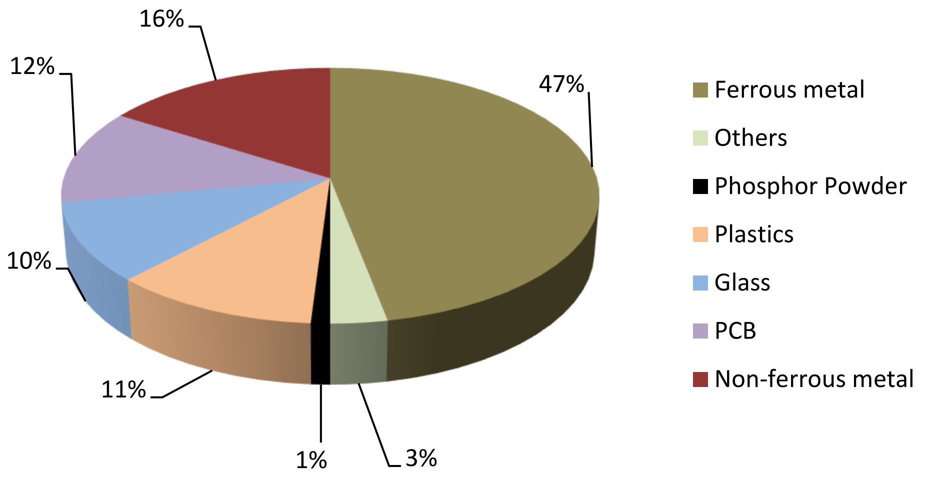

Figure1: Composition of e-waste streams, adapted from [2]

From its production, the PCB is a polymetallic resource containing different precious and base metal values. When removed from an end-of-life (eol) appliance, it actually becomes a commodity, but a really complex one to define and characterize. The actual composition varies widely based on endless varying design for different functionality as technologies advance. Accordingly, the worth varies across a very broad spectrum. For insight into the value this commodity harbours, this work tries to compile the range of compositions of PCBs, estimate range of the raw value of the metallic content, project the true worth of the PCB content in the e-waste stream, and present the economic potential. Currently, South Africa's base and precious metal refiners do not process PCB to recover the metal content. This commodity will benefit the economy if this gap in the sector of the industry can be plugged. Different PCB processing options were therefore addressed.

2. PCB COMPOSITIONS AND TONNAGES IN EOL APPLIANCES

In 2013, available data shows that the Western Cape generates 3.8 million tonnes of general waste per annum, of which 70% (2.6 million tonnes) is generated by the City of Cape Town [3]. In another data, compiled by National waste information baseline report, South Africa generated 59 million tonnes of general waste in 2011, with 64 045 tons of electric and electronic equipment waste [4]. According to electronic Waste Association of South Africa (eWASA), South Africa produces approximately 322 000 tonnes of e-waste per annum [5]. Based on classification by eWASA, e-waste is classified into large, small, consumer, and information technology appliances (Table 1). Currently, only 45 000 tonnes (12%) is being recycled which is apparently low compared to the remaining large volume which are unrecycled waste. PCB is present in all types of electronics equipment and are of major interest because they are considered secondary raw materials for copper and precious metals such as gold, silver and palladium [6]. A single mobile phone can contain valuable quantity of gold (24 mg), silver (250 mg) and palladium (9 mg) [7].

Table 1: Classification of South Africa e-waste generation per annum [5, 8]

E- waste classification				
	Large Appliances (Stoves, fridges)	Consumer equipment (washing, milling machines, etc.)	Information Technology (IT) equipment (CPU, mouse, screen and keyboard etc.)	Small household appliances (toasters, kettles, etc.)
Ton per annum	125 000	78 000	77 000	40 000
Glass	1%	2%	54%	-
Plastics	13%	15.4%	13.6%	14%
Ferrous	60%	38.4%	12.3%	30%
Non ferrous	6%	32.38%	2.1%	38%
PCB	4.5%*	3%	7.8%	2.5%*
Others	16%	8.7%	10.2%	15.5%
% recycled	39%	24%	24%	13%

*** PCB content values were assigned based on assumption**

Typically PCBs contain 40% of metals, 30% of organics and 30% ceramics [2, 9].Table 2 compiles percentage compositions of ferrous and non-ferrous metal content of PCBs from ten authors. The PCBs reported herein are from different appliances such as high-grade PCBs (embedded in mainframes and smart phones), medium grade PCBs (embedded in PCs, laptops and handheld computers) and low-grade PCBs (e.g. embedded in TVs, monitors printers and cordless phones) [10]. Some elements not indicated in Table 2 shows the authors perhaps are not interested in such element during the course of their research. Averages of only available data are therefore computed for the different elements. Averages computed for the different elements in the compositions show precious metals such as gold and palladium assaying about 600 and 100 ppm in eol PCB stream, while copper is the highest of the non-ferrous metal content at 21.6%.

Table 2: Percentage compositions and tonnage of element in PCB

Metals in PCBs	% [11]	% [12]	% [13]	% [14]	% [15]	% [16]	% [17]	% [18]	% [19]	% [18]	Ave %
Ag	0.2	0.33	0.124	0.13	0.3301	0.1	0.2	0.21	-	0.16	0.198
Al	2	4.7	-	4.78	1.33	5	-	0.26	-	0.16	2.604
Au	0.1	0.008	0.042	0.035	0.057	0.025	0.1	-	0.035	0.13	0.059
Cu	20	26.8	15.6	17.85	23.47	16	20	34.49	22	20.19	21.640
Fe	8	5.3	1.4	2	1.22	5	8	10.57	3.6	7.33	5.242
Ni	2	0.47	0.28	1.63	2.35	1	2	2.63	0.32	0.43	1.311
Pb	2	-	1.35	4.19	0.99	2	2	5.53	1.55	1.87	2.387
Pd	0.005	-	0.001	0.025	0.0294	0.01	0.005	-	-	-	0.013
Pt	-	-	-	0.0046	0.003	-	-	-	-	-	0.004
Sb	0.4	0.06	-	-	-	-	-	-	-	-	0.230
Sn	4	1	3.24	5.28	1.54	3	4	3.39	2.6	8.83	3.688
Zn	1	1.5	0.16	2.17	1.51	1	1	5.92	-	4.48	2.082

Based on the eWASA data that South Africa generates approximately 322 000 tonnes of e-waste annually, and e-waste can be averaged to contain 4.45 wt % PCB (based on data in Table 1), an estimate of the quantity of PCBs generated in South Africa can be put at 14 329 tons per annum. Using the average percentage composition of elements obtained in Table 2, waste PCBs generated in South Africa was estimated to about 5 653.91 tons of base and precious metals (see Table 3), while the remaining 8 675.09 tons represents the fraction of the organic and ceramic contents of the PCB.

3. ESTIMATE OF ECONOMIC VALUE OF EOL-PCBS GENERATED IN SOUTH AFRICA

Based on the estimation calculations in the previous section, from Table 3, 5 653.91 tons of raw base and precious metals reports to the electronic waste stream annually in South Africa. From current London Metal Exchange (LME) prices (April 2017) of the different metals, the quantification of this tonnage, and its monetary equivalent were computed as in Table 4. Over 450 million dollar worth of metals, which translates to about 5.7 billion rand (at US $1 = ZAR 12.77) reports to the eol PCB streams, with gold accounting for 74.81% of this value. Currently, most collection and recycling companies in South Africa retrieve these PCBs, carry out some physical processing, crush the PCB for assaying and export the raw resource for a fraction of the monetary value of the metal content. The potential this sector of the economy harbours is undermined as this raw value is exported, and efforts must be geared toward extracting these metals within the country.

Table 3: Estimated quantity of metals in waste PCB generated in South Africa

Metals in PCBs	Average % abundance in PCB	Tons per annum
Ag	0.198	28.37
Al	2.604	373.12
Au	0.059	8.45
Cu	21.640	3100.80
Fe	5.242	751.13
Ni	1.311	187.85
Pb	2.387	342.03
Pd	0.013	1.86
Pt	0.004	0.57
Sb	0.230	32.95
Sn	3.688	528.45
Zn	2.082	298.33
Total		5 653.91

Table 4: Monetary value of metallic content in eol PCBs generated in South Africa annually

Metals in PCBs	US $/ton [20]	Tons in PCB per annum	Value in US $
Ag	16.95 /Oz	28.37	15,387,888
Al	1930.61	373.12	720,349
Au	1255.80 /Oz	8.45	339,568,320
Cu	5697.36	3100.80	17,666,374
Fe	70	751.13	52,579
Ni	9664.86	187.85	1,815,544
Pb	2230.78	342.03	762,994
Pd	824 /Oz	1.86	49,044,480
Pt	946 /Oz	0.57	17,255,040
Sb	8653	32.95	285,116
Sn	19981.94	528.45	10,559,456
Zn	2632.50	298.33	785,354
Total		5 653.35	453,903,494

4. PCB PROCESSING IN SOUTH AFRICA

There is no single processing technique capable of processing all types of waste PCB material, being a very heterogeneous material stream. The task of recycling internally generated waste electrical components is performed by scrap metal merchants and electronic recycling companies in the country. The comparative activities of indigenous PCB processing companies in South Africa are summarized in Table 5. The obtained outputs of these indigenous establishments are exported for further processing to Europe, Asia or Canada while others are sold to local secondary buyers such as foundries.

Most of these available recycling merchant operations centre on physical and mechanical separation processes. For instance, at Universal Recycling Company the dirt on the PCBs is firstly suctioned. Other operations involves crushing through a 1200 horse power shredder which breaks up the material into pieces of up to 130mm and less. The shredding process breaks up the electronic scrap so that the various materials can be separated. A rotary magnet removes the ferrous fraction, which is sold to steel mills and foundries as raw material. The non-magnetic fraction is then screened in three sizes, using heavy media (dense medium separation), eddy current magnets and water separation tables. PCB material streams are then separated into organics (plastic, wood and paper), the heavy fractions (copper, brass, zinc, lead and non-magnetic stainless steels) and the light fraction (aluminium). Specialist markets exist in the USA and Europe, with main outlets for gold and precious metal bearing board scrap in Belgium, Sweden or Canada [21, 22].

Table 5: Summary of operations of South Africa's e-waste recycling companies

Establishment	Operations	Tons treated in 2015	Main outputs
Africa E-waste	Collection, refurbishment of electrical waste except lighting equipment, batteries & radioactive equipment and manual dismantling. Dismantled fractions are sorted and sold off in various material groups [23].	383	PCBs, glass, plastics, ferrous and non- ferrous metals
DESCO	Operation involves collection, physical separation and sorting. Shredded PCB is sold and exported to Europe[24]	5 000	PCBs, plastics, ferrous and non-ferrous metals
Reclam	Mechanical processing of recyclable ferrous and non-ferrous, e-waste, glass, plastic and papers for both local and international sales [25].	-	Ferrous and non-ferrous metal scraps
URC	The operation is fully mechanised and uses a multitude of processing equipment, including 1200 horse power shredders, heavy media, magnetic and eddy current separation equipment and a Liquid cell multi-stage in-line scrubbing system [26].	3 000	PCBs, plastics, ferrous and non-ferrous metals

5. PCB Processing Globally

In countries such as Germany, Australia, Belgium, PCB processing goes beyond physical and mechanical separation. In different pyrometallurgical plant operations, metal contents of e-waste are recovered as described in Table 6. The process usually includes three stages: pre-treatment, separation/concentration, and mechanical/chemical treatment [27, 28]. A number of companies like Umicore, Noranda, Boliden, and Cimélia, among others, had written reports on the processing and recovery of precious and base metals [6]. These industries process various types of industrial wastes and by-products of non-ferrous metals including PCBs, recovering about 20 precious and other non-ferrous metals [29]. The processes used follow a complex flowchart, with several steps that include pyrometallurgical, hydrometallurgical and electrochemical techniques and operations [30].

Table 6: Pyrometallurgical operations of some plants for treating e-waste

Establishment	**Operations**	**Recovered elements/products**
Aurubis (Germany)	**Kayser recycling system:** Cu scrap + e-scrap and residues are smelted in Top Submerged Lance (TSL) reactor → black copper + ZnO flue dust → converting + (Sn-Pb rotary furnace) → Cu anodes + SnSb alloy → Cu electrorefining → Cu + anode slime (bearing PGMs) → PGMs refinery → PGMs [31]	Au, Ag, Cu, Pb, Zn, Sn and PGMs
Montanwerke Brixlegg (Austria)	**Pyro – Blast furnace charge**: PCB+15-60% copper slag from converter and anode furnace+8-12%Coke (heat and reducing agent) + flux → Black copper of 75%. **Converter:** Black Cu+ Cu alloy smelted with O_2 blown into the smelt to oxidize Pb, Sn, Zn. → 96% Cu purity; electro-refined to approx. 99%Cu. Anode plate electrolytic process using an acidified $CuSO_4$ electrolyte to obtain 99.99% Cu + PGM in anode slime [32].	99.99% Cu, High grade NiSO4; High grade precious metals, metal oxides (Oxides of Pb, Sn, Zn), Copper oxychloride, Flowbrix ($CuCl_2$ solution sold as active fungicide for plant protection)
Boliden	**Copper line:** Smelting → zinc fume (to	Copper, silver, gold, lead, nickel,

(Sweden)	clinkering) + molten black copper (to converter) → converting → Cu electrorefining → Cu + residue containing PMs → PMs refinery → PGMs + Se **Lead line:** Kaldo furnace → PMs containing fraction (fed to Cu converting step) + Pb fraction → Pb refinery → Pb [31].	selenium, zinc, lead
Glencore (Canada)	Feed: e-scrap+ Cu concentrate + flux + O_2 smelting at 1250ºC → anode casting (99.1%Cu) → electrorefining → 99.5%Cu + PMs slimes → PM refinery → PMs + Se, Te [33, 34, 35].	99.95% Copper, gold, platinum, palladium, selenium, tellurium, nickel sulphate, metal oxides
Outotec (Finland)	Smelting (Ausmelt TSL reactor) of WEEE in copper/lead/zinc combined processes [31]	Zinc, copper, gold, silver, indium, cadmium, germanium, and lead
Umicore (Belgium)	**Copper line:** Cu smelting (Isamelt) → Cu bullion → Cu refinery → Cu + residue containing PMs **Lead line:** Pb blast furnace → Pb bullion + spies (Ni, As) → Pb refinery → Pb, Sn, Sb, Bi + residue containing PMs PM recovery: Residue from Cu and Pb lines → cupellation → PGMs + In, Se, Te [31, 36]	Copper, nickel, arsenic, lead, lead, tin, antimony, bismuth, gold, silver, palladium, platinum, iridium, ruthenium, rhodium, indium, selenium, tellurium

At Umicore, precious metals (PMs) are extracted from e-waste using the secondary copper route. Umicore has the world's largest waste recycling facility at Hoboken, Belgium [33]. It is a specialty material group that focuses on recovering gold and silver, platinum group metals (PGMs), special metals, secondary metals, and the base metals (BMs) from various residues including e-waste. Other by-products of the Umicore plant are sulfuric acid (from off gas purification), and slag (consisting of silicon, aluminum and iron oxides) that are used as construction material. The feed material primarily compose of wastes from the non-ferrous industry, PM residues, and PCBs for copper and lead smelting plant (Figure 2) to obtain copper blister which is purified via electrowinning. The slag obtained from this converter contains lead and some other valuable metals which are charged into the lead blast furnace. Obtained anodic slime from the copper electrowinning plant and residue from the lead bullion smelting are heated in the presence of oxygen (cupellation) to oxidize less noble metals, leaving the precious metals. The off gases containing SO_2 are treated in the sulphuric acid plant to produce H_2SO_4. On average 250 000 tons of feed material are treated annually for the recovery of metals. It is the world's largest recycling facility for the extraction of PMs and has an annual production of over 50 tons of PGMs, 100 tons of gold and 2 400 tons of silver [30, 37]. The Umicore process flow sheet is composed of several pyrometallurgical, hydrometallurgical, and electrochemical processes for recovering of these metals [36].

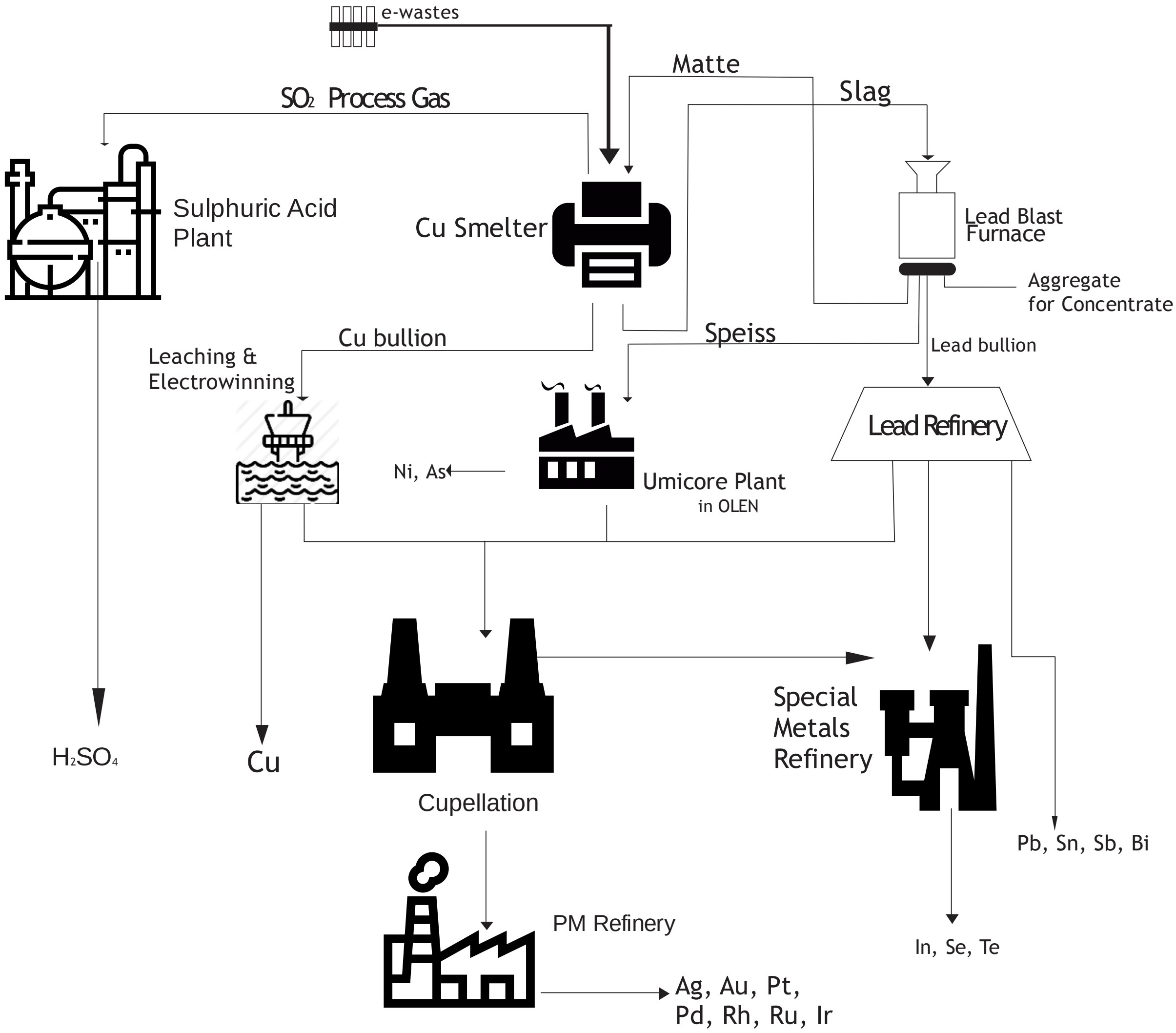

Figure 2: Umicore's integrated metals smelter and refinery flowsheet, adapted from [29, 33]

The Glencore (formerly Noranda) process is another commercial pyrometallurgical process for the recovery of metals from e-waste, and about 100 000 tons of e-waste is processed annually for metal recovery. The Horne Smelter is located in Rouyn-Noranda, Quebec, and the feed material for this process is composed of a blend e-waste, mined copper concentrates and precious metal-bearing recyclable materials, which is fed into the molten bath at 1250°C, this process temperature is maintained by injecting supercharged oxygen. The energy cost is partially reduced by combusting the plastics and other combustible materials from e-waste to produce a 99.1% copper anode [33, 34]. The schematic process flowsheet is depicted in Figure 3. During the oxidation process, impurities including iron and zinc are converted into oxides and segregated into a silica-based slag. The slag is cooled and processed for the recovery of metals before disposal. The anode is shipped to the Canadian Copper Refinery (CCR) to be converted into 99.95% copper cathodes via electrolytic process which are sold at world markets. The plant is equipped to process anodes that are high in bismuth, antimony, lead and nickel. The refinery's precious metal slimes processing plant obtains feed from internally generated, as well as externally purchased slimes. The CCR products include copper cathodes, gold, silver and other specialty metals and chemicals, including selenium, tellurium, copper sulphate, nickel sulphate and a concentrate of platinum group metals [35].

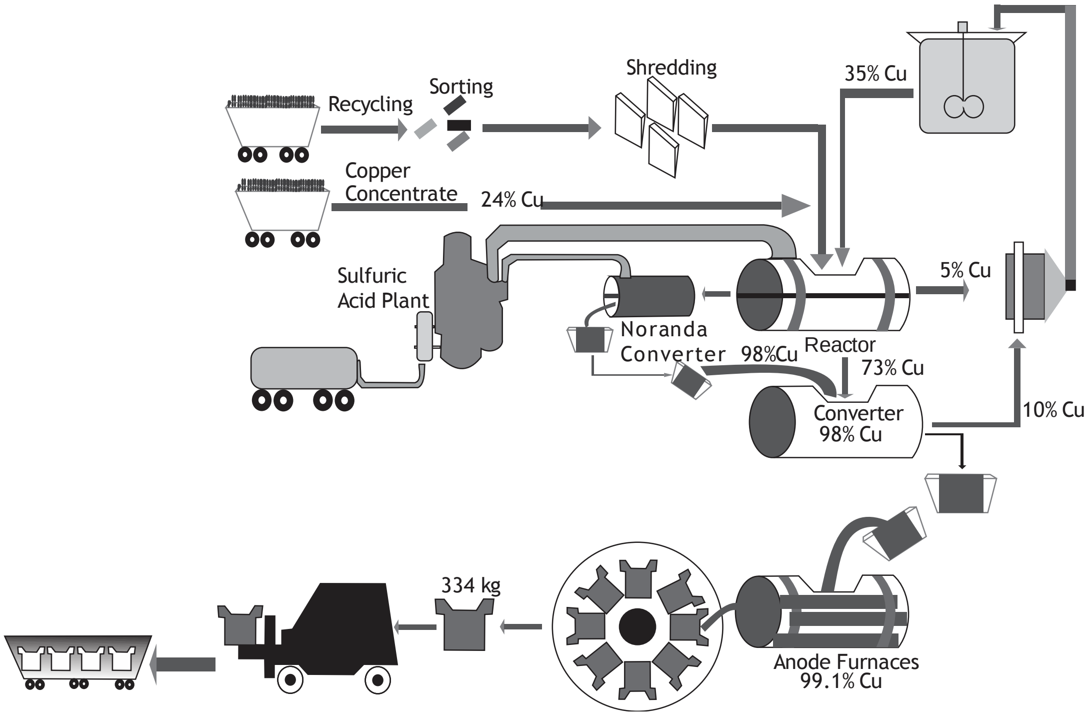

Figure 3: Schematic diagram of the Noranda smelting process, adapted from [33, 34]

Another plant that recovers metals from e-waste is the Boliden plant in Sweden. A variety of scrap from the non-ferrous and electronic industry is introduced into the process at different stages depending on the purity and requirement of the final product. The copper plant is fed by calcine from fluid bed roaster or high copper containing scrap with low-grade electronic scrap integrated alongside into the Kaldo furnace [38]. Fluxes, iron and coke are charged from separate bins above the furnace. The annual recycling of wastes (including e-waste) is more than 100 000 tons. The main steps in the Rönnskär Smelting operation are drying, roasting, smelting, converting and refining, as schematically shown in Figure 4. The Kaldo furnace produces a mixed copper alloy that is treated for the recovery of metals including Cu, Ag, Au, Pt, Pd, Ni, Se and Zn [39]. The volatile metals such as Pb, Sb, In and Cd are segregated into the vapour phase that is recovered by a separate process. The off gases emission is treated for producing sulfuric acid [31].

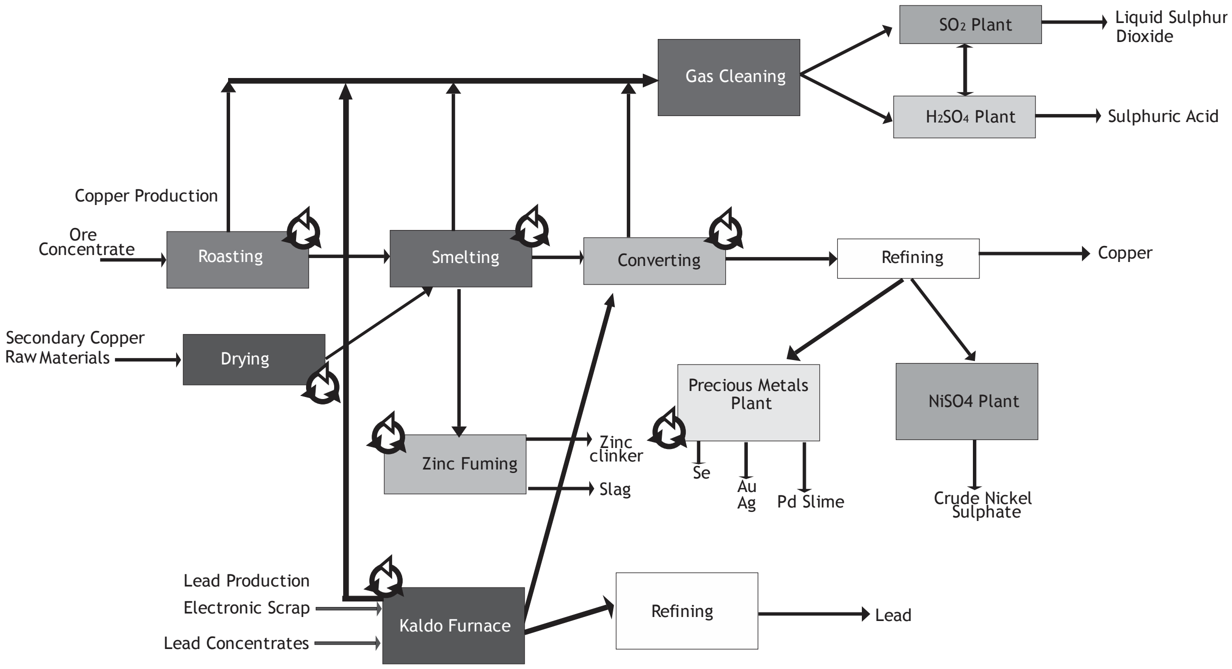

Figure 4: Flowsheet of the Rönnskär smelters [40]

6. CASE FOR INCREASED PCB RECYCLING AND PROCESSING IN SOUTH AFRICA

E-waste is the most rapidly growing segment of the municipal waste stream and the global e-waste management market is expected to reach $49.4 billion by 2020 [41]. Priority is not given to extraction of metals from PCBs in South Africa, probably because of availability of primary resources in the country. As can be seen in Figure 5, which quantifies natural resources reserve of various countries in US billion dollars, South Africa's mineral deposit is clearly the highest. This run-of-mine gives concentrates with narrow range of composition, and relatively well known smelting chemistry. However, it is well known that solid minerals are depleting resources. Continuous aggressive mining to meet mines production target while ignoring metals values in the waste PCB streams does not amount to responsible stewardship of the natural resources endowment of South Africa. Rather, these resources must be conserved, by giving attention to extraction of metals from PCBs. There are different bases for this position:

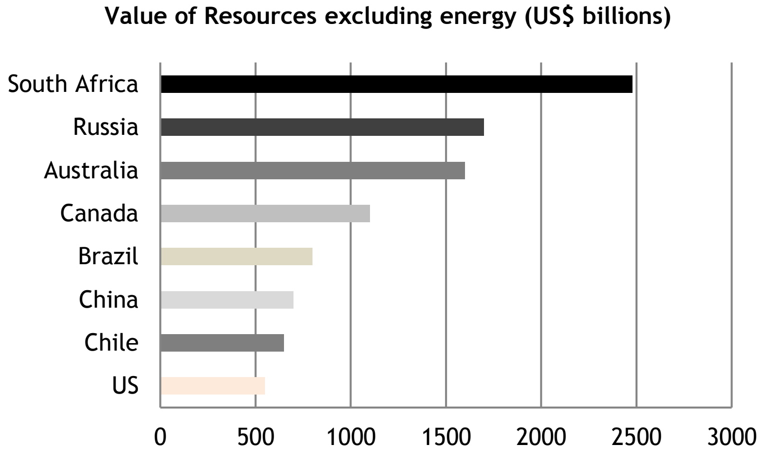

Figure 5: Availability of mineral resources in selected countries; adapted from [42]

6.1 Decreasing CO_2 Footprint of Production of Metals

Metal production today represents about 8 per cent of the total global energy consumption, and a similar percentage of fossil-fuel-related CO_2 emissions [43]. The source of electrical energy (coal, hydro, nuclear, etc) has a major impact on the quantities of greenhouse gases produced. Table 7 data shows that, of all the most widely used metals, steel production contributes the greatest quantity of greenhouse gases (7% of global CO_2) [44]. The energy required to recycle metals is a relatively small fraction of the energy required to produce metals from their ores, since energy is required largely only for melting and not smelting. Global annual production of CO_2 from fossil fuel sources is about 28 962 Mt [45]. Obviously, recycling will help decreasing this "footprint".

Table 7: Global CO_2 production for primary production of metals [44]

Metal	Route	% total global metal production	Global annual production (Mt)	Tonnes CO_2 per tonne metal	Global annual energy consumption (GJ)	Global annual CO_2 (tonnes)	% Global greenhouse gas production
Cu	Pyro	80	15.6	3.25	6.13 X 10^8	6.0X10^7	0.21
	Hydro	20		6.16			
Ni	Pyro	60	1.66	11.45	2.42X10^8	2.2X10^7	0.08
	Hydro	40		16.08			
Pb	BF	89	3.55	2.07	7.5X10^7	7.8X10^8	0.03
	ISP	11		3.18			
Zn	Electrolytic	90	10.5	4.61	4.95X10^8	4.7X10^7	0.16
Al		100	38	21.81	8.0X10^9	8.3X10^8	2.9
Steel	BF/BOF	70	924	2.19	2.1X10^{10}	2.0X10^9	7.0

6.2 Increasing Application of Metals and Demand for PMs

As society changes, its product and infrastructure requirements also change, along with the demand for a particular metal depending on its use in new or future products. With continuous increase in population the global stock of metals in-use by 2050 could be equivalent to 5 to 10 times today's level, thus demanding continuous supply [46]. There is an increasing demand for precious metals used in new energy technologies such as solar cells, batteries and the production of complex electronic devices. As there is continuous emerging technologies which are propelled towards smooth transition to a green economy, meeting the demand for these metals appears to be an essential drive. There is no option to cyclic material use to sustain the materials need of development.

6.3 Declining Ore Grades

As global demand for many metals continues to rise, more low-quality ores are mined, leading to an overall decrease in ore grades. The mining of lower-grade ore causes increased energy use and thus rising greenhouse gas emissions, despite improved extraction methods. In addition, comparison of gold concentrations in natural ores (1.4-8.3 g of gold in one ton of ore) to gold concentrations in PCB (17-81 g of gold in one ton of electric PCB, and 100-1300 g of gold in one ton of electronic PCB) justifies waste PCB as an important resource for gold and other metals [47].

6.4 GDP Increase

The Gross Domestic Product of South Africa is worth 314.57 billion US dollars in 2015 which represents 0.51 percent of the world economy [48]. The current recession in the country was reported to bring about 0.7% drop in GDP during the first quarter of 2017 [49]. There is a significant drop from the mining and manufacturing sector contribution to the GDP in 2016 - 2017. These sectors contributions can be boosted if the metallic value in waste PCB, worth over 490 million US dollar (Table 3), is processed within the country. South Africa's Gross Domestic value is projected to rise by 0.16%.

6.5 Diversification of the Extractive Sector of the Metallurgical Industry

Major strength of developed countries lies in diversification of the economy into different sectors. Currently, South Africa precious metals extractive industry relies on run-of-mines, a depleting resource. If integrated smelting to extract metal values in waste PCBs is considered and pursued in South Africa, existing metallurgical industries will experience various expansions in capacities. These companies are into direct smelting of the ores for metal production. Accepting feeds from recycling companies would entail integration and synergy within the system. The recycling operation will be more active, and precious metal production will be more robust, having another major source of raw materials. This is a more diversified system.

7. FITNESS OF THE SOUTH AFRICAN EXTRACTIVE INDUSTRY

Huge resources continuously reports to eol PCB stream. The need to be extracting the metal content and not exporting this raw resource has been emphasised. However, the extractive industry is still challenged, but still at advantage. Presently in South Africa, there are no integrated lead-copper-zinc smelters, such as in European countries (Table 6), capable of accepting the assorted fraction that PCB physical processing typically produce. Yet, quite a number of base and precious metals refining plants exist, and in active production. These include Rand Refinery, Palabora and Copalcor smelting plants [50]. These base metals smelters will not readily want to alter their current operation to accommodate PCB product fractions because the capital expenditure implication can be significant. An option is for the recycling operation to gear its physical processing towards producing non-ferrous fractions that can be acceptable in the existing smelters. The smelters will however still need to be willing to tap into the resource space and adjust the flow-sheet as will be necessary.

8. CONCLUSION

Using an average of 4.45 wt % PCB from different sources e-waste data, values of precious and base metals contained in eol PCB annually generated in South Africa was estimated to ZAR 6.2 billion. Currently, when PCB fraction are exported raw by recycling companies, only a small fraction of this estimate come to the country's gross domestic product. The present scenario of ignoring these values, while continuing aggressive mining is an impediment to South Africa's primary resources reserve.

With improved physical processing of the eol PCB, it is possible to get much cleaner products that will encourage existing copper metal smelters to accommodate the non-ferrous metal fraction. Considering the extensive resource of eol PCB within South Africa and the neighbouring countries, a good economic prospect ultimately exists for an integrated Pb-Cu-Zn smelter somewhere in the region to maximise values inherent in this urban ore.

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MANAGING COMPLEXITY WHILE INTRODUCING HIGH VOLTAGE TECHONOLOGICAL CHANGE INTO PRODUCTION LINES OF GLOBALLY COMPETITIVE AUTOMOTIVE MANUFACTURERS

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ABSTRACT

Manufacturing has moved through a number of paradigms and competition is truly global. Never before has the need to quickly adapt to market requirements and to adopt new technologies been as great at it is now. Hybrid vehicles were recently introduced to Mercedes-Benz South Africa's (MBSA) East London plant. Currently, no framework exits to guide South African automotive manufacturers in introducing high voltage technological change to their production lines. Therefore, the objective of this research study was to understand the complexity of introducing such change into production lines, to identify key elements for creating a framework to assist globally competitive automotive manufacturers during these type of change processes. General change management frameworks, case studies and methodologies were studied, suggestions from the MBSA team and interviews with specialists formed the foundation to support the researcher's own experience during the management of the change process of the Hybrid project at MBSA. Key elements for managing complexity during high voltage technological change are highlighted and the future work of creating a framework is discussed.

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1 INTRODUCTION

Poverty sustainability drives innovation [1] and therefore manufacturing paradigms are continually changing and shifting to create sustainable value. Sustainable value targets not only ecological sustainability, but also social and economic values [2]. In the current competitive economic environment, companies also struggle to accomplish production tasks alone and smart production helps to solve most product or service customisation challenges with open co-creation platforms and toolkits [3].

Smart manufacturing or production systems consists of various products (hard enablers) and processes (soft enablers), which results in various sources of complexity around the intersection of man and technology. There often remains a concerning gap between the inherent value of a technology and the ability to put it to work effectively. Artificial intelligence may reduce this complexity, but increase overall process complexity as the technology requires maintenance and; downtime is more complex to deal with. It has been shown that very few companies are able to directly measure and attribute increased costs directly to the increase in complexity [4].

Managing product and process variety has however been identified as an enabler towards improving customer-perceived value [5], and so complexity may be a direct result of a strategy for competitiveness. The ability to build and sell any product configuration are the competitiveness strategy for most automotive manufacturing plants. Where the same model is built in multiple global locations, a manufacturing plant that cannot produce a certain variant or configuration is at a disadvantage, as it cannot compete with the other plants to produce those orders.

The C350e built at MBSA's East London plant, as the first hybrid vehicle produced in Africa, pioneered high-voltage-manufacturing in South Africa. When hybrid vehicles were introduced the factory had less than a year to introduce complex, dangerous new technologies and to deliver a product meeting the stringent international Mercedes-Benz standards. The C350e's very unique and powerful high voltage Lithium-Ion battery has 88 individual cells that together produce 60kW and weighs 100kg. The battery operates at a potentially lethal 300V and the risk posed by the high voltage components, which no local automotive original equipment manufacturer (OEM) had experience with prior to Daimler's decision, caused significant initial resistance that had to be carefully managed. Additionally, while some of the new work content of the vehicle could be done separate from the existing production lines, some had to be done on the line due to the nature of the vehicle design. This required an innovative approach as the current production could not be stopped in order for the series equipment to be upgraded to accommodate the Hybrid work-content.

Currently, no framework exits to guide South African automotive manufacturers in introducing high voltage technological change to their production lines. Therefore, the objective of this research study was to understand the complexity of introducing such change into production lines, to identify key elements for creating a framework to assist globally competitive automotive manufacturers during these type of change processes. General change management frameworks, case studies and methodologies were studied, suggestions from the MBSA team and interviews with specialists formed the foundation to support the researcher's own experience during the management of the change process of the Hybrid project at MBSA.

This will enable local automotive manufacturers to react not just quickly and resource efficiently, but also safely in lieu of local legislation governing automotive manufacturing with high voltage components. It is hoped that this research study will prompt Government and industry to look at implementing specific legislation in this regard, as currently exists in Germany and China.

2 MANAGING COMPLEXITY

In order to stay globally competitive the only constant is change. In the automotive sector mega-trends like climate change, the finiteness of fossil fuels and the growing global demand for mobility, particularly in places like China, is driving change and particularly e-mobility solutions to new heights [6]. The change distance between technical promise and genuine achievement can be overcome with different models. It has been argued that in order to effectively lead change one should start by creating a sense of urgency around an idea or opportunity and then build a powerful guiding coalition, in terms of titles, information, relations and expertise [7]. Next one needs to create a vision of the change, formulating clear plans to avoid ambiguity before the vision is communicated to the broader organization. Thereafter obstacles to the change process should be removed. Often with the introduction of new technologies there are initial safety concerns. While new technologies can have many benefits, these technologies can also introduce new risks and introducing them is therefore a sensitive process. At the same time many legal obstacles exist. When hybrid vehicles were introduced no legislation in South Africa covered this new field and the Occupational Health and Safety Act of 1993 [8] only covers general duties of employers to their employees. It does not state specific safety measures required for manufacturing with high voltage components [9]. Specifically in such cases one should plan for and create short-term 'wins' to demonstrate the benefits of the process and ensure people do not give up on the idea of introducing complex technologies. The next step is to consolidate the improvements and sustain the movement before cementing the change and the process of change as an organizational culture.

It has been reported that 80% to 95% of projects fail as a result of human error, specifically miscommunication between the various project links, often the project sponsor and the project manager [10]. Other factors that complicate complex change projects include not only the scope and technical complexity, but also conflicting stakeholder objectives, standardised processes that don't accommodate the flexibility required and pressure from government and other external parties. It is known that the size of the organization, the resources available to it and the support of its management has an impact on the adoption of new technologies [11]. It is also known that once an adoption decision has been made, the attitude of management and the ultimate users' perceptions of the technology play a large role in the implementation success [12]. Part of the reason for this is that the adoption of new technologies affects not only the tasks of the users, but often changes the interdependencies between different teams and areas [13]. It is reported that the food conglomerate Kraft created a $400million annual saving by removing complexity from the manufacturing and supply operations of the Toblerone chocolate [14], [15].

Many diverse measures have been suggested within various scientific disciplines to define complexity. Thirty-two types of complexity has been defined across twelve disciplines including structural, computational, technical, project and operational complexity [16]. Manufacturing complexity is a term to describe a characteristic which is not yet possible to quantify precisely. Yet the complexity of production systems is the critical cause of many management problems [17]. Figure 1 illustrates the drivers and complexity enablers to introduce high voltage technological change in production lines to stay globally competitive [18].

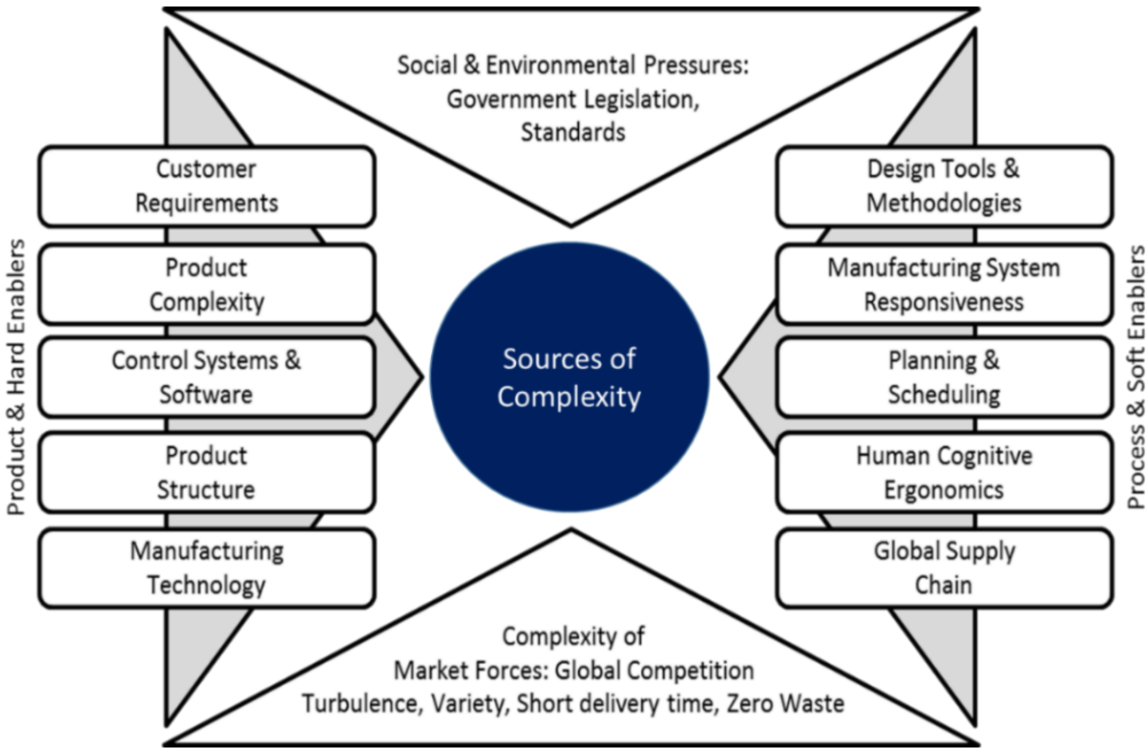

Figure 1: Drivers of manufacturing complexity to introduce high voltage technological change in production lines (Adapted from [18])

Measures of complexity are generally dependent on context and are invariably multi-dimensional. The number of parts, their size and geometry, their variety and manufacturability are indicators of complexity, as is the level of standardisation or lack thereof. Additionally the part handling and insertion attributes contribute to the time to assemble and test. The volume and speed of manufacturing or assembly contributes to complexity, as does the number of suppliers and sub-suppliers, the number and location of competitors, the level of market turbulence or certainty and any number of other sources. When engineered systems are considered, the relevant domains essentially are: product complexity, process (manufacturing system) complexity and organizational complexity [18].

2.1 Product complexity

Product complexity was defined as the degree to which the individual parts/sub-assemblies have physical attributes that cause difficulties during the handling and insertion processes in manual or automatic assembly [19]. During the period from 1975 to 1990, the number of part numbers in German companies went up by approximately 400% and by the mid-1990's 50% of assembly variants in automotive manufacturing was used in less than 5% of the units produced [20]. Both simulations and empirical data show that an increase in product variety in automotive vehicle production leads to a significant negative impact on performance both in terms of quality and productivity [21]. As illustrated in Figure 2 contemporary vehicles comprise thousands of parts and can require hundreds of fabrication steps and adding to the complexity is the fact that not only mechanical and electrical parts are assembled, but also complex software and machine-human interfaces [18].

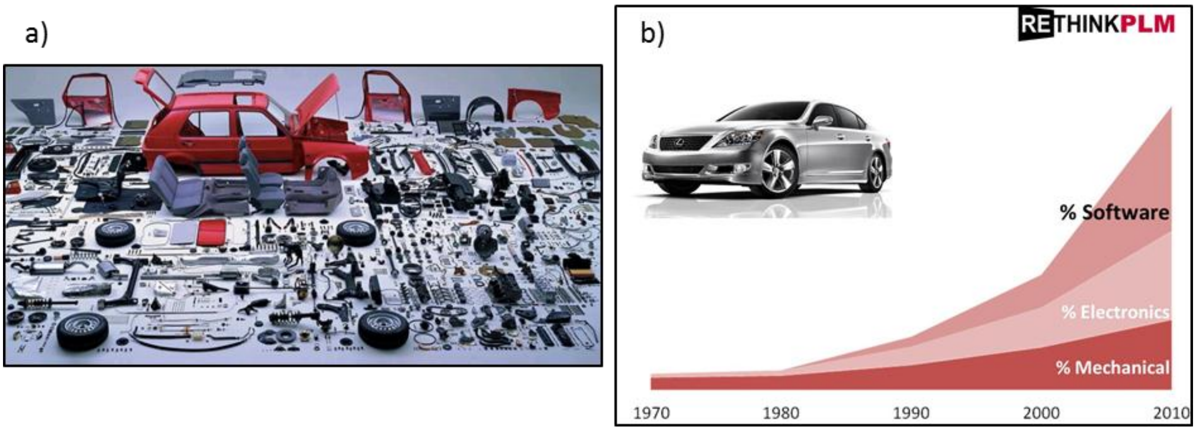

Figure 2: a) Exploded view of the 1983 Volkswagen Golf MK2 [22] and b) the exponential increase in parts since the 1970's [23]

BMW claims that every vehicle that rolls off the belt is unique and the number of possible automobile variations in the BMW 7 Series alone could reach 10^{17} [24], or stated another way, there are potentially one hundred quadrillion different variants of this model. Locally MBSA states that they have to change over 3500 parts for the 2018 C Class Facelift project alone and adds that this number represents only the unique purchase parts, not subcomponents [25]. Motorola waged a well-documented "War on Complexity". On a portfolio level Motorola defined the problem as having too many products, too many high-complexity products and too many low-volume products. At a detail level Motorola defined the problem as having not enough component re-use, having too many non-standard components, having too many parts and too complex sub-assemblies.

Technological enablers that facilitate reconfigurable systems are able to produce a high variety of different products include functional changeability, scalability and importantly modularity [5]. It has been shown that as the product variety increases, the optimal assembly supply chain configuration moves from non-modular assembly to modular assembly [21].

2.2 Production and process complexity

The physical and logical layout of a manufacturing system dictates material flow planning, particularly the movement of parts and tools to and from warehouses and on the shop floor. This complexity has a direct correlation not only to transportation costs, but to overall resource efficiency. In manual assembly, complexity is manifested in the added worker's effort to recognize, grasp, orient, insert and assemble the parts. In automatic assembly, complexity translates into additional equipment required to complete the assembly process. Their results show that higher complexity is proportional to longer assembly time in the case of manual assembly, and more equipment cost, in the case of automatic assembly. It has been noted that the layout of the various components in a system and the connectivity among them also affect its complexity [18]. Complicated products, processes and manufacturing systems cost more to design, implement, plan, operate, control and maintain and the associated cost is an important factor. A production or manufacturing system should however not be seen as a fixed object, but rather one subject to adaption and emergence [26]. Well-designed systems often have features that allow for adaption and reconfiguration, including modular design, both physically and in logic, cellular workstations, buffers and physical de-couplers.

Introducing commonality for instance common fixtures, tools or parts for multiple variants is one way of reducing complexity. The measurement of the complexity of a product's production supports manufacturing orientated product design, aids designers to reduce assembly complexity and allows for better decision making on parts, sequences, tools and layouts. Local suppliers and alternative shipping routes must be investigated as well as alternative packaging [27]. Importing technology from international suppliers can have several drawbacks, including creating a power imbalance between customer and supplier [28]. The return or discarding of damaged or non-conforming high voltage components is a critical topic as possibilities to safely ship damaged HV Batteries back to their import-suppliers or to safely discard them locally is unclear.

Outsourcing and vertical Integration can be seen in this context as extensions of the Modularity concept, where a company or several companies does pre-assemblies for an OEM, instead of the OEM doing them in-house. It increased supply chain complexity by adding an extra supplier and transport leg, but can significantly reduce in-house production complexity by procuring assemblies that previously would have had to be manufactured in-house. Volume-flexible assembly lines where it would be possible to adapt configurations to different demand requirements were analysed [29] and recently methods were proposed to cope with re-configuration of resources for capacity planning [30], but these only currently provide a scientific foundation, not yet concrete formalized tools and methods [31]. Nonetheless 'Scalability' is an option to consider when attempting to reduce complexity, specifically with regard to market fluctuation. Multi-model line (MML) is another way of coping with fluctuating demand on individual products, but this generally adds significant complexity to the system.

2.3 Organisational complexity

Complexity deals with that part of the process of work imbedded in the discretionary power of the person [32]. Not only the products produced by companies are affected by complexity, but so are the organizational structure. Effective and resource efficient work requires different and increasing levels of, as well as different combinations of discretion complexity [32]. Organisations need not have all levels of complexity to be successful. Flexible processes, enlarged product portfolio and varying market demands require that companies embrace new strategies and concepts of organizational design and structure. Globalisation, including global suppliers and a global customer base has exponentially increased the interconnectivity of activities and vastly increased complexity. Organizations have to adapt to the fast-paced disruption, or they are doomed to follow the path of, for example, Nokia. The supply network of suppliers and OEMs can be measured by both the in-degree and out-degree (the number of incoming and outgoing links) of the nodes. Every link adds complexity to the overall system. The rise of hybrid and electric cars is a driver that is likely to change the industrial structure of many organisations [33].

3 RESEARCH METHODOLOGY

The objective of this research study was to understand the complexity of introducing high voltage technological change into production lines, to identify key elements for creating a framework to assist globally competitive automotive manufacturers during these type of change processes.

This research was divided into different phases as illustrated in Figure 3. During the understanding phase general change management frameworks, case studies and methodologies were studied as theoretical foundation for MBSA's Hybrid project.

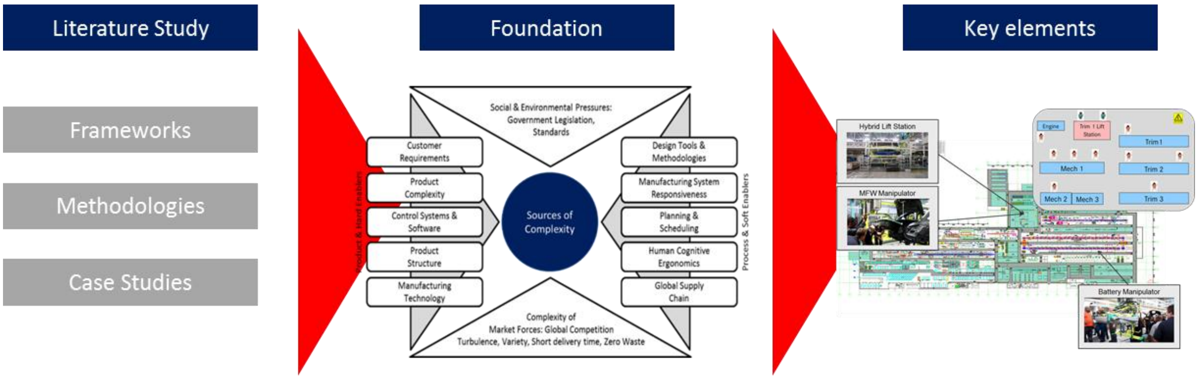

Figure 3: Research Methodology

Thereafter, suggestions from the MBSA team and interviews with specialists built on the foundation and supported the researcher’s own experience during the management of the change process of the Hybrid project at MBSA. Key elements for managing complexity during high voltage technological change are highlighted and the future work of creating a framework is discussed.

4 LESSONS LEARNED FROM MBSA’S HYBRID PROJECT

It can be argued that perhaps the competitive advantage lies not so much in the notion of a participative culture as it lies in the organisation’s ability to get its members up the participation experience curve faster and more successful than its competitors. When hybrid vehicles were introduced to Mercedes-Benz South Africa’s (MBSA) East London plant, the factory had less than a year to introduce complex, dangerous new technologies and to deliver a product meeting international Mercedes-Benz standards.

To manage the change successfully, a version of Kotter’s “8-Steps to Leading Change” to used [7]. MBSA’s management team went through an urgent visioning exercise which helped to set out the basic rules of the game and determined key strategic thrusts the organisation should focus on. The implementation team was mobilised behind the strategic intent and met, together with management and later regularly as a team, to appraise the technological change and overcome any initial reluctance with regard to the dangerous high voltage technology. The risk that caused initial resistance was that posed by the high voltage components, which no local automotive OEM had experience with prior to Daimler’s decision to build the C350e in South Africa. At the same time there was no legislation in South Africa covering the specific safety measures required for high voltage manufacturing. As the technology was only contextually new, rather than conceptually, MBSA was committed to install the same safety measures as its mother-company, Daimler AG. Doing this MBSA complied with the German (VDE) and wider European (ECE) regulations in lieu of local legislation.

Safety in this case is not just about the training of assembly operators, but also safe warehousing and quarantine of HV components, safety signage, emergency response requirements and personal protective equipment. When technology adoption was forced by the mother-company, Daimler AG, the necessary know-how did not exist in South Africa. MBSA had to look at international organizations for the training of MBSA’s staff. It was also necessary to ensure not only knowledge transfer, but to ensure that the training competence is transferred too. This will ensure that future employees can be trained and for future management of the new technology. Trainer personnel were leveraged to encourage others, by demonstrating the success of the implementation and by negating all safety concerns. An informal reward process for these employees accelerated the technology adoption by generating excitement and an eagerness in other employees. This both removed obstacles in the change management process and demonstrated a “quick win” for the project team, securing momentum for the project as a whole.

South African OEMs are all subsidiaries of larger international manufacturers based in either America, Japan or Germany. As such their management teams have little to no influence over the design of the vehicles they manufacture and are essentially contract manufacturing plants. Local plants however have an influence over the amount of part numbers that are bought, depending on the decided vertical integration and so have an influence on the increase in product complexity to some degree. The vast majority of high voltage (HV) components are not available locally and have to be imported. The import of the HV batteries specifically is very strict due to packaging and shipping regulations. Local suppliers and alternative shipping routes had to be investigated as well as alternative packaging.

With regards to Product and Process complexity, the production lines at MBSA had to be re-engineered to accommodate the added model variant, but some parts could not be accommodated due to the design of the vehicle and the current layout of the lines. This required an innovative approach as the current production could not be stopped in order for the series equipment to be upgraded or adapted to accommodate the Hybrid work-content. Representative teams from management and supervisory levels met to determine the fundamental value-adding flows and find alternatives to the existing stations. Thereafter, the work processes were made-up of the various sets of work cycles, tasks and task clusters and a modular approach was set up with some of the equipment. This modularity to a large part contributed to the project's success by limiting the increase in process complexity. Although buying some of the equipment from a European suppliers was expensive, the technology could not be built in South Africa, creating issues around maintenance and spare parts availability that needs to be resolved. Importing technology from international suppliers can also create a power imbalance between customer and supplier and this needs to be further evaluated, but within the limited timing allowed to introduce the project there were no alternatives.

Due to the relatively low build volumes and the high Hybrid-specific work content, it was unlikely that Hybrids could be fully accommodated on the existing production lines in MBSA's East London plant in a resource efficient way. It is assumed that other South African OEMs will have similar concerns, due to the limited volumes of Hybrids produced and sold worldwide.

Regardless of the low volume, a separate High Voltage responsibility line had to be installed, with qualified staff and a Chief Electrical Specialist had to be appointed to take overall responsibility for this technology in the plant. The organisation structure was based on the strategic intent of MBSA as well as ground level activities. Information and control systems were required for each individual in each level that would enable him/her to do the right work at the right time at the right place and above all, do it safely. This structure essentially had to be set up before the first batteries were installed in units, or the safety of staff would be at risk. MBSA's Organisation Culture helped to cement the new high voltage manufacturing capability and responsibilities within the organisation in very limited time. To this extent it can be argued that Organisation Culture and counteract increases in organizational complexity to some extent, or at least, minimise the disturbance.

5 CONCLUSION

This Hybrid vehicles were recently introduced to Mercedes-Benz South Africa's (MBSA) East London plant. Currently, no framework exits to guide South African automotive manufacturers in introducing high voltage technological change to their production lines. Therefore, the objective of this research study was to understand the complexity of introducing such change into production lines, to identify key elements for creating a framework to assist globally competitive automotive manufacturers during these type of change processes. General change management frameworks, case studies and methodologies were studied, suggestions from the MBSA team and interviews with specialists formed the foundation to support the researcher's own experience during the management of the change process of the Hybrid project at MBSA. Key elements for such a framework has been shown to be product complexity, production complexity, as well as organisational complexity and general change management.

It was shown that contemporary vehicles comprise thousands of parts and can require hundreds of fabrication steps. A BMW 7series could have as many as one hundred quadrillion different variants and dealing with this type of product complexity is not easily. Vertical Integration, buying parts as sub-assemblies rather than single components, is one way of addressing this type of complexity. Modularity has been shown to be an effective way to counter increases in process complexity. By fabricating some sub-assemblies separate from the main assembly line it is possible to reduce the complexity of the line itself, though perhaps not the overall system. Organisational complexity can be addressed in large part by organisational culture and open lines of communication across the hierarchy. Reducing incoming and outgoing links to and from suppliers and customers etc can also facilitate a reduction in organisational complexity and this can be tied back into Vertical Integration, as the organisation needs to deal with less suppliers.

MBSA has managed to do what no other OEM in Africa has done and has produced Hybrid Vehicles in a landmark project, but a framework to guide automotive manufacturers in introducing high voltage technological change to their production lines is still lacking. This is an industry need that academia needs to address.

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IMPROVING DATA MANAGEMENT OF A MOBILE DATA COLLECTION SYSTEM BY USING WEB-SERVICES

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ABSTRACT

The popularity and moderate cost of mobile devices, has led to the development of data collection applications as an alternative to manual recordings and automated data collection systems. A previous mobile system had various shortfalls that became evident during implementation. Initially, neither configuration data nor collected data were stored in a central repository which caused restrictions from a maintenance perspective. Of greater concern however, was that no versioning or data tracking facilities were available. Further shortfalls were caused by an inefficient unidirectional data transfer channel. This one way communication did not allow feedback to mobile units and did not account for data transfer errors. Furthermore, configuration data and data collected using other devices could not be synchronised among linked remote devices. A centralised management application was subsequently developed to manage data and maintain a centralised dataset. Additionally, the management application provides interfaces used to create configurations, while maintaining a version history and change logs. Bidirectional system communication tasks are also handled by the management application. The updated data collection system was implemented as a data collection solution on numerous industrial facilities within South Africa. System capabilities and their impact on industrial activities are discussed in case studies.

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1. INTRODUCTION

1.1 Challenges surrounding the industrial sector

The global economic crisis at the start of the twenty first century affected established and developing countries alike. This had a lasting effect on many countries including South Africa. Statistics South Africa [1] reported that the country's economic growth slowed from 5%, for the period ranging between 2004 and 2007, to 2% between 2008 and 2012.

International economic constraints have led to a decrease in the demand for various items. Commodity prices linked to certain precious metals have therefore reduced significantly, causing increased pressure on affected industries. Mineral extraction and processing, forms large portions of South Africa's economy [2]. As a result South African organisations are struggling to remain competitive in global markets [3].

Additional challenges that plague the gold mining industry include declining ore grades, labour disruptions, reduced productivity and escalating operational expenses [4], [5], [6]. A large portion of the increased operational expenses can be linked to electricity tariff hikes. In 2016, electricity tariffs had risen by 290% to that of equivalent rates in the year 2000 [7].

Another struggling industry is the steel production industry. Decreased economic growth has reduced the demand for steel in many countries. This has led to a global oversupply of steel especially from China [8]. Two factors that contribute to China's oversupply are their low labour costs [9] and government funding [10]. This allows China to flood the steel market with low cost steel, making it increasingly more difficult for other countries, including South Africa, to compete.

1.2 Data collection and management needs

Along with the challenges discussed in the preceding section, industrial organisations have increasing data needs. Two main factors contributing to these increased data needs are stricter reporting requirements and system optimisation. These raise the need to collect additional data as well as ensure that collected data is traceable. Organisations must therefore implement additional data collection systems to collect relevant data.

The research team had access to multiple industrial organisations in which South Africa's data collection and management needs were investigated. Data needs associated with environmental reporting, maintenance management and human resource utilisation were considered. Five common data needs were identified and are presented in the following sections.

Data traceability

A general need for traceable data was observed across a wide range of industries. Poor reporting standards and abundant inexpensive resources, promoted a culture of wasteful consumption. This wasteful consumption has serious environmental and financial implications with narrower profit margins and stricter legislation; organisations are placed under increasing pressure to improve data management associated with resources.

In recent years environmental sustainability reporting has received more attention. Governments have entered into agreements to reduce environmental impacts and are starting to enforce change. Due to this, affected organisations must provide evidence of reported values during annual audits.

Organisations stand to gain financial assistance from multiple sources. These sources include tax rebates and energy efficiency funding programmes. Financial offerings are offered based on performance, such as verifiable reductions of energy consumption. Non-compliance with agreed targets can however result in financial penalties; therefore source documentation should be preserved for verification purposes.

Human resource utilisation

Human resource expenditures add up to a large portion of operational costs within industrial activities, with not only labour cost being considered, but also training and development costs. In order to attract and maintain skilled workers, organisations must fulfil financial goals and provide career growth opportunities

The utilisation of unskilled personnel is a cost-effective method to manage human resources. Although personnel can be trained, it is an expensive and time-consuming process. Therefore, unskilled personnel can be employed to perform basic tasks, such as remote data collection if sufficient guidance can be provided. This also allows the workload of skilled employees to be reduced, allowing for more time to attend to advanced tasks. Utilisation of unskilled workers will also provide promotion opportunities and improve worker satisfaction rates.

Modern computer based systems can be utilised to assist users while performing a range of actions. These systems can be used to perform tasks such as item detection and data validation. This will support users while collecting data to ensure that appropriate and accurate data is collected. Furthermore, this handles decision making and reduces the opportunity for human error. In many cases, this will allow organisations to utilise unskilled workers more effectively.

Data quality

Data accuracy is an important aspect when compiling reports, particularly when the decisions based off of the reported figures, have significant financial implications for the organisation. Often data collection systems are associated with a specific data collection tasks, and do not allow the collection of unrelated data. In these cases manual data collection and reporting is typically implemented however, this exposes the data to human interaction and possible errors.

Thus, a generic data management system will allow users to collect a wide range of data with a single familiar system, as well as reduce training needs. Furthermore, automated capabilities (as mentioned in the human resource utilisation section) can include item and data set detection as well as validation such as statistical analysis on historic data.

Data validation and verification tests will improve the accuracy of recorded data. During the data collection phase substantiating data must be collected. This can be in the form of photographs or similar records. This data must be stored with the collected data and can be used to validate or correct data during audit processes.

Maintenance and awareness

Components of the infrastructure within industrial settings are often exposed to harsh environments. The mining industry therefore relies on ongoing maintenance and updates as certain network elements are disused. Ongoing maintenance is therefore required to ensure that corrective actions are performed to reduce wastages. Effective maintenance will also reduce wastages in systems that are subject to saving initiatives. It is therefore crucial to maintain affected systems to ensure adequate performance.

Effective maintenance is only possible if the state of the system is well documented and available at the time of decision making. This will allow maintenance staff to prioritise tasks and prepare more accurate budgets. Improved maintenance structures will help maintenance staff to track maintenance activities, if adequate structures are in place. Collected data must therefore be processed, managed and displayed using effective structures.

In the long term, comprehensive data sets will allow for the generation of maintenance reports. These reports can be used for multiple management applications, including task scheduling and verification tasks. Patterns and high risk areas can be identified and addressed with preventative maintenance activities. Lastly, automated systems can be integrated with specific maintenance software to improve workflows.

System integration

Organisations rely on a range of systems and applications to operate. Many systems are used to perform specific tasks or manage particular business elements. In many cases, support systems will improve the performance of related systems and must therefore be integrated to extract its full potential. However, integration is not always achievable due to system restrictions and incompatibility issues among suppliers.

Operators require specialised training in order to utilise the advanced features offered by the various software systems. This places the organisation at risk due to its reliance on a specific person. This risk increases when the organisation relies on multiple specialists to manage its systems. If any of these users are unavailable, those systems cannot be utilised and may influence other dependent systems.

A unified system will allow users to perform a range of tasks with expert knowledge of a single interface. This will allow many users to be trained in the use of a single platform. Users who are familiar with the platform will be able to utilise additional systems with minimal additional training. Integration of multiple systems will eliminate work duplication and reduce human errors.

1.3 Industrial data collection systems

Automated data collection systems
Large industrial organisations typically rely on sensor networks hosted by Supervisory Control and Data Acquisition (SCADA) systems. SCADA systems, in isolation, are not full control systems, but only allow supervisory access to data [11]. Additional hardware is therefore implemented to host control systems that control systems based on predefined rules.

Advantages of SCADA systems include [12]:

- The ability to record and store large amounts of data;
- Users have real time access to detailed data;
- A Simple interface offer great functionality due to strong development history;
- Minimal knowledge required from end user; and
- The systems are robust and are ideal for industries with high reliability requirements.

Although SCADA systems offer high levels of data security and are well suited for data management associated with multiple industrial activities, these systems do not always offer the best solution. SCADA systems rely on fixed infrastructure networks. In many cases, expansion is rigid with major cost implications. These systems are therefore better suited to monitor mission critical data collection tasks.

Manual data collection methods
Industrial data collection needs extend beyond data related to the primary business application. In most cases, automated systems are used for critical data collection related to the operation. However, due to the high costs associated with automated systems, such systems are not widely utilised for auxiliary applications. Auxiliary data is therefore collected using manual processes.

Manual data collection is usually performed using a pen and paper approach, which is considered a laborious task [13]. Furthermore, manual data collection requires additional manual labour to prepare base maps, collect support data and process the collected data. Due to these factors, manual data collection restricts the opportunity for timely decision making as problems can easily be missed or are not recorded properly [14].

Although manual data collection initially offers a simple and cost effective solution, the extensive amount of manual labour required to process data and lost time are major concerns. Erroneous and falsified data are introduced by human interaction with the data. Therefore, support data must be collected to substantiate claims. However, this cannot be done using support systems which further complicates data processing.

Mobile device based data collection
Mobile devices can be used to enable flexible data collection [15]. Park reasoned that the use of smart devices has become ubiquitous in everyday life [14]. Furthermore, Park noted that mobile devices contain a multitude of sensors that can be used to enable effective data collection.

Mobile data collection solutions have the ability to relieve employees of tedious manual tasks [16]. An additional benefit was noted by Tomlinson [17], who indicated that mobile systems allow real-time supervision and therefore enables the detection of falsified data. These are major improvements over manual data collection systems.

Mobile data collection systems offer industrial consumers a viable alternative to fully automated and manual data collection systems. Due to the popularity of mobile devices, mobile data collection systems can be implemented at a minimal cost. These systems will relieve users of tedious tasks and ensure that data of a standard is collected and stored.

2. A COMPREHENSIVE MOBILE DATA COLLECTION AND MANAGEMENT SYSTEM

2.1 Introduction to mobile application development

In a previous study Prinsloo et al. [18], considered multiple existing mobile data collection applications. However, their investigation did not reveal a single data collection system capable of addressing all the data collection and task management needs in the industrial sector. Thus a mobile application was developed to address these needs. However, the freestanding application had maintainability shortfalls and therefore required large amounts of maintenance work.

In order to address shortfalls associated with the previous version of the system, the system was expanded on with a range of sub-systems that enable extended functionality. Interfaces were developed to enable efficient communication among sub-systems. In the next section, the extended system and its core concepts are introduced. The extended system utilises web-services to allow advanced features enable by the combination of sub-systems.

2.2 Comprehensive system structure

One of the new requirements for the system is the need to have a centralised database that consists of data from multiple sources and for different clients. In order to accomplish this, a model that represents real world structures must be created. This model will form the Logic Hierarchy. The system is a tool that is used by an Energy Service Company (ESCo) that provides services for several organisations across South Africa. In order to fulfil the needs of the individual organisations, the centralised database will consist of a database structure for each client. Each structure can be thought of as a *Group*.

An organisation using the system has business divisions that also make use of the system for different applications. This means that some form of separation needs to be accounted for within the *Group* database structure. This is accomplished using *Configurations*. A *Configuration* is customised for each application based on the requirements set by the organisation/*Group*.

Business divisions that make use of each *Configuration*, require the ability to collect several different clusters of data. These clusters of data can be thought of as questionnaires that facilitate the gathering of information. This is modelled by means of *Modes*. Each mode consists of data fields that would represent questions in a questionnaire. *Configurations* can have multiple *Modes* for multiple data cluster collections. *Groups, Configurations and Modes* model the real world structure of the interaction between the ESCo and its clients. This is the Logic Hierarchy and is shown in Figure 1.

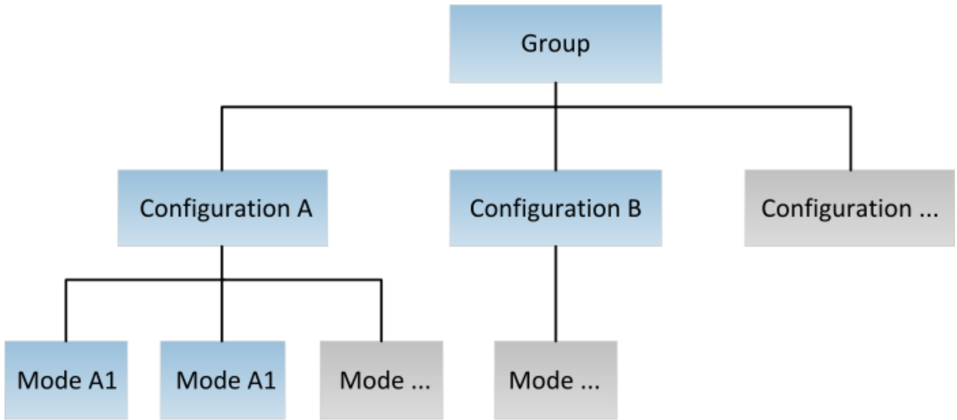

Figure 1: Logic Hierarchy

Utilising the logic hierarchy, the newly designed system consists of five subsystems that address issues that the previous system could not. Figure 2 illustrates the system's architecture. The Central Services subsystem is the primary connection point between the four other subsystems. It is responsible for hosting the *Group* database structures, communication and data transfer between subsystems and hosting a web application for database manipulation and configuration. *Group* database structures implement the model described previously. Communication and data transfer between subsystems is required in order to allow for mobile device data and *Configuration* synchronisation, as well as providing and receiving data from internal and external support systems.

The Mobile Devices subsystem of the mobile data collection system's architecture consists, of Android devices running a version of the previous application that allows for the integration of the newly added subsystems. These devices are the primary means of data collection implying that they are the most important element of the system. In terms of the Logic Hierarchy, devices are registered to *Configurations*. This allows for the synchronisation of configuration information, collection of *Mode* data clusters on the central server and synchronisation of *Mode* data to all devices registered to the *Configuration*.

Internal and External Support systems are responsible for using the collected data to gather further insight into *Mode* data clusters, or to merely display/inform interested parties of the data collected. Internal support systems are provided by the ESCo, and integration with Central Services formed an integral part of the design. Two internal support systems are currently integrated- one for creating custom reports and one for displaying data (either through direct display or after some data manipulation). External support systems are provided by clients. One such system generates automatic work orders depending on the data that is received.

The Firebase Cloud service is used by the Central Services subsystem and by the Mobile Devices. It serves as the backbone for the communication between these subsystems. The Central Services subsystem makes use of the Firebase Cloud Messaging (FCM). FCM is a cross-platform cost-free messaging solution that enables reliable message delivery between mobile devices and web servers. When the central server receives data from one of the mobile devices, it sends a notification to relevant devices that then perform data synchronisation requests.

Communication between subsystems is done using three different communication channels namely, FCM, Application Programming Interface (API) requests and email messages. Figure 2 shows three line types that represent these channels. API requests allow data transfer between the central server, mobile devices and internal support systems. Email messages are used for data transfer to external support systems.

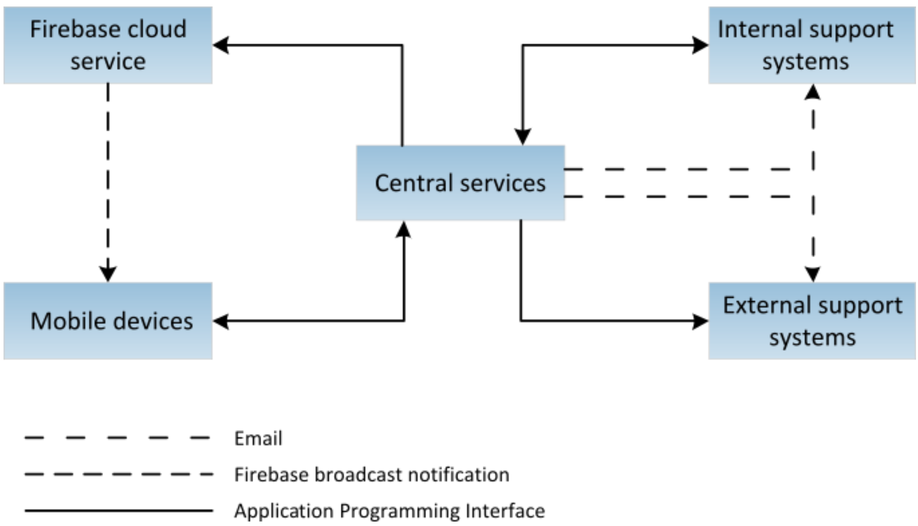

Figure 2: System Architecture

The described subsystems form the basis for allowing extensive integration options. Additionally, this architecture address shortfalls associated with the previous system. The remainder of this section is dedicated to describing system processes and provides an indication of how the discussed subsystems interact to make these processes possible.

3. IMPROVED PROCESSES UTLITISING WEB-SERVICES

3.1 Configuration management

The previous system did not make provisions for version management and configuration distribution among linked devices. This proved to be a major drawback of the system, as it required a technician to create an updated configuration file and manually update all the relevant devices. In addition to the process being cumbersome, this created a threat that certain devices were not updated and did not provide users with appropriate interfaces.

A web application was therefore developed and hosted on the central server. The application had multiple purposes among which is configuration management. A new data base structure was developed to manage configuration data along with a full version history. The web-application allowed users to see configurable items and make changes. All changes were stored in the database and synchronised with the mobile devices. The interfaces divided the configuration into logical sections which are described below.

The first part of configuration management is used to manage group data. In this section, administrators can specify lists of devices, users, modes and user-mode links. Administrators have the option to add, remove or edit entries in the database. Once these changes are saved and synchronised with linked devices, the new settings replace the previous active version and alter application behaviour.

Mode configurations are the second section of the configuration interfaces. Each mode can be seen as a unique questionnaire. Administrators have the ability to customise the mode behaviour (by adapting data fields) list options, test options and processing options. Data fields resemble questions. The text, hint and input interface associated with the data field can be adapted to address the needs of the specific case. Likewise, list items, tests and processing options can be adapted according to the specific case.

Once the administrator is satisfied with the changes, the new configuration can be saved. The system creates a new version and stores a history of changes in the database. Linked devices are notified of changes using the FCM service. When the notification is received, the mobile application requests the updated configuration from the server. The server application then gathers the data from the correct database schema, and sends it back to the device.

In order to receive FCM notifications, the device has to be registered to the relevant configuration. This is accomplished using a Quick Response (QR) code that should be scanned the first time a user runs the application. Users are given access to this code by a system administrator via the central server web application. The administrator creates a device and generates a QR code that is sent to the user of the mobile application. When the user scans the code, an API request is sent to the central server registering the device to receive FCM notifications.

3.2 Log synchronisation

The gathering of the information required for each *Mode* is known as the process of creating a log. A user creates a log using the mobile application. This process consists of selecting a mode to create a log for the completion of relevant log fields. Upon saving the log, various calculations and validations are performed on the entered data, which depend on the application's *Configuration*. After saving the log, the user has the option to synchronise the log whenever there is network access.

The process of creating the log is the same as was followed in the previous application. The difference arises when synchronising the log. Instead of sending the log to the central server via email, the log is sent to the central server using API Requests. This allows direct communication with the server and facilitates synchronising logs with other devices.

When the server receives a log it saves the log in the central database along with supporting files such as images. The server application then sends FCM notifications to devices linked to the configuration, and notifies the devices that new data is available. The devices that receive the notification connect to the central server to obtain new logs, using API requests.

3.3 Task management

Task management functionality was not included in the previous version of the mobile application. There are three task types that can be created: follow-up tasks, assigned tasks and recurring tasks. Follow-up tasks can be created to remind users to re-evaluate a certain log. Assigned tasks can be used to assign specific users to tasks.

The final task type, a recurring task, is the most complex as it is automatically generated by the application. The application uses previously created logs to determine if these logs are created on a routine basis. In routine cases, the application creates a task for each repeating log entry. The system refers to the log history to establish a list of items that is recorded at regular intervals. Tasks are then created using this list. If an entry for the current time period exists, no additional tasks will be created.

Tasks are synchronised with the central server and then distributed to linked devices using FCM notifications and API requests, similar to Log synchronisation. Furthermore, automatic task creation relies on an up to date local database to create relevant tasks. Log synchronisation can therefore be implemented as a tool to assist with co-operation within a team, by allowing users to create logs based on outstanding log entries usually created by a specific person.

3.4 Data consolidation and processing

As stated in section 3.2, logs are synchronised by different devices that are registered for the same configuration. Upon receiving the data, the central server can perform different actions based on preferences set by system administrators. An example of these actions is sending data to external processing systems. Depending on the type of external processing system, the data is required to be in a certain format. The central system processes the data to get it into the correct format, and then sends the data to the external system using one of the three possible communication methods.

Another form of data consolidation and processing consists of sending personal email alerts that depend on the type of data received. Email alerts can be configured to be triggered on a per mode basis. Rules are set that dictate the actions that can occur based on the value and type of data that it received for the mode. Every time a log is received by the server, the server iterates through the rules that are set for the mode and performs the actions dictated by the rule.

4. SYSTEM IMPLEMENTATION

The improved system has been implemented on four large industrial groups in South Africa. Applications ranged from single audits to a permanent replacement for paper-based work. Two implementations were selected and are discussed in more detail in this section. Integration with web-services to achieve specific outcomes is highlighted.

4.1 Implementation 1: Meter readings

In this implementation, the application is used to capture monthly meter readings in the mining industry. These readings do not influence production and therefore do not justify the installation of expensive, accurate monitoring equipment. These readings are however used for intra-organisational reporting, as well as environmental reporting purposes.

The collected data must therefore be accurate and traceable. GPS co-ordinates, time stamp, user authentication and photographic evidence can be used to achieve this. In addition to traceability requirements, the use of a mobile application opens up the possibility to utilise verification tests and task management functions to guide less skilled workers to complete data collection tasks.

The client used the previous version of the system and enjoyed several advantages it offered above paper forms. However, updates to the system proved difficult due to the isolation between the client and the system distributer. The client used the system actively and requested changes to users and list options on a regular basis. The update process relied on a specialised desktop application that was too complicated to use without special system knowledge, and needed to be improved in order to allow regular changes.

To solve this issue, the web based application was developed. The web-application allows access from any device that can connect to the internet. Users can log in and adapt the applicable configuration at will. The web-application on the central server was used to create a duplication of the latest configuration of the client's system. The web-platform can then be used to publish these configurations, to linked devices, remotely. Figure 3 shows the web interface used to publish configurations.

After the configuration was created, the client was supplied with the updated mobile application and a two dimensional barcode with an embedded licence key. Upon start-up, the application requests users to scan a licence code, as indicated in Figure 4. The licence code is used to link a user to a specific group. If the licence code is valid, the server accepts the registration request. The application receives the response and automatically requests configuration data, previous logs and task data from the server.

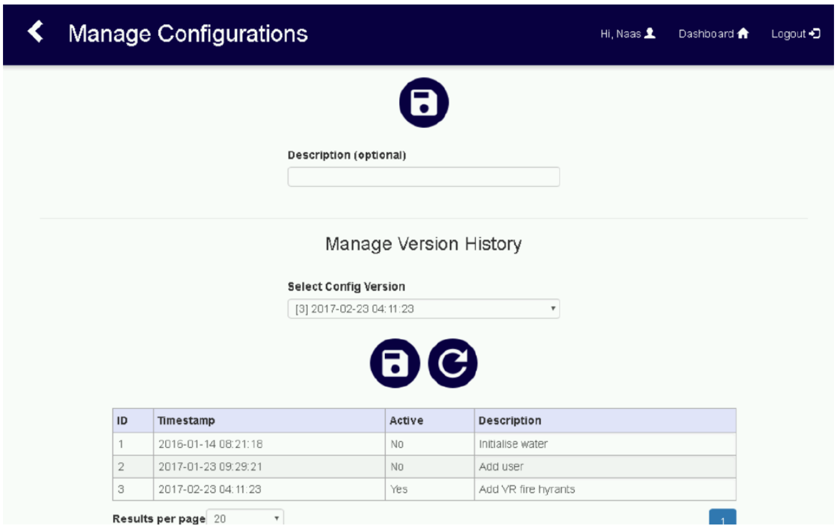

Figure 3: Configuration version interface

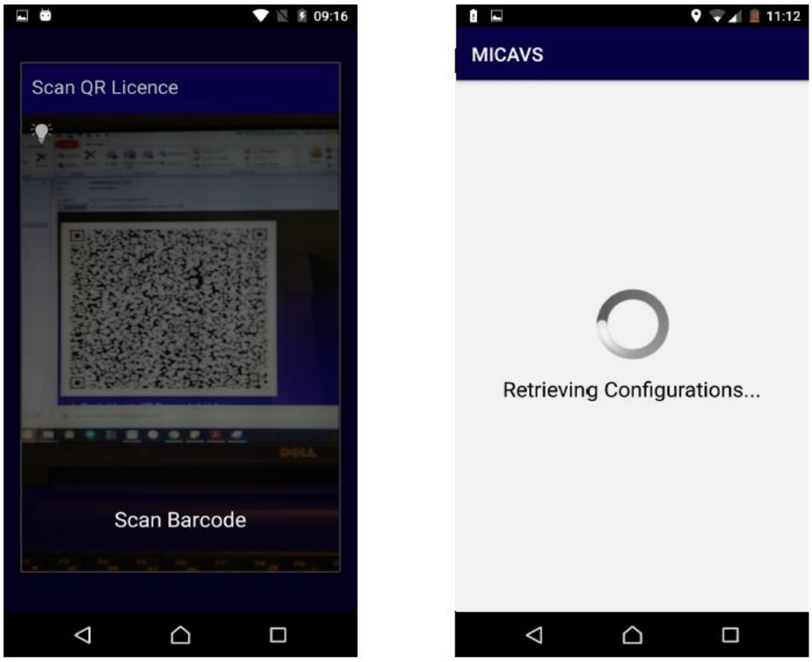

Figure 4: Registration and configuration process

In the following months, the application was used to collect meter readings. When updates were required, the changes were applied using the web-interface. When the changes were published, the server successfully sent notifications to the linked devices. This allowed the support staff to provide remote assistance to the application users. The system could therefore be expanded and updated regularly without physical updates and fieldwork requirements.

Due to the repetitive nature of meter, reading application specific users are responsible for the collection of a specific list of meter readings at a regular interval. The system can therefore be used to determine a list of meters associated with a specific user. The automatic task generation feature was tested on the data set, and allowed users to create task lists based on historic meter readings collected by colleagues. Figure 5 Shows the task generation interface, and list of generated tasks.

As the client's employees had internet access at the office, immediate log uploads were therefore disabled to save mobile data. Log entries were therefore temporarily saved on the mobile devices and uploaded to the central server from the office. Once the server received an upload request, the supporting data was used to create a corresponding log entry on the central database. The server provided the uploading device with a unique identifying key for the log entry. Lastly, other linked devices were notified of the new data.

Data is shared among linked devices; however this only assists within application activities such as task creation and data validation. Data stored in the central database can be accessed by internal support systems. Specialised interfaces were developed for a web-based energy information system. This allows registered users to view and export data from any location as soon as logs have been uploaded.

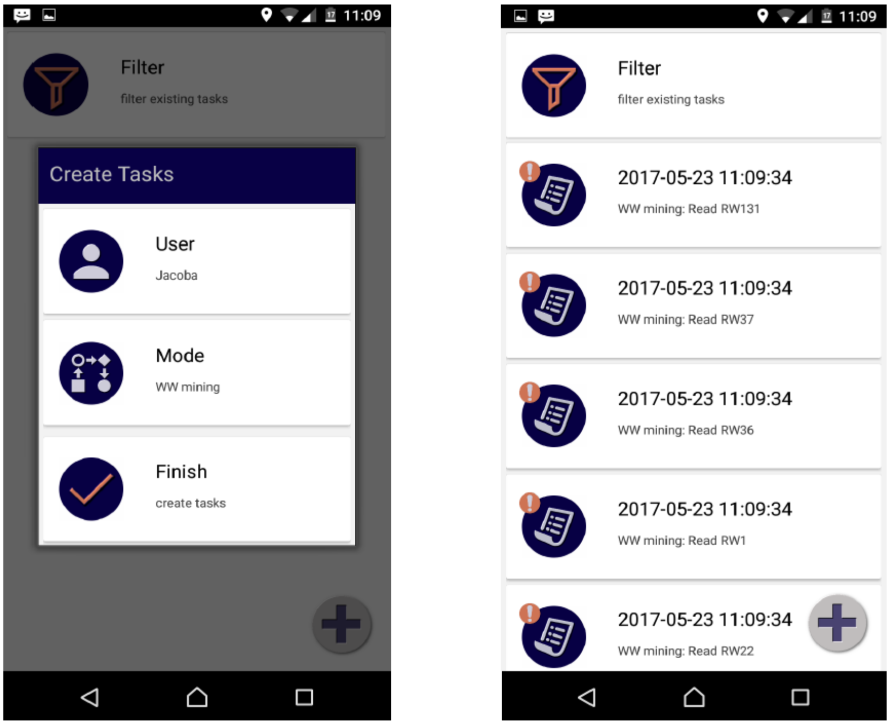

Figure 5: Task generation

4.2 Implementation 2: Energy alerts

The second implementation was used to promote a culture of efficiency on an industrial facility. The application was configured to create energy alerts. A generic structure was therefore developed to allow users to create multiple log entries using a fixed structure. This allows users to create multiple alerts using a single familiar interface. Furthermore, this enables users to perform a range of inspections on the facility and have a common platform that consolidates the results.

Support staff used the web-based configuration platform to construct the relevant configuration. Modes were used to define specialised versions of the generic structure according to business units. Similar data fields were therefore specified for each mode, with the modification that each mode only contains options relevant to the specific plant section.
Once log entries were created and uploaded, the server saved a copy of the log and distributed a new data notification to linked devices. Additional processing options allowed for the creation of customisable email notifications. When the server receives a new log, the log is compared to the available rules. Rules are based on predefined options for specific data fields. If all the rules are satisfied by the data contained in the log entry, a notification is generated and distributed to linked users.

The notification is an email message with standard body text. Attached to the email is a text file, along with optional images as an extension. Administrators can configure rules as desired and customise the linked file as well. The linked file contains basic log information, such as a time stamp, GPS co-ordinates, and user identification. Additional data fields can be linked or omitted from the file through a linking process. Figure 6 shows an example of a notification email.

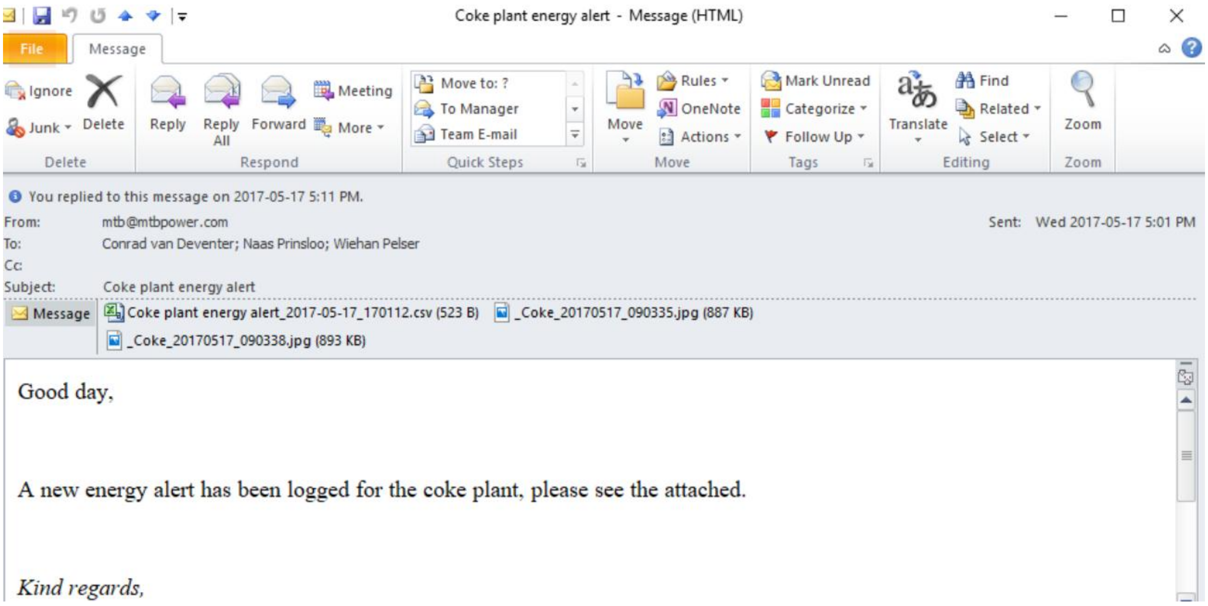

Figure 6: Notification email

In addition to email notifications, data is made available to users through integration with a web-based energy information system. Specialised interfaces were created to display consolidated data. These interfaces allowed users to view logs and export files that could be used for manual processing in spreadsheet applications. The web based system provides access to visual tools such as graphs and colour coded values to promote effective information transfer.

5. CONCLUSION

Despite financial hardships in current economic conditions, industrial organisations have growing data needs. Automated and manual data collection methods can be implemented to address these needs. Automatic data collection is typically too expensive to implement in all cases and have a restrictive structure. Manual data collection offers a flexible solution, but exposes data to human operators which opens up the possibility of data corruption.

A mobile data collection system was developed as a cost effective alternative to perform industrial data collection tasks. Mobile device-based data collection offers many advantages above manual methods. These devices have the capability to record substantiating data and ensure that data is not tampered with. Furthermore, many user guidance tools can be used to guide users.

Mobile data collection offers users with powerful data collection and management tools. However, these systems offer limited advantages in isolation. Web-services allow mobile devices to communicate and share data among other devices in the network. These services were used to allow configuration management, log synchronisation among devices, task management and advanced data consolidation and processing needs.

The extended mobile data collection system that makes use of the above mentioned web-services was successfully implemented in practice. Web-services relieved support staff and enabled effective data consolidation and distribution in industrial settings. The key concerns including data traceability, human resource utilisation, data quality, maintenance and awareness as well as system integration, were successfully addressed by the system.

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MONITORING THE FACE OF THE FUTURE FACTORY

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ABSTRACT

A new and exciting programme was designed to revolutionise the way in which undergraduate engineers are trained and factory operators are developed. A group of roughly thirty second and third year, mechanical and industrial engineering students were placed at a brand new fast moving, consumer goods factory as operators for a full year before returning to their studies. The purpose of this secondment was to give students real working experience, improving their performance at university upon their return and better preparing them for the working world upon graduation. In this same period, students were encouraged and expected to add value to the factory through their problem solving skills - generating an improvement culture at operator level. The first cohort of students is now back at university and a second cohort are busy with their year in the factory. This initiative is unique not only because it changes the structure of an undergraduate engineering degree but because it aims to improve the undergraduate engineering experience while influencing improvement culture at an operator level in a South African context. The challenge with an initiative like this is evaluating whether or not the overall purpose is being achieved. This paper introduces a framework for evaluating the programme which was developed based on observations and experiences during the first year of the programme.

1. INTRODUCTION

Mark had had an interesting journey through life, which meant he only came to University at the age of 40. Mark was an orphan who had become a soldier, and then a small time, and eventually big time entrepreneur. By the age of 40, Mark had finally amassed a sufficient fortune to afford to take four years off from life and return as a mature student. In his last venture prior to becoming a student, Mark had started a candy business that ended up listed on the stock exchange. In the early days, Mark was the confectioner.

It was in a second year thermodynamics class that a small benefit of Mark's curious life emerged. When the lecturer explained the idea of thermal conductivity, Mark exclaimed for all to hear "aha! That makes so much sense now. When I started my sweets company, I tried to make the candies on food grade stainless steel countertops, but they always cracked. A lot later we tried solidifying the candy on marble countertops and the candy came out perfectly".

In that moment, Mark was able to construct his knowledge around an experience that he had had. Vygotsky sees human experiences and prior knowledge as a scaffold on which people can build their ideas and their understanding [1]. The richer the scaffolding, the more hooks there are for ideas to be hung [2].

This paper is the second in a series of papers. The first paper describes a programme that was designed to give engineering students a richer scaffold, equipping them with more hooks. This paper describes some observations and approaches to designing a model for measuring the programme in the medium term and in the long term.

1.1 Background

The University of the Witwatersrand and the Unilever Khanyisa factory have embarked on an initiative to immerse students in industry, mid-way through their studies[3]. Each year, approximately 30 mechanical and industrial engineering students, at the end of their second or third years of study, are recruited to spend one full year working as factory operators at the Khanyisa factory which produces liquid homecare products for the South African market.

This initiative is inspired by Unilever's philosophy of doing well by doing good and a desire by the University to better prepare students for their studies at university and the working world. There are therefore two key drivers behind the programme: developing engineering students and supporting the development of an improvement culture in the workplace.

Most engineering students have limited exposure to the working world and the practical challenges of engineering problems before starting university. Although vacation work, typically located at the end of the students' second and third years of study for a period of 6-8 weeks, can have some influence on this experience, the level of organisational problems that students are exposed to in such a short space of time is limited. Students usually spend most of their time familiarising themselves with different aspects of the business and as a result, the intricacies of operational challenges and detail as well as complexity of engineering processes and systems is often overlooked.

From observations and supported by [4] mature students (those who have delayed their entry to university by a few years or many – in other words, Mark) outperform their classmates as a result of their increased motivation, maturity and real world experience, however this is often offset by mature students' more complicated socio economic conditions, leading to drop outs. Nevertheless, if more students are like Mark they are likely to succeed more at University, and in turn in their careers.

It is believed that the under preparedness for the working world is a well-known phenomenon, occurring globally and in South Africa [5] Graduates themselves realise this disconnect, highlighted by a study of South African Chemical Engineering graduates, stating that although they are theoretically prepared, they have little exposure at university to multidisciplinary teamwork, management and practical experience [6]. Leading on from this, companies often place students on one-year graduate experience programmes where graduates are sent from area to area of a business, again obtaining a superficial overview of the business without a real understanding of day to day operational challenges and experiences at a factory floor level. It is rare that a company will see the value of a graduate spending time doing "non-traditional" engineering work (operator level experience). Most graduates, within their first few years of experience will end up in junior management positions often without having a real appreciation for factory floor level work.

This programme aims to address both of these problems by allowing students to gain real working experience prior to their major years of study so their understanding of concepts and theory taught in class can be enhanced through the ability to relate these ideas more readily to the real world. The programme also gives students the "luxury" of a year spent working as operators with limited engineering responsibility so that they can truly experience what factory level work is about. There is a hope that this experience will result in graduates who are both better engineers and managers. In addition to the year of work experience, students are also provided with an obligation-free bursary that covers the costs of their tuition fees upon return to university.

When Unilever commissioned their new liquids factory, they wanted to create a factory that was different – both in terms of the technology and processes that were used and the culture of the workforce. The Khanyisa "dream" is to develop a factory that sets a new precedent for workplace culture. A part of this new culture is the development of a factory floor level team that really identifies and drives problem solving and improvement. It was believed that populating the existing factory operators with thirty engineering students each year could facilitate this process.

A comprehensive study of key engineering programmes incorporating *authentic* or *experiential* elements to address the gap in practical working experience was conducted in the 70s [7]. Many engineering programmes today now incorporate some of these approaches. A study, similar, in purpose and nature to this initiative has however not been found in the literature.

This initiative is therefore truly unique due to the dual intention of the programme. As a result, there is a need to adapt approaches that have been used before both for development of an organisational improvement culture and development of a student industry based experience.

Early monitoring methods of the programme required a great deal of reporting, which was burdensome and did not target the programme aims. As a result it was decided to abandon these approaches in favour of a limited number of more fundamental measures. It was observed that an over-emphasis of the financial cost saving potential of the programme had led to the neglect of student development, and a corresponding over-emphasis on risk sharing improvement projects. From this observation, it was clear that one of the main issues the measurement framework would need to address is to enable behaviour that aligns more closely with the programmatic aims.

1.2 Purpose

Any initiative needs to be measured to ensure that outcomes are being achieved but most importantly to guide programme improvement efforts over time. While it has been suggested that this programme needs to be measured, the development of a measurement framework has been approached with caution. Experience has shown, that having the incorrect measures can drive dysfunctional behaviours which can ultimately jeopardise the entire programme. As stated previously, this programme is unique due to the variety of overall programme aims and wide spread of stakeholders. For this reason, merely using measurement frameworks from other initiatives is not possible.

The purpose of the efforts presented in this paper, was to develop a measurement framework which could adequately track programme performance over time while ensuring that the initial aims of the programme were met without encouraging any unwanted behaviours.

1.3 Research question and objectives

How can the Wits-Unilever programme be measured and developed to support sustainability and ensure programme success over time?

This research question will be explored by developing a measurement framework that aligns to the programme aims, which are to develop future engineers through a real life operator level experience, whilst using the students as vehicles for the introduction of an improvement culture at the site.

2. LITERATURE SURVEY

This section explores the nature of measures in organisations and gives some guidelines for their design. This section highlights the pitfalls of setting targets, introduces the principle of less is more and further shows the difficulty experienced when trying to measure an improvement culture.

It is generally agreed in literature that organisations need some form of measurement to excel [8-10]. The nature of these measures however varies. Measures are used by organisations amongst other purposes as reporting mechanisms – the now ubiquitous dashboards [9] –, strategy devolution [11] or control [12].

Dashboards are used to assess whether projects are on target, whether major goals are being met and whether the overall project is "on track". Indeed the project management environment favours this approach, as it is able to summarise complex projects into strategic high-level performance measures[10, 13]. To achieve this reductionist insight, allowing for management support and worker clarity on requirements, measures have to be well, and intentionally designed [14].

Whether in construction [13] automotive or manufacturing [15], a general trend in designing measures, is to match them to organisational (or project) strategic elements or goals. Where measures are designed for an entire company, it is common to align these to the organisational mission and vision [16]. Where measures are designed to reflect a project, the project aims have to be clearly articulated to ensure that there is adequate stakeholder satisfaction [10].

These high level aims in turn have to be translated down according to the hierarchical models to which they correspond to create meaningful targets for each level in an organisation [8]. This mirrors the approach of the Lean philosophy of *Hoshin Kanri* (Policy Deployment) [17] which provides a link between strategic intent and the daily management of its realisation[18]

Although a design trend for measures is to attempt essentially to measure "everything" [8], this is not a proactive approach, and results in "team members spending too much of their time collecting data and monitoring their activities, and not enough time managing the project" [9].

The thinking that drives the above, comes from a paternalistic structure that takes the truism that you have to measure every behaviour that you wish to control. This is in contrast to good design practice, that urges that measures are designed by the people who are to be measured or at least in concert with them [9]. Out of this emerges the principle of "less is more".

Perhaps the most currently fashionable approach to measuring performance is through balanced scorecards [19]. Designed by Kaplan [8], these scorecards rely on four dimensions to create "balance" in measurement. These dimensions focus on measuring: value to shareholders, company internal processes, customer perception and commitment to innovation and improvement. Making use of such a model is wise, however it was found that only a third of employees understood the organisational goals better due to their use [19]. Other approaches that have been followed include targets, which are famously in use in the National Health Service (NHS) in the United Kingdom.

In the NHS, points of care, ambulance services and clinicians are awarded a star-rating based on their performance. In general, these performances are based on adherence to an (often arbitrary) norm. Remuneration is based on the "best to best" system, where the most funding attaches to the parties with the "most stars". In pursuing good scores, people frequently adopt wrong behaviours, which often leads to unintended consequences [20].

Some organisations use measures as punitive tools to inflict what Bevan calls "Soviet style Terror" [12]. This introduces the perverse incentive, that a deceptive act, incorrect reporting and gaming allows entities and individuals to reduce their exposure to systemic wrath, and in so doing manage their own survival or indeed prosperity.

For example, in the NHS, it was found that surgeons (who were measured on mortality) would decline to operate on patients most critically in need of surgery, as a single additional death would reflect poorly on the surgeon, thus gaming this metric by preferentially only performing surgeries where the outcomes were ear certain. Indeed, their study found that "there is enough evidence of significant gaming to indicate that the problem was far from trivial". This culture of control [21] is counterproductive to the organisation achieving its actual aims, and is a consequence of the direct, and proportional attachment of financial benefit to metrics that can be gamed.

Counter intuitively, It was found that where measures are not used for management control, but are rather designed for teams to excel independently [9], success is maximised.

Lean thinking emphasises that improvement is not a set of actions, but rather a culture [22, 23]. Perhaps the reason that lean has been so successful in Japan [24] is because the cultural dimensions of respect, frugality and honour common to Japanese culture are also key cultural elements of lean. Such a culture is however foreign to most working environments and to transpose such cultural values is difficult. Nevertheless It is believed that measuring the extent to which an organisation is concerned with improvement is important.

To measure organisational culture is complicated further by recognising that as Meglino et al claim, “Culture is not something that an organization *has*, but rather it is something that the organisation *is*.” Therefore, when trying to measure the organisation’s improvement culture it must be remembered that the phenomenon is far more complex than simple measurement would permit [25]. Detert [26] presents a fundamental framework that explores elements of improvement culture, and highlights eight fields for general enquiry to assess. These fields are rich and their assessment would require qualitative methods, including assessing people’s motivation, or their attitude towards a stable working environment compared to a more dynamic one, the self-perception of personal growth and the commitment to collaborate and cooperate on growth.

Given such a complex assessment space, many organisations prefer the use of some form of key performance indicators (KPIs) as more measurable proxies for underlying cultural phenomena. Research into a variety of organisations has shown that the number of KPIs for assessing the improvement culture ranges between 15 and 135, and are generally measured using Likert scales [27]. Regardless of the relative ease of use, the number of KPIs violates the principle of less is more, and so becomes a more detached proxy of the underlying improvement culture that is the organisation.

Having a system of measures in place in a modern organisation is necessary and virtuous, however measures must be well designed. This usually means that measures must be aligned to organisational goals; otherwise they can drive wrong behaviours resulting in unintended consequences. Counter intuitively, the most effective measures are few, designed by teams for themselves and serve as a guide for teams rather than as a control mechanism for management. The goal of a measure should be to help the team succeed, rather than to give top management a way to measure their success. Good measures have clear goals, the gaming of which is impossible, or ideally unnecessary, because reward does not directly attach to their attainment.

3. METHOD

The framework was developed in consultation with the major stakeholders of this programme, being the students, the university and the company. It was determined that the two original aims of the programme should be decomposed into a framework of specific measures, to ensure that the aims can be correctly monitored and evaluated. To achieve this, the team worked backwards from programmatic aims, and grounded in literature and common observations, constructed a framework of indicators that reflect the key outcome. In this regard, the framework was designed using Popper’s interpretation of instrumentalism [28].

Iterative approaches were used to create the system of measures, using a modified action research approach [29]. Measures are adapted on an ongoing basis, to calibrate set points, but also to omit measures whose results do not adequately describe the underlying situation, or that drive the wrong behaviours.

The measures are designed to provide data for monitoring of the active cohort and allow for longitudinal monitoring across cohorts to assess long term programme success.

4. OBSERVATIONS

This section details preliminary observations relating to programme measurement that have been made by the authors since the start of the programme in 2016. These observations act as initial hypotheses which if measured and tracked can be tested as the programme continues and data is collected.

4.1 Developing engineering students

The first aim of the programme, related to student development, is to:

> Develop students who are more likely to succeed at university and in their future workplaces.

At the time of writing this paper, 28 students have completed a year of work experience and have returned to university to complete their degrees. A second cohort of 29 students are currently deployed at the factory. The programme has also provided a practical place of research and investigation for 9 final year industrial and mechanical engineering students.

The financial stability of students is a critical factor in the success of engineering students. A lack of funding and resources is a known indicator of poor university performance [30]. Whilst the bursary offered to students on the programme has removed the academic costs of attending university, graduates of the programme are still faced with the financial pressure of living costs, the most significant of which is food and accommodation. Whilst deployed at the factory for the year, students are mentored to encourage them to save a portion of their salary to support themselves on their return to university. It is evident from discussions with students, that many did not manage to save enough money to entirely remove the financial pressure for the remainder of their degree. This situation has been exacerbated by the expectations of students' families of financial support. Despite the fact that the financial position of students has not been entirely removed as a risk to university success, the financial position of all students is considerably better than before. Understanding the financial impact of the programme on students is therefore an important factor that should be tracked.

Students' university performance is a quantitative measure that can be used to evaluate student development. Measuring student success using academic performance or grades alone is a complicated matter which needs to consider the way in which these grades are assessed. At this stage, the authors are cautious to compare the performance of the group to the general class. University performance will need to be considered holistically, considering marks but including a more qualitative approach to understanding students' experiences. Anecdotally, based on informal lecturer observation and discussions, we believe that student engagement in lectures is high. This is attributed to the exposure students have received from being immersed in an engineering and technical environment, making concepts presented in the classroom more relatable. The authors are expecting higher pass rates from programme graduates.

It is difficult to make a comparison to how the students might have developed had they not been on the programme. It is believed that the year of 'hard' labour has motivated students and given them additional reason to commit themselves to completing their degree. There is a noticeable change in attitude of students as they progressed through their year at the factory – with a noticeable emphasis on commitment, accountability and the value of hard work. Students have returned to university with a far more realistic view of the working world and their potential within it. It was also noticed that other operators at the factory placed their ambition and expectation on their young colleagues to return to University and make 'Khanyisa proud'.

The unity a cohort gains from spending a year working together has provided students with a large support base of shared resources and knowledge to support them as they continue with their studies. This is evident from observations of students studying, doing group projects and forming a social network with each other.

It is too soon to determine what the impact of this programme will be on graduates' careers. It is believed by the authors, that students have a major experience advantage over their peers and have been initiated in the hardships and challenges of the 'real' world. This is hoped to benefit graduates of the programme once they enter the working world, better prepared to be future leaders.

4.2 Development of an improvement culture in the workplace

The second aim of the programme, related to an improvement culture in the workplace, is to:

> Develop a problem solving and improvement culture in the workplace through integration of student engineers as operators.

The programme aims to create a workforce at all levels, shop floor to senior management, that embraces improvement and actively identifies and solves problems. This aim is set with the belief that an active, engaged and problem solving workforce would have a significant impact on the factory's overall performance. The importance of ensuring the programme has an impact on the overall problem solving and improvement culture and ultimately the improvement of the organisation is also critical to the sustainability of this initiative.

The identification and ownership of improvement projects has been a challenge and much of the first 18 months of the programme has been spent refining processes around improvement project tracking. It has been realised that the culture around problem solving and improvement is as important to measure as the projects themselves. It is also critical to track the impact that the initiative is having on overall factory performance measures. Although the programme has largely moved away from tracking financial and performance measures alone, due to the complex nature of any measurement system and the behaviour it drives, measuring overall factory performance is seen as important.

The level of employee engagement at the factory has been measured and while performance is above the South African benchmark for employee engagement, there is further room for improvement in comparison to international benchmarks.

Currently the student programme is seen as a development programme taking place within the factory. In future, it is hoped that the initiatives currently aimed at developing students should be expanded for all staff. This desire has been met with some challenges, especially balancing these long term goals with the day to day operational needs of the business.

5. FRAMEWORK DEVELOPMENT

5.1 Introduction to the framework

While developing the framework, several iterations were considered to include the agenda of the three key stakeholders. It was finally decided that the best way to measure the programme was in a way that holistically considered the programme aims. The framework is therefore divided into two sections which address these aims.

The first aim of the programme is to develop engineering students. The intention has many facets but includes removing barriers to success while studying, increasing practical experience and exposure to make concepts and theory easier to relate to and to better prepare students for both studying and the working world by developing personal skills such as time management, discipline, motivation, leadership and people skills. It is hoped that all of these aspects will result in better academic success at university and better preparedness for the working world.

The second aim of the programme is to create a workforce that is actively engaged in problem solving and improvement. The role that the programme plays in this process is two-fold. Firstly, the intention is for the problem solving and analytical thinking skills of the engineering students to be transferred to operators in the factory. Secondly, due to the strong programme focus on developing and encouraging students to initiate continuous improvement projects on their respective lines, factory operators will be involved in these projects as part of the team, observing and learning the skills associated with solving problems.

The framework was developed in such a way that it considers these aims, specific measures to each aim as well as proposed methods of data collection and data collection timelines.

5.2 Proposed framework

Table 1 presents the developed framework. The framework is structured into four areas. The first highlights, once again the overall aim followed by a set of proposed measures, proposed methods of data collection and collection timelines.

At this stage the framework is described at a very high level. The next steps will include the development of detailed research instruments that will ensure trustworthiness in the measurement process. Where applicable, extensive use of appropriate literature will be used in constructing the research instruments.

Table 1: Measurement framework

AIM	MEASURES	DATA COLLECTION	TIMELINES
Developing students			
• Develop students who are more likely to succeed at university and in their future workplaces	• Number of students enrolled in the programme per year • Retention of students on the programme and at university • Financial stability of students • Academic performance pre programme vs post programme including academic grades and qualitative factors such as motivation and engagement • Career tracking	• Surveys of students on the programme • Surveys of graduates who were on the programme • Academic grades	• Surveys of students pre and post their year at Khanyisa • Surveys of students and graduates every year after completing the Khanyisa year for a period of 5-10 years
Developing an improvement culture			
• Develop a problem solving and improvement culture in the workplace through integration of student engineers as operators	• Number of improvement projects initiated • Factory performance measures driven by improvement projects • Levels of employee engagement • Problem solving awareness and behaviour • Absenteeism	• Improvement project capturing and tracking • Tracking of relevant factory measures • Employee engagement surveys • Problem solving audit and survey	• Ongoing factory measures tracking • Quarterly evaluation of improvement projects • Annual employee surveys and audit

5.3 Measurement challenges

This section discusses some of the challenges that are anticipated with the proposed framework.

The first (and widely recognised) challenge with performance frameworks is that, if poorly designed, it can quite easily lead to the wrong behaviour. This inherit challenge is exacerbated in the case of this programme, since the aims of the programme are very philosophical in nature. This leads directly to challenges of measuring these aims, and thus the performance framework for this programme is more sensitive to (without intention) driving the wrong behaviour.

The second challenge in relation to the programme and measurement frameworks relates to the requirement that the framework must provide an accurate and fair evaluation of each of the stakeholder's performances. Put differently, the presence of a number of separate stakeholders (at an organisational level) in the same programme compounds the difficulty of designing a useful measurement framework. Having different stakeholders with different ultimate purposes has the potential to pull the programme in conflicting directions. It is therefore important to keep the framework aligned to the original intention of the programme in a very holistic sense.

A further anticipated challenge associated with the framework is the large volume and variety of data collection that is proposed. This will need to be monitored on an ongoing basis and adjustments made if necessary. However, at this point in the process, it is felt that the broad nature of the data which is proposed will provide a rich basis on which to assess the programme.

6. CONCLUSION

The framework presented in this paper has been designed with best practice measurement in mind. The framework has been developed to be as immune to gaming as possible, chiefly because there is little incentive in doing so. It is believed that use of this framework will enable long-term tracking of the programme and improvement of the programme design and operating conditions.

This framework also addresses the unique, dual nature of this initiative which in itself will provide interesting results in the near future.

Ultimately, this initiative has the potential to shift the interaction between engineers (future managers) and all employees in an organisation towards something that will unleash the true potential of every individual and like Toyota, who started their journey by developing "people before parts" [31] it can be shown that we too can build a future South African factory.

7. FUTURE WORK

Future work around the design of the framework includes an annual critical review of the framework itself: a review to be conducted by those close to the project employing anecdotal observations and evaluating whether the framework is "fit for purpose".

The data collection for the framework requires development to reliably confirm observations made on the programme and its influence on the wider organisational culture going forward.

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THE ROLE OF INDUSTRIAL ENGINEERING IN PUBLIC SERVICE DELIVERY

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ABSTRACT

Government institutions exercise public administration and the delivery of public services takes place at all three spheres of government. Section 195 of the Constitution of the Republic of South Africa, 1996, requires that government service delivery must comply with certain democratic values and principles in order to be effective and efficient. This article attempts to describe what public administration and public service delivery encompass, as well as how Industrial Engineering can be part of and enhance these. The contribution of this article is twofold. Firstly, to reflect how Industrial Engineering can benefit the public sector. Secondly, to explain various untapped opportunities that are available to Industrial Engineers to apply and implement their skills to the advantage of the public sector.

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1. INTRODUCTION

Section 195 of the Constitution of the Republic of South Africa, 1996, requires that government service delivery must comply with certain democratic values and principles in order to be effective and efficient [10]. Section 195 also states that this requirement applies to public administration performed by every sphere of government, organs of state and public enterprises.

Chapter 2 of the Constitution, 1996, contains the Bill of Rights with a list of basic (fundamental) rights, which must be respected, protected and upheld by all persons and all organs of state (section 7). Section 8 states that the Bill of Rights obliges all three spheres of government and parastatals of the government, when performing public administration, to respect, protect, promote and fulfil the rights set out in the Bill of Rights. This implies that public services must be rendered in a professional manner, responsibly, with integrity and fairly in order to comply with the requirements of the Constitution, 1996.

Despite the mentioned constitutional obligation to deliver public services in a particular and an acceptable manner, government does in fact experience difficulties to deliver many public services due to the lack of professional artisans in many facets. The failure to deliver public services is just as unacceptable as the delivery of deficient public services. This situation results in dissatisfaction amongst the public and leads to protests against poor public service delivery. It appears that government is often reluctant to involve the private sector to ensure actual delivery and improve the delivery of public services. In particular circumstances private companies often have to be involved to assist with the delivery of certain services, such as with the waste removal in Tshwane.

There may be many benefits from involving the private sector to apply their specialised knowledge in especially major development initiatives of government. This article accordingly attempts to describe what public administration and public service delivery encompass, as well as how Industrial Engineering can be part of and enhance these. The contribution of this article is twofold. Firstly, to reflect how Industrial Engineering can benefit the public sector. Secondly, to explain various untapped opportunities that are available to Industrial Engineers to apply and implement their skills to the advantage of the public sector.

2. GOVERNMENT STRUCTURES

The Constitution, 1996, governs the manner in which the public administration of the state must be exercised, so as to provide for a well established relationship between the people and all the government authorities. A further description of the public administration is provided next.

2.1 Public administration

The Constitution, 1996, states how the public administration must be performed in all public institutions and the manner in which functionaries must act in executing their functions to ensure that their actions and decisions are governed by the democratic and ethical values and principles enshrined in the Constitution.

Section 195(1) of the Constitution, 1996, spells out the values and principles that govern public administration. Subsection (2) states that these principles apply to public administration in every sphere of government and to public enterprises. A few of these principles are:

- (a) the promotion and maintenance of a high standard of professional ethics;
- (b) the promotion of efficient, economic and effective use of resources;
- (c) a responsiveness to people's needs and the encouragement of the public to participate in policy-making;
- (d) the fostering of transparency by providing the public with timely, accessible and accurate information.

A vital aspect is that section 195 of the Constitution, 1996, requires that the delivery of public services should satisfy the broad and complex variety of needs of the people. Section 195(1) also reflects the democratic values and principles that govern public activities and services and that these should include effectiveness, efficiency, transparency, responsiveness, accountability, integrity and interest. Section 195(1) therefore creates a duty for every sphere of government and public enterprises to achieve and uphold an accountable, open, transparent, fair and honest administration which serves the interests of the general public. This furthermore requires co-operation between all institutions involved.

2.2 Co-operative governance

The governing function in South Africa and the delivery of public services are performed at different levels. South Africa has three spheres or levels of government and section 40(1) of the Constitution, 1996, makes provision for "co-operative governance" when it states that in the Republic, government is constituted as national, provincial and local spheres of government which are distinctive, interdependent and interrelated. Section 40(2) states that these spheres of government must conduct their activities within the parameters of the Constitution. This implies that although each sphere of government has its own distinctive characteristics and operates on a different level, it is dependent on the other spheres and interrelated to them in terms of the relationship created in section 40.

As concerns the manner in which public powers and functions must be exercised, section 41(1)(g) and (h) of the Constitution, 1996, provides that all three spheres of government and all "organs of state" must exercise their powers in a manner that does not encroach on the functions of other spheres, co-operate with one another and assist one another on matters of common interest.

2.3 Organs of state

It is noteworthy that the Constitution, 1996, mentions "organs of state" in section 41(1). Section 239 of the Constitution, 1996, defines an "organ of state" as a department of state in the national, provincial or local sphere of government or any other functionary or institution performing a public power or public function in terms of the Constitution or in terms of any legislation. This implies that the functions of public institutions can be exercised by an entity that is not, strictly speaking, part of the three spheres of government and that normally functions outside of these usual spheres and also in the private sector. This, accordingly, includes a person or institution, such as a statutory council, ESKOM and the CSIR, which exercises a public power or a public function in terms of legislation.

The intention of section 239 of the Constitution, 1996, is that the use of a private sector entity is needed to enhance the performance of the public sector. In this regard, co-operative governance and intergovernmental relations should contain measures and mechanisms to encourage a co-operative spirit and relationship between the spheres of government in order to increase government efficiency. This situation should include recognition of interdependency as the public sector cannot function in isolation and needs the expertise, co-operation, co-ordination, joint planning and the sharing of resources of the private sector. In the next paragraph, the role of local government is explained.

2.4 Local government

As concerns local government, section 155 of the Constitution, 1996, arranges the "establishment of municipalities" and section 156 arranges the "powers and functions of municipalities". From these sections, as well as section 151, it appears that the role of local government is to govern the local government affairs of its community and to cooperate with national and provincial government to strengthen the capability of local government. In terms of sections 153 and 154, provision is made in national and provincial legislation for particular functional areas to be allocated to local government, for example local roads and transport. Although local government functions as an autonomous and self-governing sphere of government, it is not independent and cannot function in isolation.

In terms of sections 152 and 153 of the Constitution, 1996, local government must deliver public services and oversee the application of these services. This means that a local authority works and delivers services within broader provincial and national frameworks and in conjunction with other "organs of state". This co-operation may relate to the provision of public services in the local area by entering into an agreement between the municipality and, for example, the Rand Water Board or Eskom or the CSIR, for the provision of particular services. Section 154(2) of the Constitution, 1996, requires that persons and institutions outside of government be involved in local government affairs to ensure expertise and quality of service. Government is also involved with parastatals and this aspect is now discussed.

2.5 State-owned parastatals

Since 1995, government has developed a privatisation programme so as to involve selected equity partners in certain enterprises in the telecommunication and airways sectors. Labour unions were excluded from the original policy decision-making process and with the threat of job losses, the unions resisted the decision by government and expressed this by means of various protests. Although government proceeded with its privatisation programme, it did not, for example, enter into any Public-Private Partnership agreements with any institutions during the 2013/14 financial year [3].

The government currently has a large number of state-owned parastatals that function in capacities such as commissions, corporations, institutes, for example Eskom, the South African Post Office and the CSIR. All such parastatals are involved in the economy in fields such as transport, construction, agriculture, water, electricity, and others. The involvement of the parastatals in the different fields means that not only are government departments responsible for the delivery of public services in South Africa, but parastatals are in fact also involved in the delivery of services on the national, provincial and local spheres. Whereas similar government departments on the different spheres often deliver similar services, a state-owned-parastatal is allocated a particular service with a full or partial monopoly over that particular service. The result is that the parastatal dominates the market in respect of that particular service and does not allow any other entity, institution or person to perform a similar service [1].

As mentioned above, section 41 of the Constitution, 1996, requires co-operation between all institutions and organs of state involved in the delivery of public services. This includes the requirement to source alternative modes of assistance.

2.6 Alternative modes of service delivery

All spheres of government have the obligation, in terms of sections 152, 153 and 195 of the Constitution, 1996, to monitor the effectiveness and efficiency of their respective public service delivery programmes. It may occur that a certain mode of service delivery fails or is not as effective as expected. In such a case, the relevant government department is compelled to source an alternative mode of service delivery. This is because the department must still comply with the constitutional prescriptions and fulfil its mandate of ensuring that public services are delivered to meet the expectations of consumers. Stacey [16] argues that the necessity to search for alternative modes of service delivery can be attributed to the existence of factors such as low productivity, poor financial management, inadequate risk management, and soft budget constraints on the part of government.

In terms of the White Paper on Local Government, 1998 (section F, paragraph 2) [2], municipalities have to consider new approaches to service delivery from a range of delivery options to enhance service provision. They need to strategically assess and plan the most appropriate forms of service delivery for their areas. The choices about delivery options should be guided by criteria such as coverage, cost, quality and the socio-economic objectives of the municipality. The modes of service delivery that a municipality can consider (section F, paragraph 2.2) include the following:

- Building on existing capacity;
- Corporatisation;
- Public-public partnerships;
- Partnerships with community-based organisations and non-governmental organisations;
- Contracting out;
- Leases and concessions (public-private partnerships); and
- Transfer of ownership (privatisation).

When a municipality assesses the appropriateness of different modes of service delivery, the real issue facing each municipality is to find an appropriate combination of options which most effectively achieves its policy objectives (section F, paragraph 2.3).

3. MAJOR DEVELOPMENT INITIATIVES

In view of the fact that government institutions as well as parastatals are involved in the delivery of public services, a few of government's major development initiatives are discussed.

3.1 The National Development Plan

To improve the country's economic growth and competitiveness, government introduced the National Development Plan in 2011 [12]. Among the six priorities in this plan, there are three to take note of in particular:

- Bringing about faster economic growth, higher investment and greater labour absorption.
- Focusing on key capabilities of people and the state. Building a capable and developmental state.
- Encouraging strong leadership throughout society to work together to solve problems.

Government has struggled to bring about these priorities. Higher economic growth from higher investment necessitates appropriate implementation strategies that include the resources to implement these. To this extent, a capable and developmental state is required, but this does not mean that the state should attempt to do everything alone. In fact, the strategic use of expert knowledge in both parastatals and the private sector should be encouraged. Strong leadership would guide this strategic partnership and ultimately problems should be approached in a holistic manner, which includes public sector, private sector, and public participation.

Among the critical actions in the NDP, a few should be highlighted again. *Action 3* calls for the state to professionalise the public service. To achieve this, requires advanced training in various fields, which very often derives from parastatals or the private sector. *Action 7* calls for an increase in public infrastructure investment, especially through public-private partnerships and with a focus on transport, energy and water. *Action 9* calls for the densification of cities, transport improvements, and better job location. These actions require appropriate and focused research programmes so as to develop sustainable solutions.

3.2 The National Infrastructure Plan

Government subsequently developed the National Infrastructure Plan [13]. Through the Presidential Infrastructure Coordinating Committee (PICC), 18 Strategic Integrated Projects (SIPs) were developed to invest more than R1-trillion in infrastructure across the country. The developments include, among other, logistics corridor development, enhancement of import and export facilities, aerotropolis developments, road and water infrastructure investment, densification of transport corridors, upgrades and optimal placement of social facilities, higher education infrastructure and expansion of communication networks. All these programmes require proper project management and monitoring and evaluation to ensure the on-time and within-budget realisation thereof.

3.3 The 9 Point Plan

In a further attempt by Government to accelerate growth, the 9 Point Plan was developed in 2016 [14]. Initiatives include the revitalisation of agriculture value chains, the encouragement of private sector investment, and boosting the role of state-owned companies and infrastructure. To adequately realise this plan, requires proper value chain mapping, business process re-engineering, programme management and infrastructure investment prioritisation.

3.4 Planning Processes for Infrastructure Investment

At municipal level, Capital Investment Frameworks (CIF) are used to implement or realise projects as part of a spatial strategy. This strategy normally stems from the Provincial Spatial Development Framework, which informs the Regional Spatial Development Framework and culminates in a Metropolitan Spatial Development Framework (MSDF). Capital Expenditure (CAPEX) is allocated to infrastructure investment projects and capital investment prioritisation is normally a tough task as budgets decrease while requirements and needs increase. There is a great need to determine how to use limited budgets optimally, colloquially known as “getting the best bang for your buck”, while the implementation of these strategies require the participation of highly skilled professionals.

The Division of Revenue Act, 1 of 2015 [11], requires Municipalities to prepare a Built Environment Performance Plan (BEPP) [7] in which they are to report the intended use of infrastructure grants. The BEPP therefore responds to principles set out in the Spatial Planning and Land Use Management Act, 16 of 2013 [15]. It is informed by the Built Environment Value Chain [7], as depicted in Figure 1, with the aim of aligning financial resource allocation to development objectives.

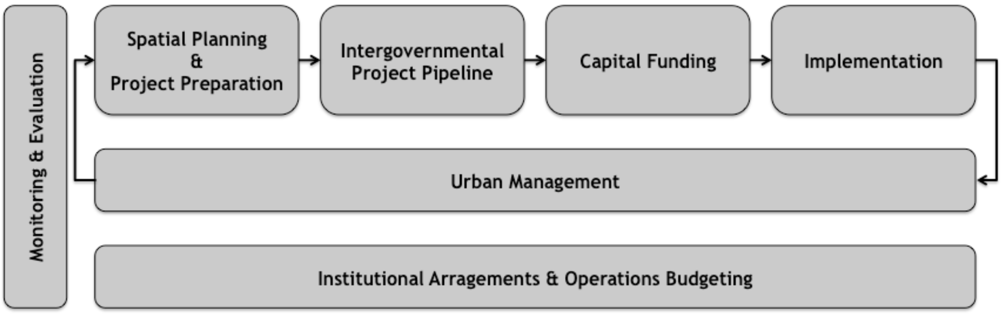

Figure 1: The Built Environment Value Chain

The Department of Planning, Monitoring and Evaluation (DPME) has the mandate to monitor and evaluate the performance of national, provincial, and municipal governments. To adequately do so, requires the collection of the most appropriate data, business analytics, and the creation of proper Key Performance Indicators (KPIs).

4. AN OVERVIEW OF INDUSTRIAL ENGINEERING

Before reflecting a connection between the needs of the public sector and the skills of Industrial Engineers (IEs), an overview of the field of Industrial Engineering is provided. Industrial Engineers are notorious for their capability to take a holistic and systems view of problems, to be able to learn a new environment quickly and to be the interface between multiple domains. Furthermore, IEs have the capability to translate a real world scenario into a model that represents the reality to be used for simulation and optimisation purposes.

4.1 Methodologies used

Industrial Engineers use and apply different methodologies when being involved in the various environments. These are described next.

4.1.1 The Engineering Methodology

The Engineering Methodology (based on and adapted from Ertas and Jones [21]), as is shown in Figure 2, is a very useful process to follow when encountering a problem in practice or academia. It normally commences with a problem definition or a research question, which sets the tone for the study at hand. Literature is then consulted to obtain useful tools and methodologies already in existance with which to approach the problem. The problem is then analysed further to ascertain the exact requirements of the client/solution/product. Once the requirements are captured, a solution methodology is designed, which in essence is a set of steps to follow to be able to deal with the problem at hand. This step is informed by the literature review and the requirements specification. A model is normally developed to represent reality with which one can test various interventions and scenarios so as to identify improvement opportunities and likely outcomes. The model is tested and verified to ensure accuracy so as to build trust in the model and normally sensitivity analyses are done to ensure robustness of the model. Results could be communicated through reports, dashboards, analytics and other visual means.

Figure 2: The Engineering Methodology

While the Engineering Methodology is useful, it also allows for modification and adaptation. Various other methodologies are also used in practice and many of the steps are evident in all these methodologies.

4.1.2 Define, Measure, Analyse, Improve, Control

The *Define, Measure, Analyse, Improve, Control* (DMAIC) [4] procedure is a Six Sigma methodology that is often used for process improvement. It starts with a problem definition or an opportunity for improvement as well as the sought after goal. Thereafter, process performance is measured and root causes of variation are determined. The process performance is improved and controlled by eliminating the root causes of variation.

4.1.3 PRINCE2©

The *Projects in Controlled Environments* (PRINCE2©) methodology is a project management methodology, which consists of seven themes that are essentially principles to be applied to a project at the commencement of the project, and then monitored throughout the project. The seven themes for project management include the following:

- A *Business Case* in which the business justification is provided; it provides the evidence to show that a project is worthwhile pursuing.
- *Organisation* relates to how roles and responsibilities are determined.
- *Quality* is related to quality assurance and quality management principles.
- *Plans* define targets, how these will be attained, project costing, and associated benefits.
- *Risk* provides an overview of the threats and opportunities that could manifest themselves.
- *Change* includes changes in the project as well as issues that may occur.
- *Progress* includes the monitoring and evaluation of the project.

4.1.4 Plan-Do-Study-Act

The Plan-Do-Study-Act (PDSA) cycle [18] is commonly used to gain insight for the purposes of continuous improvement. The *Plan* step involves identifying a goal or purpose, the definition of metrics, and the design of a plan of action. Next, the plan is executed in the *Do* step. The *Study* step essentially involves where success, progress and validity are monitored. The cycle is closed through the *Act* step, which makes use of the results in the *Study* step to set a new goal and repeat the process.

4.2 Industrial Engineering Training and Competencies

Industrial Engineers are known to work in a variety of industries, ranging from the finance industry to a typical production environment. To be able to unpack the skills that Industrial Engineers can bring to the table, the curricula of 4 Universities in South Africa, that offer studies in Industrial Engineering, were investigated. These include the following:

- University of Pretoria (UP) [20]
- University of Stellenbosch (USB) [17]
- North West University (NWU) [9]
- University of Johannesburg (UJ) [19]

Table 1 illustrates a subset of the various modules offered by these institutions.

Table 1: Typical Industrial Engineering modules in curricula at UP, USB, NWU, UJ

Business Law	*Engineering Activity & Group Work*	*Business Engineering/Enterprise Design*	*Manufacturing Systems*	*Labour Relations*
Information Systems Design	Control Systems	*Systems Engineering*	*Facilities Planning*	*Quality Assurance*
Industrial Logistics	*Electrical Drive Systems*	*Engineering Professionalism*	*Operational Research*	*Ergonomics*
Operational Management	*Engineering Statistics*	*Engineering Economics*	*Mathematics*	*Supply chain management*
Practical Training	*Philosophy and Ethics*	*Management Accounting*	*Programming*	*Industrial Analysis*
Simulation Modelling	*Production Managements*	*Environmental Engineering*	*Ergonomics*	*Industrial*
Financial Management	*Electronics*	*Manufacturing Systems*	*Systems Dynamics*	*Project Management*

It is evident that a degree in Industrial Engineering includes a variety of modules of different domains to equip an Industrial Engineer with tools and techniques to use in a variety of industries.

5. TAKING UP STEWARDSHIP THROUGH UNTAPPED OPPORTUNITIES

As stated previously, section 195(1) of the Constitution, 1996, contains the values and principles that govern public administration. To illustrate the role that Industrial Engineers can fulfil to assist in the successful execution of these principles, some of the principles are now listed and specific words are placed in italics for emphasis. The selected principles of section 195(1) are:

(b) the promotion of *efficient, economic and effective use of resources*;
(e) a *responsiveness to people's needs* and the encouragement of the public to participate in policy-making;
(g) the fostering of transparency by providing the public with *timely, accessible and accurate information*;

5.1 Matching the need with the supply

Efficiency, efficacy, optimality, responsiveness, timeliness, and accuracy are all principles that could be achieved through the utilisation of Industrial Engineering tools and techniques. To this end, Table 2 provides a summary of some governmental needs, matched with what Industrial Engineers can offer.

Table 2: Matching governmental needs with Industrial Engineering supply

Governmental Need	IE Supply	IE Tools & Techniques & Methodologies
Bulk infrastructure investment decision making	Decision support	Simulation modelling and analysis
Programme management	Project management, monitoring and evaluation	PMP, PRINCE2©, DMAIC, PDSA, analytics, systems thinking
Optimal placement of social facilities	Optimisation	Operations research
Risk management	Risk mitigation and minimisation	Monte Carlo methods, modelling, operations research, risk analysis
Professionalise the public service	Skills transfer and training	Multiple
Densification of cities	Modelling and decision support	Transport modelling, urban growth modelling, geospatial analysis
Transport improvements	Modelling and decision support	Transport modelling, operations research
Better job location	Optimisation	Operations research
Logistics corridor improvements	Supply chain management and logistics	Supply chain analysis, gap analyses
Revitalisation of value chains	Value chain improvement	Business process re-engineering, value chain mapping,
Optimal use of budgets	Optimisation, prioritisation	Financial management, operations research
Monitoring and evaluation	Monitoring and evaluation	Requirements analysis and specification, database design, data collection and maintenance, Key performance indicator development, business analytics, quality assurance

5.2 Taking up stewardship

Stewardship stems from the word *steward*, which encapsulates the notions of serving and taking care of others as well as managing the supply and distribution of goods. In the business environment, the concept has been established that -

"as a steward, you try to leave the company in better shape for your successor than it was handed over to you by your predecessor." [5]

While Industrial Engineers have been playing a big role in the private sector to improve operations and the functioning of the sector, there remain many untapped opportunities in the public sector that could help to improve the country's economic competitiveness. To realise all the plans in the public sector requires that the public sector reaches out to the private sector to assist with the technical execution of many tasks, but also to train and transfer skills to officials to enable them to undertake similar tasks in future. It is therefore a collaborative approach, to make sure that the country is left in a better shape for the generations to come, through the responsible planning, use, and management of the country's resources.

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USING THE GTFS FORMAT TO IMPROVE PUBLIC TRANSPORT DATA ACCESSIBILITY IN GAUTENG

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ABSTRACT

Public transport plays an important role in cities. It is a less expensive option than private transport and could reduce congestion and improve accessibility to jobs. However, ridership could be hampered when information regarding an operator's routes, schedules and fares is not readily available. Furthermore, public transport operators seem to maintain their data in different formats and not all data are updated frequently. From a planning perspective, this makes it difficult to determine the state of public transport at a provincial level. Converting public transport data into a standard format, such as the General Transit Feed Specification (GTFS) format, can be beneficial to operators as well as provincial officials, since it can be integrated in journey planning applications such as Google Maps. This increases accessibility of public transport information and can possibly increase ridership. In this paper we discuss the benefits of converting data into the GTFS format, benchmark the data of three public transport operators in Gauteng, and discuss the role that Industrial Engineers can play in using the data in the GTFS format to, for instance, optimise public transport networks.

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1. INTRODUCTION

Public transport plays an important role in cities. It is a less expensive option than private transport and could reduce congestion and improve accessibility to jobs. However, ridership could be hampered when information regarding an operator's routes, schedules and fares is not readily available, outdated or incorrect. This is especially true in a developing country such as South Africa.

South Africa's public transport system consists of formal operators, such as municipal bus services, bus rapid transit services and commuter rail services, as well as informal operators in the form of mini-bus taxis. A large part of the population rely on public transport to get to work, therefore it is imperative that the public transport services be of high quality. Unfortunately, this is not the case, as the public transport industry in South Africa is plagued with problems ranging from unroadworthy vehicles, to overloading, to taxi associations fighting over territory.

Furthermore, public transport operators seem to maintain their data in different formats and not all data are updated frequently. From a planning perspective, this makes it difficult to determine the state of public transport at a provincial level, let alone improve or even optimise the network.

By making use of a data standard is useful in many ways. It removes ambiguity and allows data capturers to know exactly what data to capture and in which format to maintain these. If a standard is used across the industry, it allows much better control and analysis of the data, as generic analyses can be developed because the data format will always be the same for each operator. There are a number of public transport data formats used throughout the world. The *General Transit Feed Specification* (*GTFS*) [1] is a well-known example in the public transport space. *TransXChange* [2] is a United Kingdom national xml-based format used to maintain bus schedules and related information. Kauffman [3] explains that the *HAFAS Rohdatenformat* and *DIVA* are two proprietary public transport data formats that are widely used in Germany. In this paper, we focus on the GTFS format.

Many public transport operators in South Africa do not publish transit information and those that do, normally publish it in PDF format on their websites. This makes it extremely difficult for commuters to access the information. The use of the GTFS format can be beneficial to commuters, since it can be integrated in journey planning applications such as Google Maps or the recently released VayaMoja app [4] of the City of Johannesburg. This increases accessibility of public transport information and can possibly increase ridership.

Data standards are easier to implement in developed countries where data are more accessible. A standard such as GTFS could be extremely valuable in a developing country such as South Africa, both from a commuter perspective as well as a modelling perspective.

In this paper we discuss the benefits of converting data into the GTFS format, showcase a case study where two Gauteng Bus Rapid Transit (BRT) operators have been uploaded onto Google Maps, benchmark the data and operational situations of a number of public transport operators in Gauteng, and discuss the role that Industrial Engineers can play in using the data in the GTFS format to, for instance, optimise public transport networks or do transport modelling.

2. THE GENERAL TRANSIT FEED SPECIFICATION (GTFS)

GTFS, or General Transport Feed Specification, is an international format in which public transport agencies can maintain their data. GTFS was developed by Google in collaboration with TriMet, a public transport agency in Portland, Oregon [5]. The reference documentation is maintained and updated regularly by a number of transit agencies, developers and other stakeholders who use GTFS [6], as well as Google Developers [7]. Since its inception, there are over 400 GTFS feeds that have been made publicly available [8]. Thus far, Cape Town is the only city in South Africa that has adopted this trend by uploading their bus rapid transit system, MyCiTi, onto Google Maps [9].

When the GTFS format is used to maintain public transport data, it can be included in self-developed journey planning applications, or existing platforms such as Google Maps, the largest mapping site in the world. The route planner in Google Maps uses the existing road network and GTFS feeds to find directions between selected origins and destinations using public transport.

When public transport schedules and routes are published on Google Maps, visibility of the public transport service is increased, since the information is easily accessible by commuters. Seasoned riders may discover new routes, private vehicle owners may be convinced to opt for using public transport instead, and tourists will be able to more easily travel in foreign countries. The contact details and websites of the operators are also published on Google Maps, ensuring that commuters have all the information regarding the service.

2.1 GTFS Static

A GTFS feed requires a collection of comma-separated text files, six mandatory and seven optional. For each file, there are required fields and optional fields. The required field names must always be present in the files, even if some entries have blank values for those fields. For detailed information on the fields, the reader is referred to the GTFS Reference website [1].

The required files contain details about the agency, routes, trips, stops, stop times, and calendar dates of service. The optional files include information about the fares, any calendar dates that deviate from the standard service, rules for transfers between routes, and the route shape information to ensure that routes displayed on Google Maps follow the curves of the road. A summary of the required files can be seen in Table 1 and the optional files are shown in Table 2. The relationships between the files can be seen in Figure 1.

Table 1: A summary of the required GTFS files.

File name	Purpose
agency.txt	Details of the public transport agencies providing the data for this GTFS feed, such as the name and contact details.
routes.txt	Details about the routes (also called lines) covered by each agency, such as the name of the route and mode of transport used on that route.
trips.txt	The trips for each route. A trip is a journey made by a public transport vehicle on a route. Each route generally has two trips, one in each direction. A trip can occur multiple times per day, at specific times of the day or at certain frequencies.
stops.txt	Geo-coded locations of stops where passengers board and alight. Stations (containing multiple stops) are also listed in this file.
stop_times.txt	The time that the vehicle arrives and departs at each stop for each trip.
calendar.txt	Periods during which the service is available. Some schedules may change on a monthly basis and the exact dates of operation can be specified in this file.

Table 2: A summary of the optional GTFS files.

File name	Purpose
calendar_dates.txt	Exceptions from the services specified in the calendar.txt file. For example, there may be public holidays that occur in the period specified in the calendar.txt file. If the service does not operate as usual on these public holidays, these dates can be specified in the calendar_dates.txt file.
fare_rules.txt	Fare rules are defined in this file, specifying the price and currency of each rule.
fare_attributes.txt	Fare rules are allocated to specific routes.
frequencies.txt	When trips do not have exact stop times, the frequencies file can be used to specify the frequency of service.
transfers.txt	Rules for making connections at transfer stations between routes.
shapes.txt	Rules for drawing lines on a map to represent routes.
feed_info.txt	Additional information about the feed, such as the organisation responsible for maintaining the feed and the feed version.

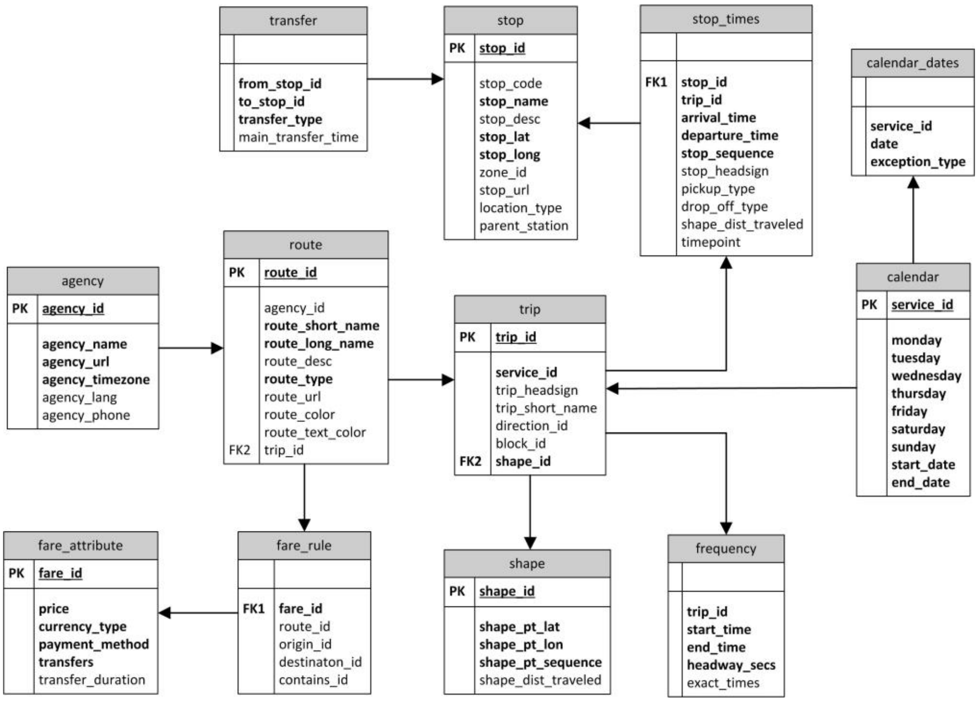

Figure 1: Entity relationship diagram showing the relationships between the different GTFS files, adapted from [1].

The logic of the required files is as follows. A public transport *agency* can have one or many routes. A *route,* also known as a line, is the path followed by a public transport vehicle when picking up and dropping off passengers. A route is made up of one or many *trips*. A trip is a single journey taken by a public transport vehicle on a specific route at a specific time and for a specific service, such as a weekday or weekend service. Different services are captured in the *calendar* file. A trip is further defined by a sequence of *stop times*, which indicates the times at which each *stop* along the route is visited. All stops are geo-located using coordinates, and have names and descriptions that are recognisable to commuters.

The optional files provide extra information regarding the services offered by the agency. Stations contain multiple stops at the same location and allow for *transfers* between different routes. A typical example would be the Marlboro Gautrain station where commuters can transfer from the main line to travel to the O.R. Tambo International airport. A transfer is made up of two stops; the stop where a passenger must get off on the first route and the stop where the passenger must get onto the second route to continue the journey to the destination. These two stops can differ or it can be the same stop, depending on the service. The fare of a route is determined by *fare rules.* There are three different fare rules, namely: zone-based, which is a fare that is dependent on the zones through which the commuter passes; trip-based, which is a fare that is dependent on the route taken, irrespective of the origin and destination stops; and distance-based, which is a fare that is dependent on the combination of origin and destination stops. Each route has a fare rule which is defined by different *fare attributes*, such as the cost and currency of the fare. When there are deviations from the standard service specified in the *calendar* file, these exception dates are specified in the *calendar_dates* file. An example is when a weekday, which normally falls under the weekday service, now follows a Sunday service because it is a public holiday.

2.2 GTFS Realtime

The GTFS Static specification, per se, is already beneficial for numerous reasons, as already discussed. The GTFS Static feed can be used to develop and implement the GTFS Realtime extension [11], with the ultimate aim of enhancing user experience.

GTFS Realtime essentially allows operators to provide realtime updates regarding their operations and fleet, such as delays, route changes, cancellations, the impact of unforeseen events on the network, actual vehicle positions, and live congestion levels. These factors are beneficial to the commuter as the commuter can better plan actual travel time and any possible delays that could occur throughout the journey.

While the benefits of GTFS Realtime are plentiful, the focus of this paper is on GTFS Static as the first stepping stone to obtaining better quality public transport data and making these available to the public. GTFS Realtime will be the natural next step and will be taken into account throughout the design process of a central database for public transport data.

2.3 GTFS usage in developing countries

A World Bank team concluded a pilot program in 2015 where they assisted three Asian developing countries in establishing a GTFS database [11]. These cities were the capital city of the Philippines, Manila; Zhengzhou, a city in central China; and Haiphong, the largest city in Vietnam.

In Manila, there were no complete maps or databases for the transit system, which includes a wide variety of services, such as buses, jeepnies, minivans, and rail. While the different operators in Zhengzhou have information regarding the services they operate, there was no central database integrating all transit information. Haiphong used an outdated map to operate their bus service, and there were no maps capturing the local road network.

Many of the challenges faced by these countries are similar in South Africa. The major problem facing the Gauteng Province is a lack of integration between public transit services. While each operator maintains information to an extent, there is no central database available to get a snapshot of the state of public transport in the province.

Since Zhengzhou's transit data were captured across multiple platforms, the World Bank team used an experienced technical specialist to develop algorithms able to convert all the data into the correct format. For Haiphong and Manila, they had to commence their GTFS project by capturing the data from scratch. From their experience, they estimate that the time and cost of the data collection effort would be 25% more than the expected time and cost. This is due to the number of new illegal routes being operated of which the agencies and government may not be aware of. They suggest that the data cleaning required when using a mobile application to capture all routes takes approximately 15% person-hours more than it took to capture the data. When conventional GPS devices are used to map routes, they suggest adding 50% to the total person-hours.

Once the GTFS databases were completed, the World Bank team ended off their project by establishing a hand-over process. Central stakeholders were identified who are able to provide the required technical and financial resources to host and maintain the GTFS data. In Manila, the National Department of Transport and Communications was identified to lead the GTFS project, while the Department of Science and Technology was identified to host the database. Since China had a longer-term objective of uploading GTFS feeds on a national scale, the National Ministry of Transport took over the GTFS project, while the local city Department of Transport took over responsibility of this task in Haiphong.

It was also critical to consider how the cities would be able to continually maintain and update their GTFS databases. Two open-source packages, developed as a result of the World Bank's pilot study, were made available to the agencies. This included a mobile application TransitWand [12], which can be used to capture route information, and GTFS Editor, a web-platform that can be used to edit data and export into the GTFS format.

Lesson learnt from the World Bank project can be applied to a South African context, since there are similarities between the operators. One concern of pursuing usage of the GTFS format in South Africa is that of people's access to the internet. However, a Pew Research Group study [13] conducted in 2015 indicates that 37% of South African adults report to owning a smartphone, and 42% report to using the internet. Millenials, aged 18 – 34, are more likely to own a smartphone or use the internet than those above the age of 35.

While this study indicates that more than half of the South African adult population does not own smartphones or have access to the internet, there is still a large part of the population who could benefit from accessing transit information on Google Maps. It is also believed that recent campaigns by municipalities to increase access to free wi-fi has allowed more South Africans to access to the internet. Using a standard, though, would allow for the development of software that can query the database and integrate alternative options such as SMS or USSD for non smartphone users.

2.4 Using GTFS for Transport Planning

The value of GTFS is not only found in increased accessibility to public transport information. It can also be leveraged by transport modellers to build more accurate transport models by including up-to-date transit information in a format that can easily be used by the software.

One example is MATSim [14], the Multi-Agent Transport Simulation Toolkit. MATSim is used to model transport vehicles as individual agents with decision-making capabilities. Agents are able to score their transport-related decisions and try out alternative options in the next iteration of the model. Other than private vehicles, MATSim has incorporated freight and public transport vehicles into their models in order to simulate real-life traffic conditions. The GTFS format is used to specify the routes and schedules used by public transport vehicles.

There are a number of route planning software packages available. Scotty [15] is a widely-used Austrian commercial route planning tool to plan rail and bus routes in Europe. OpenTripPlanner [16] is an open source multi-modal journey planning application which is able to determine the shortest path between origins and destinations, given the available road network and public transport services. The GTFS format is also used by OpenTripPlanner to specify transit routes and schedules. The CSIR has used OpenTripPlanner to determine least-cost paths between zones in municipalities, which feed into urban growth models [17].

If South Africa's transit operators would more readily capture and maintain their data in the GTFS format, transport modellers would have access to high quality data that can feed into models that are able to assist the government in transport planning.

While there are many challenges in South Africa inhibiting immediate adoption of the GTFS format, the literature shows that it is possible to capture and maintain transit data in this format in developing countries. In the next section, we elaborate on the methodology followed to capture and upload two GTFS feeds onto Google Maps.

3. GTFS GENERATION FOR GAUTENG'S BUS RAPID TRANSIT (BRT) SYSTEMS

To show the value of using the GTFS format and having information readily available online, a proof of concept (POC) exercise was undertaken to convert the data of Gauteng's Bus Rapid Transit (BRT) systems to the GTFS format and to upload these to Google Maps. This also served as a means to develop a methodology to follow to convert and upload data of any public transport operator in future.

There are currently two operational BRT systems in Gauteng: the City of Johannesburg's *Rea Vaya* and the City of Tshwane's *A Re Yeng*. Ekurhuleni is still in the planning phase of their BRT system, *Harambee*, thus they do not currently have data to convert and upload to Google Maps.

Rea Vaya was launched in 2009 and has three trunk routes, 12 feeder routes and five complementary routes. The trunk routes operate between Thokoza Park and Ellis Park East, between Thokoza Park and Braamfontein, and between Thokoza Park and Library Gardens East. A Re Yeng has been operational since 2014 and has two trunk routes, of which the second one was launched recently on 1 May 2017. The trunk routes cover Pretoria CBD to Hatfield and Pretoria CBD to Wonderboom. There are five feeder routes, and there are plans to extend the operations to the East of Pretoria.

3.1 Collecting raw data

The Gauteng Department of Roads and Transport provided the initial contact with each metropolitan's Head of Transport, who referred us to the appropriate persons in the BRT offices.

Face-to-face meetings were held with the agencies as these enable them to better understand the purpose and value of the project. When there is buy-in from the agencies, it greatly improves communication and willingness to provide the required assistance. Further to this, it is very important to make contact with the person with the most appropriate designation. Unfortunately this is difficult to determine from initial contact, since one initially does not have a full understanding of the operations at the agency. If the designated contact person is one who does not have direct access to the data, or does not have the appropriate authority to get access to the data, it introduces unnecessary delays in the conversion process.

There were also delays when the data had to be collected from multiple sources. It often occurs that agencies have separate departments working with route, schedule, and fare information. Each department captures their data differently and there is no entity responsible for merging all data into a central database. Conversely, when all route, schedule, and fare information are collected and maintained in a central database and a single person can be contacted to collect all required information, it greatly reduces response times. When data are maintained in a database, it is also easier to convert the data into the GTFS format, since the relationships in the database can be leveraged by a script that can automatically write the data into the correct GTFS files.

Often, while the conversion was taking place, we found that queries arose regarding the raw data collected. When there is a single contact person who is knowledgeable about the data, it is easier to gain clarification about the data.

3.2 Manually converting raw data

Data collected from different sources often have to be consolidated before the GTFS conversion can take place. Additionally, if some data are captured in Word of PDF documents, it prolongs the conversion process. Manually capturing and converting raw data also requires extra validation efforts, since human error can occur when reading in text data.

3.3 Automatically converting raw data

When data are captured in a centralised relational database, a script can be used to read in all the data and write it to the appropriate GTFS file. Unfortunately, when data are incorrectly or inconsistently captured into the database, the script needs to be adjusted to allow for these deviations. Again, this illustrates the need for operators to capture and maintain their data consistently.

3.4 Validating GTFS feeds

Before the GTFS feeds were uploaded onto Google Maps, an online GTFS Validator [18] was used to ensure that the data were captured in the correct manner. The validator runs through a variety of checks such as whether required fields or files have been excluded, whether invalid values are entered into specific fields, whether stop times between stops make sense in terms of the distance between stops and most likely vehicle speed, etc. While this tool cannot determine whether the information captured is correct, it does help to ensure that validation errors are resolved before uploading it onto Google's Partner Dashboard. Once it is uploaded, Google performs a variety of validation checks which pick up finer nuances in the data that may hamper the end user experience.

3.5 Uploading GTFS feeds onto Google Maps

Limited information is available about the process that needs to be followed to upload GTFS data to Google Maps. Only when the process is undertaken does one really understand the effort that is required to publish a high quality GTFS feed. The steps that were followed are listed in Table 3. The timeframes listed in the table specify the actual time it took to complete each step. These timeframe will differ for each agency, since the timeframes are heavily dependent on the responsiveness of the agency to react to the requests. Also note that there was a publisher involved in this process, who acted as the middleman on behalf of the agencies to publish their data onto Google Maps. In many instances time delays occurred due to the back and forth communication between Google, the publisher, and the agencies. Therefore the timeframes could be reduced if the agencies had direct contact with Google and could immediately respond to their requests.

Table 3 : Summary of steps followed and approximate timeframes to upload GTFS data onto Google Maps.

Step	Timeframe	Responsibility
Submit interest form	< 1 day	Publisher
Send letter of endorsement	2 - 11 days	Agency
Register designated signing authority	1 - 22 days	Publisher
Sign online agreement	1 - 2 days	Agency
Create Google Account	< 1 day	Publisher
Provide access to Transit Partner Dashboard	1 day	Google
Upload GTFS data	1 - 6 days	Publisher
Generate private Google Maps view	2 - 3 days	Google
Validate GTFS data	2 - 3 weeks	Agency, Publisher
Submit pre-launch checklist	1 day	Publisher
Run quality assurance tests	2 - 3 weeks	Google
Final review	1 week	Google
Decide on official launch date	1 week	Agency, Publisher
Launch GTFS data	Depends on launch date agreed upon	Google
Expected total time	**1-2 months**	

The first step was for the publisher to submit an interest form, providing the websites of the agencies to be uploaded. Google uses this information to evaluate whether the agency meets all the requirements to be uploaded onto Google Maps. The agency is required to follow a pre-determined schedule, be open to the public, and not allow reservation of seats.

Since the agencies did not upload the data themselves, they were required to send an endorsement letter to Google Transit specifying that they endorse the publisher to act on their behalf to upload their data. There were some delays in this step since the contact persons at the agencies had to get a higher authority to sign the endorsement letter.

Once the endorsement letter was received by Google, the publisher had to register a designated signing authority at each agency. The designated signing authority is the contact person at the agency that was required to sign an electronic form indicating their agreement to Google's terms and conditions. The online agreement form had to be accepted by each agency before the process could continue.

Once the online agreement was signed by the designated signing authority, a new Google Account had to be registered and sent to Google Transit. Only this Google Account has permission to upload GTFS data. Once the Google Account was created, access was granted to the Transit Partner Dashboard. The Transit Partner Dashboard is a platform where GTFS data can be uploaded to Google. There are two options to do this, namely a manual push of the GTFS data, or by specifying a URL where Google can fetch the data. Once the data was successfully uploaded, a validation report was generated on the dashboard reporting on any validation warnings and errors identified by Google.

The GTFS feed is then included by Google in the next build cycle and a private Google Maps view is generated, which usually takes 2 – 3 days. Google encourages the publisher and agencies to log on to Google Maps using the new Google account to validate the data. It is strongly suggested to include the agencies in this step, since they have a better understanding of the services offered. The private view displays all the information that would be visible to the public if the GTFS feed was launched.

The validation process also includes going through the validation report, addressing all issues to ensure that all routing information is correctly displayed to commuters. Any errors identified need to be addressed and the updated GTFS feed uploaded onto the dashboard again, repeating the process until the agency is satisfied with the quality of the data.

A pre-launch checklist has to be completed by the publisher before communicating to Google that the GTFS feed can be launched. Google then performs quality assurance tests to ensure that the data conforms to their standards. Once the GTFS feed successfully passes the quality review assurance tests, a final review is done on the feed, where additional concerns may be raised. Once these are all successfully resolved, the agencies and publisher decide on a launch date. Finally, the GTFS feed is launched to the public on the specified date.

At the time of writing, A Re Yeng's GTFS data successfully passed all review processes, and has been launched on Google Maps. An example of directions using A Re Yeng routes can be accessed here: https://goo.gl/maps/E89rtDRsNEn, and a screenshot of these directions are shown in Figure 2. Rea Vaya's data are still being validated, and concerns in the raw data are being addressed. The aim is to launch both feeds during South Africa's Transport Month in October.

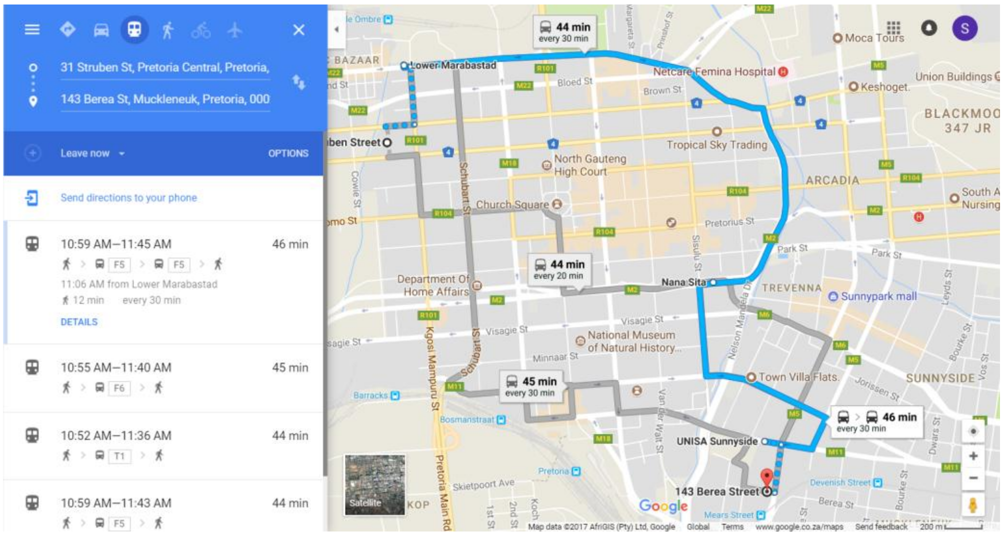

Figure 2 – Directions in Google Maps using A Re Yeng bus services.

4. BENCHMARK OF OTHER PUBLIC TRANSPORT OPERATORS

Six additional public transport operators were visited to understand their operations, data procedures, as well as to determine the quality of their data in order to assess how plausible it would be to convert their data to GTFS. There was a mix of full state-owned entities, semi-state operators, as well as municipal and provincial operators. Five of the operators visited provide bus services and one of them rail services. The taxi industry was not included in this exercise since they do not have fixed stop locations, as required by the GTFS format.

4.1 Operations

All operators who operate on a provincial level have to provide services according to their contractual agreements with the Gauteng Province. The contracts describe the routes that they service, when these routes are operated, and the subsidies earned per kilometre.

To extend operations, operators are required to apply for contract amendments to ensure that they receive subsidies for the additional services that they want to provide. This is a cumbersome process, often resulting in operators failing to apply to provide the additional services. Since municipal operators are funded by the municipalities themselves, they have more freedom in planning their routes.

4.2 Planning and Scheduling

Planning and scheduling are often done manually by the operators. Data collection methods for planning purposes differ for each operator. Some use surveys to determine where demand for new services arises, while other operators look at developments around the province to assist their planning decisions. Some operators require their bus drivers to log ridership information, which informs the planning department on which routes are over- and underserved. Other operators are using their electronic fare collection systems to capture information regarding ridership.

In most cases, a single employee is responsible for scheduling. This makes the operators vulnerable, since their service is dependent on one person who can retire or resign at any given moment.

Various methods are used by the operators to schedule their buses. In one instance, a complete manual process is followed using outdated planning boards. Although this process has been captured in a policy document, no knowledge transfer is taking place to ensure that the work can continue if something were to happen to the person responsible for scheduling.

Some operators use software to schedule their buses, however most of the software packages are extremely outdated and not user-friendly. Most of the operators stated that the software also does not comply with all their requirements, and therefore still need to rely on manual processes to perform their scheduling.

4.3 Fare collection

Some operators are still operating on out-of-date paper bus ticketing systems, where weekly or monthly bus tickets can be bought at specific stations around the province. Some of these operators still allow commuters to pay cash on the bus, although this is discouraged by the operators due to theft. Other operators have started migrating to electronic fare collection systems, which also allows them to capture more detailed information about their ridership.

4.4 Data formats

All operators capture and maintain their data in different ways. In most cases, the operators communicated that they have all data required by the GTFS format. The one thing they have in common is that none of them have a centralised database or server containing all the route, schedule and fare data. Route descriptions are often captured as text in Word documents or in outdated maps displaying the routes. Oftentimes, schedules are captured in Excel spreadsheets. There is also a lack of time-series data, which makes it impossible to obtain historic data of routes and changes to itineraries.

There were three exceptions where the operators' data were already captured and made available on Google Maps. The operators were approached by consultants working in the public transport domain, who are attempting to make public transport data more readily available to the general public.

4.5 Specific issues brought up by the operators

On two occasions, the issues surrounding subsidies and contract renewals were brought up. Some operators are still operating on subsidies that were awarded many years ago (as far back as the 1990s), without being adjusted. Because of this, operators are operating at very low subsidies making it difficult to improve and maintain their fleets. As a result, a lot of them continue to operate with old and unstable fleets making it difficult for them to provide quality services to their users.

4.6 Summary of the benchmarking exercise

The benchmarking exercise proved useful since it helped gain a clearer understanding of the state of operations at various public transport operators in Gauteng. From the data gathered, two categories of operators were identified: those with high operating cost and low ridership, and those with low operating cost and high ridership.

The issues faced by the operators in each category are similar, in that operators in the former category mostly struggle with planning and scheduling, and hence have low ridership values. Although operators in the latter category also struggle with their planning and scheduling, a greater struggle is that of funding and providing quality day-to-day operations. Since the routes covered by these operators have a high demand, these buses are often operating over capacity.

A recommendation that can be made to all operators, irrespective of the type of operator, is that the capturing and maintaining of data be standardised, and that all datasets be hosted on a central server or database.

For operators who are struggling with low ridership, it is recommended that their data be converted into the GTFS format and uploaded onto Google Maps. In this way, visibility of their services can be increased and ridership could possibly increase.

For operators that are struggling with day-to-day operations as a lack of funding, it is recommended to perform business process re-engineering in order to improve efficiencies in day-to-day operations. Studies can also be done to identify wastes in the system and decrease operating costs, freeing up a greater part of the budget for proper maintenance of their fleet.

5. CONCLUSION

As found by the Pew Research Group, more than half of South Africa's adults do not own smart phones or have access to the internet. This is a problem facing many developing countries, as new technologies cannot be readily applied to improve service delivery. Although these challenges exist, it has been shown in literature and by this case study that it is still possible to make public transport data more accessible to the general public in developing countries.

By uploading the two Gauteng BRT operators onto Google Maps the visibility to the services has been increased. It will, however, take a few months to determine whether this project has had a direct impact on ridership and awareness of the services. To determine the impact, A Re Yeng and Rea Vaya could include a question into their registration process where commuters are asked to indicate where they heard of the service, and if their presence on Google Maps has in any way influence them to use the service.

Even though most operators evaluated in the benchmarking exercise have all the data required to set up a GTFS feed, standardised transit data capturing and maintenance procedures are still missing in Gauteng. Standardisation could inform operators on what data to maintain and how often to update it. It also ensures that the provincial government has access to the same set of information for all operators, assisting in their transport planning.

There are many ways in which Industrial Engineers can take up stewardship and improve public transport in South Africa. Since the operators struggle with their day-to-day operations, Industrial Engineers could assist public transport operators in establishing processes to improve data standardisation across the public transport sector. Using database design, Industrial Engineers could also play an integral role in establishing a central GTFS database for the Province, and even the country. The CSIR could also play a strategic role by hosting the central GTFS database, and being the link between the operators and the government.

Another avenue for future work is the establishment of an open data GTFS Exchange platform, where South African public transport operators can upload their GTFS feeds, and the general public and researchers alike can access the data.

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UNDERSTANDING THE LINKS BETWEEN THE SUCCESS AND FAILURE FACTORS OF MICRO-ENTERPRISES AND BUSINESS INCUBATORS IN SOUTH AFRICA: AN EXPLORATORY STUDY

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ABSTRACT

South Africa, like other developing economies, is viewing business incubation as a viable solution to develop sustainable enterprises that can grow the economy and reduce unemployment. The current economic climate has prompted all stakeholders to achieve sustainable and inclusive growth, and business incubation has been identified as a way to achieve this. Business incubators, however, experience challenges, and certain factors lead to their successes and failures that impact on the success or failure of the micro-enterprises they are supporting. Therefore, an exploratory study was undertaken to determine potential links between business incubators and micro-enterprises.

Case studies involving a combination of a business incubator and its associated micro-enterprise were conducted. Unstructured interviews were conducted with Business Incubator managers and Micro-Enterprise owners all located in the Johannesburg area. These were analysed using thematic content analysis and causal loop diagramming. Relationships that depicted the nature of the success and failure factors of the business incubator and micro-enterprise emerged.

The success of the micro-enterprise and business incubator relies in the fact that both entities need to function as a for-profit business through adequate funding. Micro-Enterprises continue to have a strong focus on business operations and business incubators continue to be focused on development. Both entities need to have a sound business strategy and operating model to be sustainable and successful.

Key words: Business Incubator, Micro-Enterprise, inclusive growth, success factors, failure factors

1. INTRODUCTION

Enterprise growth leads to a strong economy, increase in disposable income and the boom of entrepreneurial activity [1]. South Africa's entrepreneurial segments have led it to diversify the economy and incorporate certain elements of the free market characteristics of mixed economies, whereby the state plays a crucial role in the economy but is equally open to individuals to trade freely in the form of enterprises. Free-market characteristics are those such as ownership of private property, individuals have the freedom of choice to trade and transact freely and compete on price, which enhances an enterprise environment [2]. In addition, the state has strived to promote entrepreneurship as a juggernaut overhaul to solve the unemployment and low economic growth phenomena in the country [3] . However, in recent times and owing to tough local macro-economic conditions, the growth of entrepreneurial activity has decreased considerably [4].

South Africa, however, ranks among the top 80 for ease-of-doing-business indexes and has a relatively strong business environment, now being the largest economy in Africa [5]. There are several macro-economic features conducive to promoting business growth such as exports and ICT opportunities. Other factors include, a sophisticated banking sector, a conducive business environment, stable political environment, a growing middle class population, a highly sophisticated tax collection environment, a sophisticated business networking environments, a diversified and newly industrialised economy, stable legal conditions and access to courts and legal structures and independent institutions. Given all these, the question arises as to why South Africa's entrepreneurial intentions and their conversion into entrepreneurial behaviour are so low. Globally, South Africa also ranks low against its international peers when it comes to Total Entrepreneurial Activity measures as per the GEM report [6]. In essence, entrepreneurship in South Africa is not at the levels that it can be.

The current economic climate in South Africa has brought together three main parties of the economy for the first time in several years. Government, private sector and labour have joined hands at looking at ways to inclusively grow the economy. One of the ways that has been identified and earmarked by all three parties is the need to create and initiate SME development and sustainability. Micro-enterprises particularly are viewed as the key tool and measure for inclusive growth [7]. Business incubators provide services to new and existing businesses in the economy and have also been identified as a possible engine for growth to ensure entrepreneurial and business growth [8]. Business incubators have come into existence to allow for the harbouring of skills and businesses and the growth of these. [9]. These entities, however, experience challenges, and certain factors lead to business incubator successes and failures that impact on the success or failure of the micro-enterprises they are supporting [10]. The purpose of this research is to investigate the relationship between the success and failure factors of business incubators and those of the businesses (micro-enterprises) they are supporting [11].

2. LITERATURE REVIEW

2.1 Business Incubators

When a business enters the market, it would be typically categorised as a micro-enterprise [14]. In South Africa, a micro enterprise is categorised as a business with a turnover of less than ZAR 200 000.00 [15] and employs less than 5 people within the business. These businesses experience several challenges and only a very small percentage of businesses are able to break out of the introductory business life cycle phase [16]. A critical success factor lies in the progression of these businesses into the next phase of the business life cycle growth phase [17]. One mechanism created by the private and public sector that can facilitate this progression is a business incubator. Business incubators can be broadly defined as units of businesses that can provide discretionary and systems support to new and introductory entrepreneurs. Both sectors have created various types of public-sector led incubators in South Africa to harness specialised skills and market new technologies [9]. These Incubators typically would measure their success by how many businesses they can make sustainable over a period of time. Private sector led incubators operate in a similar manner. Most of these incubators would typically attempt in incubating businesses to do business with them first, and then incubate them later become fully sustainable. Post 1995, the Department of Tarde and Industry sought strategic initiatives to foster small businesses that could contribute to the South African economy and diversify it. As a result, they looked at various possibilities around the world and settled on the business incubation model. The business incubation model has proved to be a great success factor in developed countries such as the USA [9].

Business incubators do not target any small entrepreneurs, and many operate in a very niche-focused market. In South Africa, the business incubation landscape is categorised by two major environments, namely technology centres and business incubation. Business incubators have proven to provide a nurturing platform for Micro, Small and Medium Enterprises in developed and developing countries [19]. However, in developing countries in particular, business incubators continue to face operating challenges and barriers. This is particularly true for South Africa where, as previously stated, business failure and unemployment still continue to be particularly high [6].

Business incubators, however, are not **necessarily** the most equipped to deal with business successes [20]. In some cases, they lack the skills to continue to provide entrepreneurs with the necessary knowledge that they need to provide and the ability to successfully incubate their ideas. Selecting and attracting adequately skilled professionals to manage various business functions within business incubation is a precarious task for many incubators. Several researchers such as Nieman and Niewenhuizen [9] agree that one of the main factors that contribute to successful incubation is the correct entrepreneurial talent instilled to grow businesses. Incubator managers need to be intensely creative and innovative in fulfilling incubation functions. The following functions are critical for business incubation success:

a. Management direction
b. Technical support
c. Consulting style

In addition, partnership and sustainability is important for developing successful incubators. Incubators should also consider the following strategic imperatives:

a. Incubators should create a board to govern activities
b. Experienced and knowledgeable staff should be hired to guide and lead business incubation
c. An incubator should attract as many investors as possible, private and public.

There is considerable evidence in literature that states that entrepreneurship actually requires intense technical support, entrepreneurial skills, and management experience to mention a few [9]. In addition, entrepreneurial activities do not pay enough attention to technicalities, efficiency and financial education. Some can argue that business incubation in developing countries continue to face multiple challenges with respect to creativity and innovation. Business incubators need to function in a high-growth macro-economic environment. Lack of growth in a business incubation environment is measured by the incubators ability to raise capital, employ qualified people, and maintain the resources to run the incubator efficiently and productively [21]. Incubators need to be up to date with the latest forms of technology to succeed. The correct form of information regarding access to markets, appropriate space and flexible leases in the market, shared basic services and equipment and technology services are some of the factors that have been mentioned as key to incubation successes. Technology renders change management easier and access to information is faster, thus rendering services faster to clients and providing information that is more applicable to changing times. One of the key factors for incubators to succeed is access to funding and sponsorship. Incubator access to successful funding and sponsorship is good management. Good management is also tied to ideal access to entrepreneurial management and leadership. Incubators may be privately or publicly funded. Public funding would come from state or public entities such as SEDA (Small Enterprise Development Agency) and the Incubation Support Program (ISP) through the Department of Trade and Industry (DTI). Private incubators would typically need to have their own program for funding. These private incubators actually have to function as a profit making entity [22] in order to sustain itself (linked to sustainability above)

2.2 Micro-Enterprises

The success and failure factors of micro-enterprises are synonymous with the reasons why most businesses fail. Minimal research has been done in South African micro-enterprises. However, based on a study that was done on the success and failure factors, some of the reasons for business failures are (among others) [21] are deficient planning, location and infrastructure, and lack of business education training, employee satisfaction, customer relations, budget management, and technology. Poor planning, an extension of efficient mismanagement is a cause of failure for micro-enterprises. Managers tend to, at times, fail to plan strategically for the business and not coordinate managerial tasks correctly. Examples of these managerial tasks may include planning, organising, leading and controlling, among others. In some cases, this is largely to do with strategic planning and direction [21]. Albeit contentious, one of the main reasons of micro-enterprise failure is lack of sufficient business education and planning. Most business personnel are ill informed about the legal aspects concerning the business. There is also a lack of understanding of the business risks associated with investment decisions and operations [10].

Owing to lack of buying power and formalised structures, micro-enterprises tend to hire family and friends to assist in the operations. Research has also shown that funds from the business may be used for personal needs of the family. At other times, relatives may not necessarily possess the relative skills and experience to run micro-enterprise operations. The personality of the micro-enterprise is such that they are sensitive, positive and helpful; qualities which may be compromised should a family member being more involved in the micro-enterprise [23]. Most micro-enterprises fail because of lack of daily contact with customers, lack of special promotions, price changes, and lack of new product features. That is why the customers may be the first to hear about significant changes in the competitors' distribution network. Many micro-enterprises also fail to understand the customer buying patterns and trends [24].

Some experts argue that micro-enterprises face problems in terms of using discounted cash flows for capital budgeting and procurement. In essence, funds need to be allocated for micro-enterprises to expand customer base and failure to adhere to prudent financial management in the infancy stages of the businesses will result in failure for the business [25].
Micro-enterprises that are contemplating purchasing new technology have great difficulties since they do not possess the knowledge and the high opportunity cost of scarce management time, in isolating the cash flows pertaining to the project [26]. Many micro-enterprises lack time, resources, technology or expertise to research and develop new business ideas and innovations. This weakness can become a critical factor limiting growth and expansion in small businesses. Location is everything when determining the success of the businesses. Having an ideally located business to customers and distribution points allows for businesses to be more connected in the supply chain of goods and services [27]. However, owing to survivalist nature of micro-enterprises and the lack of adequate financial resources in businesses, micro-enterprises tend to open businesses wherever convenient to the business owner. In some cases, a location may be chosen where premises are empty and low rent.

The literature review highlights the context of this research, and provides reasons, as to why micro-enterprises fail, and the challenges and success factors of business incubators. It also depicts that the South African economic landscape has recognised the roles of micro-enterprises, and by extension, Small-Medium Enterprises, and that of business incubators.

3. RESEARCH METHOD

Owing to the limited information pertaining to micro-enterprises, business incubators and the relationship or links thereof, an exploratory study through qualitative research was selected as an appropriate research tool. Semi-structured interviews were chosen for this study as they provided rich insights into operations, strategies and success and failure factors. They also provided direct and personal contact with the relevant people/personnel at the business incubators and the micro-enterprises, and were done in the natural setting. The researcher was the interviewer, therefore, the key facilitator.

The preliminary literature review provided the research with the basis of discussion. The interviews focused on understanding:

- the history of the business incubators and micro-enterprises
- the key focus areas for business incubators and micro-enterprises
- the economic aspects of the business incubators and the micro-enterprises
- the social and political economy aspects of business incubators and micro-enterprises
- the operating model of business incubators and micro-enterprises
- and identifying the success factors and failure factors for business incubators and micro-enterprises

The interviews were conducted with 6 interviewees (3 interviewees for business incubators and 3 interviewees for micro-enterprises) at the case sites. The interview sessions ranged from 30 to 60 minutes. A set of interview guides with a list of questions were crafted in such a way that they are mostly the same for all interviewees. The interviewees were:

Table 1: List of interviewees

Micro-Enterprise	Business Incubator	Industry/Sector
Micro-Enterprise A	Business Incubator A	Textile
Micro-Enterprise B	Business Incubator B	Corporate
Micro-Enterprise C	Business Incubator C	ICT/.I/Start-Up

Lists of questions were compiled and were not ardently followed but provided a basis of discussion. Since this was an exploratory study, the objectives of the discussion were to allow for it to remain open and allow for the interviewees to explain perspectives on various topics. Causal loop diagrams were employed to facilitate the interview and to map the links between the success and failure factors and other categories and themes. The causal loop diagrams also depicted the level of emphasis between certain categories and themes. The causal loop diagrams provided a visual basis for the discussion.

Content analysis was used to analyse the data. This method relies on the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns. The process was designed to reduce the collected into categories. The themes and categories were subjective, but the literature provided an insight into how the content could be categorised. However, the content analysis depended on the nature of the responses and the content of the interview between the interviewer and interviewee.

Analysing the data from the six sources ensured triangulation, data quality, integrity, reliability and validity of the research.

4. RESULTS

4.1Themes, functions and Enablers

The semi-structured interviews were used to explore any problems and successes related to the factors of business incubators and micro-enterprises. The discussion focused around on the success and failure factors of business incubators and micro-enterprises. The content analysis was conducted through a three-level cascading coding structure. The first level typically indicated theme, while the second level indicated the function. The function supported the theme and provided an overall direction for the theme. The third level indicated the objectives. The enablers guided what was required to achieve the functions. The three-level coding system moved beyond conventional content analysis methods and allowed for perspective on the various topics that emerged from the interviews. The enablers were observed as the bulls-eye and a crucial cog indicated in the bulls-eye diagram in Fig. 1. These were because the themes were redundant without the links of the functions and the enablers.

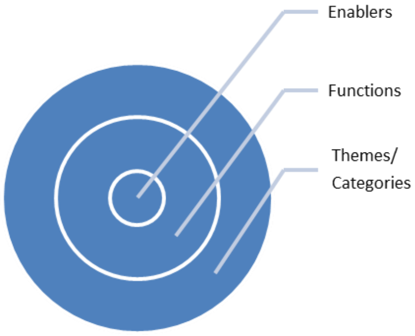

Figure 1: Structure for coding and content analysis

Frequencies work well in quantifying qualitative data [28]. In this research, the frequency served more as a count to identify areas of emphasis and focus by looking at the repetition. Code frequency charts were developed for the three interview sets to indicate the level of emphasis of each of the relevant theme, function and enablers. An example is provided for the interview between a business incubator and micro-enterprise operating within the textile industry.

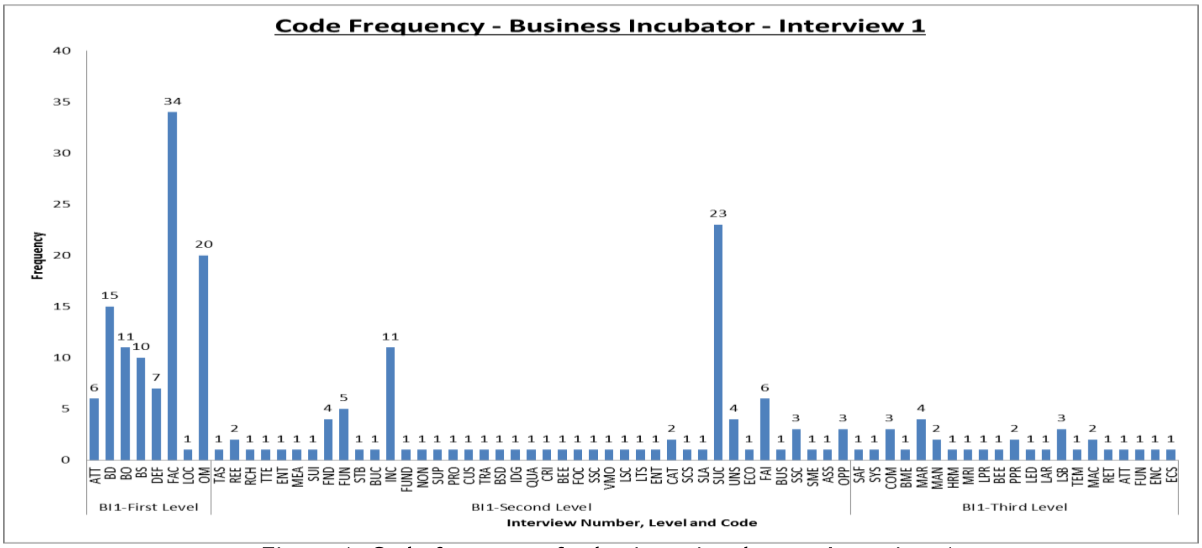

Figure 1: Code frequency for business incubator - Interview 1

As an example, the casual loop diagram for Interview 1 is shown in Figure 2.

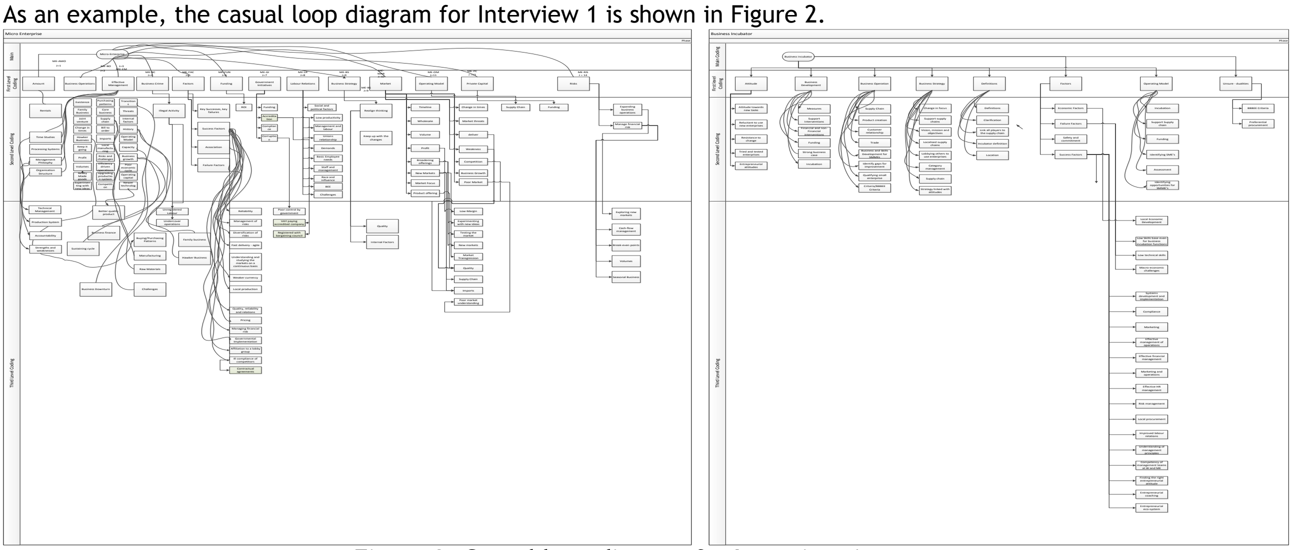

Figure 2: Causal loop diagram for Interview 1

The most predominant themes which emerged during the content analysis and the determination of the links between success and failure factors were Business Operations, Business Strategy, Operating Model and Factors. The most prominent functions that emerged during the analysis were Learnership/Internship programs, Incubation methodologies, Procurement Strategies, Success Factors and Failure Factors. The most prominent enablers that emerged were Procurement Strategies, Training, Funding, Financial Management and Sustainability.

There were also several cross-functional elements that arose. These were typically links that were found, interchangeably, between themes, functions and enablers. Some of these that had emerged from the analysis were Risks, Company history, Funding, Incubation methodologies, Strategic initiatives, Entrepreneurship, Learnership/Internship programs, Procurement Strategies, Market, Competition, General Management, BBBEE policies and Technical Management.

4.2 Links between business incubators and micro-enterprises

A scoring scale was created for themes, functions and enablers that correlated for micro-enterprises and business incubator data sets. These were completed in an attempt to determine where the links were and whether or not there was a direct correlation between corresponding themes, functions and enablers. Links were classified as (in ascending order) very low, low, medium, high and very high and very (very high). Each link was placed in a table and a formula was created to determine a scoring chart. The values for each link can be seen in the table below:

Table 2: Scoring Table

Description	Very Low	Low	Medium	High	Very High	Very (very high)
Very Low	9.00	13.74	15.21	15.92	16.35	10.53
Low	13.74	19.00	25.55	28.74	30.63	22.22
Medium	15.21	25.55	29.00	36.44	40.84	33.92
High	15.92	28.74	36.44	39.00	46.96	45.61
Very High	16.35	30.63	40.84	46.96	49.00	57.31
Very (Very High)	10.53	22.22	33.92	45.61	57.31	59

Table 3: Links and scores for Interview 1

Main-1st	ME	Level - ME	BI	Level - BI	Linked Score	Factor	MAX	Cumulitive	Overall Score (%)
BO	47.00	Very High	11.00	Low	30.63	0.23	49.00	30.63	51.23
BS	4.00	Very Low	10.00	Low	13.74	0.40	98.00	44.37	
FAC	20.00	Medium	34.00	High	40.84	0.59	147.00	85.21	
OM	1.00	Very Low	20.00	Medium	15.21	0.05	196.00	100.41	
1st/2nd									18.37
FUN	2.00	Very Low	2.00	Very Low	9.00	1.00	49.00	9.00	
PRO	5.00	Very Low	1.00	Very Low	9.00	0.20	98.00	18.00	
FAI	2.00	Very Low	1.00	Very Low	9.00	0.50	147.00	27.00	
ASS	1.00	Very Low	1.00	Very Low	9.00	1.00	196.00	36.00	
SUC	3.00	Very Low	1.00	Very Low	9.00	0.33	245.00	45.00	
BEE	1.00	Very Low	1.00	Very Low	9.00	1.00	294.00	54.00	
FOC	1.00	Very Low	1.00	Very Low	9.00	1.00	343.00	63.00	
1st/3rd									18.37
MAN	1.00	Very Low	1.00	Very Low	9.00	1.00	49.00	9.00	
TEM	1.00	Very Low	1.00	Very Low	9.00	1.00	98.00	18.00	
MAR	2.00	Very Low	1.00	Very Low	9.00	0.50	147.00	27.00	
COM	2.00	Very Low	1.00	Very Low	9.00	0.50	196.00	36.00	
2nd/3rd									18.37
COM	1.00	Very Low	1.00	Very Low	9.00	1.00	49.00	9.00	
TEM	1.00	Very Low	1.00	Very Low	9.00	1.00	98.00	18.00	
MAN	1.00	Very Low	1.00	Very Low	9.00	1.00	147.00	27.00	
MAR	1.00	Very Low	1.00	Very Low	9.00	1.00	196.00	36.00	
Me-1st/BI-Main									0.00
N/A									
ME-1st/BI-2nd									18.37
FUN	1.00	Very Low	2.00	Very Low	9.00		49.00	9.00	
ME-1st/BI-3rd									18.37
FUN	1.00	Very Low	1.00	Very Low	9.00		49.00	9.00	
MAR	1.00	Very Low	1.00	Very Low	9.00		98.00	18.00	
ME-2nd/BI-Main									0.00
N/A									
Me-2nd/BI-3rd									18.37
MAN	3.00	Very Low	1.00	Very Low	9.00		49.00	9.00	
COM	3.00	Very Low	1.00	Very Low	9.00		98.00	18.00	
SAF	1.00	Very Low	0.00	Very Low	9.00		147.00	27.00	
FUN	2.00	Very Low	1.00	Very Low	9.00		196.00	36.00	
MAR	1.00	Very Low	1.00	Very Low	9.00		245.00	45.00	
BEE	1.00	Very Low	1.00	Very Low	9.00		294.00	54.00	
TEM	0.00	Very Low	1.00	Very Low	9.00		343.00	63.00	

5. DISCUSSION

5.1Textile sector pair

Interview 1 was conducted between Micro-Enterprise A and Business Incubator A operating within the textile sector. Micro-Enterprise A had been in the market for over the last 30 years and the history of the micro-enterprise was very well emphasized in the function of the interview as this was mentioned 3 times. The function came up regularly in the theme of business operations. The business operations, refers to the general administration of business services in order to create the highest level of efficiency in the organisation [28]. The business operations for Micro-Enterprise A formed an important part of their existence. This was confirmed with the frequency for this at 47 times. A study conducted on the relevance of operational skills on SMME manufacturers [29] showed that a focus on business operations for SMME's provided a viable statute for sustainability. This also seemed to have a proved case for the emphasis for a strong focus on business strategy. Business strategy was mentioned 4 times in the interview. The business strategy was also geared towards sustainability, and the micro-enterprise's long-term existence. Micro-Enterprise A was very cognisant of the factors that made them successful in the market. These were reflected in the functions section of the code by them listing a range of success and failure factors. Among the several success factors that were mentioned were providing a reliable service, successful market conditions, having agility in the operations, understanding the market that the micro-enterprise is operating in, weaker currency (taking into account current conditions), local production or manufacturing, manufacturing quality products and deepening customer relationship, selling products at a reasonable price and managing financial risk. The failure factors that were mentioned by Micro-Enterprise A were a lack of legal compliance for competitors. These factors mentioned above were validated through a study that identified factors that affect SME success [30].

Business Incubator A provided even more interesting insights. There were several similarities and differences in the analysis. It seems to suggest that Business Incubator A had a stronger business objective on traditional management themes (frequencies indicated in brackets) such as operating model (20), understanding the factors (34), business development (15), business operations (11) and business strategy (10). These traditional management concepts [31] enhance the ability of Business Incubator A to adhere to its objectives of successful business incubation. The strong focus on factors [32] and identifying the failure and success factor functions in the second level code suggested that the business incubator places metrics in place that allow it to track whether the incubation process is successful. It also suggests that Business Incubator A has a strong focus on their function and enabler has an economic entity [33]. Business Incubator A realised that funding was very important to sustain business growth. However, the data seems to suggest that Business Incubator A had several enablers that allowed for successful incubation. These were, in no particular order (with only 1 frequency associated with each; this list included the success and failure factors as well), marketing, effective management of operations, effective HR management, BBBEE criteria, Preferential Procurement, low skills base, low technical skills, macro-economic Challenges, entrepreneurial objectives such as coaching and ecosystems, and location.

5.2 Corporate pair

The second interview occurred between Micro-Enterprise B and Business Incubator B. Business Incubator B was part of a listed corporate in South Africa, and Micro-Enterprise B was being supported by the corporate by providing services to it. This is termed as enterprise and supplier development and supports the supply chain in the corporate [1].

It is suggested from the frequencies of the themes of Micro-Enterprise B, and the business incubation for this, Micro-Enterprise B had a strong focus on their business strategy (with frequency of 30). This business strategy focus suggests that the business strategy of that with that the enterprise and supplier development hub of that the Business Incubator B (Business Incubator B has a frequency of 31 for the Business Strategy). In addition, it is suggested that the factors theme mentioned for Micro-Enterprise B refers to performance metrics that are, in turn, used by Business Incubator B for their performance metrics. This suggestion is reinforced by the fact that Micro-Enterprise B had a frequency of 26 for the factors theme, and Business Incubator B had a frequency of 62 for its respective factors theme. It is also interesting to note that the Business Operations theme for Micro-Enterprise B and Business Incubator B have a closely related business processes within one another. This is confirmed by their frequency of 12 and 14 for Micro-Enterprise B and Business Incubator B respectively.

The functions for Micro-Enterprise B posed more towards the corporate capabilities. A crucial cog for the Business Incubator B was the level of BBBEE certification for Micro-Enterprise B. With the broadening of the BBBEE Framework in 2015, many corporates and the enterprise and supplier development hub have been advocating BBBEE compliant companies. With a frequency of 2, it was sufficient to suggest that Micro-Enterprise B were ensuring that they continued to remain on the vendor list of the corporate, and in return, continue to be incubated by Business Incubator B. This pattern is suggested by the frequency of 20 for the function of incubation. The behaviour of the interviewee for Micro-Enterprise B was such that they were ambitious and driven to make a success out of the business. A frequency of 16 for the success factors may have suggested these claims. Micro-Enterprise B competed for business from corporate through tendering. This tendering process was completed via the corporate's supply chain facilities and ensured supplier and enterprise development through the outsourcing of the non-core business activities. This function of outsourcing also emerged through the content analysis. Among the key success factors that were identified as enablers for Micro-Enterprise B were, tendering success rate, networking, good leadership, possessing sufficient cash flow in the business and maintaining liquidity, drawing results from successful incubation, training, good Technical skills, good Management Skills, good negotiation skills, good financial and HR skills, and the correct form of mentorship. Among some of the failure factors that were identified were lack of focus among Business Incubator B and the Micro-Enterprise B, Lack of implementation of solutions, lack of business skills, and lack of strategic oversight.

It was also interesting to note that incubation emerged as both a function and an enabler. This may have been because of the Lack of focus during the coding and content analysis process, and Incubation acts both as a function and an enabler for Micro-Enterprise B which is necessary as a crucial cog for supplier and enterprise development for the corporate.

As mentioned before, Business Incubator B not only acted as an incubator for the corporate but also as an enterprise and supplier development functions to integrate the supply chain and make it more competitive as well. In addition, this was also a way for the company to adhere to stricter BBBEE legislation as mentioned above [35]. The theme of incubation, with a frequency of 30, suggested that Business Incubator B understood their job functions relatively well and realised the importance of their function as a crucial economic entity. In addition, the corporate was located far from the economic hub of the country, Johannesburg. Official data suggests that migration to cities in South Africa has increased substantially over the last 20 years. This proves that the corporate realises that they have an important responsibility towards the economic and sustainable development of surrounding communities. As a result, they have enacted a decision to support emerging entrepreneurships by outsourcing non-core business activities. A focus on factors, success and failure was the largest frequency in the themes. This suggests that factors were used as metrics and this determined the performance of Business Incubator B [36]. Business Incubator B also realised the funding was crucial for sustaining their activities and that of Micro-Enterprise B [37]. The success factors for Business Incubator B were, Focus on all stakeholders, compliance to systems, measurable and good quality financial indicators, number of jobs created, growth in business, and continuous improvement. Some of the failure factors mentioned by Business Incubator B were Unsupportive government policies and failure mind set/entrepreneurial attitude. These success and failure factors acted as enablers for the incubation process.

5.3 ICT Pair

The third interview was conducted between Micro-Enterprise C and Business Incubator C. Both these entities operate within the ICT (Information and Communication Technology) industry. It was a great opportunity for the research to gain exploratory perspectives and insights into this since ICT start-ups are an upcoming industry around the world and crucial cog to the service industry in South Africa [38].

Micro-Enterprise C is very technologically focused, a recurring enabler that had a frequency count of 22. Like Micro-Enterprise A and B, the themes that emerged in the high frequency count were business operations, business strategy and a focus on the factors that would guarantee their success. Being a relatively new business in the market (the company had only started in 2015 by students at a tertiary institution in Johannesburg), there was a focus on getting their business model and business development correct. However, the book, the Lean Start-Up strongly advocates that an ICT start-up has one of two options to survive, namely, persevere or pivot [39]. This mind set is suggested by the high frequency count of 21, 39 and 82 for the business operations, business strategy and factors respectively. Micro-Enterprise C had attempted to ensure that their employees were as skilled as possible, and this is reflective in their emphasis on transparency and communication in their teams with a frequency of 10. The Lean Start-Up [39] advocates the use of transparency in start-ups to stream lines processes and systems. Some of the key success factors (enablers) for Micro-Enterprise C were use of technology, teamwork, continuous learning, Business Education, fluidity in internal processes and solution generation, building a strong brand and reputation and diversification. Some of the failure factors for Micro-Enterprise C were lack of funding, suitable access to markets, lack of technological skills, lack of business research, lack of funding, lack of human resources, lack of government support, and poor work culture. These failure factors are fairly common in the ICT industry owing to its lack of understanding in the South African context [40]. However, South Africa, like many emerging markets are realising the value of ICT and technological start-ups and are steadily embracing the industry [41]. This seems to be reflected by the enablers, or the success factors mentioned of Micro-Enterprise C.

Business Incubator C had a strong focus on the factors that defined their incubation success and failures. This was reflective with a frequency of 28. However, like Micro-Enterprise C, they were actively involved in their business operation, with a frequency of 12. It was interesting to note that Business Incubator C did not have a large frequency count for funding, but may have realised that the best way to incubate a technology start-up in the ICT industry was through sufficient understanding of the market [42]. This is suggested by this recurring in the theme, function and enabler during the content analysis. As expected, Business Incubator C realised its core function as an incubator, with the function of incubation appearing with the frequency count of 12 during the content analysis. The success factors (enablers) identified were Micro-Enterprise C winning large contracts, Micro-Enterprise C's tender success rates for large corporates, SME's and government businesses, Capacity building for Business Incubator C and Micro-Enterprise C, Mentorship and guidance, Dedicated specialist for incubation, Organisational effectiveness, Networking, and a Positive attitude in personnel for Business Incubator C and Micro-Enterprise C. The failure factors identified were Lack of understanding of the environment of Business Incubator C and Micro-Enterprise C. The failure factor identified proves that the recurrence of understanding of market is very important for any start-up in the ICT sector [43].

5.4 Key linkages

The linkages for Interview 1 can be seen in Table 3. The factor column quantified the link. The key linkages for the business incubators and micro-enterprises that emerged for themes were business operations, business strategy, business model and factors. The linkages for the corporate correlated well. A possible reason for this could be because Micro-Enterprise B required good integration into the supply chain of the corporate. Business Incubator B realised this and focused its attention into ensuring successful integration. The only other theme that contained high level of links was factors.

There seemed to be a low level of linkage between the functions and enablers that were identified. However, it should also be noted that the level of linkage depended on the frequency of each function and enabler that were identified. Some of the functions that were identified that contained a low link were incubation, BBBEE legislation and internships. However, and as expected, success and failure factor functions were identified as having high linkages, even though their overall scores were very low.

There seemed to be a low level of linkage for the enablers. Some of the enablers that linked, but had a low or very low level of link but a high factorial score were good management, favourable market conditions, competition, sound understanding of management principles, preferential procurement, funding, training and sustainability. There were also cases of topics that came up cross-functionally such as risks, funding, entrepreneurship techniques and incubation. This served to show that certain enablers, functions and themes acted in co-existence.

All themes, functions and enablers were validated using existing data and research pertaining to success and failure factors of micro-enterprises and business incubators in the South African context.

6. CONCLUSION

The success of the micro-enterprise and business incubator relies in the fact that both entities need to function as a for-profit business. Micro-Enterprises continue to have a strong focus on business operations and business incubators continue to be focused on development. There is a common thread of incubation for both micro-enterprises and business incubators. They realise the need for this to be done sustainably, and requires skilled management, adequate funding and the correct form of entrepreneurship. The links existed predominantly at the theme level, but minimally on the function and enabler level. This depicts that there is some level of link between the success and failure factors of micro-enterprises and business incubators. This also suggests that although incubation is a viable economic development tool, more attention should be given at a granular or enablement level that will improve incubation and business development.

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AN ARCHITECTURE FOR CUSTOMER EXPERIENCE IN A PARTNERING VENTURE

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ABSTRACT

We live in a digital world where technology is becoming dominant and the question arises on how do we look after our customers. To investigate it, a research study is conducted to determine how big data analytics together with business partnering can be used to manage the experience a customer has with a product or service. Our aim is to develop a demonstrator as a possible solution to the question. A system architecture for the demonstrator will be constructed based on a case study. In this article, we report on the current state of the research and discuss preliminary findings and future work.

OPSOMMING

Ons leef in 'n digitale wêreld waar tegnologie oorneem en die vraag ontstaan oor hoe ons na ons kliënte omsien. Om dit te ondersoek, word 'n navorsingstudie gedoen om vas te stel hoe data analise saam met vennootskappe tussen besighede gebruik kan word om die ervaring van 'n kliënt met 'n produk of diens te bestuur. Ons doel is om 'n demonstrator te ontwikkel as 'n moontlike oplossing vir die vraag. 'n Argitektuur vir die stelsel vir die demonstrator sal gebou word op grond van 'n gevallestudie. In hierdie artikel rapporteer ons oor die huidige status van die navorsing en bespreek voorlopige bevindings en toekomstige werk.

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1. INTRODUCTION

We live in a world known as the “digital world", where technology is becoming more prominent and replacing the “old ways" of doing things. Technology opens many opportunities for businesses and they now have access to large volumes of data. Furthermore, technology provides the opportunity for businesses to partner to enhance their products and/or services. But while this is happening, how is the customer being looked after?

Therefore, for a business to keep up with this technological transformation of the world while still looking after their customers, the business should shift from a *business centric* to a *customer centric* view according to Rich [1]. For this to happen, businesses should first determine what their customers’ needs are and how to satisfy them, while still bringing value to the market. However, there is still a gap between the customer perspective and the company perspective. A survey performed by Bain & Company [2] has shown that 80% of managers believe their company delivers a superior experience to their customers, when in fact only 8% of the companies achieved that based on the customers’ answers. With this comes in the factor as mentioned by Meyer & Schwager [3] that a customer’s experience consists out of every aspect of what a company offers. These aspects include the quality of customer care, advertising, packaging, product and service features, ease of use, reliability, etc. Therefore, a study needs to be conducted to determine how to manage the experience a customer has with the products and/or services of a business.

The aim of this study is to determine how to use big data analytics and business partnering to manage a customer’s experience. The study is an ongoing research project and forms part of a mutual, ongoing project done by the Unit for Systems Modelling and Analysis (USMA) research group in the Industrial Engineering department at Stellenbosch University. In this research project, a *capability demonstrator* will be developed to determine how to manage customer experience by using big data analytics. The demonstrator will take the form of a digital information and support system known as the *trip planner*. The research project is based on a case study, and the purpose of the case study is to show how the proposed trip planner plans a trip for an individual, assuming the individual needs different modes of transport and stays at least one night away from home. The individual will inform the system about where she wants to go, what date she wants to leave, what date she wants to return and the budget for the trip. The system will then plan and book the trip based on her historical behaviour and her preferences. By doing this, the system should deliver a ‘superior’ experience for the customer by addressing her needs in the way that she desires.

The remainder of this paper describes the ongoing research project and how it is being done. The first section gives a condensed overview of the literature to understand how the demonstrator should be designed and how customer experience management, big data analytics, and business partnering relate and integrate with one another. The second section describes the proposed model for the demonstrator that will be used to complete the research project. The third section gives the status of the project based on a toy problem. The last section describes the future work that needs to be done to complete the research project. The conclusion section provides a summary of the key concepts discussed throughout this paper, the future studies and how the authors’ work relates to the mutual project of the USMA research group.

2. LITERATURE STUDY

In the first part of this ongoing project, research was done on customer experience management, big data analytics, and business partnering to understand key concepts as well as how these subjects interact with one another. A condensed overview of these three subjects will be discussed in this section.

2.1 Customer Experience Management

Customer experience management is a management approach used to control and improve a customer’s experience. To understand it in more depth, firstly customer experience will be discussed, and secondly, management approaches for customer experience will be discussed with the focus on customer relationship management and customer experience management, followed by a comparison between them. Lastly, a brief overview will be given on the customer journey and the customer sentiment and its influences on customer experience management.

2.1.1 Customer Experience

Customer experience (CX) has been present from the start of trading. The first recorded customer complaint has been engraved on a clay clip and can now be seen in the *British Museum* [4], [5]. But a customer complaint is only a way in which a customer expresses his/her problem or dissatisfaction with a product and/or service. CX expands beyond the observation of how satisfied a customer is. It can be defined as the sum-total of experiences a customer has with a product and/or service. It expands throughout the entire journey of interaction with the particular product and/or service. CX starts at the first business interaction, before the buying phase until after discontinued use of the product or service [3], [6], [7].

To measure these experiences, it is important to know when is the 'right' time to do it. A customer has an experience with a product and/or service during specific touch points and it can be used by a company to capture a customer experience [6]. According to Meyer & Schwager [3], touch points are "instances of direct contact with either the product and/or service itself or with representations of it by the company or some third parties." At these touch points, measurements are used to capture the experiences. Most of these measurements are customer satisfaction measurements [8]–[13]. These touch points are then recorded over the customer journey.

But why is it important to know what CX is and why would a company want to measure it? It is a critical success factor to a company because as the customer experience is improving, it will lead to an increase in profit and customer loyalty [14]. For a company to achieve this, the following three aspects should always be present, according to Dandridge [15]:

1. See everything through the customer's eyes.
2. Listen to your customer.
3. Empower the employee to ensure the customer is being looked after.

To achieve the 'superior' CX, it is important to know how to manage it.

2.1.2 How to manage Customer Experience

Several management approaches for customer experience have been defined in literature. The most common management approaches for customer experience are:

- Customer Relationship Management
- Customer Interaction Management
- Customer Knowledge Management
- Customer Experience Management
- Service Quality Management

Of these five management approaches the two approaches most used by industry are customer relationship management (CRM) and customer experience management (CEM). CRM is the popular approach and has been present for over a decade, whereas CEM is a novel approach [3], [7], [16], [17].

According to Payne & Frow [18] CRM is "a strategic approach that is concerned with creating improved shareholder value through the development of appropriate relationships with key customers and customer segments." Therefore, it enables businesses to critically assess their internal components after interactions with a customer as they determine what can be changed with regards to their processes, systems and skills of the business itself.

CEM on the other hand is a strategic management approach that manages all the experiences a customer has with a product and/or service. As Walden [16] points out, it is not managing an experience without a customer. Rather it determines how a business should proactively respond to the drives and needs of a customer. As mentioned by Best et al. [7] "it is an approach where a business is transformed from a business centric to customer centric approach." The business looks at ways to deliver high value to their customers and change the processes, systems and skills accordingly. One might even say that the goal of CEM is to optimize the CX.

Therefore, there is a difference between them. A comparison between CRM and CEM can be seen in Table 1. It is important to note that CEM is not necessarily a replacement of CRM, but CEM is built on top of good CRM processes and practices to take the business a step closer to customers. Another important distinction is that CEM is not only focussing on transactions, but will rather go beyond it to build rich relationships with their customers [17].

Table 1 — Comparison of CEM and CRM ([3] modified)

	CRM	CEM
Strategy / Approach	"Inside-out" Thinking (business centric)	"Outside-in" Thinking (customer centric)
Focus	Inward	Outward
What	Captures and distributes what a company knows about a customer	Captures and distributes what the customer thinks of a company
When	After recorded customer interaction	At customer interaction points

How	• Point of sale • Market Research • Tracking of sales	• Targeted studies • Observational studies • Voice-of-customer research
Who	Customer-focused groups	Business of functional leaders
Relevance for Future Performance	**Lagging:** Drives cross-selling by bundling in products in demand with ones that are not	**Leading:** Locates places to add offerings in the gaps between expectations and experiences

The next aspect to look at is how the customer journey and sentiment influence the CX and the impact of it on CEM.

2.1.3 Customer journey and sentiment

A customer journey as defined by Lemon & Verhoef [19] is "the journey a customer has with a firm over time during the purchase cycle across multiple touchpoints". The customer journey can be viewed over three distinct phases namely the (i) pre-purchased (buying), (ii) purchased (using) and (iii) post-purchased phase (sharing) [20]. These three phases can then be further subdivided. During these phases, the CX is recorded at various touch points. Each customer has his/her own unique customer journey. An outline of it can be seen in Figure 1. It is important to note that the customer journey happens across multiple channels and that these channels also have an impact on the customer journey. When the CX is captured by using the customer journey, it improves the ability to manage it.

Customer sentiment is defined by Mitra & Kawecki [21] as the "differences between customers (specifically human users) in terms of their subjective perception of their experiences." These perceptions can be in terms of the customers' diverse opinions and observations. It is dependent on the context, situation and arbitrary factors of the customer surroundings.

Therefore, customer journey is a way to capture the CX and customer sentiment is required to understand the context in which a CX occurs. In the next section, big data analytics will be discussed.

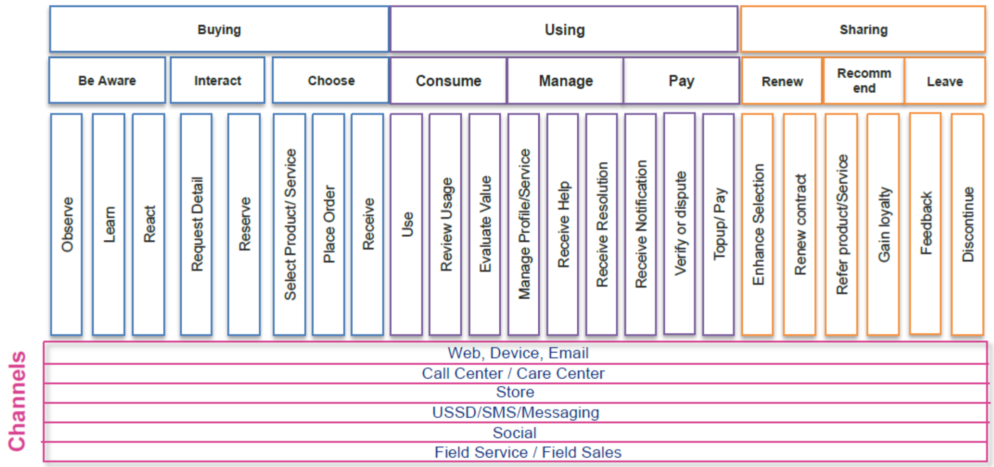

Figure 1 — Outline of the Customer Journey [20]

2.2 Big Data Analytics

According to USMA [22], "Big Data Analytics (BDA) is a methodology used to analyse big data sets in order to create value for an enterprise." To understand this methodology in more depth, big data will be discussed to understand what is meant by it and when is a set of data classified as big data. Thereafter, BDA will be discussed based on how it used as a methodology for the analysis of big data sets.

2.2.1 Big Data

An important question regarding big data is, when do one know that a data set can be classified as a big data set? According to Anderson & Semmelroth [23], big data refers to "sets of data that are far too massive to be handled with traditional hardware." In other words, those sets of data that are too large to be analysed in traditional ways and advanced hardware or software is needed. To understand big data in a broader sense, it is important to look at its definition.

In literature, big data can be defined by using various dimensions. The first authoritative definition of big data is defined by Laney [24] who states that big data can be defined according to the three Vs. The three Vs are *Volume, Variety* and *Velocity*. The industry standard is to define it based on these three Vs [25]. The three Vs, represent the following data characteristics:

1. *Volume*: The large quantity of data that is gathered.
2. *Variety*: The wide variety of formats in which data is captured.
3. *Velocity*: The rate at which data is gathered and/or captured.

Currently, most enterprises only store these big data sets but have no clue on what to do with them. According to Zikopoulos et al. [26], "no one has ever delivered a single penny of value out of storing data and most enterprises do not have the ability to do more than just store these large sets of data." Therefore, a methodology should be used to understand how to create value out of these data sets. BDA is such a methodology.

2.2.2 Big Data Analytics

From Figure 2, BDA can be explained as follows. It is a methodology that is composed of various knowledge management processes. These processes are used to gain knowledge from big data in a structured way by undergoing various phases or steps. The three common processes used are *KDD* (Knowledge Discovery in Databases), *SEMMA* (Sample, Explore, Modify, Model and Assess) and *CRISP* (Cross-Industry Standard Process). A comparison of these three processes was done by Azevedo & Santos [27]. Other processes that are mostly derived from KDD and CRISP can also be used as defined by Mariscal et al. [28]

These processes consist of several phases or steps, including the data mining phase or step. The data mining phases or steps are the process of discovering patterns in data [29]. The tools and techniques used to perform these data mining phases or steps are done by machine learning. Machine learning is when a computer is programmed to learn from a set of input data fed to them [30]. By learning, the computer can perform a process of converting experience into expertise or knowledge that can be used to generate value.

As stated earlier, machine learning consists of tools and techniques. The four types of tools used are supervised learning, reinforcement learning, active learning or unsupervised learning. The two most common tools used is that of supervised and unsupervised learning [30]. Supervised learning is when test data sets are provided for training to develop the desired output. For example, when data about customers should be sorted based on their accommodation preference, test data with the category of whether the preference is hotel or guest house is given, to analyse the dataset. Whereas unsupervised learning is when no test datasets are provided but the goal is to come up with ways on how to cluster the data correctly. For example, here the analysis of customers' preferences of accommodation type is sorted but the learner should detect by itself whether the customer prefers a hotel or guest house. The tools are composed of various techniques. These techniques are as stipulated in Figure 2 and for the various tools, either one or a combination of techniques can be used to perform machine learning.

Therefore, BDA is a methodology that consists of knowledge management processes. These processes contain data mining phases or steps, which are responsible for performing machine learning. By doing this, an enterprise can create value from their big data sets. In the next section, business partnering will be discussed.

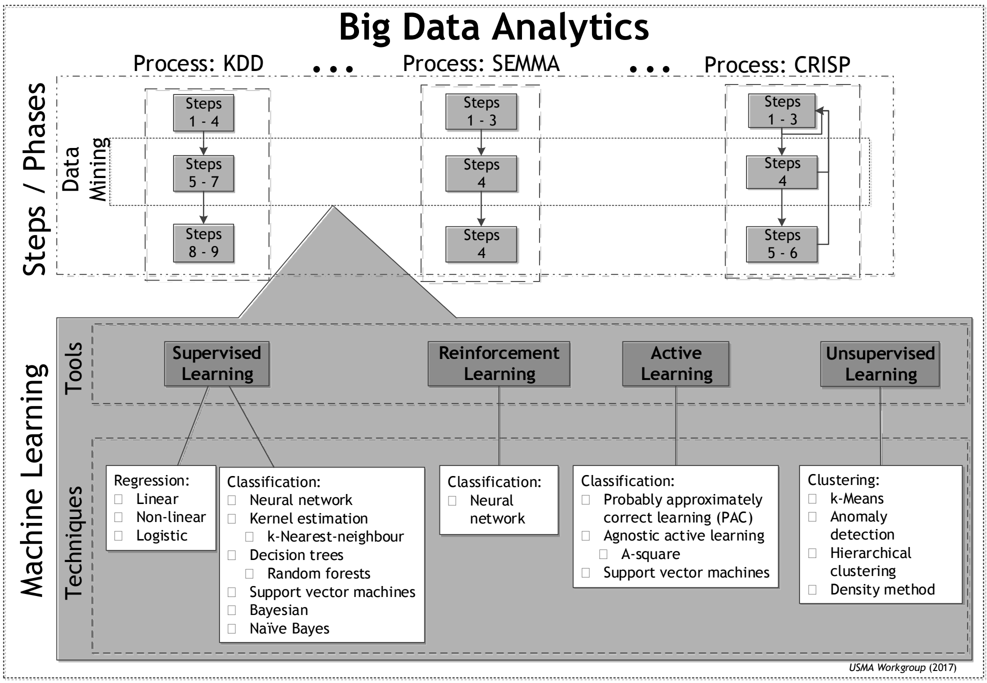

Figure 2 — Big Data Analytics [22]

2.3 Business Partnering

Business partnering can take on various forms and can be viewed from various angles. According to Sheth & Parvatiyar [31], "business partnering can be among competitors and non-competitors and it may exist for operational or strategic reasons." For the purpose of the research project, the definition by Ellram & Hendrick [32] will be used which states that "business partnering is an ongoing relationship between two (or more) firms that involves a commitment over an extended time period, and a mutual sharing of information and the risks and rewards of the relationship." According to Wucherer [33] the benefit of it is that these businesses produce economically relevant innovations into the market and they improve their competitiveness and market position.

For such a relationship to be a success, the following elements should be present [33]-[35]:

- At all levels of the participating businesses, there should be a continuous and maturing culture of mutual cooperation.
- The businesses should completely trust each other.
- All the businesses should contribute to the relationship and play an active role in it.
- All the businesses should be capable of
    - Knowing where the money is made in the business,
    - Managing risks and opportunities by valuing trade-offs and
    - Understand the partnering requirements and develop a roadmap to assess the feasibility of it.
- The businesses should have hard skills, for example, be IT proficient and have a broad business understanding. They should also have soft skills, for example, communication, interpersonal skills and strong conviction and persuasion.

If these elements are present, the participating businesses stay committed and work towards a common goal, the business partnering should be a success. In the next section, the interrelationship between BDA, business partnering and CEM will be discussed.

2.4 Big Data Analytics and Business Partnering impact on Customer Experience Management

Now that an overview was given for BDA, CEM and business partnering, the question is how do these three concepts integrate with each other to manage a customer experience in the best way possible?

In Figure 3 the relationship between BDA and CEM can be seen. From Figure 3, BDA is used to analyse data about the customer. From this analysis, trends about the customer can be identified in terms of their expectations and behaviour. By using this knowledge together with the principles of CEM, a customer experience can be improved to add value to the business. But how does 'business partnering' fit in? Business partnering acts as the enabler for businesses to partner with each other to understand their customers by using data of the customers on a cross-functional platform and by partnering, the businesses are then able to improve the customer experience. The business partnering cross-functional platform will be a technology platform that is information based.

With the knowledge gained from these three subjects, together with system architecture and simulation, a demonstrator can be designed and constructed to further determine how these three subjects interrelate and what limitations exist with it. A proposed model for the demonstrator will be discussed in the next section.

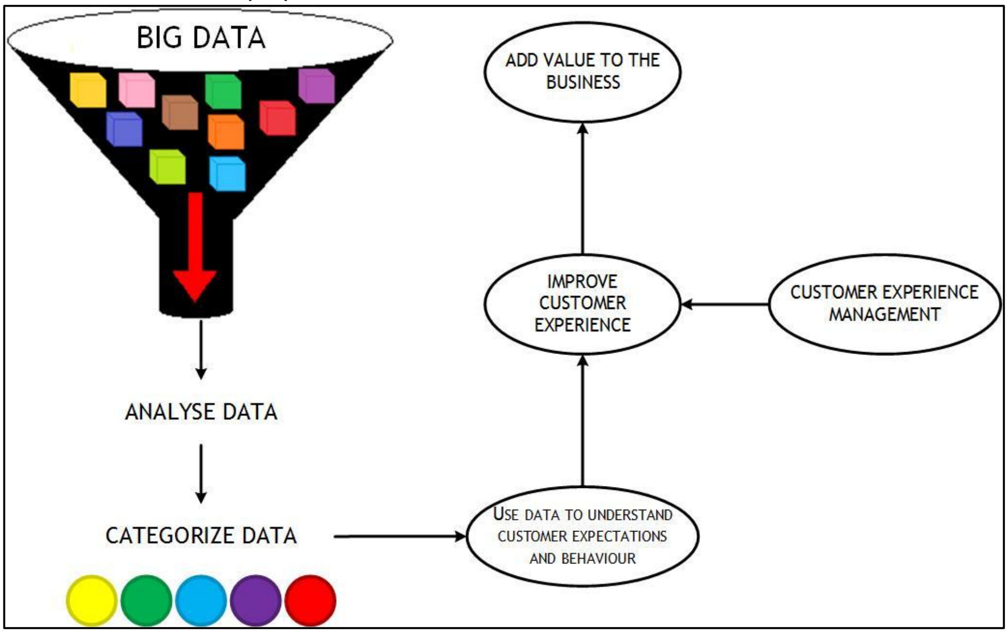

Figure 3 — Big Data Analytics together with Customer Experience Management [22]

3. PROPOSED MODEL

For the ongoing research project, a demonstrator needs to be developed. The demonstrator will be implemented as a digital system known as the *trip planner*. Conceptually, this system should allow a person to provide a date of departure, point of departure, arrival date(s) and destination(s), as well as a budget. The trip planner will then plan a trip for the customer using the resources of the participating business partners, as well as data of the customer (if existing). The activities of the trip planner will be realised with a simulator. Therefore, the proposed model will be presented as a system architecture to fulfil the needs of the demonstrator. Note that many other digital systems could be used for a demonstrator, for example *TripIt*, *TripCase* and *WorldMate*.

The architecture for the proposed model was designed using the Object-Process Methodology (OPM) as developed by Dori [36]. OPM is an ISO standard (ISO19450) and it is an approach in which systems can be represented as a set of Object-Process Diagrams (OPD) and corresponding Object-Process Language (OPL), which is a collection of sentences describing the OPD. By using OPM, the structure and behaviour of a system can be integrated into a single model. The model contains the two important elements of a system, the objects and processes. The objects are static things in the system that can be changed by the processes.

The graphical representation (OPD) for the proposed model architecture can be seen in Figure 4 and the semantic representation (OPL) for it can be seen in Figure 5. The proposed model consists of two processes.

The first process is the trip planning. For this process, BDA is required to analyse all the inputs to create the desired trip plan for the customer based on the trip details, the historical behaviour of the customer and the customers' preferences. Business partnering is also required, as it will be used to enable companies from the main forms of transportation, destination forms of transportation and accommodation to partner with one another in the system to enable the trip planner to develop the desired trip plan for the customer. This partnering should happen across a platform, where this platform represents the business model of the demonstrator.

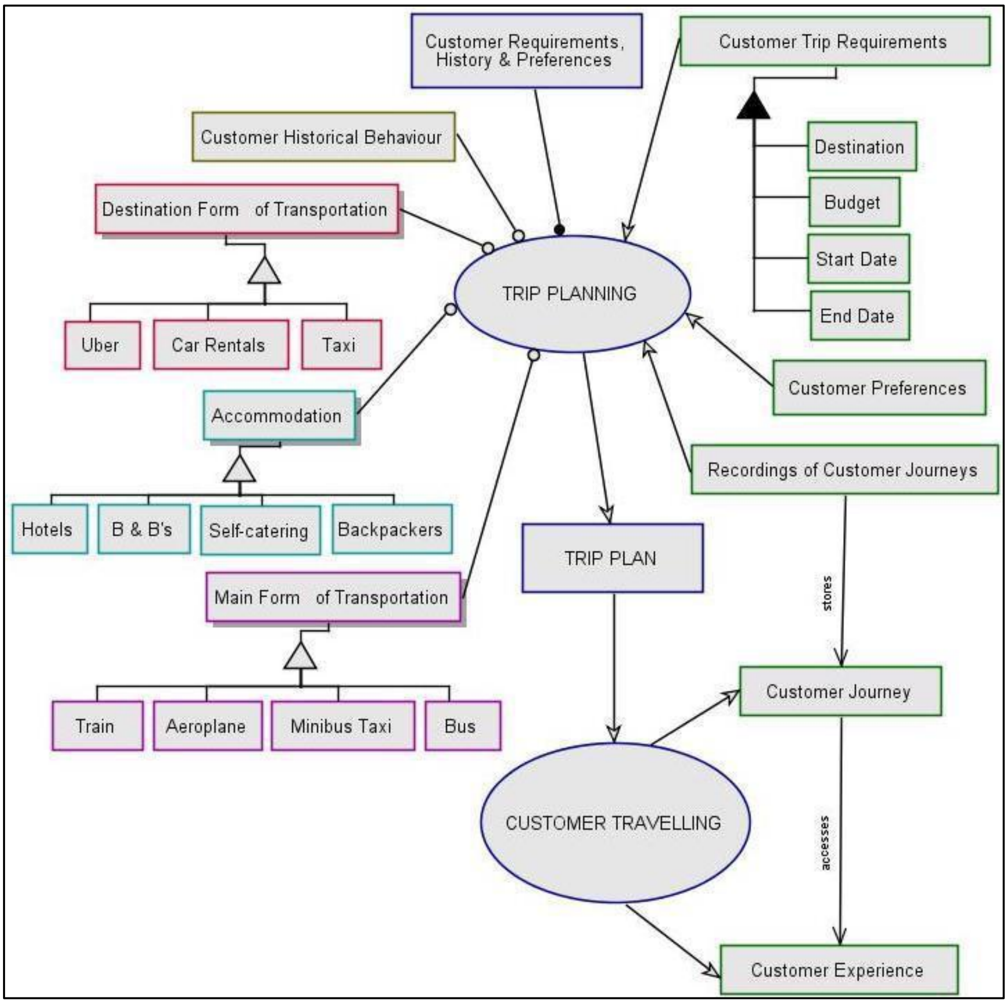

Figure 4 — OPD for Proposed Model Architecture

The difference between the main form of transportation and destination form of transportation is that the first type of transportation is the mode used to get the customers to their destination point and the second type of transportation is the mode of transportation used at the customer's destination point.

The second process is the customer travelling process. During this process, the customer will get notified by the system on details of the trip at the right time and place. After the customer has completed each activity of the trip plan, the experience will be recorded on the customer journey. After a customer completed the trip, the customer journey will be stored as a record in a data store. The historical customer journeys will be used as an extra input into the trip planning system.

The analysis for this research project, will be done by considering all the unique customer journeys. By doing analysis on them, it should be determined, how well the customer expectations were met and whether the customer left as a satisfied customer or not. In the next section, the status of the project will be discussed based on a toy problem.

Main Form of Transportation is physical.
Destination Form of Transportation is physical.
Accommodation is physical.
Customer Trip Requirements consists of Start Date, End Date, Budget, and Destination.
Customer Requirements, History & Preferences handles TRIP PLANNING.
Customer Journey accesses Customer Experience.
Recordings of Customer Journeys stores Customer Journey.
Aeroplane is a Main Form of Transportation.
Bus is a Main Form of Transportation.
Minibus Taxi is a Main Form of Transportation.
Train is a Main Form of Transportation.
Uber is a Destination Form of Transportation.
Taxi is a Destination Form of Transportation.
Car Rentals is a Destination Form of Transportation.
Hotels is an Accommodation.
B & B's is an Accommodation.
Self-catering is an Accommodation.
Backpackers is an Accommodation.
TRIP PLANNING requires Customer Historical Behaviour, Accommodation, Destination Form of Transportation, and Main Form of Transportation.
TRIP PLANNING consumes Recordings of Customer Journeys, Customer Trip Requirements, and Customer Preferences.
TRIP PLANNING yields TRIP PLAN.
CUSTOMER TRAVELLING consumes TRIP PLAN.
CUSTOMER TRAVELLING yields Customer Journey and Customer Experience.

Figure 5 — OPL for Proposed Model Architecture

4. STATUS OF THE PROJECT

The status of the project represents what has been derived from the literature and how the proposed model can be used to solve a small-scale problem. A toy problem, which is a simplified problem that imitates the bigger problem, will show how the demonstrator will manage a customer experience.

The toy problem is as follows, with an illustration in Figure 6. Suppose we have a customer with the name Thandi. She lives in Cape Town and wants to attend her cousin's wedding just outside Durban this Saturday. She indicates to the system that she wants to leave Cape Town, after work on Friday and wants to be back by Sunday afternoon. The system then books and pays for the flights and accommodation based on Thandi's preferences and history. Thandi will be notified by the system on all her flight and accommodation details as well as how she will be getting around in Durban. The system will notify Thandi by using the channel she preferred. Thandi has indicated that she wants to receive all notifications on her mobile device and by e-mail.

The system will then perform the following steps, based on the numbering in Figure 6. The numbering represents instances when Thandi will receive these notifications. After an action is performed, Thandi has the opportunity to give the system feedback on her experience.

At 1, the system informs Thandi an hour beforehand on who will pick her up and at what time, as well as what documentation she should take along with her on the trip. Since she only used Uber in the past, the system books an Uber vehicle for her. At 2, the system informs Thandi that her boarding pass is available on her mobile device and the counter number she should go to and drop her bags off. At 3, the system informs Thandi just as she goes through the security gates, that there is a special at her favourite coffee shop, which is located five minutes away from her boarding gate. Since Thandi still has 45 minutes to spare, she decided to order her favourite latte with a double chocolate muffin and pays for it by using her banking app. At this point she notifies the system that she is satisfied with her trip thus far and she is glad about the notification about the special.

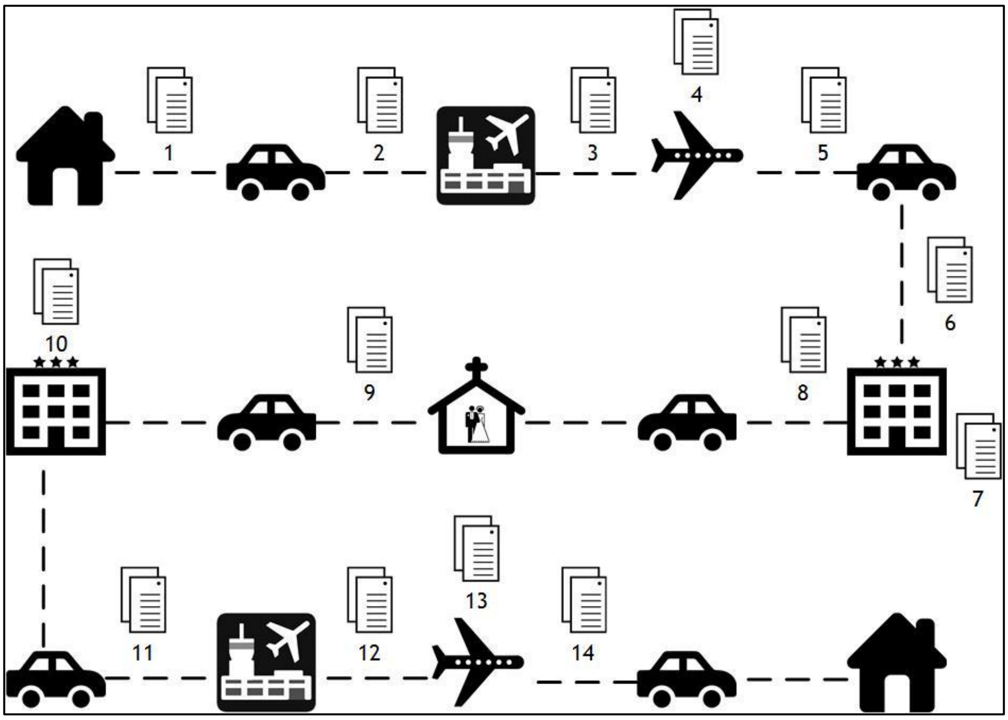

Figure 6 — Toy Problem

At 4, when Thandi boards the plane and finds her seat, the system informs her that she still has 60% left to read of the book on her kindle and that the soundtrack of the latest movie she watched has been downloaded and is available on both her kindle and mobile device. Thandi decides to only listen to the music, as she is not in the mood to read and notifies the system accordingly. At 5, the aeroplane lands in Durban, and the system informs her that Virat's Taxi will be at the drop-and-go in 20 minutes, which gives her more than enough time to collect her bags. At 6, she is taking to the hotel and the system informs the receptionist that Thandi will be arriving in 15 minutes. When Thandi arrives at the hotel, she notifies the system that she was not satisfied with her ride and prefers Uber. When she enters the hotel, the reception staff are awaiting her and she is taken to her room.

At 7, on the morning of the wedding, the system wakes Thandi up, two hours before her Uber vehicle will be arriving. The system knows Thandi takes one and a half hour on average to prepare. At 8, the system notifies Thandi that the Uber will be arriving in five minutes and that she can wait in the foyer of the hotel. The Uber vehicle drops her off 10 minutes before the wedding starts and Thandi notifies the system that she did not like the music of the Uber driver.

Thandi informs the system that she will be needing a lift in 15 minutes to take her back as she noticed that the wedding party is slowly starting to end. At 9, similar actions are performed as at 8. The Uber vehicle eventually takes her back to the hotel. She meets some of her friends and have a few drinks in the bar of the hotel. At 10, the system informs her that it is 11 o'clock and she needs to be up at 9am latest to catch her flight back home. The system also informs her that the hotel awarded her with a free ride to the airport. Therefore, she decides to go to bed.

On the Sunday, Thandi arrives 10 minutes before 11am in the foyer to wait for her ride to the airport. At 11 the same actions are performed as at 1. At 12, just as Thandi passes the security gate, the system informs her that her favourite restaurant is open and that the book store has specials. Since Thandi is not hungry and not in the mood for spending money, she decides to read the book on her kindle while she waits for her flight and informs the system accordingly.

At 13 and 14, similar actions occur as at 4 and 5. The Uber vehicle drops Thandi safely at her home Sunday afternoon and Thandi gives an overall rating for her trip and notified the system that the rest of the Uber drivers after 8, played music that was according to her taste.

This toy problem assumes the ideal world — everything works as planned. Of course, exceptions and problems will eventually be considered. In the next section the future work for the project will be discussed.

5. FUTURE WORK

The work that still needs to be done for this research project is to implement the architecture for the proposed model into a simulation model by using a software package, while the analysis of the results gathered needs to be analysed with BDA. Currently, the Technomatix software will be used for simulation model, as the system activities occur at discrete time points. The results of the simulation model will be unique customer journeys in which the customer experience is captured. Matlab software will be used for the analysis of the results.

Based on the analysis of the results, suggestions will be made to show how big data analytics and business partnering as a platform can be used to perform customer experience management. Aspects will also be considered to determine what obstacles one will encounter with going ahead with such a venture, for example systems integration and the physical and software platform needed.

6. CONCLUSION

In this article, the work for the mutual ongoing research project has been recorded based on what has been done and what will be done in the future. This research project is part of an effort by the USMA Research group, and it contributes to the findings around big data analytics and how big data analytics can be used in various domains of a business.

It was seen that together with BDA and CEM, the experience a customer has with a product and/or service over the entire journey of interaction can be controlled and improved. A business partnering platform can be added to this business model as an enabler, in order to manage a customer's experience to a greater extend.

All these require understanding of systems, integration and interfacing subsystems, and above all, the importance of human being as part of such complex systems. The industrial engineer is the best suited person to drive and implement such developments, because industrial engineers have an understanding of systems, system integration and resources like people, IT and finances.

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THE APPLICATION OF PRODUCTION-RELATED INFORMATION TECHNOLOGY ARCHITECTURE TO IMPROVE ON VISUAL MANAGEMENT SYSTEMS WITHIN THE MANUFACTURING INDUSTRY

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ABSTRACT

This research investigates the relationship between the advancements in information technology and the effects thereof in the manufacturing industry in relation to the increasing complexity of modern production. Specifically, the study focuses on the use of Production-Related Information Technology Architecture (PRITA) to improve data sourcing, processing and communication within the manufacturing environment in order to improve the use of Visual Management Systems (VMS). Case studies were developed and investigated with the aim of identifying the elements of VMS that facilitate data sourcing and processing to yield production-related information that can then be displayed digitally. The results revealed that the VMS was considered an important value-adding element to the manufacturing industry and was supported by the majority of the expert interview participants. VMS provided the functionalities of trend analytics that could provide information regarding the operational condition of production and making conservative predictions of the production scheduling using current cycle time trend analysis. VMS can provide the solution to understanding and relaying information to improve on the traditional flow of information. This new method will involve an increased amount of data collection on lower operation levels. The information can flow up through managerial levels to produce action items for lower level execution. The study concluded with an effect and benefit summary of the PRITA and VMS model, a cost and labour analysis and a discussion of research limitations.

OPSOMMING

Hierdie navorsing ondersoek die verband tussen die vooruitgang van inligtingstegnologie en die effek daarvan op die vervaardigingsbedryf in verhouding met die toenemende kompleksiteit van moderne produksie. Die studie fokus meer spesifiek op die gebruik van Produksieverwante Inligtingstegnologie-Argitektuur (PVITA) om data-verkryging, verwerking en kommunikasie binne die vervaardigingsomgewing te verbeter ten einde die gebruik van Visuele Bestuurstelsels (VBS) te verbeter. Gevallestudies is ontwikkel en ondersoek met die doel om die elemente van VMS te identifiseer wat data-verkryging en verwerking fasiliteer om produksieverwante inligting digital te kan vertoon. Die resultate het getoon dat die VBS as 'n belangrike waardetoevoegende element in die vervaardigingsbedryf beskou kan word. Die resultate word ook ondersteun deur die meerderheid van die kenner onderhoude. VBS het die funksionaliteit van tendensanalise inligting oor die operasionele toestand van produksie verskaf en konserwatiewe voorspellings van die produksieskedulering deur gebruik te maak van huidige siklustyd-ontleding bewerkstellig. VBS kan die oplossing bied om inligting te verstaan en om die tradisionele vloei van inligting te verbeter. Hierdie nuwe metode sal 'n toename in data-insameling op laer bedryfsvlakke teweegbring. Verwerkte inligting kan opwaarts vloei deur bestuursvlakke om aksie-items vir laer vlakuitvoering te produseer. Die studie het afgesluit met 'n effek- en voordeelopsomming van die PVITA- en VMS-model, 'n koste- en arbeidsanalise en 'n bespreking van navorsingsbeperkings.

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1. INTRODUCTION

According to literature, the previous three notable industrial revolutions were triggered by the evolution of technology [1]-[4]. The three technology advancements in question are: the invention of steam powered mechanical actions in 1784; the invention of the electrical motor in 1870; and the invention of programmable logic controllers (PLC) for automation purposes in 1969 [1]-[4]. These three technology advancements were able to increase the complexity of production operations within manufacturing industry and were, therefore, responsible for producing the next improved production paradigm. The three production paradigms were characterised by an increase in productivity and each came after notable technology advancement [5], [6]. They were: craft production in 1850; mass production in 1913; and followed by flexible production paradigm in 1970 [5], [6]. Now, when looking at the current technology advancements within the information age that led to the invention of the internet, then the question becomes: are the next production paradigm going to be led by the technology advancement of the information age? Such a progression of information technology (IT) may change the future of production when Internet of Things (IoT) and related technologies expand into the manufacturing industry and information sourcing, processing and analysing can become more precise and instantaneous [8], [9].

Considering the setting of the study in the South African context, the focus needs to shift to how productivity levels of low skilled workers can be increased using simple and easy understanding information communication techniques. South Africa, with its low technology maturity and limited funding, serves as a textbook candidate for research and development in the field of visual stimuli to convey information more effectively to the workforce. The objective is to increasing productivity levels of production operations and investigate further opportunities for manufacturing industries to incorporate visualization techniques [7].

The goal of this study is to investigate the role that effective information communication can play in improving production efficiency and to investigate production-related information technology architecture (PRITA) within a manufacturing environment and highlight the beneficial effects of a visual management systems (VMS). This study is guided by the following research question: What are the effects and benefits of applying PRITA to produce a VMS within the manufacturing industry?

2. LITERATURE STUDY

2.1 Cyber-Physical Production System

A CPPS is the union of computer science, information and communication technologies and manufacturing science and technologies [10]. CPPS is the unification of Cyber-Physical Systems (CPS) and production systems, and is prominently promoted in the principles of Industry 4.0 as the future of production systems [1], [2], [11], [12]. The theoretical system elements that resemble all the functionalities of CPPS are the following [10]:

(i) Intelligent manufacturing systems which are expected to solve, within certain limits, unprecedented, unforeseen problems on the basis even of incomplete and imprecise information,
(ii) Biological manufacturing systems, which are based on biologically inspired ideas such as self-growth, self- organisation, adaptation and evolution,
(iii) Holonic manufacturing systems (HMS), agent-based manufacturing, where autonomy and cooperation are the main characteristics of the entities.

CPPS could be considered an important step in the future development of manufacturing systems. Whether this step would be regarded as the fourth industrial revolution will be decided by the coming generations. Nevertheless, for now, CPPS could be looked at for inspiration with regard to future developments in the field of operation and control within the manufacturing industry.

2.2 Smart Production System

The objective of a smart production system is to process multiple types of operations simultaneously using communication and artificial intelligence principles to plan and execute production value streams [13]. The new smart production line will support rapid changeover and automatic setup for product variants by sourcing all the necessary information for processing and planning purposes from the master resource planner (MRP). Data collected from heterogeneous sources are being collectively processed to aid in the production process [2], [4], [11], [12], [14]-[16]. Information systems handling data from products and operators can be between shared machines, the workforce and smart factories [13], [15].

Being a promising production concept, there are challenges that have to be taken into account before smart production systems can be incorporated successfully [10], [13], [14]. For the purpose of this research the definition of smart production systems will be the following: Smart production systems collect big data in a smart factory via CPPS and intelligently filter information to convert knowledge into commercial value. Note that this definition includes big data, which is a concept that entails information mining from multiple commercial data sources [4], [17], but for the purpose of this research, only data within the smart factory manufacturing industry scope will be incorporated for concept demonstration.

2.3 Visual Management System

VMS is a set of techniques for creating a workplace that embraces visual communication in the work environment. Visual management is a tool that is focussed on improving organisational performance through connecting and aligning organisational vision, core values, goals and culture with other managerial levels of an industry by means of visual stimuli [18]. These stimuli communicate quality information which helps people make sense of the organisational processes and progress, in context and at a glance [19]–[21]. The information will have the following characteristics: necessary, relevant, correct, immediate, easy to-understand and stimulating for quick actions. It is a managerial approach that utilises either one or more visual devices to communicate information more quickly and easily. In so doing, the whole working environment becomes increasingly self-explanatory, self-ordering, self-regulating and self-improving for the individuals that is trying to make sense of it [22].

Visual management utilizes a range of functions in an organisation and tracks operations and processes over multiple managerial levels [18], [20], [23]. According to Tezel et al (2005) [22], [23], visual management tools can provide nine different functions within any organisation: transparency, discipline, continuous improvement, helping with job facilitations and on-the-job training, creates shared ownership and teamwork opportunities, management by facts, simplification and unification.

Figure 1: ***Deploying VMS according to Tezel et al (2005)*** [23]

According to Tezel et al (2005), VMSs can be deployed for the following reasons [23]: To see the problem, to communicate recommendations, to easily solve problems, to communicate the problem solving solution, and to communicate results to others involved. Currently, there is a great number of established manual VMS that have been developed, deployed and depended on. However, due to the advances in information technology, the implementation capabilities thereof have also evolved [23]. The new digital age can make real-time improvements in measurements, make big data collecting possible from multiple sources to produce holonic information of an organisation. Communication and interpretation of the information can consequently lead to improved behaviour analysis of an organisation and provide quick response to change [19], [20], [23]. Digital VMSs provide new functionalities that include real time updates, being clear and concise, flexible and customizable.

2.4 Internet of Things

According to Stankovic (2014), IoT can be defined as an intelligent network of connected things that communicate with each over the internet [24]. The purpose of the IoT and the reason for the recent interest in the field results from the revolutionary information exchange between sensing devices and is categorized as the first means of connecting the physical with the cyber world [15], [24]–[26]. Thousands of heterogeneous devices can gather information and present them to one another. Currently, this technology is used in home automation and weather monitoring, but in the near future, IoT would most likely see implementations in the form of smart cities, smart transportation and digital health amongst others [24], [27]. Future developments, according to Chen et al (2014), include improved data gathering techniques and intelligent processing [25]. He also suggests that before its general recognition, certain challenges must be addressed if IoT is to be fully harnessed. These challenges include the standardization of the architecture, communication, privacy and security as well as the related business model of IoT [25], [26].

According to literature, the next phase of IoT would consist of creating business models around the accessibility of information [15], [24], [28]. With the physical and the cyber world now more closely integrated, the opportunities for smart services using smart products will become possible in the near future [8], [15]. New possibilities of self-organizing systems, smart production systems and energy management systems would arrange themselves from the collection of data and the intercommunications of devices over the internet [8], [25], [27]. Therefore, there are emerging opportunities for IoT and research within PRITA and VMS will be investigated.

3. RESEARCH METHODOLOGY

The systematic approach of this chapter details the two exploratory process sections detailing the development phase of the PRITA and VMS model, followed by a case study section that investigates the model. Through defining and discussing VMS's capabilities and then addressing the implementation areas in which it can flourish, VMS's importance in the manufacturing industry became apparent. Thereafter, integration of VMS within the manufacturing industry started at IoT implementation investigation to produce the PRITA supporting functions. Figure 2 describes the research methodology.

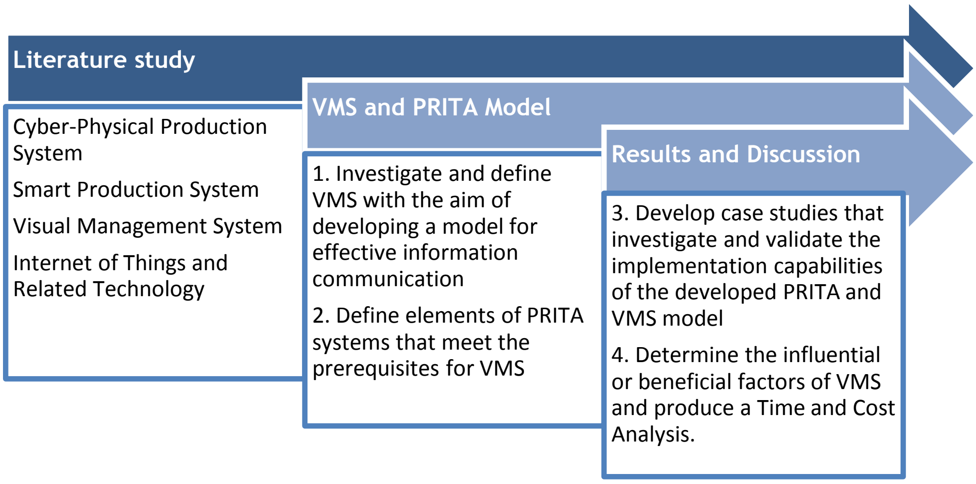


Figure 2: Research Methodology

This chapter details the results of the methodology and discusses it in retrospect to the research objectives. The objectives are to:

- (i) Investigate and define VMS with the aim of developing a model for effective information communication,
- (ii) Define elements of PRITA systems that meet the prerequisites for VMS,
- (iii) Develop case studies that investigate and validate the implementation capabilities of the developed PRITA and VMS model, and to
- (iv) Determine the influential or beneficial factors of VMS and produce a Time and Cost Analysis.

Figure 3, illustrates an example of the collection of systems, their corresponding functions and the correlation or co-dependency to each other. It demonstrates the first VMS model element (visualization tools) and how the different functions of VMS and PRITA models are connected to produce a process of data and information flow. In doing so, deconstructs the black-box to input-output elements thereof.

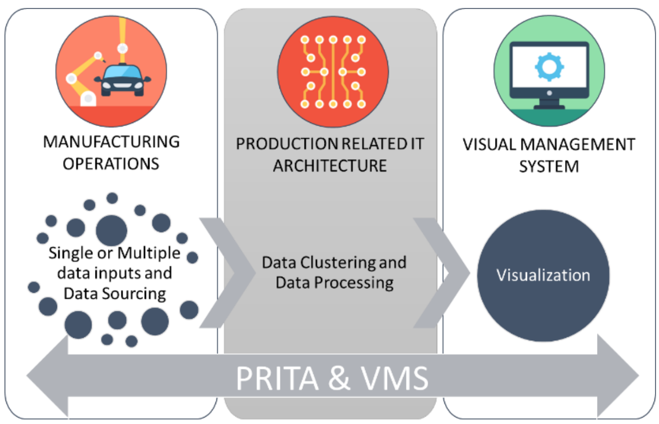


Figure 3: *Prototypical VMS and PRITA example of first VMS element – Visualization Tools*

In the prototypical example representing the first element of the VMS model in Figure 3, the process of data sourcing from manufacturing operations, clustered and processed with PRITA and then visualized with VMS, is represented. This demonstrates the process in principle of creating presentable information from different production process' data sources. The full model is discussed in the next section.

4. RESULTS AND DISCUSSION

To validate this model in practice, case studies of all the VMS elements require development, validation and documentation of results to meet the next objectives. This objective would be considered to have been met when all four of the PRITAs and VMS model elements have been incorporated into a production environment specifically to test the implementation capabilities of the model element. A breakdown of the technology that was developed before the study could proceed are shown in the most left block of Figure 4, with the matching case study details on the far right.

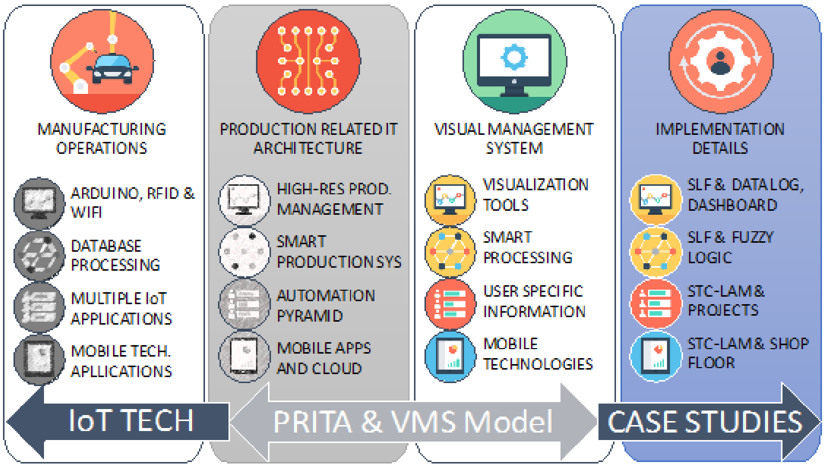


Figure 4: *IoT Technology and Case Studies of the VMS and PRITA model*

The four case studies were implemented in two different production environments. The first is the Stellenbosch Learning Factory (SLF), which is an education tool used to simulate the production environment for educational and experimental purposes. These type of production environments facilitate the opportunity for students to experience the manufacturing industry with the goal of understanding and integrating knowledge into contextual circumstances. Currently, the SLF focusses on teaching lean tools through the process of building small model trains in a typical South African manufacturing SME environment.

The other production environment is the Stellenbosch Technology Centre – Laboratory of Advance Manufacturing (STC-LAM), which was founded to incorporate internal and external projects, making the laboratory a centre that would provide the opportunity to research manufacturing operations. The STC-LAM is an institution that now provides excellent quality products in small quantities with high precision.

4.1 Case Study 1 – Visualisation Tool

The goal of the first case was to develop a real-time, online accessible dashboard with open source technology to be used as an information displaying tool for the data capturing device. This application corresponds with the opportunity in South Africa to communicate information more effectively to low skilled workers. A data logger was developed to souring data from the SLF production line. This data logger consisted of an Arduino Uno microprocessor, Adafruid RFID shield and ESP8266 Wi-Fi module. It is able to post scanned RFID tags, with its timestamp, onto an online Google Spreadsheet. On this spreadsheet, a dashboard was developed to display production line information consisting of timestamps that details operation start- and completion events between workstations. The dashboard is then setup to process the data to display uptime percentage, cycle time deviation, scrap and rework count, and productivity information in percentage, and can be seen in Figure 5.

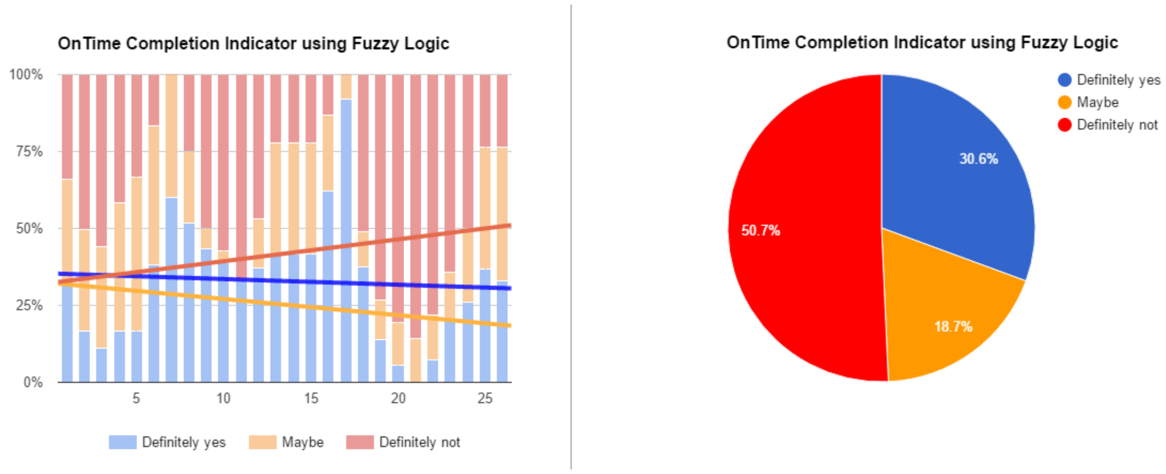
(a) (b)

Figure 5: The SLF setup with (a) the online KPI Dashboard, and (b) the data logger installed on workstation

The results of the study indicate that it was possible to develop and implement an open source dashboard within a functioning production line. When presented with the dashboard and asked if they agree that VMS is becoming an important industrial tool, 71% of the questionnaire participants comprising of various academic field experts (that consisted of fifteen academic and industry representatives, and lab personnel of the Rapid Prototyping and Development Laboratory and STC-LAM research group) agreed that VMS is becoming important within the manufacturing industry. The participants also agreed that on a scale from 0% to 100%, they can comprehend 43% more information displayed on a dashboard than the traditional method of tabulated data.

4.2 Case Study 2 – Smart Processing

This case study built on the previous and incorporates the same data set. It then integrates fuzzy logic algorithms to determine the condition of operations to meeting a deadline. The goal was to establish if it was possible to predict the ability of the product line to complete on time in real-time. This was accomplished by creating two rules using the cycle time and fault count data sets and then creating an algorithm that can produce a condition for how well the production is performing using the linguistic variable method of fuzzy logic. The process compares two case studies for both no-fault and two-fault count that produce a positive condition and a negative condition respectively for validation purposes. The two-fault case smart dashboard can be seen in Figure 6.



(a) **(b)**

Figure 6: ***SLF's smart dashboard showing second case's (a) trend lines of cycle times and the (b) possibility of on time completion linguistic variable pie chart***

The results of the fuzzy logic algorithm are displayed using an extension dashboard visualization tool to provide more information than just the previous case's dashboard. The first is a timeline of historic operation conditions on which a five point moving average trend line has been added. The second dashboard component consisted of a pie chart showing the projected completion condition of 'definitely yes', 'maybe' and 'definitely no' linguistic variables in percentage.

A questionnaire was sent to the same participants as the previous study and the results show that 77% of the participants agreed that VMS can successfully implement fuzzy logic algorithms to replicate smart processing capabilities. The participants were capable of comprehending the production line condition will not able to finish in time with more than 50% accuracy. Additional results using the longitudinal research design method showed that after this visual tool was added, the participants become more conservative with their predictions of the production line outcome and 38% of the participants adjusted their response to a lower expectation of on-time completion condition compared to a 'perfect run' condition.

4.3 Case Study 3 – User Specific Information

This objective required the STC-LAM and Institute for Advance Tooling (IAT) as a setting for the case study. They provided a managerial structure for the implementation of the automation pyramid PRITA. The goal of this case study was to investigate the information value stream of the production line and evaluate where and how information communication points can be introduced to improve on traditional communication channels. From the information value stream of their institution, three points therein were identified: the inventory and warehouse control, the production checklist of machine and part setup, and the client fill in form (where user specific information can be collected and communicated). These three points of contact are important and provide managers three different levels of information vital to manage manufacturing resources effectively. Therefore, an investigation was launched to assess the modernisation of the traditional method of information flow. Whereas the traditional method only consisted of instructions being communicated downwards through the managerial levels, the modern approach sources and clusters data from the bottom upwards. Due to sensitivity of information value stream within the STC-LAM and IAT, the final result could not be included in this study.

4.4 Case Study 4 – Mobile Technologies and Cloud Computing

This case study again builds on the previous with the goal of investigating the effects of mobile technology and cloud computing when it is introduced into STC-LAM and IAT information communication. This was accomplished by creating three mobile applications that collect data from different operations throughout the organisation, and capturing production related information easily and quickly by different users. The goal of the case study was to develop mobile application platforms that can support the information communication points as presented in the previous section to promote modernisation of information capturing procedures. A mobile application for each was developed using the open source online mobile application called AppSheet and the dashboard developed with the help of Freeboard.io. The client fill in form is represented in Figure 7.

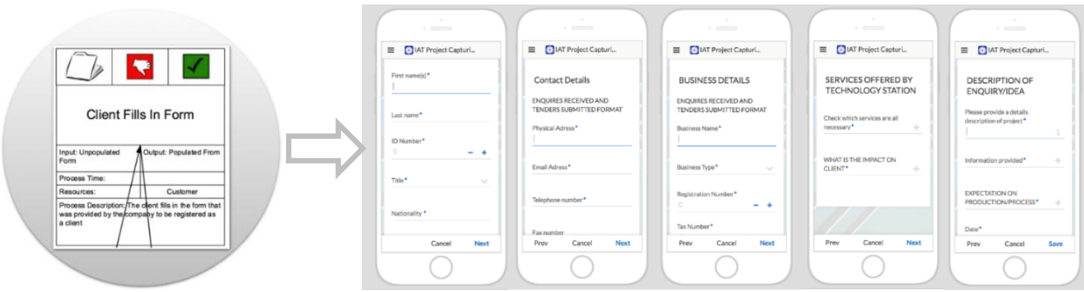


Figure 7: Mobile Application based on a Client Capturing Form of IAT

In an expert interview of a IAT staff member, it was determined that the mobile application that was developed to replicate the project capturing process from the client was unsuccessful due to administrative procedures not being met. However, the introduction of a mobile application and dashboard combination that investigated inventory management that can communicate inventory levels and project prerequisite information with the use of Freeboard.io's visualisation techniques were found to be quite beneficial.

In the South African context, these type of technology advancements must be implemented to bridge the problem of unsystematic approaches within the project execution. The use of mobile technology or online sign-in solutions will increase the traceability of documentation and responsibility monitoring purposes. Challenges within the methods of capturing information and updating the process to a more digital friendly version needs addressing, but this case study serves as a proof of concept for the implementation thereof.

4.5 Influential or beneficial factors of VMS

After the completion of the objectives and the knowledge gained from the case studies and their results, the following influential or beneficial factors of VMS became apparent:

(i) Visualisation techniques within the manufacturing industry can be implemented within organisations and are effective at conveying information to employees. The use of VMS can help with improving production line-related operation information comprehension.
(ii) Smart processing of data to produce suggestions and recommendations is a feature that can be added considering the amount of information that is readily made available by PRITA incorporation.
(iii) Influencing the production decision making process by determining trends and investigating possible solutions with visual problem-solving algorithms.
(iv) Information can be distributed throughout the organisation on a secure and need to know basis, where data flows upwards from the shop floor and information filters downwards to the shop floor according to the automation pyramid architecture.
(v) The use of mobile technology and cloud computing increases processing and accessibility to information while providing users with immediate responsive capabilities.
(vi) IoT and related technology have provided a solid development platform to perform all the necessary framework support for information handling to produce visual output devices.
(vii) The VMS model and its elements can be customised to meet the need of the client, customer or user.

4.6 Time and Cost Study

In Table 1 below, a breakdown of the hours and component cost that tabulates information regarding each of the individual case studies is provided.

Table 1: *Time and Cost Breakdown*

	Case Study	Details	Hours	Labour Cost	Component Cost
1	HRPM	Arduino UNO	0.0	R0.00	R109.00
		Adafruit RFID and Cards	0.0	R0.00	R541.49
		ESP8266 WIFI Module	0.0	R0.00	R33.34
		Prototyping Shield, Rails, Wiring and Soldering	4.0	R600.00	R100.00
		Google Sheets and PushingBox Accounts	0.5	R75.00	R0.00
		Google Sheets and PushingBox Setup	2.5	R375.00	R0.00
		Arduino Coding	23.0	R3,450.00	R0.00
		Total	30.0	R4,500.00	R783.83
2	Smart Production System	Arduino Coding	2.0	R300.00	R0.00
		Fuzzy Logic Research and Coding	8.0	R1,200.00	R0.00
		Google Sheet Dashboard Setup	3.0	R450.00	R0.00
		Total	13.0	R1,950.00	R0.00
3	Automation Pyramid	Google Sheet, Freeboard.io and AppSheet Account	0.5	R75.00	R0.00
		Freeboard.io and Google Sheet Setup	1.5	R225.00	R0.00
		AppSheet Development	15.0	R2,250.00	R0.00
		AppSheet Deployment and Testing	7.0	R1,050.00	R0.00
		Total	24.0	R3,600.00	R0.00
4	Mobile Tech and Cloud	Google Sheet, Freeboard.io and AppSheet Account	0.5	R75.00	R0.00
		Freeboard.io and Google Sheet Setup	1.0	R150.00	R0.00
		AppSheet Development	13.0	R1,950.00	R0.00
		AppSheet Deployment and Testing	2.0	R300.00	R0.00
		Total	16.5	R2,475.00	R0.00
	Total		**83.5**	**R12,525.00**	**R783.83**

The time and cost breakdown shows the contribution in monetary value of each aspect of the case study implementation process. It is interesting to notice that, when a labour price per hour of R150 is introduced, the development cost consists mostly of the labour costs. For instance, the first case study's component cost totalled to less than a fifth of the total cost. A pie chart displaying the comparing component and labour costs can be seen in Figure 8, for both the first case study and the overall expenditures of all four case studies.

(a) **(b)**

Figure 8: ***Component and labour cost comparison of (a) Case study 1 and (b) total cost comparison***.

When comparing it to the total cost distribution, a trend emerges. As these case studies use open platforms and free online services, the majority of the expenses are contributed to the labour and the time it took to integrate and implement the VMS model. The major drawback of the self-developed system is that it is less dependable and will have security and scalability issues. Therefore, a recommendation to organisations would be to develop their own open source and organisation-specific solution using open source technology first to create a scope of work before investing in a proper industrial solution.

4.7 Limitations of the Research

Currently the future of technology incorporation into the manufacturing industry looks very promising. These new technologies will allow increased knowledge development in the production process. VMS will provide the solution to understanding and relating the information to improve on the traditional flow of information. This new method will involve an increased amount of data collection on lower operation levels from which the information can flow up through managerial levels, produce action items, followed by information flowing down the model again. A number of limitations influenced the research outcome:

(i) Seeing that this research was carried out in a South African context, all the PRITAs or development tools used to develop the case studies were open-source or freeware solutions,

(ii) The development and integration of the case studies was not based on plug-and-play principles of future technology. Rather, the case studies took some time to develop and the integration included complicated methods of programming application interfaces, and

(iii) Concurrent design and general acceptance of this methodology will generally change in the near future due to technological improvements. Therefore, this study is limited to the current model.

5. CONCLUSION

The methodology of this research process required development of a VMS model and investigate the extent to which its elements can influence production productivity. The model was investigated using case studies to exploit niche opportunities within the South African manufacturing industry context. These niche opportunities involve presenting production information in quick and easily comprehendible fashion with the goal of increasing workforce productivity of the low skilled using PRITA and VMS solutions.

The first objective involved the process of investigating and defining VMS with the aim of developing a model for effective information- communication and/or displaying. This was achieved by investigation into the needs of users that will benefit from using visual communication techniques and produced four VMS model elements. The second objective therefore involved the process of investigating PRITA systems that meet the prerequisites of VMS. The four VMS elements were then used as basis for further exploration into the next objective where the current technology solutions were investigated that can support the sourcing and processing of data from production processes. PRITAs provide the intermediate process of sourcing the data from manufacturing activities that can be generated by machinery or human operations. The third objective was to develop case studies that investigate and validate the implementation capabilities of the developed PRITA and VMS model. Four case studies were developed that investigated the effectiveness of the VMS model with information communication. The fourth objective was to determine the influential or beneficial factors of VMS. The four previously mentioned case studies revealed that the VMS was considered an important value-adding element to the manufacturing industry with majority of the expert interview participants agreeing.

The research found that the PRITA and VMS model was implementable within the manufacturing industry using limited funding and open source and/or freeware IoT solutions can be achieved. It successfully investigated the sourcing of production data to produce digital visualization of production KPI information that is dynamically updated as new data sets are presented. It also investigated methods of improving information communication within an organisation to improve on the traditional downward flow to a modern upwards flow with processing and storing levels for increased transparency and control of production process on the shop floor.

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PROPOSING A GLOBAL VALUE CHAIN SUSTAINABILITY ANALYSIS FRAMEWORK: TOWARD THE ANALYSIS OF REGIONAL VALUE CAPTURE

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ABSTRACT

Global value chain (GVC) analysis has been increasingly used in the field of development studies. This article identifies three specific weaknesses of this methodology: the lack of concurrent consideration of economic, environmental and social elements concurrently; measuring only relative impact, instead of absolute impact; and a limited scope that excludes externalities and regional impacts. To address these weaknesses, the article proposes a global value chain sustainability (GVCS) analysis approach that includes a local value capture dimension. The value of this proposed approach is shown by applying it to the example of the mineral resources industry.

OPSOMMING

Globale waardeketting (GWK) analise word al hoe meer gebruik in die veld van ontwikkelingstudies. Hierdie artikel identifiseer drie spesifieke swakpunte van hierdie metodologie: ekonomiese, omgewings en sosiale elemente word nie saam geanaliseer nie, slegs relatiewe impak, in plaas van absolute impak, word gemeet; en dit is ‘n beperkte fokus wat eksternaliteite en streeksimpakte uitsluit. Om hierdie swakpunte aan te spreek, stel hierdie artikel ‘n uitgebreide globale waardeketting volhoubaarheid (GWK) analise benadering voor wat ‘n plaaslike waarde toevoeging dimensie insluit. Die waarde van hierdie voorgestelde benadering, word gedemonstreer deur dit toe te pas op ‘n voorbeeld vanuit die minerale hulpbronne industrie.

1. INTRODUCTION

Nations are becoming increasingly focussed on not only "inserting" themselves into global production networks, but also ensuring that they capture more value from the activities in which they are involved. As such, there is increasing emphasis on ensuring that economic activities do not only provide economic benefits to their host nations, but also enable social upliftment and ensure environmental sustainability.

Within this context, there exists a need for tools to support the evaluation of how countries and regions capture value from their participation in global value chains and how different policy options may affect this value. Such tools should provide a holistic triple bottom line (TBL) perspective (thus including economic, social and environmental concerns) and consider the global contexts within which policies are situated.

One promising tool that has been increasingly used within organisations that consider development within a global context is global value chain (GVC) analysis [1]. There have also been attempts to extend GVC analysis to better address the TBL elements through the introduction of the concept of "upgrading", for example [2]. However, these generally only include one or two of the TBL elements. Furthermore, they generally only refer to relative improvements and have not succeeded in providing an integrated and holistic TBL adaptation of GVC analysis that also allows the measurement of the absolute impact of value chains. These extensions also generally include a relatively narrow scope, thereby not considering indirect impacts and regional concerns. Towards addressing these shortcomings, this article proposes the addition of a "value capture" analysis dimension to the traditional GVC analysis framework as conceptually proposed by Henderson et al. [3] in the global production network literature. Building on [3], we show how this can be practically added to the GVC framework. The resulting analysis framework is intended to enable the inclusion of all three elements of the TBL in the analysis of global value chains. This is done by allowing for the consideration of absolute impact and by allowing for the inclusion of indirect and regional impacts of the value chain. The mineral resources industry is used as an example to illustrate the benefit of the inclusion of the "value capture" dimension in the extended framework vis-a`-vis the traditional GVC approach and literature.

The main advantage of the proposed operationalisation of the value capture dimension is that it provides an explicit way of indicating the sustainability impact of particular activities that form part of the global value chain. We thus refer to the extended framework proposed in this paper as the *global value chain sustainability* (GVCS) framework to acknowledge the root of the framework, but also emphasise the proposed addition.

The next section (Section 2) presents an overview of the existing GVC analysis frameworks and their shortcomings in relation to the inclusion of the TBL elements. This is followed by Section 3 which defines and contextualises the proposed "value capture" analysis dimension. Section 4 presents the mineral industry example. Finally, Section 5 contains the conclusion to the article.

2. GLOBAL VALUE CHAIN ANALYSIS

The GVC analysis framework originated in the global commodity chain (GCC) literature of Gereffi and Korzeniewicz [4] and Gereffi [2]. Gereffi [2] identified that GCCs, consist of four primary dimensions: (1) the input-out structure; (2) geographical dispersion of activities; (3) governance structure between firms; and (4) the institutional context both at a national and international level.

Gereffi [5] and Humphrey and Schmitz [6] extended these four dimensions by also establishing the concept of "upgrading". Gereffi [5] identified that developing nations can insert themselves into global value chains and incrementally "upgrade" to capture more of the value chain and more value from the value chain. Typically, this will entail entering the value chain with competitive labour-intensive low-skilled operations and gradually moving into higher-skilled areas of the value chain.

Humphrey and Schmitz [4], building on the work of Gereffi [5], identified four types of upgrading in GVCs: *process upgrading*, referring to "transforming inputs into outputs more efficiently"; *product upgrading*, referring to "moving into more sophisticated product lines"; *functional upgrading*, referring to "acquiring new functions (or abandoning existing functions) to increase the overall skill content of activities"; and *inter-sectoral upgrading* (also known as chain upgrading), that happens when "firms of clusters move into new productive activities".

This concept of "upgrading" thus specifically refers to the type of activities countries are involved in. Its introduction added a temporal dimension enabling the analysis of how local participation in GVCs evolve over time. However, it does not address the continual impact that these activities have on the host regions and rather view any change to higher skills and more of the value chain as a beneficial change for the host region. It thus focusses on relative improvements along specific dimensions, instead of measuring absolute performance or impact across multiple dimensions.

More recently, as the awareness regarding sustainability has grown, the concept of "upgrading" has also been extended to include both social and environmental elements more explicitly. For example, Barrientos et al. [7] have made a notable contribution in terms of *social upgrading* in GVCs. They defined social upgrading as denoting the process of improvement in the rights and entitlements of workers as social actors, which enhances the quality of their employment. As such, they identify three types of social upgrading in GVCs: *small-scale worker upgrading*, referring to where workers "remain within home-based production (agriculture or manufacturing), but are able to enjoy improvements in their working conditions"; *labour-intensive upgrading*, referring to where workers "move to better types of labour-intensive work where they can also obtain better working conditions"; and *higher-skill upgrading* where workers "move towards better types of paid employment associated with progressive social upgrading".

Building on the work by Barrientos et al. [7], Gereffi and Lee [8] also make a contribution in terms of social upgrading by drawing from the industrial clusters literature. They highlight six pathways for social upgrading and suggest the importance of what they term "synergistic governance". They also highlight the need for linking economic and social upgrading from the perspective of the GVC and cluster literature.

Similar to the relative nature of the original economic conceptualisation of upgrading, all these definitions of social upgrading place a primary focus on the workers directly involved in production activities. In the process, these conceptualisations do not extensively take account of the external effects of productive activities on surrounding communities, societies and those external to the direct activities of the value chain. Furthermore, these conceptualisations also have a focus on relative improvement and do not include the ongoing impact of activities.

Research linking environmental concerns to the GVC analysis framework has been less prevalent. Nonetheless, De Marchi et al. [9] leverage the governance focus of the traditional GVC literature and identify two governing approaches that lead firms can follow that can lead to "greener" value chains (*standard-driven* and *mentoring-driven*). Similar to the other applications of "upgrading" in the GVC literature, the work of De Marchi et al. [9] emphasises some change of the GVC from one state to another, without regard for the absolute impact of the current or future state of the value chain on the environment.

It thus appears that one key weakness of the "upgrading" approach employed in the GVC literature to address triple bottom line (TBL) aspects, is that it does not inherently assess the absolute impact of the existing or future state of the value chain. Instead, "upgrading", as used in the GVC literature, refers to an improvement on or extension of a previously existing state and such extension of or improvement on is viewed as an inherently positive development, irrespective of the original state and its ongoing impact.

The current GVC literature also generally restricts the scope of focus to a relatively narrow view that does not consider the direct and indirect impacts of the value chain activities beyond the borders of the firms involved in the specific value chain. It thus excludes the possible positive and negative externalities that might result from participation in the value chain.

Finally, the current GVC analysis literature generally only addresses one or at most two of the TBL elements in any one analysis framework. This leads to the risk of underestimating or not being aware of specific trade-offs that might be present between the different TBL elements during analysis.

This article aims to address these three shortcomings of GVC analysis by introducing and defining an additional "local value capture" dimension within the GVC analysis framework. The resulting framework may be regarded as a global value chain sustainability (GVCS) analysis framework. This "local value capture" dimension is defined in the next section (Section 3). Thereafter, the value of the GVCS approach is illustrated through the use of an example, presented in Section 4.

3. CONCEPTUALISING NATIONAL VALUE CAPTURE WITHIN THE GVC

The elements of the traditional GVC analysis framework, along with the related concept of "upgrading" is represented in Figure 1.

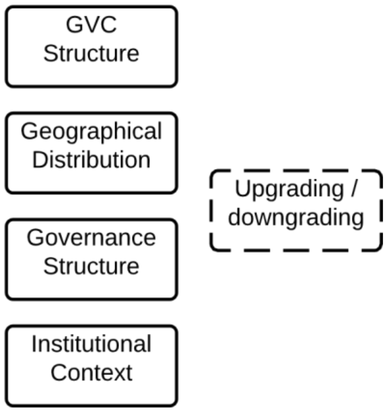

Figure 1: The elements of traditional GVC analysis.

To enable the conceptualisation of national (or regional) value capture, it is necessary to establish the activities that form part of the GVC under consideration that currently take place within a focal region or country. This is referred to here as the "local footprint" and is a function of the GVC structure and the geographical distribution of this structure. This local footprint then translates into a specific local value capture for the focal region as shown in Figure 2. It is proposed that the value that is captured from the local footprint can be conceptualised according to the three sustainability elements of the TBL concept, popularised by Elkington [10]. Each of these elements can also be conceptualised as entailing gain and cost, as the complex impacts of activities can have both positive and negative effects on the host nations, as will be illustrated in the example in the following section. This conceptualisation enables the evaluation of the current impact of the value chain on the host region. This impact implied by the local value capture dimensions enables an absolute measurement of the impact of GVC activities within a region. For example, the economic gain of an economic activity can be measured in contribution to GDP or employment. Similarly, environmental cost can be measured by evaluating the carbon footprint of the activity. The value capture element thus allows the direct linking of impact to activities. The specific impacts measured in a study will depend on the goals and design of the study, but the suggested framework provides a framework for including such measures.

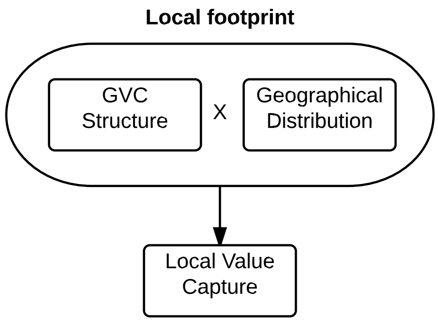

Figure 2: A conceptualisation of value capture within the GVC framework.

Upgrading then refers to a change in the local footprint in a focal region (e.g. when a company relocates a factory into a region, the local footprint of that activity in the location located to increases) or a change in the translation of this footprint to value for the region (e.g. when a multinational company increases the wages it offers the workers within a country). This relationship between value capture and upgrading is illustrated in Figure 3. It indicates that upgrading can be considered to be the change in the local footprint or value capture between different longitudinal states of the same local value chain at two points in time (these points are shown as T_0 and T_1). The inclusion of all three dimensions of the TBL enables the appreciation of the trade-offs that the change of footprint might imply. For example, the introduction of a new activity might lead to improved economic results for a region, yet will likely also increase the environmental degradation in the region. Furthermore, this new activity might have a stabilising or disruptive effect on the social fabric in this region. This broader view is crucial for policy makers to appreciate the trade-offs that any policy decision invariably entails.

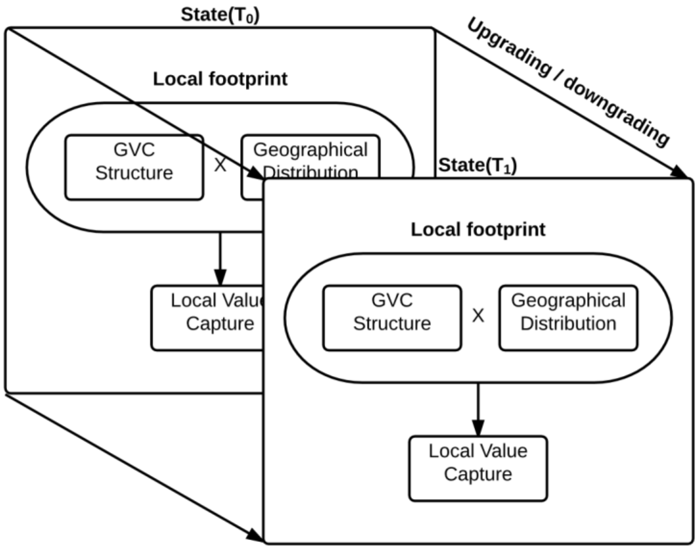

Figure 3: The relationship between value capture and upgrading

4. MINERAL RESOURCES EXAMPLE

To illustrate the benefit of the proposed GVCS framework an example of the factors that may be considered in the mineral resources industry is presented. The example aims to illustrate the additional TBL impacts that can be included in analysis when using the GVCS framework vis-a-vis the existing GVC analysis frameworks. The example is based on a review of the 304 articles published in the journal *Resources Policy* since the start of 2010 up until 12 July 2015. These articles were analysed to identify potential impacts (value capture) of mineral resources related activities on host regions (Table 1 to 5). These impacts were then categorised according to whether they are likely to fall within the general scope of existing GVC analysis frameworks or whether they would likely only be considered under the broader GVCS analysis framework proposed in this article (Table 6).

Table 1 and 2 indicate the positive and negative economic value capture impacts identified from the review. Table 3 and 4 do the same for the social element of the TBL. As far as minerals and the environment is concerned, the focus in literature and elsewhere is generally on minimising the negative impacts on the environment. Therefore, Table 5 indicates only the negative environmental value capture impacts identified. In the review, one positive impact was identified, namely, the creation of man-made habitats for protected birds [11] (#41). The results of the analysis regarding whether each of the identified impacts will likely fall within the scope of the existing GVC analysis framework or only in that of the extended GVCS analysis framework, is shown in Table 6. The categorisation of specific identified aspects may be disputed in either direction, but the overall results, and subsequently, the clear value of the GVCS approach, is robust.

Table 1: Identified impacts: positive economic value capture

#	Impact	Source
1	Appreciation of the national currency	[12]
2	Capital investment	[12-14]
3	Diversification of exports	[15]
4	Economic growth	[12]
5	Employment in other sectors	[16-19]
6	Employment sustained	[12, 14, 16, 18, 20, 21]
7	Local value added	[20]
8	Lower inequality	[21, 22]
9	Improved income levels	[12, 14, 18, 21, 23]
10	Infrastructure development	[13, 24]
11	Other linkages	[1, 2, 12, 14, 25-35]
12	Shareholder returns	[12]
13	Tax revenue	[12, 18, 36-38]

Table 2: Identified impacts: negative economic value capture

#	Impact	Source
14	Exhaustion of minerals	[12]
15	Low job spillovers into manufacturing and agriculture	[17]
16	Opportunity cost	[12, 17]
17	Outflow of revenue to foreign investors	[39]
18	Poorer financial development	[40]
19	Possible slower national economic growth	[41]
20	Regional economic problems such as low entrepreneurial activity, pressure on local services and infrastructure, specialisation on minerals and unaffordable housing	[12, 42, 43]
21	Resource dependence of the economy which may lead to the crowding out of other sectors, instability and insecurity due to the dependence on the fluctuating external demand	[12]

Table 3: Identified impacts: positive social value capture

#	Impact	Source
22	Better education	[23]
23	Improved communication access	[23]
24	Improved income levels	[12, 18, 23, 44]
25	Increase in disease prevention initiatives	[45]
26	Lower unemployment	[21]
27	More equitable distribution of income	[18]
28	Reduction in poverty	[46]

Table 4: Identified impacts: negative social value capture

#	Impact	Source
29	Conflict	[36, 41, 47]
30	Corruption	[41, 48]
31	Human rights suppression	[49]
32	Inequality	[41]
33	Poorer education	[12]
34	Poor working conditions	[42]
35	Rentier states	[41]
36	Risks to human health	[49-51]
37	Stranded regions	[12]
38	The aggravation of societal issues through the white washing effect of corporate social responsibility	[52, 53]
39	The displacement and relocation of communities	[36, 54, 55]
40	The disruption of traditional cultures	[52]

Table 5: Identified impacts: negative environmental value capture

#	Impact	Source
42	Air quality degradation	[59, 56]
43	Deforestation	[42]
44	Degraded recreational resources	[57]
45	Ecosystem degradation	[50, 57]
46	Erosion	[42, 57]
47	General environmental degradation	[41, 48, 49]
48	Heavy metal contamination	[49]
49	The introduction of non-native species	[57]
50	The loss of fauna	[52]
51	The loss of habitats for fauna	[57]
52	Risks to clean water supplies	[56, 57, 41]
53	Toxic spills	[49]
54	Visual degradation	[56]

Table 6: Classification of identified impacts

	Likely to be captured by existing GVC analysis frameworks	Likely only to be captured by extended GVCS analysis framework
Economic gain	2,4,6,7,9	1,3,5,8,10,11,12,13
Economic cost		14,15,16,17,18,19,20,21
Social gain	24,26,28	22,23,25,27,29
Social cost	31,34	29,30,32,33,35,36,37,38,39,40
Environmental gain		41
Environmental cost		42,43,44,45,46,47,48,49,50,51,52,53,54

The tables indicate that the existing GVC analysis frameworks addressed only ten of the fifty-four impacts identified. This included five of the thirteen economic gains identified, three of the seven social gains identified, two of the twelve social costs identified and none of the economic costs, environmental gains or environmental costs identified. The example highlights the ability of GVCS analysis to incorporate all three dimensions of the TBL in one holistic framework. It also broadens the scope of the impacts assessed beyond the boundaries of the firm. This makes the framework more useful for policy makers that need to also consider possible externalities. This broader scope also allows for the integration of regional concerns in the analysis, something that has thus far been lacking in GVC analysis framework. By adding the value capture dimension to the GVC framework, the GVCS framework allows for the consideration of any number of absolute impacts of activities. This then adds to the current limited focus on relative improvements afforded by the exclusive use of “upgrading” as an analysis dimension

The extension thus addresses the three weaknesses of the existing approach identified in the literature review. Firstly, it enables the assessment of the absolute impact by reviewing the TBL impact explicitly and not just the change in the impact under the form of “upgrading”. Secondly, the value capture dimensions as proposed in this article allows for the consideration of externalities that are not limited to the firm executing the activities. This includes impacts such as erosion and corruption. Finally, the framework allows for the concurrent evaluation of all three TBL dimensions, thus providing for the evaluation of the trade-offs between the dimensions that may be inherent in changes to the GVC.

5. CONCLUSION

The article presents an overview of existing GVC analysis frameworks and their shortcomings in addressing the TBL elements. Three specific weaknesses of the common “upgrading” approach to evaluating the TBL elements were identified. Firstly, the upgrading approach only focusses on relative impact improvements and does not enable the consideration of absolute impacts occurring due to GVC participation. Secondly, the general scope employed in the GVC literature is generally limited to the impact on the firm(s) directly involved in a particular GVC within a narrow perspective. Thirdly, the existing frameworks generally focus on only one or two elements of the TBL. This then excludes the analysis of externalities and regional aspects of GVC impacts. The article thus proposed a global value chain sustainability analysis approach that includes a local value capture dimension and contextualises this in relation to "upgrading". The article then illustrates the value of this proposed approach through applying it to the example of the mineral resources industry. The example highlights the additional TBL impacts that can be considered when applying the GVCS analysis approach vis-à-vis the traditional GVC literature. Based on the results, it is concluded that the proposed GVCS analysis framework addresses all three identified weaknesses of GVC analysis. The GVCS approach thus extends the existing approach to provide a broader, more flexible tool with which to analyse the impacts of various GVCs and enables the analysis of various policies that aim to attain better TBL outcomes for a particular region or country.

Further work is needed to further test and refine the proposed approach. This could take various forms, including specific case study applications using the approach and comparing the outcomes to the traditional GVC frameworks. The article has focussed on the structure, geography, local value capture and upgrading within GVCs. Further studies could evaluate what effect, if any, the use of the GVCS analysis framework has on the evaluation of the institutional context and governance structure of value chains.

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BIG DATA AND DEMAND DRIVEN SUPPLY CHAIN MANAGEMENT: POTENTIAL BENEFITS FOR HEALTHCARE SUPPLY CHAIN MANAGEMENT IN SOUTH AFRICA

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ABSTRACT

Effective and efficient healthcare supply networks are prerequisites for supporting public healthcare systems in their search to meet the needs of especially the poor and economically marginalized. The core objective of healthcare supply chain management is to ensure access to medical drugs at the right time, at a convenient place and in the right quantities. The intersection of private and public supply chains coupled with the concept of big data analytics may enable real time data access and analysis for increased agility and efficiency. Through a review of salient literature, the paper outlines the barriers to essential medicines access and describes the opportunities that demand driven supply chain management (DDSCM) presents to the public healthcare systems and the role that Big Data could play in the improvement of public healthcare in South Africa.

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1. INTRODUCTION AND PROBLEM STATEMENT

A supply chain consists of activities and processes for the seamless acquisition and delivering of physical items, information and financial flows from manufacturer to the end user. The management of supply chains in turn requires the coordination of these activities while controlling costs [1] [2]. The outcomes of such coordination in the supply chain include customer satisfaction and enhanced clinical outcomes. In Healthcare, the supply chain actors that facilitate the flow and coordination of these activities and processes include medicine manufacturers, distributors, medical providers, government medicine control regulators, insurance companies, patients and end-users [1]. The overarching goal of healthcare supply chains is to enable the provision of cost effective patient care.

Some studies have pointed out that up to date even developed nations such as the United States of America still have healthcare supply chains primarily focusing on purchasing, materials management and contracts management [3][4]. This illustrates that the healthcare supply chains have not yet applied all the principles of SCM and this has contributed to one of the many reasons why the healthcare sector has not reaped commensurate benefits from the SCM concept.

However, the advent of healthcare reforms in the United States of America has led to the concept of holistically managed SCM to gain recognition in the public healthcare sector as opposed to being limited to production and manufacturing industries during the industrialization era [4] [1]. Despite the health reforms , the healthcare SCM still remains complex in the sense that it is customer centric [1] and demand for each drug is highly uncertain and may be affected by seasonal changes [5]. Some studies in healthcare supply chain in United States of America and India observed some notable complexities that affect access to medications in the healthcare sector which include lack of an integrated information system [1], conflicting supply chain objectives, poor relationships among supply chain partners and lack of quality data [3][4]. This results in limited collaborations which in turn act as a barrier to information sharing [1]. However, despite these barriers, SCM concepts such as coordination, collaboration and integration are gaining increasing attention in the Public Healthcare Sector (PHCS). The key and prime objective of SCM concepts in PHCS is to reduce operational costs and ultimately improve access to a diversity of medications to a large but widely distributed population when and where the medication is needed [4].

Within the South African context, the PHCS is faced by the challenge of continuous escalating healthcare costs [6] and multiple barriers to medication access as outlined in Table 1. Since the prime purpose of healthcare facilities is to treat or reduce severe effects of different illnesses using various drugs and medications, medications stock outs such as antiretroviral drugs, this has compromised the effective running of the PHCS operations in South Africa [7], [8].

Table 1: Barriers to medication access in South Africa [7], [8]

Aspect	Overview
Technology	• Lack of real time data (visibility) and information exchange resulting in poor forecasts • Failure to track products in transit
People /organizations	• Lack of technical capacity of staff in healthcare facilities resulting in poor planning • Inadequate staff in healthcare facilities
Processes/systems	• Procurement through the tendering system which is inflexible • Untimely payment of medicines manufacturers resulting in suppliers holding stock • Challenges during contracts transition period especially when the manufacturer contract expires and the department of health only realizes that when they want to order from that manufacturer. There is no contract tracking system. • Supplier failure to deliver products due to small lot purchases ordered (supplier wait to accumulate amounts of orders before effecting deliveries) • Some products where tenders are not awarded, provinces have to source these through quotation system and constraints in sourcing for theses quotations
Infrastructure	• Inadequate storage space at most PHC facilities result in small lot purchases of stock

	• Poor communication infrastructure such as phones, fax and internet connection • Rural areas have poor road infrastructures
Logistics, distribution & warehousing	• Lack of inventory management system (currently the deployment of the stock visibility solution (SVS) IN 3126 clinics across SA) • Availability of transportation system and fuel to go and collect stock from main depots to health facilities

From Table 1 the barriers that limit access to medications in South Africa primary healthcare sector can be classified as technology, people, processes and policy related. Technology and information sharing can enhance coordination and collaboration between supply chain partners. Also to improve supply chain planning activities there is need for skilled people supported by optimized system and processes. Policy reinforces all organizational activities and the absence of a policy which highlights the technology, the people skill and the processes act as a great barrier to success. [7], [8].

2. RESEARCH BACKGROUND

Emulating from the proven private sector operating model used by companies such as Unilever and Proctor and Gamble (PG), the National Department of Health (NDoH) developed a Visibility and Analytics Network (VAN) blueprint in 2015. This was done with funding from the Bill and Melinda Gates Foundation and input from multiple global health organizations and African governments [9]. Unilever has visibility and management control of multiple transport movements across Europe. It is now able to offer higher customer service at lower cost and with lower carbon emissions. PG has installed 'control towers' to handle global distribution structures. The aim was to improve medication availability in PHSC. Fig 1 shows the transformational stages of the healthcare supply chain outlined by the VAN concept.

Stage 1, uninformed push, represents a generic approach whereby the upstream supply chain partners, with little training of supply chain management send stock to health facilities based on assumptions and rough calculations. The current approach, stage 2, uninformed pull, is when trained "demanders" make orders for their health facilities but not fully utilizing the available data. Stage 3, informed push/or advised pull, is a stage when trained and informed planners have total visibility of inventory level and consumption patterns of health facilities and they recommend orders based on this data. The desired stage 4, informed pull, utilizes an automated ordering system where technology recommends orders to demanders and they only authorize spending [9].

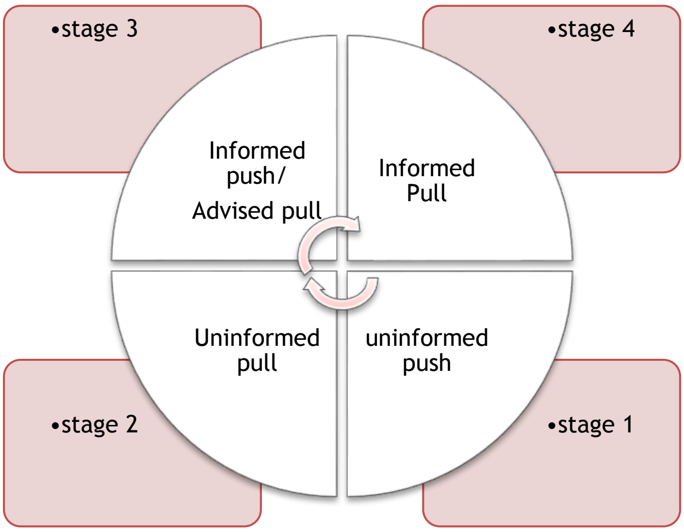

Figure 1: VAN stages of supply chain strategy
Source: [Llewellyn, 2016]

The Healthcare supply chain transformation under the VAN concept, from one stage to another is enabled by 4 factors which include technology, people, process, and policy [9] as shown in Table 2.

Table 2: The VAN Operating Model [9]

Element	**The VAN**	**The VAN is more than just:**
People	A team of dedicated professionals with defined roles and responsibilities, the right skills and knowledge, and is patient-centered, proactive approach to evidence-based quality improvement	• A new name for existing roles • Minor changes to organizational structures • A small once off change management effort
Processes	Data driven processes that use analytical methods to continually plan, proactively respond to changes and recommend improvements	• New standard operating procedures • Business process re-engineering • One-off system re-design
Technology	The integration of multiple data systems, to generate alerts and actionable insight across the value chain with automation wherever possible	• A new logistics and information system to support procurement and stock transactions
Policy	A cross-cutting governance framework with clear responsibilities and accountability and empowered decision makers with defined 'spans of control' across the value chain	• An improvement mechanism of one domain such as procurement and warehouse management • A project to improve Key Performance Indicators

These factors are interdependent and should not exist in isolation from one another. To address the technology barrier the department of health and Vodacom developed a custom-built mobile application called Stock Visibility Solution (SVS) which provides real time visibility of drug stocks at primary healthcare facilities [10]. SVS coupled with other multiple data systems can enhance the generation of alerts and actionable insights across the entire supply chain and support end-to-end healthcare supply chain visibility [9], [10]. Secondly, the people factor consists of adequate skilled staff with a proactive approach to evidence based quality improvements. Further, the process factor includes data driven processes that utilizes analytics for planning and proactive response. The final factor is the policy aspect which consists of government framework explicitly outlining clear responsibilities and accountabilities of empowered decision makers across the supply chain [9].

Within this context, this study proceeds to develop a framework for a Demand Driven Supply Chain Management (DDSCM) approach, outlining the enablers for DDSCM and its potential benefits for PHCS. This framework represents a proposed supporting structure for the VAN concept. Section 2 discussed the research background, section 3 of the study outlines the methodology used for this study, section 4, discusses the potential benefits of DDSCM in PHCS and section 5 and section 6 is the conclusion and future work proposed.

3. STUDY METHODOLOGY

In this section we outline the research method for this study. Through a literature review, this study explores the potential benefits that demand driven supply chain management can bring to the public health care sector. This is an attempt to enhance access to medications to the public health care sector. It finally develops a conceptual framework for demand driven supply chain management using ideas from Jabareen (2009) who outlines the process of building conceptual frameworks [11] as shown in Figure 2 and explained in Table 3.

Figure 2: Jabareen Conceptual Development Methodology
Source: [Jabareen, 2009]

Jabareen Conceptual Development consists of seven stages. This study utilized on six. The conceptual framework was developed from literature review but has not yet been validated. The next phase of this study would be validation of this framework in public healthcare sector.

Table 3: Study Methodology for conceptual framework development

Activities	Overview of activities performed
Data of conceptual framework analysis	• Articles, conference papers and books from online databases such as Scopus, Science Direct and Google Scholar were used during data collection
Process of conceptual framework analysis	• Using key search terms such as “healthcare demand chain management” and “healthcare” ”demand chain management”. Screening was based on relevant title, abstract and the whole article
Procedure of conceptual framework analysis	• Firstly the authors mapped the literature on supply chain management, demand driven supply chain and big data application in supply chain. Articles were also collected from references of initial searched articles. • Secondly extensive reading and categorization was completed of the selected data and subsequently identifying and naming concepts. • Thirdly the concepts are deconstructed so as to identify concepts attributes. Fourth, the similar concepts were grouped into one new concept. • Finally the concepts are synthesized into a conceptual framework.

4. THE POTENTIAL BENEFITS OF DEMAND DRIVEN SUPPLY CHAIN MANAGEMENT IN PHCS

The DDSCM concept is generated from the conventional SCM concept. The coupling of the supply chain (push) concept and demand chain (pull) concept gave birth to DDSCM [12]. This also leads to the development of a demand-driven supply network, which is a system of technologies and business processes that sense and respond to demand signals in real time [13]. DDSCM is extensive and broad in nature [14] and accentuates the need to comprehend customer demand and subsequent transforming such insights into a blue print that can be utilized by the entire supply chain [15] in its attempt to match supply to demand. This is the central concept in demand driven supply chain management. It also highlights the importance of customer demand coupled with product and service deployment to satisfy customers' needs. Figure 3 provides an overview of a Demand Driven Supply Chain in a healthcare context.

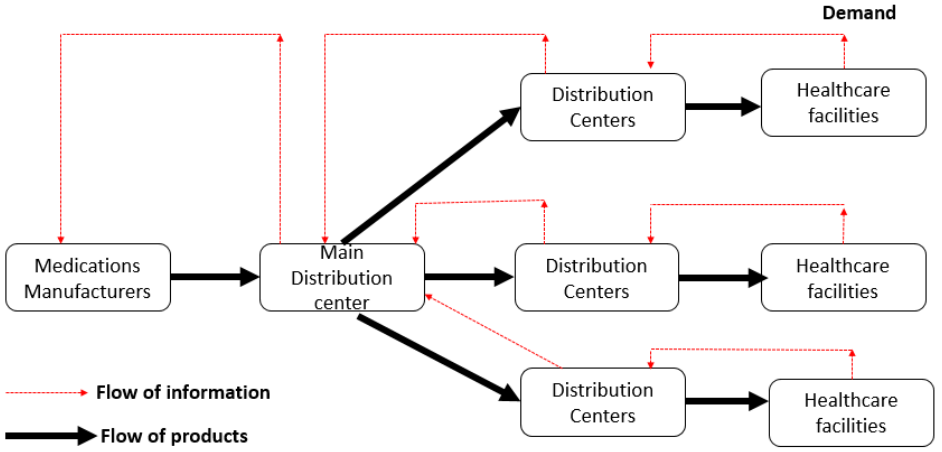

Figure 3: A healthcare Demand Driven Supply Chain (DDSC)

Source: (Mendes, 2011)

End-to-end supply chain visibility enables information sharing across the entire supply chain. Every supply chain node has the ability to "see" the inventory levels of another partner. This is important for supply chain planning purposes for instance if inventory levels fall, the preceding node of the supply chain can automatically replenishes the succeeding node [13]. This highlights the importance of end-to-end supply chain visibility [16]. End-to-end visibility also facilitates the collaboration and coordination of the entire network between supply chain partners. The goal is to create and deliver value to every supply chain partner [17].

The concept is a pull system and it emphasizes the need to transition from strategies such as make-to-stock to either make-to-order or hybrid push-pull strategies [12]. According to the push system, the order planning and information flow start with manufacturer to the end customer. This strategy is well suited for low-cost products with low demand uncertainty. However, in a pull system the succeeding nodes are placing the orders with the preceding node attempting to satisfy that order as shown in Figure 3. The strategy works for costly products with high demand uncertainty for which poor forecast will cause undesirable effects to the network. Moreover, in a hybrid push-pull system, succeeding nodes trigger the order, and the preceding node replenishes from stock, which is rebuilt immediately. In the latter, products are "pushed" in some stages of the SC and "pulled" in other stages. This supply chain strategy is highly applicable when there is high demand uncertainty of products, long lead times, and economies of scale in manufacturing/distribution is vital [12].

DDSCM therefore involves the integration of all supply chain actors through collaboration and relationships management. This in turn results in reliable information flows and subsequently leads to improvements in supply chain performance and customer satisfaction [18]. It involves the holistic integration and relationship between creation of demand and fulfillment of that demand [19] [20]. DDSCM illustrates the need for a greater degree of market mediation to acquire demand information [18]. The PHSC can have multiple benefits from the DDSCM approach as highlighted in Table 4.

Table 4: Opportunities and benefits of DDSCM

Author	Heikkila (2002)[21]	Frohlich & Westbrook (2002)[20]	Treville,, Shapiro & Hameri (2004)[22]	Ayers, (2006)[16]	Baltacioglu, Adaand & Kaplan, (2007)[23]	Juttner & Christopher,(2007)[17]	Bonomi & Antone,, (2014)[18]	Chong & Zhou, (2014)[24]
Cost efficiency				x	x	x	x	
Enhanced Competitiveness		x			x		x	x
Enhanced Responsiveness		x	x		x		x	
Improved communication		x	x		x		x	
Supply chain flexibility				x		x		
Supply chain excellence & performance	x	x	x			x	x	
Coordination of supply chain processes					x	x		
Effective inventory management		x	x		x	x		
Customer value and satisfaction		x			x	x		
Reduction in lead-times		x			x			
Collaboration among supply chain actors			x		x	x		

Drawing from the various authors' arguments in Table 4, the healthcare supply chain can experience an improvement of supply chain performance and excellence which complement other benefits such as reduction in supply chain operating costs, a significant improvement in terms of inventory management, enhanced supply chain responsiveness, enhanced competitiveness, an improvement in terms of information sharing and communication among partners and furthermore customer value and satisfaction is enhanced as stocks are replenished quickly. The DDSCM approach is however supported by technologies that facilitate information exchange about activities at different healthcare supply chain nodes.

4.1 ENABLERS OF DDSCM IN PHSC

This section explores the potential tools that enable the DDSCM in PHSC. It also highlights the potential benefits that can be reaped from these enablers.

4.1.1 ICT AND BIG DATA

The advent of new technologies has caused a paradigmatic shift with regards to data and information processing that enables agility and informed descriptive, prescriptive and predictive decision making in supply chains. For instance, the use of structured and unstructured data in the supply chain from quick response codes (QR), wireless sensor networks, RFID and trackers has culminated in large volumes of data, in different formats and generated at a tremendous rate [25]. This new era is called "big data" and it can be applied in demand planning, procurement, product life cycle, inventory management and managing real time organizational performance by enhancing supply chain visibility [26] [27] [28]. Contemporary technologies are now allowing seamless information exchange and end-to-end supply chain visibility [26].

Figure 4 outlines how supply chain actors collect data across the entire supply chain through RFID technologies, global positioning system (GPS), and wireless sensor networks (WSNs) among other technologies [25]. Homogeneous data sources enable great value and actionable information to be derived from big data [26]. The sensors generate big data. Predictive analysis on the data is conducted over a cloud infrastructure platform. Finally, business insights, problems, opportunities and decisions are generated [26], [27]. Brinch et al., (2017) suggested that this big data capability can be applied in the SCM processes such as sourcing, manufacturing, service, logistics, planning, and return.

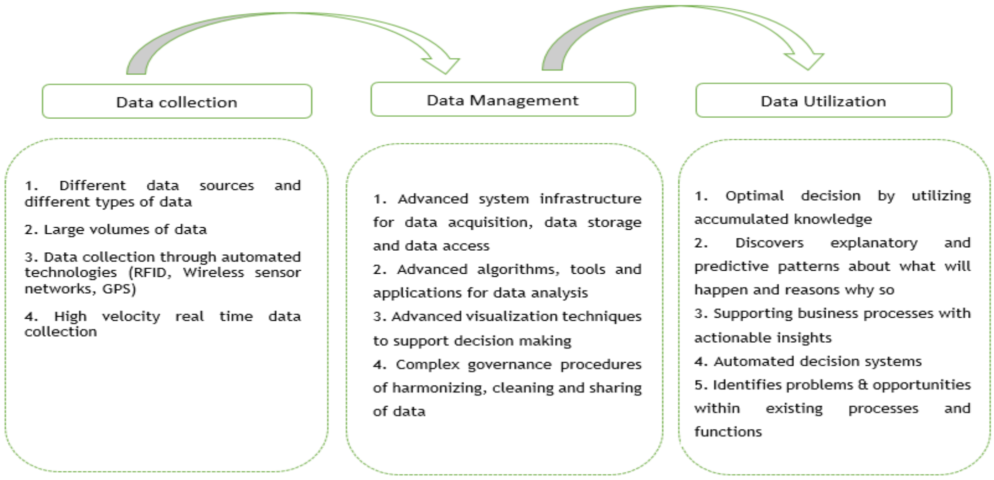

Figure 4: Big Data Application in PHSC

As illustrated in Figure 3, the collected real time data from various technologies is stored, managed, analyzed using advanced algorithms and tools. Finally the data is used to create optimum actionable decisions. In addition, the data can also be utilized to identify problems in a supply chain and identify opportunities for improvement. Advanced data utilization will involve automated decision making which is synchronized with the stage 4 of the VAN concept. Table 5 outlines benefits that can be realized by the utilization of ICT and big data in healthcare supply chain management.

Table 5: Opportunities for ICT and Big Data in PHSC

Author	Russo, Confente & Borghesi (2015) [28]	Wang & Alexander (2015)[27]	Chaouni et al., (2016)[29]	Brinch & Stentoft, (2017)[26]
Cost effectiveness	x			
Management of supply chain risk	x			
Insights of customer consumption patterns	x	x		
Collaboration of supply chain actors	x			
Real time Supply chain visibility	x		x	x
Demand forecast and trends analysis	x			
Route optimization and track product movement	x	x	x	x
Enhanced decision making			x	
Supply chain efficiencies	x		x	

Based on the various authors' ideas, ICT and Big Data can be fully utilized in route optimization, enhanced real time supply chain visibility, drawing insights of customer consumption patterns and improvement of supply chain efficiency.

Table 6 illustrates complementing tools that can be utilized to enable the DDSCM approach in PHSC. These tools have been fully deployed with measurable rewards in the commercial industry. In this study we discuss the most relevant enablers to healthcare sector performance improvement.

Table 6: Potential tools that enable DDSCM in PHCS

Tools	Focus	Potential Benefits for PHCS
Customer Relationship Management (CRM) [23]	Development of relationships and partnerships between organizations and its customers to determine customer demand and management of orders. Extends to identification of all customers and their respective characteristics.	• Development of partnerships • Enhanced information exchange with regards to stock levels and anticipated demand • Customer satisfaction
Strategic Supplier Relationship Management (SSRM) [23], [30]	Integration of suppliers and organizations in the value chain through collaboration and engagements in activities such as joint decisions in procurement, contracts management, distribution and logistics.	• Cost reductions and cost prevention • Enhanced product quality • Improved logistics performance • Facilitates supply chain innovation leading to new products in the healthcare • Reduction in lead-time and enhanced flexibility • Reduced stock outs and inventory
Demand Management (DM) [31]	Creation of an equilibrium between customers' needs and supply chain capacity to satisfy the needs.	• Demand can be predicted and systems can be put in place to proactively respond to that demand
Cross Docking (CD) [32].	Warehouse and distribution strategy supported by an information system where inbound trucks deliver products to warehouse and the products are quickly sorted and loaded to outbound trucks based on customer demands and routes without inventory being held in the warehouse	• No stock holding cost thereby reducing storage costs and scrapping costs of products • Reduction in logistics cost • Reduced time to customer • Products destined for a similar end point can be transported as a full load
Vendor Management Inventory (VMI) [3]	Collaborative platform that optimizes the supply chain. It creates a nexus between manufacturers and distributors, between distributors and wholesalers and between wholesalers and providers. The manufacturer has access to the provider's inventory data and maintaining provider's inventory level. VMI opens up partnerships between manufacturer and providers. This results in reduced lead time and overall reduction in supply chain cost	• Inventory level optimization • Reduce forecasting errors • Reduce data entry error • Reduction in stock outs • Improvement of lead time • Reduction in ordering costs • Reduction of supply chain cost
Collaborative Planning Forecasting Replenishment (CPFR) [3]	A system of people, processes and technology that transforms a fragmented forecast based push supply chain to an integrated demand driven supply chain through joint business plan and forecast. Enhances the collaboration of manufacturers and providers to improve flow of products.	• Reduction in lead time • Inventory levels optimization • Reduction of stock outs for PHCS • Minimize forecast error through collaboration • Reduction of warehouse and distribution costs

These tools include ICT and big data, strategic supplier relationship management (SSRM), cross docking (CD), demand management (DM), vendor management inventory (VMI), collaborative planning forecasting replenishment (CPFR). The benefits that can be reaped by utilizing the tools in the PHCS are outlined in Table 5. It can then be argued that, the creation of partnerships and collaborations through integration between customers and suppliers enhances relevant and timely information exchange across the entire supply chain. This improves end-to-end supply chain visibility [33] and thereby significantly contribute to a supply chain that has the capability to sense and respond with agility to demand. Lead times are also reduced and there is an improvement in inventory management resulting in cost reductions with regards to warehouse space and inventory holding cost. Moreover the end customer will receive greater value and satisfaction.

5. CONCLUSION AND DISCUSSION

This study outlined some of the tools that can be useful to the PHCS and the benefits that can be reaped upon full utilization of such tools. Despite disparities between the commercial sector and the health sector, a trade-off is that both sectors consist of seamless flow of information, products and finances. Therefore, various concepts of supply chain management which has been extensively deployed in the commercial sector, and which have produced measurable benefits, may also be implemented in the health sector. It is under the same context that this study proposes the improved application of supply chain management tools in the South African healthcare system. To implement these tools there is a need for real-time, accurate and relevant information across the entire supply chain.

Therefore, the huge data sets in various formats generated in the healthcare supply chain could be captured, managed and analyzed using technologies such as big data analytics, cloud computing, predictive algorithms and sensor technologies. The data is processed to provide actionable insights and enable informed decision making.

The flow of data across each node of the supply chain improves supply chain visibility. Information communication technology also plays a vital role in enhancing healthcare supply chains through the integration of supply chain processes [2]. This leads to a better understanding of current and future demand of patients with regards to medication needs. This in turn supports the DDSCM approach in healthcare. DDSCM plays a vital role by recognizing that the patient is the starting point of any effective supply chain. This concept reduces overstocking and stock outs of drugs and medication, reduces supply chain costs, enhances supply chain performance and flexibility, results in improved supply chain actors relationships, efficient logistics deliveries, reduced supply chain lead times, and enhanced supply chain forecasting accuracy which finally lead to patient satisfaction. Figure 5 provides a conceptual framework of how these elements interlink.

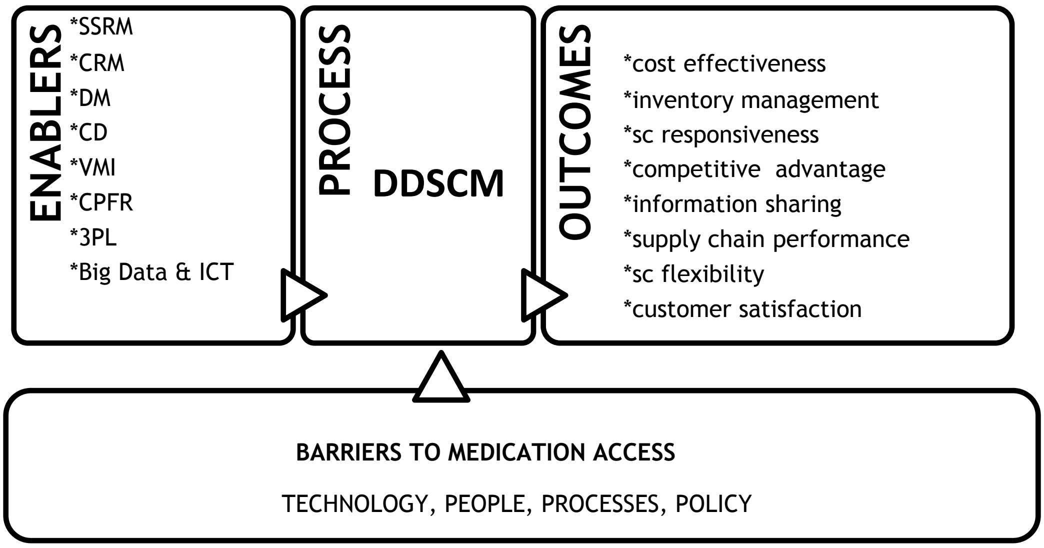

Figure 5: Conceptual Framework

The conceptual framework summarizes the core concepts covered in this paper: it outlines the broader barriers to medication access in South Africa; proposes that the implementation of the DDSCM approach in PHCS could eliminate some of the barriers to medication access; and highlights that the success of a DDSCM approach could be facilitated through eight enablers that work in concert with one another.

6. LIMITATION AND FUTURE WORK

The study focused mostly on reviewing salient literature and provides a basis for future empirical research. The authors in future will also look at what healthcare supply chain visibility entail, how real time healthcare supply chain visibility could be achieved.

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EVALUATING EMPLOYEE ENGAGEMENT AT A FMCG MANUFACTURING FACILITY

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ABSTRACT

This study provides a practical industry example that measures the engagement of employees at a fast-moving consumer goods manufacturing facility using the Gallup Q12 survey. The measured engagement is then related to initiatives aimed at promoting employee engagement at the factory in order to determine the effectiveness of these initiatives. The survey results show that the current degree of engagement across the organisation is 17%. The study shows that the factory's focus on engagement is having an overall positive impact as the factory has been shown to have significantly more engaged employees and fewer actively disengaged employees than the South African norm. There is however a lack of initiatives that support the direct relationship between employees and their supervisors. This study shows that measuring and understanding engagement within an organisation is useful to improve engagement through directed intervention initiatives.

1. INTRODUCTION

1.1 Background

There is a positive correlation between organisational performance and employee engagement. Companies that have a larger percentage of their employees engaged are more likely to outperform their industry peers in revenue growth rates. In addition, there is a positive correlation between employee engagement and customer satisfaction [1].

There are typically three levels of employee engagement: engaged, not engaged and actively dis-engaged [2]. Engaged employees exhibit behaviours that allow their organisation to outperform their competitors. Engaged employees advocate for the organisation to potential employees, colleagues and customers. They also invest extra time and effort in their jobs, take initiative and are committed to stay at their organisation.

Knowing this, a South African fast-moving consumer goods (FMCG) company has invested in implementing an employee engagement strategy at its newest facility. The factory leadership believes that creating an engaged workforce will create an environment where people enjoy coming to work, are more invested in solving problems and contribute to improvement. Management is committed to creating an engaged workforce because it is the right thing to do and because they believe it will lead to improved performance.

1.2 Motivation for this study

The initial employee engagement strategy employed by the factory did not adhere strictly to any theoretical framework but evolved based on the experience and ideas of the leadership team. Due to the considerable thought and resources that went into creating this strategy, it was decided, at a point into the journey, that it would be useful to understand if the initiatives that were being used were transferred into some form of measurable employee engagement attributes.

1.3 Context of the study

The factory's 'shop floor' is staffed by 155 employees across three shifts with a support and management team of 35 employees.

The following initiatives were initially employed at the factory, with the overall aim of creating engaged employees:

i. Clear Values

The factory prides itself in having a clear set of values that, not only guide behaviour, but are designed with employee engagement in mind. The stated values are;
To add real value through:
- Trust, Respect and Accountability
- Having a real connection with one another
- Having fun at work

ii. Mass Meetings

A meeting with management is held every two weeks, with each shift. This is a general meeting where anyone in the factory can raise and discuss issues. This aims to involve everyone in decision making, facilitates a level of transparency and creates a platform for communication at all factory levels.

iii. Variable Pay Model

The variable pay (VP) model is an incentive programme where employees are financially incentivised for meeting quarterly production targets. The VP model aims to directly motivate line workers for their output and ensure that support teams provide production lines with resources required to reach production targets.

iv. Social Events

To facilitate a real connection among employees, the factory holds social events which aim to encourage social interactions between employees and improve social cohesion. Employees' families are also included in these events to make them feel a part of the organisation.

Social events also include larger, after-work projects and long-term challenges. A major project completed by the company involves a team of employees building a house at a nearby informal settlement with a limited budget and no additional labour or expertise. Several houses have already been completed as part of this project. Long-term challenges have included a half marathon, a cycling race and a several-day mountain hike. It is not only the event itself, but the planning, organising, and training for events that is aimed at building strong inter-personal relationships between employees at the factory and encouraging employees to work diligently and consistently towards an end goal.

v. **Common Working Areas**

Shared spaces create an environment where people can connect, interact, collaborate and be updated on new developments or projects at the factory. The factory was designed in a way that maximises the use of common and shared spaces. All management and support staff are situated in an open plan office on a mezzanine level overlooking the factory. Access to these office areas is through the factory, requiring management and support staff to walk through the operating areas to get to the office area. There is a single cafeteria with subsidised meals to encourage all employees to eat together. There is only one set of locker room and bathroom facilities which is shared by all sections.

vi. Common Uniforms

All employees at the factory are required to wear standard, factory overalls regardless of their role. The office area is situated in the factory, so that all staff, regardless of role need to wear the standard overalls to work. This includes all support staff and management. Use of the common uniforms aims to remove hierarchies and division between production, management and support employees. It is hoped that this creates an environment where everyone is equally approachable and accountable.

vii. Skills development

One of the ways in which the company aims to create engagement is through a strong focus on skills and development. Significant resources have been committed to this ideal, including the employment of a learning co-ordinator and a substantial training budget which includes offering three year learnerships to employees to become certified artisans.

2. LITERATURE REVIEW

Over the last century, terms such as employee commitment, job satisfaction and organisational citizenship behaviour have become more popular in conjunction with management styles that harness employees' ability and commitment to improve organisational efficiency and productivity. This has laid the foundation for the development of employee engagement as a major concept within organisational culture. [3]

Employee engagement evolved from empirical research in organisational commitment and organisational citizen behaviour and has similarities with both concepts [2]. There are several key distinctions between employee engagement and these two concepts. The first is that employee engagement is a two-way, mutual process between the organisation and the employee [4] and the second is the extent to which employee engagement measures aspects of a workplace that are under the control of management [5].

There is no fixed definition of employee engagement, however this paper defines employee engagement as "*an employee's involvement with the company and their enthusiasm to work*" [6]. Thus, an engaged employee is aware of the business and the business goals and is committed to perform in their job for both the benefit of the company and for their own satisfaction [2].

Employee engagement is sometimes confused as employee satisfaction [1]. Employee satisfaction relates to an employee's loyalty to the employer, and can be viewed as a component of employee engagement. Full job engagement is however a result of both a feeling of contribution and satisfaction.

2.1 Assessing Employee engagement

Gallup is a research based consulting company that investigates and reports on employee engagement worldwide. Gallup has been conducting surveys which measure employee satisfaction and engagement over the last 60 years [5]. They have identified 12 elements that affect employee engagement and have refined these elements in the Gallup Q12 questionnaire to assess employee engagement [8].

The Gallup 12 elements are outlined below [9]:

1. Knowing what's expected

This element looks at whether employees understand what is expected of them and how their efforts coordinate and contribute to their work groups and the company.

2. Materials and Equipment

Employees require familiarity and reliability at the workplace. Employees get emotional security from having their own items and personalizing their workplaces. When employees are supplied with all they require to be productive; this creates an impression that the company is supportive of the employee and their work. This also reduces job stress.

3. The Opportunity to Do What I Do Best

Research indicates that each human has a unique set of strengths and weaknesses which determine their competency in certain tasks. This makes matching the right people to the right task a crucial element in ensuring engagement.

4. Recognition and Praise

If employees' efforts go unnoticed this can lead to dissatisfaction which can have negative implications on the organisation.

5. Someone at Work Cares About Me as a Person

Social experiments show that people that know each other invest more in each other and each other's work. This leads to increased talent retention, trustworthiness and employee enthusiasm. Whether someone feels personally cared for is also a significant predictor of employee honesty.

6. Someone at Work Encourages My Development

Mentorship is an effective way of teaching. The mentor-mentee relationship is important not only because of the sharing of skills and knowledge, but also through counselling, validation, and friendship. The mentees also feel that they matter and belong at work.

7. My Opinions Seem to Count

Employees are the most familiar with their jobs and as a result, often have better ideas. Employees are also most likely to commit to their own ideas than ideas that were passed over to them.

8. A Connection with the Mission of the Company

Workers that are connected with the missions of the company view their job as part of them whilst workers that don't, view their job as - just a job, a means to live. Employees that are not fully engaged with the mission of the company, view their job as a means to rise up in their careers.

9. Co-workers Committed to Doing Quality Work

Employees invest more in their jobs when they see others around them also investing in their jobs. Companies where most employees feel that their co-workers are committed to doing quality work have better customer satisfaction, fewer safety incidents and have more employees that are productive and committed.

10. A Best Friend at Work

A best friend at work is a way of employees asserting that their colleagues matter to them and that they matter to their colleagues. Mutual support between colleagues results in low turnover and lower safety incidents. There are strong links between improved performance and having a best friend at work. Research shows that friends feel a sense of commitment and belonging hence they can dedicate themselves to group goals and they work hard to achieve these goals. This means companies should leverage social relations between their employees.

11. Talking About Progress

Talking about progress relates to the feedback that employees get on the work they have done and how they can improve. Each employee requires regular feedback on their progress. It is also suggested that feedback and performance evaluation is tailored to a person's job and personality.

12. Opportunities to Learn and Grow

This element relates an employee's perceived opportunities to progress in their careers. This includes learning new skills and being aware of spaces in the organisation that they can move into. An employee's direct supervisor needs to identify potential in people and encourage their development.

It is important to note that Gallup's 12 elements do not include questions which relate to financial benefits. Financial compensation in communities where employees can afford their basic lifestyle does not improve employee engagement [9]. Financial benefits can interfere with teamwork and relational connections and disagreement can be created by payment differences which have a negative impact on engagement. Although a competitive salary is important to ensure an employee's motivation, a generous salary is less important than recognition and praise.

Employee engagement is typically made up of stages [8]. The primary stage addresses the expectations and resources an employee needs to perform their job and is linked to the first two Gallup elements. The next level of engagement, relating to Gallup elements three to six, is linked to an employee's individual esteem and worth. In this stage, managers play an important role in the way that employees perceive value. Then next four elements relate to the sense of belonging which employees feel at their workplace. The final stage is when employees look to grow beyond their current positions. These stages form a hierarchy of needs. Employees cannot advance to the next stage of engagement if the stage below has not been attained. These stages and their model of hierarchy are presented in Figure 1:

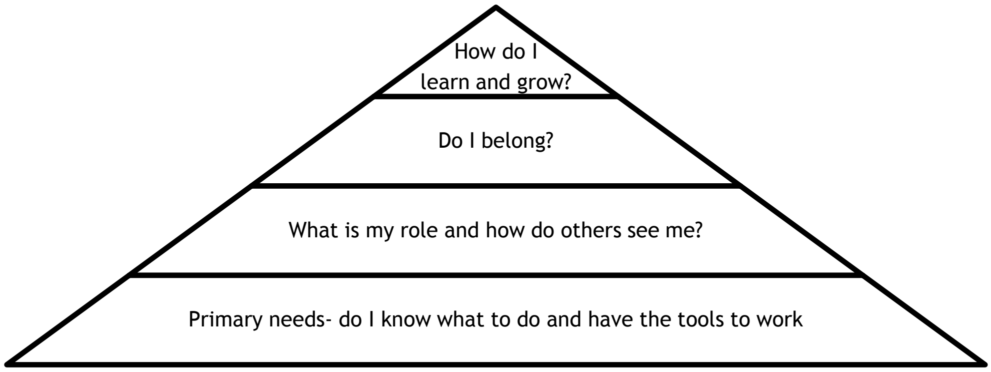

Figure 1: Hierarchy Of engagement [10]

When assessing employee engagement using the Gallup Q12 survey, employees are categorised into three levels of engagement; Engaged, Not Engaged and Actively Disengaged [10].

i. **Engaged employees**
Engaged employees are committed, energetic and involved in their work. They drive initiatives that build the company and improve their jobs.

ii. **Not engaged employees**
Not engaged employees are not easy to identify. They show up at work but do not concern themselves with any organisational outcomes or activities that will generate improvement. They look forward to the next break or the end of their work day. They are not disruptive thus they do not directly undermine the activities of engaged employees.

iii. **Actively disengaged employees**
Employees that are actively disengaged directly cause damage to the organisation. They have high rates of absenteeism, turnover and job accidents. They are often responsible for most quality defects. As a result, they undermine the actions of engaged employees.

2.1.1 Employee engagement in South Africa

Gallup conducted a global study on employee engagement in 2011 and 2012. Figure 2 compares the South African and global results [10].

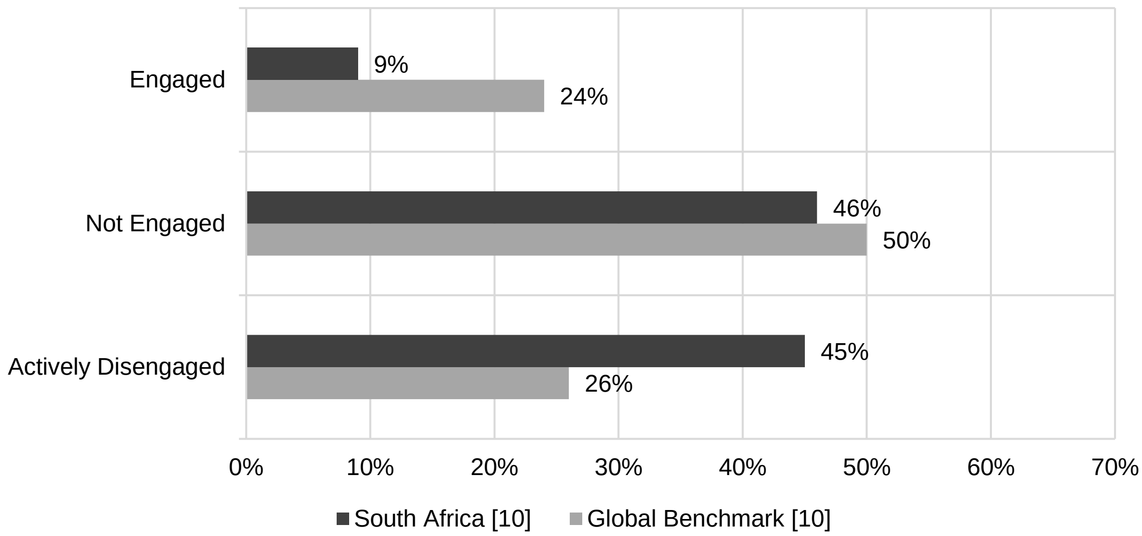

Figure 2: Gallup Benchmark

On average, 9% of employees are engaged in South Africa which is lower than the global average of 24%. What stands out in South Africa is that 45% of the workforce is actively dis-engaged which is significantly higher than the 13% globally. Gallup's assessment found that the breakdown of trust between employees and leadership in organisations is the main reason for dis-engagement in South Africa. According to Gallup's 2013 study, less than 25% of South African employees surveyed strongly agree that their opinions count at work or that their supervisors encourage their development. This points to the lack of positive employee-management relations in South Africa [10].

The literature shows that employee engagement can have a positive impact on organisational performance. It is essential however to remember that it occurs in definable stages that precede each other in the hierarchy of employee engagement. Most drivers that are identified in literature are non-financial. This presents an opportunity for managers to achieve their desired employee engagement at potentially low costs.

3. OBJECTIVES

This investigation aims to answer the following research question:

What is the degree of employee engagement at the factory and are initiatives aimed at engaging employees effective?

This leads into the following research objectives:

i. Determine employee engagement across the factory.
ii. Relate factors which affect engagement to initiatives aimed at engaging employees.
iii. Evaluate the effectiveness of initiatives in engaging employees.

4. METHODOLOGY

In order to answer the research question, the Gallup Q12 survey was chosen as it has been applied worldwide and provides benchmark data from global studies.

A framework was then developed which aims to relate the factory initiatives to Gallup's 12 elements of engagement in order to determine the effectiveness of the initiatives.

Finally, observations and informal discussions with both workers and managers at the factory are drawn upon to enrich and assist in explaining the results.

4.1 The Gallup Q12 Survey

The Gallup Q12 asks 12 questions with each question relating directly to the 12 elements of engagement identified by Gallup. The Gallup Q12 questions are [7].

1. I know what is expected of me at work.
2. I have the materials and equipment I need to do my work right.
3. At work, I have the opportunity to do what I do best every day.
4. In the last seven days, I have received recognition or praise for doing good work.
5. My supervisor, or someone at work, seems to care about me as a person.
6. There is someone at work who encourages my development.
7. At work, my opinions seem to count.
8. The mission/purpose of the Factory makes me feel my job is important.
9. My associates (fellow employees) are committed to doing quality work.
10. I have a best friend at work.
11. In the last six months, someone at work has talked to me about my progress.
12. This last year, I have had opportunities at work to learn and grow.

The Gallup Q12 survey questions use a feedback method in which respondents answer with one of 5 options: strongly agree, agree, neutral, disagree and strongly disagree. Each response is associated with a score between 1 and 5 which allows for numerical analysis of the survey responses. A fully engaged employee should answer "Strongly Agree" for all 12 questions [6]. The relationship between survey responses, the level of engagement and the Gallup scoring system is summarised in Table 1.

Table 1: Answers and level of engagement

Answer	Level of Engagement	Score
Strongly Agree	Engaged	5
Agree	Not Engaged	4
Neutral	Not Engaged	3
Disagree	Actively Disengaged	2
Strongly Disagree	Actively Disengaged	1

For this study, in addition to the Gallup Q12 questions, respondents were asked to select which section of the factory they work in as well as how long they have been working at the company. This was done in order to evaluate the engagement across different factory sections and across the organisational hierarchy as well as to determine if there is a relationship between tenure and engagement. These are important factors when considering future interventions at improving and sustaining engaged employees.

4.2 Linking initiatives to survey questions

In order to evaluate the effectiveness of the factories engagement initiatives, a framework was developed which attempts to link the 12 Gallup elements to initiatives aimed at engaging employees in the factory. The scores for each Gallup elements are then used to infer how effective the initiatives have been.

It is important to reiterate at this point that the factory initiatives were not designed with a theoretical employee engagement framework in place. Therefore, the alignment between initiatives and the Gallup Q12 questions may not always be ideal. The purpose of the framework is to try and identify which initiatives are affecting which engagement factors. A degree of intuition was therefore used when developing this framework.

It was felt that some initiatives directly address an element of engagement whilst most have an indirect influence on an element of engagement. The relationship is considered direct if the initiative proactively and clearly addresses an engagement element. An indirect relationship is considered if the initiatives may reinforce engagement or create an opportunity for engagement to take place. It is important to note that identified relationships do not imply that a particular initiative will influence a particular element of engagement. The identified relationships indicate a possibility for an initiative to influence the element. There may be other ways in which elements are affected by other factors external to those identified as part of the engagement initiatives.

The framework of relationships is presented in Table 2.

Table 2: Linking Factory Initiatives to the Gallup Q12 Elements of Engagement

Gallup 12 Elements of Engagement	Clear Values	Social Events	Mass Meetings	Variable Pay Model	Common working Areas	Uniforms	Training and learner-ships
1. Knowing what's expected	x	-	o	x	o	-	
2. Materials and equipment	-	-	o	-	o	x	o
3. The opportunity to do what I do best	o	-	o	-	o	-	o
4. Recognition and praise	-	-	o	x	o	-	-
5. Someone at work cares about me as a person	o	x	-	-	o	-	-
6. Someone at work encourages my development	-	o	-	-	-	-	x
7. My opinions seem to count	o	-	x	-	-	o	-
8. A connection with the mission of the company	o	-	o	o	-	o	-
9. Co-workers committed to doing quality work	o	-	o	o	-	-	-
10. A best friend at work	-	x	-	-	o	-	-
11. Talking about progress	-	-	o	-	-	-	o
12. Opportunities to learn and grow	-	-	-	-	-	-	x

Direct Relationship	x	Indirect Relationship	o	No Relationship	-

4.3 Data Analysis

In order to analyse the survey results, scores and engagement percentages are calculated for both the overall factory and for each Gallup Q12 element. The score and percentage calculation are defined below.

i. Grand Mean Score

This is the total average score for all respondents over all Gallup Q12 elements. The grand mean score represents the overall engagement level of the factory.

ii. Mean score per element

Mean scores were calculated for each of the Gallup Q12 elements. Elements scoring above the grand mean score can be considered areas of strength whilst elements below the grand mean score require attention.

iii. Overall engagement

The overall engagement of the factory is determined by counting the number of employees whose average scores matched the engagement category detailed in Table 3.

Table 3: Overall engagement

Mean Score Range	Level of Engagement
4 to 5	Engaged
3 to 4.99	Not Engaged
1 to 2.99	Actively Disengaged

Overall engagement percentages are directly comparable to benchmark data from Gallup global studies.

iv. Engagement per element

This is calculated for each question by counting the number of employees who scored in each category as listed in Table 3, and converting to a percentage.

4.4 Data Collection

The survey (in paper form) was administered to 150 employees at the factory across all sections and shifts. 127 employees responded, a response rate of 84.7%, 4 surveys were spoiled and could not be used. Thus, a total of 123 respondents, 65% of the factory, made up the response sample. During data collection, the objectives of the research were explained to employees. They were also reassured that the survey would be anonymous.

5. RESULTS AND DISCUSSION

This section provides the results of the survey and discusses the status of employee engagement at the factory. The relationship between Gallup's 12 elements of engagement and the effectiveness of the factory's initiatives are then discussed.

Figure 3 shows that on average, 17% of employees are engaged at the factory, 23% are actively disengaged and the majority, 60% of the employees are not engaged. These results are compared to the South African and Global benchmark.

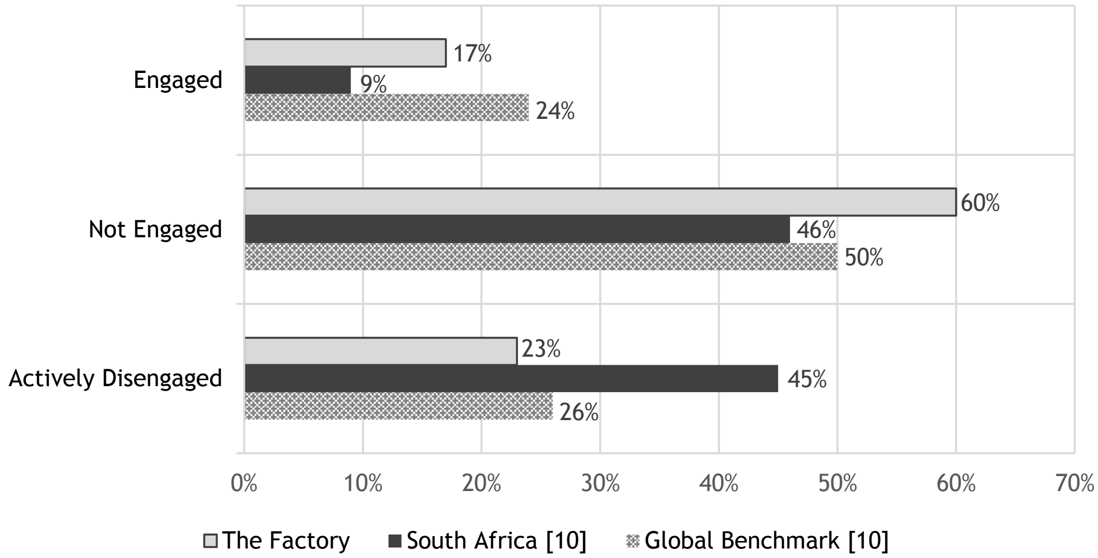

Figure 3: Overall Engagement Results

The Factory's engagement levels are better than the South African standard with 22% less workers *actively disengaged* and 8% more *engaged* at the company. This result suggests that the factory's focus on engagement has resulted in a more engaged workforce than the South African norm. This is especially noticeable in the low levels of *actively disengaged* workers at the factory where the factory performs even better than the global standard. The 60% of *not engaged* employees represents an opportunity for the factory to focus on the potential of engaging this group.

Figure 4 shows the overall results for the factory for each of Gallup's 12 elements of employee engagement. The figure shows the percentage of employees at the factory who fit into the three categories of engagement and the mean score for all respondents for that element. These results are used to discuss how well the factory is performing in each element and the degree to which initiatives are directly and indirectly affecting each element.

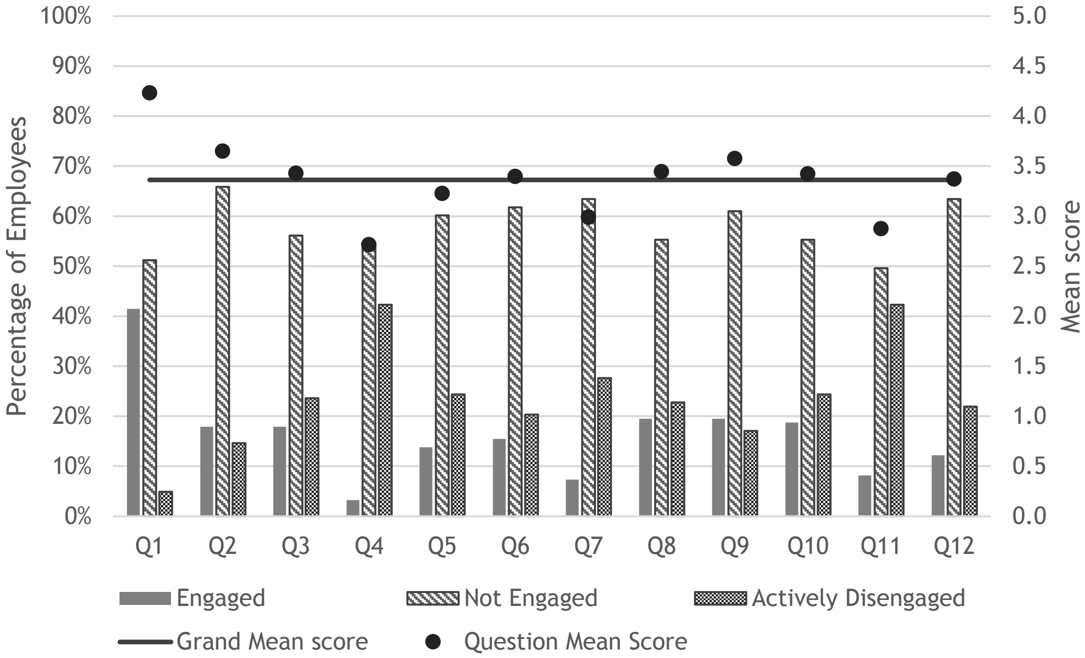

Figure 4: Results for Each Element

1. ***Knowing what's expected***

Element 1 - Knowing what's expected, was the highest performing element, scoring 4.24 with 41% of employees engaged and only 5% actively disengaged. Knowing what is expected is directly related to the clear values of the organisation as well as the variable pay model. The clear values provide a clear expectation of what behaviour is expected from employees. The variable pay model gives workers clear and measurable goals to work towards each quarter and allows employees to link their work to the objectives of the factory. The mass meetings and common working areas are also expected to contribute positively to this result as these initiatives encourage interaction between management and workers.

2. ***Materials and Equipment***

The company uniform and common working area are directly related to this category which scored 3.65 and is above the grand mean score of 3.36. An employees' uniform is part of the equipment that one needs to enter the factory, thus the factory providing uniforms to workers helps workers feel that they have what they need to do their job, this is also an unintended benefit of this initiative which was intended to remove communication barriers. The large proportion of employees who are not engaged in this element indicates that while workers may have the resources required to do their jobs, they do not feel they have control over these resources. For example, it was observed that there is a lengthy administrative process associated with getting something from the store which makes some employees feel they are not trusted.

3. ***The Opportunity to Do What I Do Best***

Only 18% employees feel that they are given the opportunity to do what they do best. Furthermore, 24% of employees are actively disengaged in this element, indicating a significant proportion of workers who may actively wish to move from their current role. Initiatives indirectly related to this element include the company's values, mass meetings, common working areas and training and learnerships. The link between these initiatives and this element is mostly focused on providing a platform for an employee's direct manager to provide direct tasks to the most suitable persons. This element of engagement requires a deeper approach which recognises the need of individuals to have meaningful and valued work [11]. This also requires a work environment that enables experimentation without fear. Supervisors play an important role in supporting this type of work environment [12]. There appears to be a need for a more specific initiative to address this element.

4. ***Recognition and Praise***

Recognition and praise scored the lowest out of all elements with a mean score of 2.27 and 42% of workers actively disengaging from this element. Poor mean scores indicate that managers are failing to recognize employees in the right way or frequently enough [9]. The variable pay model is the only initiative directly related to this element. The quarterly performance bonus is too infrequent to positively influence this element and circumstances outside of the employees control can result in teams not achieving their quarterly target. An important aspect of employee engagement is an individual's ability to contribute [13]. It is important to ensure that individual performance can directly be linked to organisational performance, again emphasising the importance of being able to relate performance bonuses to factors that are within an individual's control. The indirect initiatives of mass meetings and common working areas are not being effectively used as a platform to recognise and praise effort and achievement. There is a need for a more regular, non-financial initiative to praise and recognise employees in the factory.

5. Someone at Work Cares About Me as a Person

This element scored fourth lowest out of all the elements. The factory's values are directly linked to this initiative as the value of real connection is intended to create a work environment in which fellow employees know and care for one another. The poor performance of this element indicates that the company has a long way to go to create the culture that the values intend. Whilst social events are intended to create an opportunity for employees to establish a social connection, it does not seem to be creating that connection where it counts, between direct supervisor and worker roles and within a team.

6. Someone at Work Encourages My Development

Training and learnerships are the only directly related initiative where an employee's development can be encouraged. There is however, a link missing between identifying employee's development needs and sending them on training.

7. My Opinions Seem to Count

This element scored third lowest with a mean score of 2.99. Mass meetings are the only directly related initiative designed to ensure employees can table their opinion. Mass meetings may not be having the intended effect as they are too large a forum for meaningful contribution of opinions. It could also be difficult for employees to get feedback or action based on their opinion in such a large forum. Although consultation or being 'in on things' is an important aspect of engagement [13], it is the ability to have a feeling of choice or control that truly engages employees [11]. This low score again points to a need for direct supervisors to consider and action the opinions of their subordinates. The low score in this element also indicates that the benefit of an employee's experience and potential contribution that they can make to improve the factory is not being realised.

8. A Connection with the Mission of the Company

It is encouraging that 20% of employees have a strong connection to the mission of the company. These are people who view their job as part of their identity and will continue to engage. Whist the majority of employees view their job as just a job, it is concerning that 23% of employees are actively disengaged from the company's mission. Whilst the factory has clear values it is evident that these values are not being 'lived' by the factory, resulting in a gap between what people expect from the factory and what they perceive. More focus is thus required to bring the values 'to life'.

9. Co-workers Committed to Doing Quality Work

This element scored significantly higher than the grand mean and indicates that the values are creating a commitment to quality at the factory. This is strengthened by the variable pay model which results in financial consequences for poor quality.

10.A Best Friend at Work

This element scored above the grand mean of 3.37 and indicates that the initiatives of social events and common working and eating areas is having a positive result.

11.Talking About Progress

This was the second lowest scoring element. There are no directly linked initiatives to this element. Similar to element 7, there is a need for structured time to discuss individual progress and development at the factory.

12.Opportunities to Learn and Grow

Relating to opportunities to learn and grow, 63% of employees are not engaged in this element. This indicates that while there is a focus on training and development, this needs to be linked to element 7 and 11, so that employees feel that training and learnerships are both available to them and will link to their development and progress at the organisation.

Overall it appears that the initiatives at the factory are having a positive effect on encouraging engagement at the factory. The factory's clear values are ensuring clear expectations and lay the foundation for employees to have strong relational connections. Even though these conditions are not yet realised, the factory values of trust, respect and accountability, real connection and having fun are aligned with creating an engaging working environment. However, values by themselves cannot create engagement unless the factory undertakes initiatives to instil these values into the culture of the organisation.

Social events are directly related to employee relational connections. Social events do not appear to be having the desired effect of improving relations. There needs to be more focus on improving the relationships within a team and with an employee's direct line manager. This relationship is deemed to be weak as element 4 and 5 are low scoring and indicate a breakdown of trust between management and employees, similar to findings for the rest of South Africa [10]. On the same theme, mass meetings, although related to several elements, do not appear to be effective as these meetings were observed to be too large for management to listen to and action employee's opinions. It is felt that smaller, more regular forums would encourage stronger relationships within a team and between teams and their direct supervisors.

The variable pay model is useful for ensuring that employees are aware of what is expected of them but it is deemed to have a negative effect on the recognition and praise that employees feel they receive. The feedback loop of the variable pay model is too long, at 3 months, and factors outside of an employee's control can result in employees not reaching their bonus target even though they gave their best. It is recommended that an initiative to encourage praise and recognition that is not connected to income is established as supported by literature [9].

Common working areas do not have a direct relationship to any of Gallup's elements. There are however several indirect relationships which indicate that this is a positive initiative. Common areas reduce barriers to communication, especially between departments and across levels of supervision. The common uniform does not appear to remove barriers to communication as a manager in a uniform is still known to be a manager and therefore more direct initiatives are required to create stronger communication ties between managers and works. That said, uniforms have had the unintended positive contribution of ensuring that an employee has their own uniform to wear, creating a stronger feeling of having the tools and equipment required to do their job.

It is unclear how effective training and learnerships are at facilitating professional development, but it is evident that there is a need for more focus on individual, personal development plans which point to relational elements, most notably, to the relationship between a worker and their direct supervisor. Improving this factor will allow employees to relate training and learnerships to their career path and future at the company.

It should also be mentioned that the initiative of deciding to measure employee engagement at the factory in and of itself contributes to engagement as management are taking active steps in assessing and focusing their efforts. It is however imperative that feedback is provided so that employees feel that their input is valued and to ensure that future studies are meaningful with the same or higher levels of participation.

13. CONCLUSIONS AND RECOMMENDATIONS

The factory's focus on engagement is having an overall positive impact as the factory has been shown to have significantly more engaged employees and fewer actively disengaged employees than the South African norm. The 60% of not engaged employees represents an opportunity to continue to foster a culture of engagement and improve their engagement over time.

There is however a lack of initiatives that support the direct relationship between employees and their supervisors which needs to be addressed before higher levels of engagement can be achieved.

Finally, it is recommended that the continual measuring and monitoring of engagement at the factory will allow management to track the improvement of engagement as this study forms an initial internal benchmark. The Gallup Q12 elements and their relationship to initiatives at the factory should also be used to direct the decision making on future initiatives.

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EXPLORING KEY CONCEPTS IN THE TECHNOLOGY PLATFORM LITERATURE: A SYSTEMATIC REVIEW

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ABSTRACT

Technology platforms, specifically in healthcare, provide a basis for innovative solutions to aspects of access, quicker turnaround times for tests and ease of access to patient data. The focus of this article is the methodology and results of a systematic review on technology platforms. This forms the foundation of a future conceptual framework for the design, development and evaluation of these platforms in the African healthcare context. The results included the key concepts, characteristics and the diverse nature of technology platforms within innovation ecosystems.

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1. INTRODUCTION AND PROBLEM STATEMENT

1.1 Background

Technology is transforming the way humans communicate, do business and go about their lives. Emerging technologies which are having a significant impact include 3D printing, artificial intelligence (AI), autonomous vehicles, Big Data and the Internet of Things (IoT), to name but a few. The adoption of technology platforms is an important trend. The ease of accessing data, the popularity of smartphones and the connectivity of citizens worldwide are some of the reasons why firms are shifting from traditional pipeline businesses to platform businesses. Evans and Gawer [1] state that platforms have grown to platform ecosystems and entered the worlds of social media, books, music, travel, banking, healthcare, energy and transportation.

Parker, Van Alstyne and Choudary [2], define platforms in a business context as the provision of an open, participative infrastructure where value-creating interactions can take place between producers and consumers under set governance conditions. The purpose of the platform is to consummate matches amongst users and enable value creation for all parties through the facilitation of goods, services and social currency exchange. Gawer and Cusumano [3] distinguish between internal and external platforms of a company. They define an internal platform as a set of assets organised in such a manner that the company can develop and produce a variety of derivative products. An external platform on the other hand, is similar products, services or technologies that provide the foundation upon which other companies can develop their own products, services or technologies.

The design of a platform focuses around a core interaction, which is the most important activity that occurs on the platform and results in the most value created for all participants [2]. Baldwin and Woodard [4] state that the fundamental architecture behind platforms is similar, as it comprises of set of core components and peripheral components. These enable the platform architecture to act as a modular system which facilitates innovation [5]. This facilitation is possible as it helps to manage the complexity of the platform and it allows for specialisation and division of innovative labour through the reduction of the scope of information to which designers must design these modules [6].

A platform connects people, resources and other participants in an interactive ecosystem within which value can both be created and exchanged [2]. Thomas and Autio define an ecosystem as “a network of interconnected organisations, organised around a focal firm or a platform and incorporating both production and use side participants” [7]. More recently, Autio and Thomas [8] defined an innovation ecosystem similar as before, but with a specific focus on developing new value through innovation. Both these definitions highlight the importance of networks, network effects in these platform ecosystems.

1.2 Technology platforms in the African healthcare context

Although technological innovation has the potential to improve the quality of life of all, an industry that has been resistant to the adoption of technology platforms is the healthcare industry. Specifically in Africa, where primary healthcare is a critical issue, healthcare platforms have the potential to provide solutions. Healthcare quality and accessibility can be improved through platform enablers such as the accessibility of large volumes of health-related data obtained from sources such as electronic medical records (EMRs), data banks, IoT sensors, other data-obtaining medical devices and mHealth applications [9].

Africa Health Stats provides insight into some critical health aspects [10]. This includes deaths related to infant mortality, neonatal mortality, malaria and the number of citizens receiving treatment for tuberculosis and HIV/Aids. Some of the most critical aspects of African healthcare could potentially be mitigated and addressed through platforms, substantiating the need for improved usage of technology platforms in African healthcare. Some platform-enabled solutions include telemedicine, stock visibility in clinics, collecting and using data in a database, better communication to patients and better decision making abilities for healthcare practitioners.

1.3 Problem statement

According to Parker, Van Alstyne and Choudary [2], the resistance of the healthcare industry to the adoption of technology platforms could be linked to industry specific barriers such as the high cost of failure, sensitive data, resource intensity and the high regulatory control in the healthcare environment. In addition to this, healthcare platforms specifically tailored to the African context have not been researched to the same extent as those in developed countries. There is currently no specific framework for implementation in this context known to the researchers. With the advancement in digital technology and the popularity of mobile devices throughout Africa [11], the implementation of technology platforms could provide some of the much needed solutions in African healthcare.

The researchers envisage to address this problem through the subsequent development of a conceptual framework to contribute to the uptake of technology platforms in the African healthcare context. However, this paper only focuses on the first step towards this goal by presenting the methodology and results of a systematic review conducted on technology platforms. The results of the review form the foundation for the future conceptual framework. Figure 1 illustrates the context of the systematic review and contribution of this paper (first block/circled), within the conceptual framework development process.

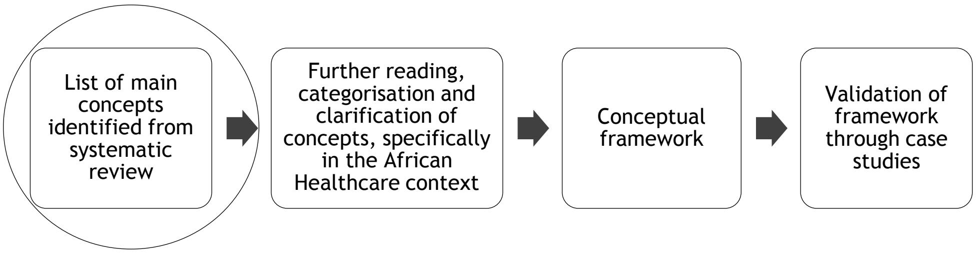

Figure 1: Systematic review context (first block (circled) is this paper)

2. METHODOLOGY

The guidelines followed for the conduction of the systematic review comprised of a combination of three literature sources. Firstly, the requirements of the conceptual framework development process outlined by Jabareen [12] and shown in the first column of Table 1 are followed. Secondly, the systematic review process suggested by Petticrew and Roberts [13] and the guidelines from Kitchenham and Charters [14] were incorporated. Table 1 gives a summary of the methodology which emerged from the combination and adaptation of these three resources and subsequently followed for undertaking this systematic review. A detailed description of each phase follows below.

Table 1: Systematic review methodology

Stage in framework development context adapted from Jabareen [12]	Systematic review guidelines adapted from Petticrew and Roberts [13] and Kitchenham and Charters [14].
Phase 1: Planning the review	• Substantiate gap in literature • Gather an advisory group • Write and review a protocol including review question(s), methodology, data synthesis method and criteria
Phase 2: Mapping of data sources	• Literature search/ identification of research from database. • Documentation of search process
Phase 3: Reading and categorising of data	• Screening of references • Assess against predetermined criteria • Document process of identifying primary studies • Critical appraisal
Phase 4: Identifying, naming, deconstructing and categorising of concepts	• Data extraction • Read and re-reading of studies • Synthesis of primary studies • Identifying characteristics and categorisation
Phase 5: Post review documentation	• Consider bias • Writing of the report and evaluating results • Wider dissemination

2.1 Phase 1: Planning the review

The first phase included substantiating the gap in the literature, defining the questions to be answered by the systematic review, identifying an advisory group and writing a protocol for the review. The protocol included the review question(s), methodology, how the studies are to be identified, the appraisal of the studies and how they will be synthesised [13]. It also included the study selection criteria and procedures, data extraction and synthesis strategy and the dissemination strategy of the review. The selection criteria was included in the protocol to reduce possible bias [14]. The systematic review questions were developed following the guidelines from Higgins & Green [15] and adapting it for qualitative studies [16] resulting in the following questions to be answered by the systematic review:

- What are key concepts relating to technology platforms in innovation ecosystems?
- What are the definitions and characteristics of technology platforms?
- What are the different approaches to viewing and analysing technology platforms and innovation ecosystems?

The research database, Scopus, was used to obtain the studies. The results of the final search were exported to MS Excel and synthesised according to predetermined criteria. The MS Excel document was adapted to allow for the coding of the pre-determined categories as defined in the research protocol. These new categories included the research approaches, the research methodology (empirical, literature review), the key concepts, citation numbers, geographic applications of the studies and what framework or theory was used.

The inclusion and exclusion criteria were based on the review questions as suggested by Kitchenham and Charters [14]. The criteria were classified into two categories, C1 and C2, to distinguish which criteria would be applied at what stage of the process of primary study identification. The criteria can be seen in Table 2.

Table 2: Search criteria

Criteria category	Criteria	Description
C1	Type of paper	Excluding conference reviews, panel discussions and lecture notes.
C1	Language	English only and language quality.
C1	Irrelevant studies	Studies focusing on aspects not related to the research questions. For example the title of an article could serve as first criteria and articles referring to innovation platforms, IoT, cloud computing, marine biotechnology etcetera are excluded.
C2	Empirical soundness	Methodology used to conduct the study and its validity. For studies using case studies, incorporating questionnaires and interviews, the number of questionnaires, response rates and interviewees were considered.
C2	Academic rigour of paper	The article should be referenced properly and clear theoretical concepts used. It should follow a proper methodology and state thorough conclusions. The length of the paper was also considered. (Critical appraisal)

2.2 Phase 2: Mapping of data sources

The main objective of this phase was to map all literature sources on the chosen topic [12]. For digital libraries, Kitchenham and Charters [14] suggest including the name of the database, the search strategy, the date of search and the years covered by the search as part of the complete search process documentation shown in Table 3. The search strategy was based on search terms in order of descending relation to the research questions up to the point where the number of papers were an acceptable amount. By searching for the term 'Platform', the search yielded 483301 results which were reduced to 97620 after adding 'Technology'. This was still a considerable amount of papers and the term 'Innovation' was added reducing the results to 4388. As the authors decided on an ecosystem approach, the term 'Ecosystem' was added, resulting in a final amount of 173 results.

Table 3: Search results from Scopus search

Name of Database	Scopus	
Search strategy	Search Terms:	Results (nr):
	Platform	483301
	Platform AND Technology	97620
	Platform AND Technology AND Innovation	4388
	Platform AND Technology AND Innovation AND Ecosystem	173
Date of search	30 May 2017	
Years covered by search	No limitation on publication year	

2.3 Phase 3: Reading and categorising of data

The next phase included choosing the final data sources to be used in the systematic review through assessing the above search results against the inclusion criteria where after it was read and reread in order to characterise the data [12]. The first step was the application of basic inclusion and exclusion criteria to the identified data sources. The data sources were limited to exclusively English, leaving 166 search results. Thereafter the remaining studies were exported from Scopus into MS Excel for further screening and eventual categorisation. The exported data included authors, paper title, publication date, affiliations, source title, abstract, keywords and the document type. The process of identifying the primary studies is illustrated in Figure 2.

After applying the category 1 (C1) criteria to the abstracts of the studies and eliminating evident non-relevant studies, all conference reviews and panel discussions amongst other criteria, a total of 59 papers remained. The online availability of these papers were checked and only 45 could be obtained in full text. Books were also excluded, as full versions could not be found. Next, the full papers were screened and assessed against the first category (C1) and the second category of criteria (C2). This resulted in the final number of 26 papers remaining. These formed the primary studies and data used for the systematic review.

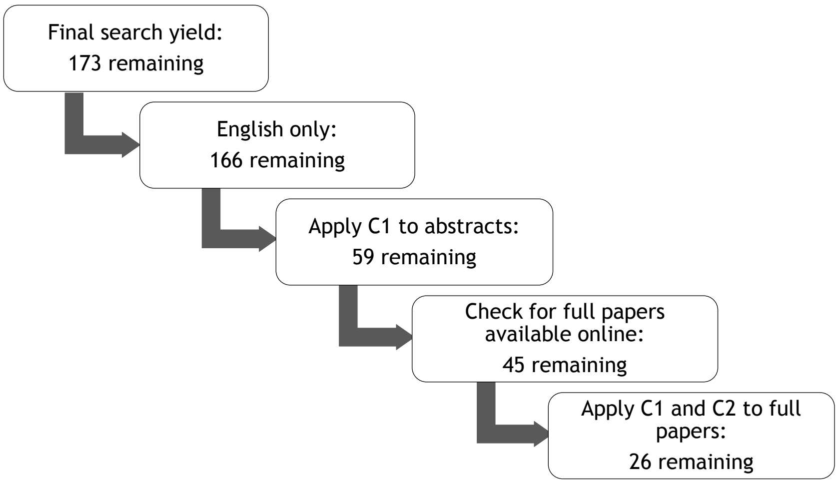

Figure 2: Process of identifying primary studies

2.4 Phase 4: Identifying, naming, deconstructing and categorising of concepts

Phase four included the re-reading of the primary studies, extracting the data and identifying and categorising the main identified concepts. Extracting the data is a systematic approach where all relevant information are extracted from the primary studies [13] specifically to address the review questions [14]. Through the detailed reading of the papers, each were critically appraised with respect to its methodological soundness. This aided with any biases and assisted the author to interpret the data as suggested by Petticrew and Roberts [13]. Phase 4 also included the synthesis of the data by systematically describing, reporting, tabulating, and integrating the results of the studies. This lead to the deconstruction of each identified concept described by Jabareen [12].

2.5 Phase 5: Post review documentation

Phase 5 of the process was the post review documentation, including documenting the results concluded from the systematic review, assessing bias and wider dissemination.

3. RESULTS

3.1 Descriptive analysis of the review

As a result of the primary studies' data, descriptive information was obtained. Figure 3 indicates the number of citations for the author(s) of each paper where the citation numbers were obtained from Google Scholar (on 8 June 2017). A limitation of this approach is that Figure 3 does not take into account the publication dates of the papers and therefore it is not the best way to illustrate the data. Figure 3 aided in identifying the seminal authors in the relevant research fields. Figure 3 also made the researcher attentive to the most cited authors, after which their names could be recognised in other papers. These authors will be noted in the further continuation of the project.

The methodology used in each paper was also examined, i.e. literature review, theory or empirical method such as a case study. By analysing the primary studies, it was determined that 77% of the studies were case studies. The other studies developed models or conducted literature reviews. The case study papers were further examined to determine the geographical application area of each. The application areas are shown in Figure 4. In Figure 4, the term 'Global' refers to the application of the case study to a firm that has a global "footprint" such as Apple, Microsoft or Intel and as a result was not country specific.

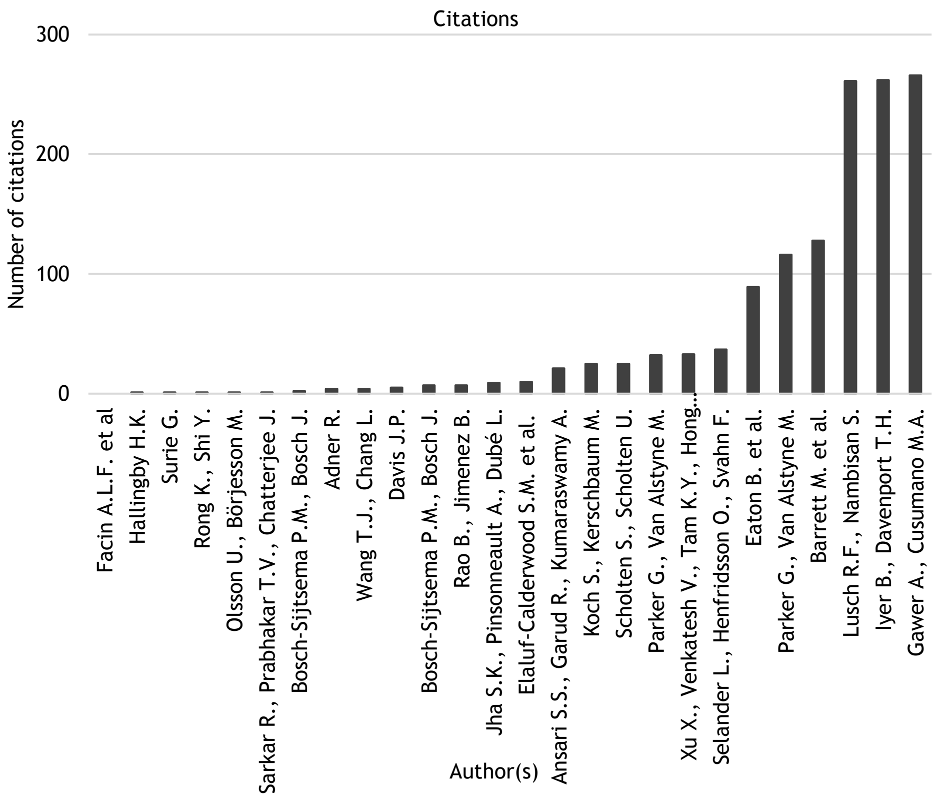

Figure 3: Citation ranking of papers

The term 'General' was allocated to studies which comprised of a literature review or had no specific application in a geographical area. From Figure 4 it can be seen that there was no papers focusing specifically on Africa, which emphasises the gap in the literature for technology platforms in an African context. 'North America' included studies in the United States and Canada. 'South America' included Mexico, Puerto Rico and Brazil. Asia included India, Taiwan and China and the European/UK studies were applied in Norway, Spain, Sweden and the UK.

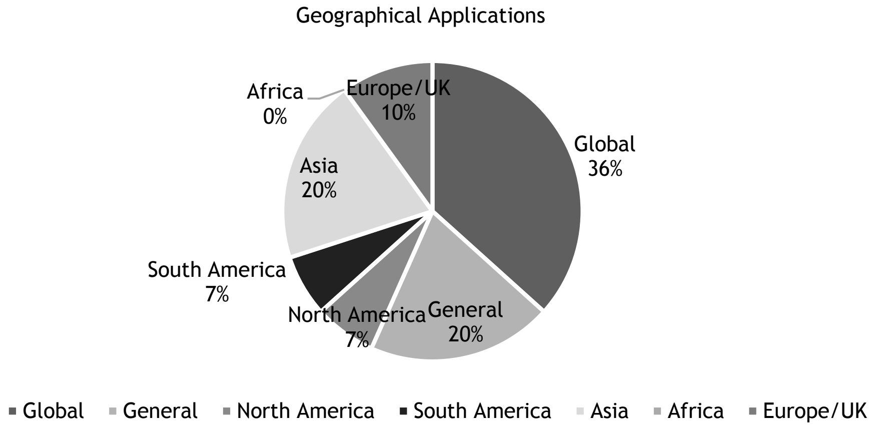

Figure 4: Geographical application areas

3.2 Conceptual insights

Reading and re-reading the primary studies [12] led to the identification and categorisation of concepts related to the search terms (platform AND technology AND innovation AND ecosystem) and thus the research questions. Firstly, the different areas of research that the primary studies' authors referred to or adopted in their papers were identified. Secondly, the key concepts identified from the primary studies were documented. Thirdly, the different application areas when referring to technology platforms, were recognised.

The different research areas featuring in the primary studies are important for the identification of the diverse nature of the field. This verifies the fact that one cannot consider technology platforms in innovation ecosystems from only one point of view, for example, from a strategic management point of view. The research indicates that the topic stretches much wider and one needs to be aware of other research fields such as group dynamics, innovation management and open innovation to get a more complete picture. The spectrum of research areas, their descriptions references are shown in Table 4. The research areas were also categorised into broader categories as shown in the first column.

Each identified research area was categorized into one of five broader categories. The first category included research areas focussing specifically on people and people relations. The research areas involving business management and entrepreneurship were categorized into the economics category. As innovation was part of the key search terms, there were studies focusing specifically on innovation related aspects including diffusion of innovations, open innovation and innovation management. The studies that adopted a system perspective involving TIS, network theory and systems engineering were categorized together. The last category included papers specifically adopting a biological perspective and how ecosystems function from a biological perspective. As a result, the diversity of fields related to technology platforms in innovation ecosystems identified act as a starting point for further research in this area.

Table 4: Different research categories

Categorisation	Research area	Description	Reference(s)
People oriented	Organisational change management	Managing new processes or changes in an organisation such as job transitions and group formation and development [17].	[18]
	Group dynamics	Looking at the dynamics in inter-organisational relationships where multiparty interactions occur.	[19]
	Technology as service delivery (servitisation)	The delivery of a service component through the technology and analysing the technology from this service perspective.	[22] [24] – [28]
Economics	Social entrepreneurship	Techniques used when entrepreneurs develop and implement solutions to social issues such as renewable energy.	[25]
	Strategic management	The strategies undertaken by management of a firm to establish and reach its goals taking into account the organisational environment.	[29] - [35]
Innovation studies	Diffusion of innovations	Explains how technology as an innovation spread across a social system.	[31] [33]
	Open innovation	Organisations using ideas across organisational boundaries to facilitate innovation.	[31] [34] [36] [38] [39]
	Innovation management	Planning, implementing and controlling innovation activities in order to realise innovative ideas.	[36] [40] [41]
Systems focus	Technological Innovation System (TIS)	A socio-technical systems perspective to analyse a technological field in terms of structures and processes that support or hamper it.	[37]
	Network theory	Study of complex interacting systems [38].	[19]
	Systems engineering	The overall design and management of the technology considering the complete system life cycle incorporating a process of steps.	[36]
Nature/ biology	Ecology	The biological functioning of ecosystems and how they relate to business and technology ecosystems.	[35]

Certain fundamental concepts regarding technology platforms occurred repetitively throughout the reading of the primary studies and could be linked and categorised with regard to their relation to each the search terms (Platform AND Technology AND innovation AND ecosystem). These key concepts are shown, explained and referenced in Table 5. The concepts provide guidelines as to what aspects to consider and to pursue in further research. They also contribute to a better understanding of the workings of technology platforms, ecosystems and innovation and how they relate to one another. The key concepts were grouped together based on their relation to each of the search categories namely technology platforms, ecosystem and innovation. The key concepts within each category were further categorised into sub-categories.

Throughout the primary studies, there were three main components that were identified as the key operational principles of technology platforms. A platform owner should take into account how the platform evolves, creates value for the firm and its ecosystem as well as the influence of network effects on the platform and its users. Technology platforms need to incorporate specific principles into their core design and architecture [4] which can potentially ease the uptake and diffusion of such platforms in their ecosystems. These design principles enable the platform to define its openness to complementors, scale the platform in relation to the user demand and establish its ease of use and integration for platform users. Platform governance incorporates the leadership, company strategy and goals and the value exchange between third parties. The last sub-category for technology platforms were the user-related concepts which are key since the platform is used by the platform owner as well as third parties/complementors. These user-related concepts ensure the user needs and requirements are satisfied and that they are used for constant improvement. The key concepts identified for technology platforms act as a starting point for understanding the core aspects regarding platform design and functioning.

As a platform connects different participants in its interactive ecosystem within which value is created and exchanged [2], the ecosystem category yields core aspects to consider in technology platform operation. The ecosystem category was divided into four subcategories. The first sub-category included the concepts that influences the functioning of, and operation within the ecosystem such as the simultaneous occurrence of competition and collaboration of firms within the ecosystem, the trust that needs to be established between ecosystem participants, the entry barriers of the ecosystem and how value is co-created between the participants within the ecosystem. The second sub-category was leadership within the ecosystem which includes the governance of the participants and the need of an ecosystem platform leader.

Business ecosystem literature commonly draws from a biological analogy. Therefore, the third sub-category, ecologic nature, includes the concepts drawn from the functioning of biological ecosystems. These include the need for ecosystem evolution, diversity within the ecosystem and resilience and resistance which are all necessary to establish and maintain the ecosystem health. The last sub-category is game theory which includes the referral to the prisoner's dilemma within ecosystems. The result of these ecosystem related concepts is a basic understanding of how the platform ecosystem should operate and the identification of aspects for further research such as ecosystem health metrics.

Table 5: Key concepts relating to search terms

Search category	Categorisation	key concepts	Description	Reference(s)
Technology platforms	Operation principles	Network effects/ Network externalities	The value of a technology depending on the number of users adopting it. It allows for the rapid adoption of the platform due to its exponential nature.	[26] [31][3] [39] [32] [37] [34] [30] [40]
		Value creation	The actions that increases the worth of the platform. Value creation can focus on creating value for users as well as stakeholders.	[37] [3] [39] [36] [23]
		Evolution	The platform operates in a dynamic nature and needs to evolve accordingly. The platform also evolves through different life phases from start-up through to maturity.	[3] [23] [41] [35] [37]
	Design Principles	Modularity	Modular components allow for design flexibility and derivative products to be developed with limited resources.	[3] [22] [20] [39] [42] [23] [32]
		Core and peripherals	The platform should focus on a core function and from there develop peripheral functions.	[3] [26] [32]
		Boundary resources	Enable the platform owner to secure control while allowing third-party participants to contribute. Includes the software tools and regulations at the interface between platform owner and developers.	[23] [22]
		Openness	The degree to which a platform owner opens its architecture to developers including levels of access to information, rules governing the platform and cost of access.	[26] [30] [3] [34] [39]
		Evaluation methods	Management of organisation should be able to evaluate the performance of the platform.	[31] [35] [42] [43]
		Scalability	The ability of the platform to adapt if there is large fluctuations in demand/usage.	[41] [27] [21]
	Leadership	Governance	There needs to be set rules and strategies to manage the platform in terms of aspects such as openness and aligning strategy with goals.	[35] [40]
	User related	User needs/usefulness	To incorporate the needs of the user and ensure it being useful. (user driven innovation)	[31][21] [43] [29]
		Feedback	The collaboration with the platform users for feedback regarding new features and products.	[29] [3] [41] [32] [39] [24] [26]
		User toolkits	Third-party developers can be enabled to use a platform sponsor's platform through the provision of user toolkits. The purpose of the toolkits are to allow the non-specialists to design custom products to	[34] [30]

Search category	Categorisation	key concepts	Description	Reference(s)
			meet their needs. Examples are software development kits (SDKs).	
Ecosystem	Functioning	Coopetition	The simultaneous occurrence of cooperation and competition within the ecosystem.	[35] [28] [35] [28]
		Entry barriers	Aspects that make it difficult for a party to enter the current ecosystem.	[3]
		Trust	In an ecosystem mutual trust is needed between ecosystem partners as trust affects the operation of ecosystem relationships and risk taking.	[22] [24] [29] [43] [29] [3] [35] [37]
		Value creation /co-creation	The participants of the ecosystem have a joint value creation effort. This is accompanied by shared goals within the ecosystem.	[40] [20] [22]
	Leadership	Governance	Within the ecosystem, it is necessary to govern the ecosystem relationships to prohibit tensions to emerge.	[29] [35] [3] [26]
		Keystone firm/ Platform leader	The firm that occupies the central position in the ecosystem and drives the innovation of the evolving ecosystem.	[29] [3] [27] [41]
	Ecologic nature	Evolution	The participants in the ecosystem co-evolve and form a part of the ecosystem life-cycle where different stages focus on different aspects.	[35] [33] [21] [29] [3] [25] [33] [41] [28]
		Diversity	Similar to species diversity, industrial diversity refers to the types of organisations. There should be organisations assuming different roles in the ecosystem for robustness and health of ecosystem.	[25]
		Resistance and resilience	Resistance refers to the ecosystem withstanding external stresses without losing functionality. Resilience refers to recovery after a disturbance.	[25]
		Symbiotic relationships	Referring to the interactions and relationships between parties of the ecosystem and the need to work together for balance. There is a balance between the health of symbiotic relationships in the ecosystem and the power exerted by the platform "leader".	[29] [27] [35]
	Game theory	Prisoners dilemma	In terms of platform ecosystems, the dilemma is where parties are not willing to open or share their contributions although they want the other ecosystem participants to do so.	[39] [26]
Innovation	Theoretical concepts to consider	Disruptors Dilemma	The need to gain the support of the very parties you are disrupting in order for success.	[28]
		Wakes of innovation	The multiple unpredictable peaks and valleys caused by technological innovation in a sociotechnical system [44].	[23]

Search category	Categorisation	key concepts	Description	Reference(s)
		Innovation diffusion	Describing how innovation is adopted from the point when first introduced.	[31] [33]

According to the primary studies, there are certain theoretical concepts that should be considered when assessing the effect that platforms have on the other ecosystem participants and the effect that their ecosystems have on its larger surroundings. Technology platforms could act as a disruption and as a result the effects on society including the occurrence of the disruptor's dilemma, its expected and unexpected innovation wakes and how it will diffuse into society are possible further research areas to investigate.

It was also recognised that the 26 primary studies referred to different aspects when referring to a (technology) platform. As mentioned previously, Gawer and Cusumano [3] distinguishes between internal and external platforms. By adopting the external platform definition, the primary studies highlighted that there are five different focus areas/levels when referring to platforms as illustrated in Figure 5.

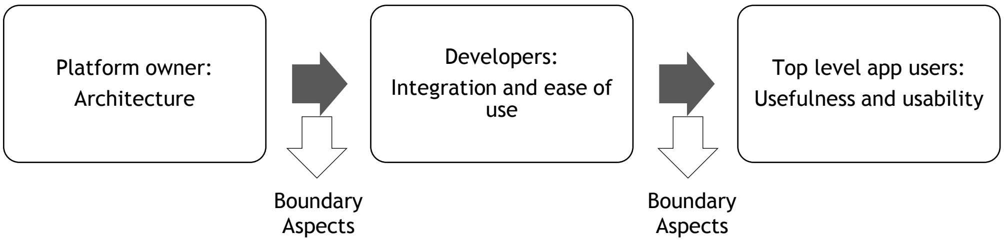

Figure 5: Five focus areas of platforms

Firstly, a number of papers focused on the platform owner. The platform owner is the software developer who establishes and focus on the architecture and internal design and functioning of the platform [34]. They also determine the level of openness of the platform [26]. An example of this will be Apple's iOS. Secondly, some authors focused on application (app) developers who can design their own apps on the platform owner's platform. An example of this is Uber who designed their app on Apple's iOS. These developers are influenced by aspects such as platform openness, technical entry barriers and network size [34]. The next area some studies considered were the final users of the app which operates on the platform owner's software platform. Some of the primary papers included aspects on how consumers use and adopt the platforms. The technology perceptions such as usefulness and ease of use as well as external influences including media and cultural aspects were investigated by Xu, Venkatesh, Tam and Hong [31].

Over and above these three focus areas, there were studies focusing on the interactions at each of the two interfaces or boundaries. There are requirements at the interface between the platform owner and the third party developers such as an application program interface (API) or software development kits (SDK)[34]. Specific considerations at the boundary between the third party developers and the users should also be taken into account. These can include the layout, design and interactivity aspects as explained by Sarkar, Prabhakar and Chatterjee [43]. If the platform owner operates as an internal platform, the middle block of Figure 5 will fall away as the platform openness is then limited.

These five areas all call for specific design requirements and the researcher should state the specific area of focus when developing design principles or conducting further literature reviewing on technology platforms as each of these streams of research highlights different aspects to consider in the technology platform ecosystem.

4. CONCLUSION

This article documented the process and results of a systematic review on technology platforms with ecosystem and innovation as added search terms. The aim was to conduct a systematic review to identify the key concepts and variety of research fields related to technology platforms operating in innovation ecosystems. The systematic review guidelines from Petticrew and Roberts [13] and Kitchenham and Charters [14] were adapted and used. Drawing from the systematic review, descriptive data and conceptual insights were presented and as a result answer the three review questions. The descriptive data included the author(s) citations, the methodologies used in the primary studies and the geographical application areas of those studies. It was evident that there was no case studies conducted specifically on the African continent within the primary studies.

The conceptual insights gathered from the systematic review were also discussed. This included the point of view from which the researchers in their respective research fields approached their study. These fields included strategic management, open innovation, social entrepreneurship and group dynamics. The primary studies also indicated the key concepts related to technology platforms and these were categorised according to their relevance to technology platforms, ecosystems and innovation. The reading and re-reading of the primary studies resulted in the distinction between five different application areas/levels when referring to technology platforms which was visually illustrated and discussed. These application areas include the platform owner, the third party developers and the top level app users as well as the two interfaces between these areas.

The further continuation of research to develop a conceptual framework for the design, development and implementation of technology platforms in the African healthcare context will build on the results from this review. The variety of research fields related to technology platforms points to the different research fields to investigate in the framework development process. The key concepts identified act as a concise summary and foundation for the understanding of technology platforms and its ecosystems. The key concepts should be investigated in more detail for a complete understanding of each concept and how they interact with one another. A vital aspect to consider in the further continuation for the process of developing the framework is the different levels when referring to technology platforms. A clear distinction should be made to which level is being referred to when reading other literature as well as when developing the framework. Specific research should be done for the platform owner level, the app developer level and the app user level.

The next step of the conceptual framework development process is a systematic review on technology platforms specifically in the African healthcare context. This will include a second systematic review focusing on these platforms in Africa and in healthcare aiming to answer questions regarding the enablers and barriers for healthcare platforms in Africa and the differences between platforms in Africa and other geographical areas.

4.1 Limitations

Only the Scopus database was used for the systematic review. The data analysis was done in MS Excel and not with a qualitative data analysis tool such as Atlas.ti which might be seen as a limitation. The primary studies were selected by a single researcher which might have resulted in possible bias [14].

5. SYSTEMATIC REVIEW PRIMARY STUDIES

Table 6 includes the number, author(s), title and reference number of the 26 primary studies of the systematic review.

Table 6: Primary studies

Number	Author(s)	Title	Reference
1	Davis J.P.	The Group Dynamics of Inter-organizational Relationships: Collaborating with Multiple Partners in Innovation Ecosystems	[19]
2	Hallingby H.K.	Key success factors for a growing technology innovation system based on SMS Application-to-Person in Norway	[37]
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IMPACT OF EFFECTIVE ORGANISATIONAL LEARNING ON OCCUPATIONAL HEALTH AND SAFETY PERFORMANCE

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ABSTRACT

Manufacturing and production organisations strive to improve their safety performance as it enhances company image and attracts prospective employees, partners, and clients. Learning from incidents and effective transfer of safety-critical knowledge is paramount to achieving this goal. Inappropriate or poor knowledge transfer can have serious safety repercussions on the operations of a manufacturing facility. The main objective of this research was to evaluate the impact of effective organisational learning practices on occupational health and safety (OHS) within a manufacturing organisation and facility. A conceptual model for effective organisational learning was formulated from current theory and models. Data on an organisation's learning practices was obtained through a survey with 166 respondents and incident statistics were obtained from the organisation's information system. Although no statistically significant correlation between the factors of effective organisational learning and occupational health and safety performance was found, a weak correlation was established.

1. INTRODUCTION

Inappropriate or poor knowledge transfer can have serious safety repercussions on the operations of a manufacturing facility. If the knowledge is not captured, utilised and transferred, it may be the major cause of high safety incident rates in manufacturing organisations. Even more so the learnings from safety incidents need to be appropriately transferred to reduce or prevent recurrence of the incident. The causes of safety incidents are not unique to the organisations and individuals involved, they also exist in other departments, organisations, industries and countries. It is not necessary that an organisation becomes part of the statistic to learn from an incident. The improvements seen may be as a result of learning from own mistakes or mistakes of others, but this learning can be improved by applying the appropriate knowledge transfer mechanisms for the relevant context. It is therefore important to understand what practices enable substantial improvements in safety. This will enrich the body of knowledge for learning from incidents.

This study identified practices that organisations use to learn from incidents and improve occupational health and safety (OHS). The practice of interest is the knowledge transfer from safety incident learnings and how this can be best used to reduce safety incident rates. The main objective of this research study was to evaluate the impact of effective organisational learning practices on occupational health and safety in the organisation.

2. LITERATURE REVIEW

Cummings & Teng [1] declares that the main objective of knowledge transfer processes is to transfer source knowledge successfully to the recipient, regardless of the context. It should not end there; the knowledge must be useful to the recipient and applied to achieve the required outcomes. The knowledge must be transformed into learning products – lessons learned – and stored in the organisational memory to be used by the members of the organisation when relevant (Jacobsson et al. [2]). A number of factors contribute to the effectiveness of the transfer mechanisms employed by organisations, and depending on how these factors are applied, some approaches may not effective in all situations as there isn't a "one size fits all" approach (Lukic et al. [3]).

2.1 Risk Management

The successful achievement of organisational goals and objectives depends on the decisions taken to contain and manage the risks and uncertainty involved (Tummala & Leung [4]). Granted that organisations strive for world class safety performance, risk management in this regard needs to support this objective. Risk is defined as *'the effect of uncertainty on objectives'* (ISO 31000 [5]). Risk management is the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events or to maximize the realization of opportunities (Wikipedia, [6]). Risk management is relevant in this study as its models are applicable to how organisations manage occupational safety and learn from safety incidents.

The approach would begin with the identification of all potential risk factors associated with occupational safety and generate corresponding consequences with their severity. Various alternatives are developed and considered to arrive at an optimal decision for controlling and managing the risks identified in order to meet the desired objectives of the organisation. In occupational safety, risk identification involves tools such as Task Risk Assessments (TRA), Fault Tree Analysis (FTA), Event Tree analysis (ETA), Potential Deviation Analysis (PDA), Cause-Consequence Analysis (CCA), Failure Mode and Effect Analysis (FMEA), etc. These tools are used to identify hazards systematically and their selection depends on the type or work and associated consequences. During risk analysis, a risk assessment matrix is typically used to rank the identified risks. This is determined using the combination of the probability of occurrence and the severity of the consequence. The hazards/risks are then ranked from highest to lowest. Risk evaluation will tackle the effectiveness of all plans developed to eliminate or mitigate the identified risks while the risk control and monitoring phase is very important in reviewing the progress continuously and taking corrective actions to accomplish the organisation's health and safety objectives (Tummala and Leung [4]).Knowledge management is critical in linking all the phases of the risk management process and completing the feedback loop which makes risk management a continuous improvement process.

2.2 Safety, Health, and Environmental management (SHE)

Lean et al. [7] says paying more attention to SHE performance has a greater potential to influence productivity when focus and emphasis is placed on raising awareness, training, safe working procedures, consultation, reporting and commitment from management. SHE training equips employees with the necessary knowledge to become productive and contribute to a safer work environment. This also provides the platform to instil beliefs and attitudes that will have a significant positive relationship towards safety, health and environment practices in an organization. Work procedures provide protection from incidents that may be caused by human error. Learnings from previous incidents are incorporated into updated procedures to prevent reoccurrence. Consultation refers to knowledge transfer throughout the organisation where employees and service providers alike participate in safety, health and environment practices. Proper reporting systems enable the employers to identify and manage safety, health and environmental matters using accurate reports of injuries or accidents that happened in the workplace. Commitment from management then sets out the organisation's culture in following through on all SHE practices.

Health and safety differs from many areas measured by managers because success results in the absence of an outcome (injuries or ill health) rather than the presence of an outcome. An incident rate is the number of recordable injuries and illnesses occurring among a given number of full-time workers (usually 100 full-time workers) over a given period of time (usually one year). Because a specific number of workers and a specific period of time are involved, these rates can help identify problems in the workplace and/or progress made in preventing work-related injuries and illnesses. But a low injury or ill-health rate, even over a period of years, is no guarantee that risks are being controlled and will not lead to injuries or ill health in the future. This is particularly true in organisations where there is a low probability of accidents but where major hazards are present. Here the historical record can be a deceptive indicator of safety performance. Organisations need to recognise that there is no single reliable measure of health and safety performance. What is required is a 'basket' of measures or a 'balanced scorecard', providing information on a range of health and safety activities. As organisations recognise the importance of managing health and safety they become aware of the problems with using injury and ill-health statistics alone as the only measure of health and safety performance.

2.3 Knowledge Management

Knowledge management encompasses knowledge creation, followed by its interpretation, dissemination and use, and then retention and refinement (McAdam & McCreedy [8]). Rai [9] says '*successful companies are those that consistently create new knowledge, disseminate it widely throughout the organization and quickly embody it in new technologies and products*'. This suggestion that knowledge management is critical to the achievement of organisational goals is consistent with its link to risk management.

One popular and simplified knowledge management model is the SECI process which suggests that knowledge is created through the conversion of explicit and tacit knowledge through socialisation, externalisation, combination and internalisation (Rai [9]). Tacit knowledge is defined as non-verbalised, intuitive and unarticulated while explicit or articulated knowledge is specified as being in writing, drawings, computer programs and so forth (McAdam & McCreedy [8]). These two types of knowledge can be created, acquired and transferred between individuals, groups and organisations interchangeably. Socialisation is when tacit knowledge is transferred within individuals in a social setting by sharing ideas, coaching and mentoring. Externalisation is when individually held tacit knowledge is codified and shared with a lager body/group such as when experiences are incorporated into models and procedures. Combination is when the codified explicit knowledge is articulated and reconfigured to be meaningful to the organisation with the use of databases and knowledge management tools. And finally, internalisation is when the organisation's body of knowledge becomes the individual's tacit knowledge through a learning culture.

Efficient knowledge management can reduce risk leading to better risk management (Massingham [10]). It is essential that knowledge management complement risk management to enable an organisation to learn from safety incidents. These two systems must enable an organisation to identify, analyse and evaluate safety risks, interpret and articulate this knowledge into useful knowledge to be embodied in organisational memory, appropriately transfer the knowledge in order to mitigate risk and achieve organisational goals, monitor and review performance to feedback into the systems, and continuously learn.

2.4 Models for appropriate knowledge transfer

The knowledge transfer mechanisms must be selected carefully to encompass all the types of knowledge related to the incident learnings being shared. The popular knowledge transfer mechanisms currently utilised by manufacturing companies includes databases, safety alerts, bulletins, investigation reports, toolbox talks, meetings, annual safety awareness training, shift hand-overs and coffee sessions. The effectiveness of these transfer mechanisms depends on knowledge context, relational context, recipient context and the activity context (Cummings & Teng [1]).

Knowledge context requires that the recipient understands the source of the knowledge (Cummings & Teng [1]). This must be communicated as part of the conceptual knowledge transfer. The employee will only be able to utilise this knowledge correctly if he/she understands the context under which it was developed. Knowledge context includes its embeddedness and ability to be articulated. Relational context refers to the transfer of knowledge across functional, geographical and organisational levels. The relational factors to be considered when transferring the knowledge are organisational distance, physical distance, knowledge distance and norm distance. Recipient context refers to the receptiveness of the recipient to the new knowledge (Cummings & Teng [1]). Knowledge may be freely available and accessible within the organisation but the recipient needs to be able to understand and apply the knowledge (Goh [11]). An important consideration in the recipient context is the choice between formal and informal learning from incidents. Formal learning is considered to be more valid as it is verifiable by experts. However, informal learning is natural and spontaneous allowing employees the freedom to talk more freely about the incidents and interact with the source of knowledge (Lukic et al. [3]). This leads to more effective and faster knowledge transfer but the discussions cannot be easily captured for future re-use. Activity context relates to the considerations that have to be made before knowledge can be transferred.

A decision must be made on how all can be integrated and transferred via an appropriate transfer mechanism. All the factors that will affect the effectiveness of the transfer need to be designed into the transfer mechanism. One of the most important activities is the packaging of the knowledge to be transferred. It is not practical to distribute the entire incident investigation report. The information needs to be condensed and contextualised in a way that it is valuable to the target recipient. Companies tend to condense the learning points into simplistic bullet points and one-liners. This is indicative of root cause seduction (Lukic et al. [3]). Most safety incidents are very complex with multiple underlying causes but accident investigations often stop at the events closest to the accident (Jacobsson et al. [2]). Root cause analysis (RCA) investigations are capable of uncovering the underlying causes and contributing factors. These findings must not be oversimplified to protect the transfer of deep contextual meaning.

Størseth & Tinmannsvik [12] describe a few aspects that promote and inhibit learning from the transferred knowledge. The major inhibitors include premature reporting, rush actions to show progress and developing many procedures to demonstrate change. The learning can be promoted by eliminating all traces of blame-game and aiming for understanding in the knowledge transferred; keeping the story alive by repeatedly refreshing the recipients and avoiding creating procedures out of all the learnings.

The dynamic knowledge transfer model defines knowledge transfer as a non-linear process that circulates and changes over time. It is a two-way process where both the source and the recipient are involved to the same degree (Raymond et al. [13]). This model expresses the effectiveness of knowledge transfer as a function of 3 capabilities:

- The diagnosis of knowledge and needs
- The development of generative, disseminative and absorptive capacities
- The integration of knowledge transfer using adaptive and responsive capacities

The diagnosis of knowledge and needs ties in with risk management. The organisation must understand and assess its capability and be able to identify gaps in its processes. The development of the organisation's generative capacity refers to its ability to discover new knowledge or to improve on existing knowledge. Disseminative capacity refers to the organisation's ability to appropriately transfer the knowledge as discussed in the previous model. The organisation must be able to situate knowledge in context, translate it into clear language and adapt, format, and disseminate it across organisational boundaries (Raymond et al. [13]). The absorptive capacity refers to the individuals, groups and organisation's ability to recognise the value of new knowledge originating from external sources. They need to be able to adopt it and put it into practice to deal with challenges and achieve positive organisational results. The integration of knowledge transfer using adaptive and responsive capacities refers to organisational learning. The organisation must be able to adapt and respond to changes in the environment. It must learn continuously and refresh/renew the knowledge transfer system.

2.5 Learning from incidents

Le Coze [14] says recent disasters in different high-risk environments call for a moment of reflexivity about learning from accidents. Organisations improve safety by using past experience like incidences, accidents, disasters and good practices (Drupsteen & Wybo [15]). The organisation learns from warning signals, precursors (Sonnemans & Körvers [16]), mistakes, near misses, incidents and accidents. An organisation learns by detecting events, by reflecting on them, by learning lessons from them and by putting these lessons into practice to prevent future incidents (Drupsteen & Guldenmund [17]). The first definition of learning from incidents is taken from (Drupsteen & Wybo [15] who terms it as *'Learning from experience means that relevant events are detected and analysed, and that lessons are determined and used for improvement of the situation and the organisation'*.

The term 'learning from experience'' is often used after negative events to claim that lessons will be learned from it, implying that such an event will not occur again.

Lindberg et al. [18] elaborates as follows: *'Learning from accidents is to extract, put together and analyse and also to communicate and bring back knowledge on accidents and near-accidents, from discovery to course of event, damage, and cause to all who need this information. The purpose is to prevent the occurrence of similar events, to limit damage, and thereby improve safety work'*. Jacobsson et al. [19] has an organisational learning view to learning from incidents: *'Learning from incidents means gathering information from the individual(s) involved in an incident and from the incident itself, and converting it into general knowledge for the whole organization, or at least for those people for whom the knowledge is important'*.

The overall theme of all three definitions is that information from incidents must be collected and processed to generate outputs that lead to safety improvements. Vastveit et al. [20] summarises this as *'the development of knowledge which will manifest itself as changes in the way individuals do their work, and the routines and systems of organisations'*.

3. CONCEPTUAL MODEL

The diagram in Figure 1 below is a conceptual model for effective organisational learning. It is centred on the models for effective knowledge transfer and supported by the models for risk management and knowledge management as a whole.

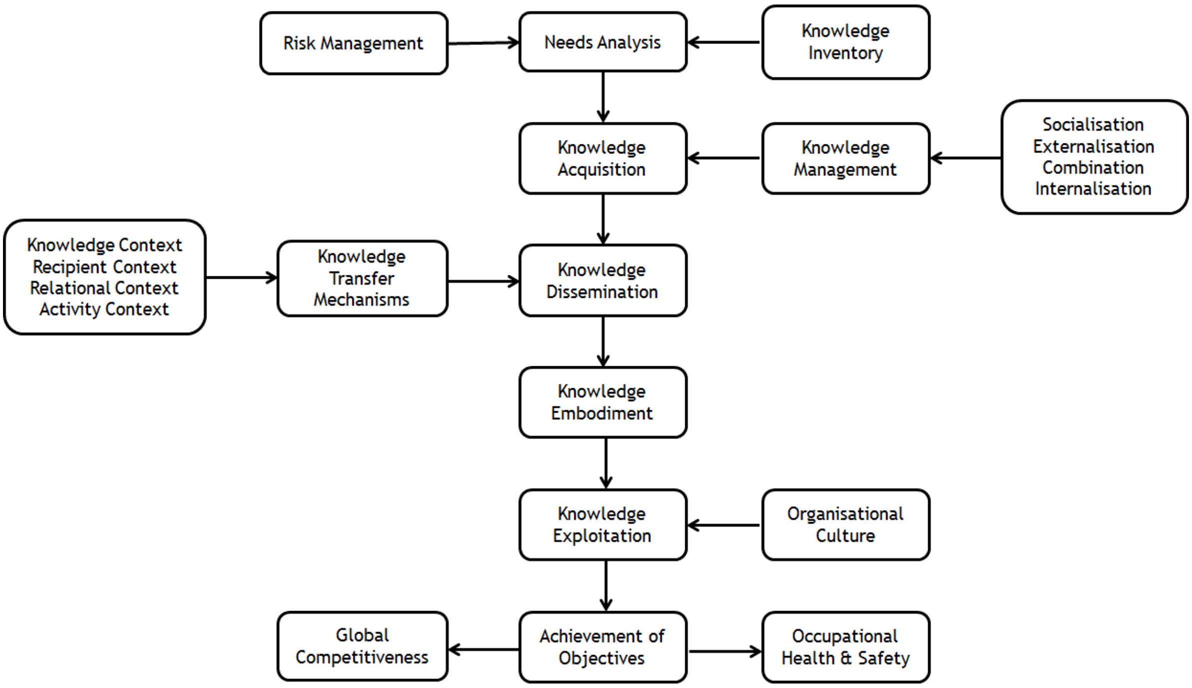

Figure 1. Conceptual model for effective organisational learning

The needs analysis is an audit of the gaps the organisation has in terms knowledge, systems, trust, human resources and technology. The organisation needs to be aware of what it already knows as a starting point. This is informed by the risk and knowledge management systems where internal and external learnings are captured and incorporated into the organisation's memory. The risk management loop will generate the gaps to be closed as the organisation grows and learns continuously. Trust is one of the essential levers in knowledge transfer. The organisation must also diagnose the level of trust so that managers can responsibly set an example and encourage a climate of trust. Raymond et al. [13]) said no improvement is possible without the generation of knowledge. This knowledge can come from the scientific or social paradigms (McAdam & McCreedy [8]). To keep the workplace safe, it is up to everyone to discover, improve and take part in generating new knowledge to promote safe decisions and safe behaviours. The knowledge management system of the organisation must enable this.

This is where the interaction between individuals, groups and organisations and their associated systems become important. The disseminative capacity is about circulating knowledge throughout the organisation. Here, the appropriateness of the knowledge transfer mechanism and the relevant contexts are very important. Knowledge management principles regarding the conversion between explicit and tacit knowledge (the SECI model) are critical enablers and foster participation and commitment within the organisation. Knowledge embodiment is the process when the transferred knowledge is absorbed into the organisational memory. The people in the organisation needs to recognise, accept, and put into practice new or improved OHS knowledge. This is enabled by the people's willingness to learn and to change, a value engrained in organisational culture. Knowledge exploitation is concerned with using available knowledge to generate new knowledge, solve current problems and ensure sustainable growth looking into the future. A key characteristic of good knowledge exploitation systems is that it becomes second nature for employees and management to adapt their OHS knowledge (Raymond et al. [13]).

The following six hypotheses were formulated for this research study.

1) H1: A well-equipped needs analysis system contributes to effective knowledge transfer in the organisation.
2) H2: A high level of trust within the organisation contributes to effective knowledge transfer.
3) H3: A well-developed capacity to generate knowledge contributes to effective knowledge transfer in the organisation.
4) H4: A well-developed capacity to disseminate knowledge contributes to effective knowledge transfer in the organisation.
5) H5: A well-developed capacity to absorb knowledge contributes to effective knowledge transfer in the organisation.
6) H6: A well-developed capacity to adapt and exploit knowledge contributes to effective knowledge transfer in the organisation.

4. RESEARCH METHODOLOGY

The research area of this study has considerable prior work therefore it is at a mature stage. The research approach therefore encompassed a quantitative study using surveys, formal hypothesis testing with statistical inference and standard statistical analysis. A cross sectional design was selected as the most appropriate as the aim is to document and test differences in subset of the population at one point in time. This design however limits causal inferences as it is conducted at one point in time and temporal priority is difficult to establish (Pinsonneault & Kraemer [21]).

The unit of analysis was the South African manufacturing industry. The population was a South African based manufacturing organisation. The sample frame was the business units within the organisation and the sample was the employees of the business units. The survey targeted all personnel working in the manufacturing organisation. This included clerks, artisans, technicians, engineers and managers in different disciplines and departments within the organisation. No prior exposure to occupational health and safety management was required as the questionnaire assessed the organisation's systems as experienced by the personnel. Response were collected from ten business units of the organisation.

The data was collected via an internet survey as it is good at collecting factual data and cost effective. Multiple data collection methods were used as supporting archival data was scanned, this is particularly important because each data collection method is limited in terms of what it can measure effectively (Pinsonneault & Kraemer [21]).

The survey questionnaire comprised of 36 multiple choice statements/questions designed to cover the 6 variables of knowledge transfer. The first 10 questions assessed the needs analysis of the organisation and the responses were used to evaluate the first hypothesis. Every set of 5 questions afterwards, assessed the organisation's level of trust, generative capacity, disseminative capacity and adaptive capacity respectively. The responses for these sets were then used to evaluate the next 5 hypotheses. A link to the questionnaire was emailed to all the employees in the business units.

The framework of this study has proposed that desired performances in occupational health and safety depend on effective systems being in place for Needs Analysis, Knowledge Acquisition, Knowledge Dissemination, Knowledge Embodiment and Knowledge Exploitation. These are the independent variables of this study and the incident rate was the dependent variable. Statistical correlations were used to determine whether causality exists between the dependent variable and independent variables.

5. RESULTS

5.1 Data collection process

A survey questionnaire was designed using the conceptual framework described in section 3 and distributed to suitable respondents via an e-mailed link. The survey was sent to personnel employed in 10 different business units (approximately 6000 potential respondents) and 169 responses were received of which 166 were fully completed. The number of respondents from each business unit is shown in Figure 2 below.

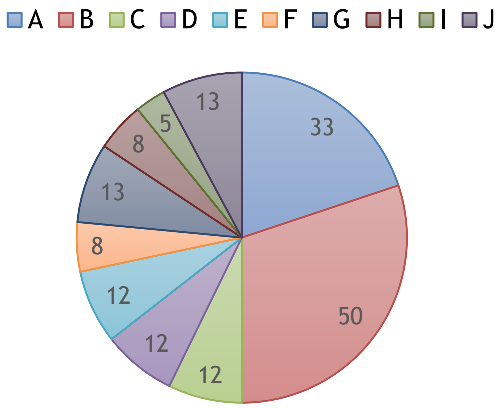

Figure 2: Number of respondents from ten business units

5.2 Summary of survey results and descriptive statistics

The survey comprised 36 questions which were divided into sections to cover the six elements of effective organisational learning, the research questions to be answered, and the hypotheses to be tested. The respondents were requested to provide a score on a 5-point Likert scale for each of the statements/questions in the questionnaire. A value of 5 represented strong agreement with a statement and a value of 1 represented strong disagreement with the statement. The data for the five highest and five lowest mean scores as well as the standard deviation (SD) is summarised in Table 1 below.

Table 1: Survey results for top 5 and bottom 5 statements

No.	Statements/Questions description	Mean	SD
H1.9	Monthly reviews of accidents and reactions to prevention activities are kept current to detect trends	4.1	0.91
H4.1	The organisation has tools and means for fostering the distribution of OHS knowledge to, and among all its employees	3.9	0.93
H1.6	The organisation uses tools and methods to identify the OHS needs of employees in the organisation and keeps them up to-date	3.9	0.97
H1.5	The organisation ensures that its employees' OHS knowledge and expertise is kept up-to-date	3.9	1.04
H5.4	Whether faced with failure or success, the employees in the organisation try to understand what occurred and what they can do the next time to maintain or improve the situation	3.8	0.89
H2.1	*The employees in the organisation trust one another, respect one another and do not hesitate to give their opinions*	3.3	1.06
H3.2	*Employees from different departments in the organisation consult one another to solve OHS problems*	3.3	1.06
H3.4	*The employees in the organisation use external information sources to create new OHS knowledge*	3.2	1.00
H2.5	*Generally. a good climate of trust reigns in the organisation*	3.2	1.10
H2.2	*Employees in the organisation openly admit and assume responsibility for their errors*	2.8	1.11

It is seen from Table 1 that the organisation values the recording and analysis of incidents and SHE data highly (H1.9). The highest score of 4.1 was for '*Monthly reviews of accidents and reactions to prevention activities are kept current to detect trends*'. The lowest scores were related to trust in the organisation (H2.1, H2.5 and H2.2). By far the lowest score (2.8) was for '*Employees in the organisation openly admit and assume responsibility for their errors*'.

5.3 Summary data for hypotheses

The mean scores for all the statements related to a specific hypothesis and for all respondents were determined and the results are shown in Figure 3.

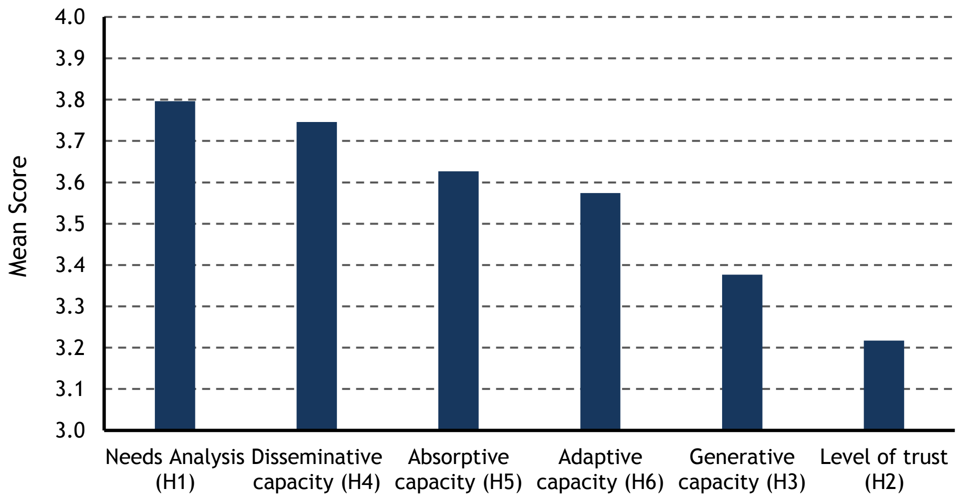

Figure 3: Mean scores for all responses and six hypotheses

It is evident that the respondents felt that safety, health and environmental (SHE) activities and practices are performed well in the organisation (score of 3.80). However, the respondents believed the level of trust in the organisation is only 'average' (score of 3.21). This confirms the findings from Table 1.

5.4 Summary data for each business unit

The total score for all respondents for each business unit was determined and the results are shown in Figure 4, ranked from highest to lowest.

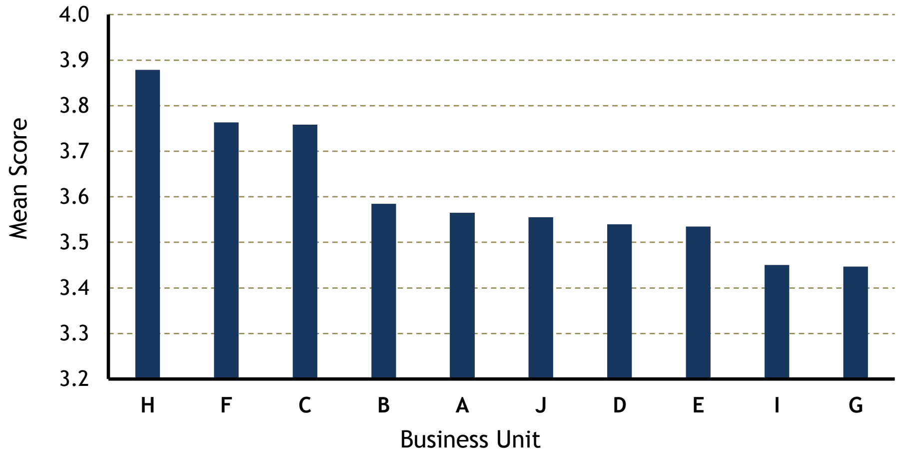

Figure 4: Mean scores for ten business units

From Figure 4 it is seen that the mean score varied from 3.45 to 3.88, indicating that the respondents from different business units perceived the SHE activities differently. This could be due to different line managers having different attitudes towards HER and different leadership styles.

5.5 Incident rate

The incident rate for each of the ten business units was obtained from plant data, i.e. the number of incidents reported and the employee hours worked. The relationship is given by equation 1. The incident rate was calculated using first aid and recordable cases.

$$\text{Incident Rate} = \frac{200000 \cdot \text{Number of incidents}}{\text{Employee hours worked}} \qquad (1)$$

The incident rate for each business unit, as calculated with equation 1, is shown in Figure 5 below, ranked from highest to lowest.

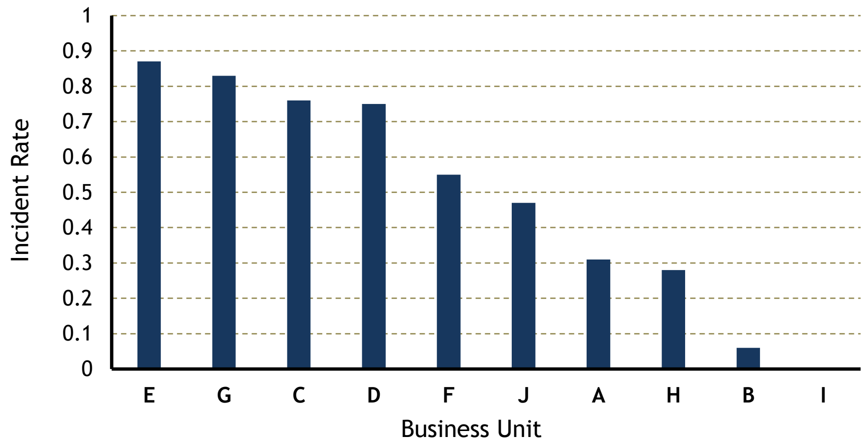

Figure 5: Incident rates for ten business units

The incident rate varied from 0 for business unit I to 0.88 for business unit E. Some business units did not experience many incidents in the time period that was analysed. Two business units, i.e. B and I, were outliers (low number of incidents) and excluded from correlation analysis in the following section.

5.6 Correlation analysis

The average score for all questions related to each of the six hypotheses was determined from the survey for each business unit. Figure 6 shows the incident rate and mean score for each business unit on an XY-plot.

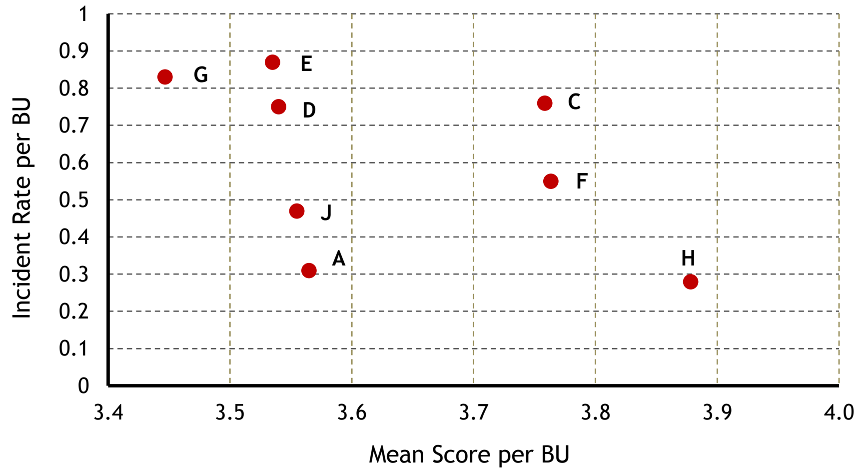

Figure 6: Incident rate vs. mean scores for eight business units (excluding B & I)

It appears from Figure 6 that there is a weak correlation between the incident rate and the overall mean values per business unit. The mean scores for each hypothesis was also determined per business unit and similar graphs as in Figure 5 were obtained.

Statistical analysis was performed on the scores from the questionnaire and incident rates. A covariance test with the data in Figure 6 produced a negative value of -0.015 which indicates that a higher mean score implies a lower incident rate for the business unit. A correlation test gave a value of -0.49 which indicates a weak correlation.

A covariance test, correlation test and Spearman Rho test were performed for each business unit and hypothesis. The results are shown in Table 2 below.

Table 2: Results of correlation tests

No.	Description	Spearman Rho test		Correlation	Covariance
		Coefficient	P-Value		
H1	Needs Analysis	-0.110	0.156	-0.53	-0.03
H2	Level of trust	-0.018	0.815	-0.28	-0.02
H3	Generative capacity	-0.063	0.419	-0.50	-0.03
H4	Disseminative capacity	-0.007	0.926	-0.32	-0.02
H5	Absorptive capacity	0.131	0.090	-0.02	0.00
H6	Adaptive capacity	0.100	0.199	+0.11	0.00

Table 2 above presents the results from the Spearman Rho correlation test, correlation and Covariance tests respectively. The covariance result indicates a negative value for the first four hypotheses which implies that a high value for Needs Analysis, Level of Trust, Generative Capacity and Disseminative Capacity lead to a lower incident rate. However, the correlation coefficient of < 0.6 indicates a weak relationship. The high p-values (>0.05) for the Spearman Rho correlation test support this finding. The null hypothesis, e.g. *'A well-equipped Needs Analysis system contributes to effective knowledge transfer in the organisation (H1)'* must therefore be rejected in favor of the alternative hypothesis. This applies to all six hypotheses.

From the results it can be concluded that there is no statistically significant correlation between any of the organisational learning variables and the occupational safety incident rate. A weak relationship was found for four of the six elements of effective organisational learning. A possible explanation of the result is that the number of respondents for some business units was quite low and the incidence rate was only determined over a short time period of one year.

6. CONCLUSIONS AND RECOMMENDATIONS

The organisation's system for effective organisational learning was evaluated by means of a survey with 166 respondents. Six elements of organisational learning were evaluated through agreement with 36 statements to which respondents had to indicate their agreement on a 5-point scale. The mean scores for each of ten business units and the six elements were tested for correlation with incident rates for each business unit that was obtained from the organisation's information system for Safety, Health and Environment.

The results of this research could not establish a clear link between the factors of effective organisational learning and occupational health and safety performance. However, a weak relationship was found for four of the elements of effective learning. This study has validated the conceptual model for effective organisational learning in that it can best be measured by the organisation's level of trust, needs analysis system, knowledge acquisition, knowledge dissemination, knowledge embodiment, and knowledge exploitation capacities.

The hypotheses proposed in this study should be tested through a longitudinal study over at least 3 years. The incident rates for the business units in this study could have large uncertainty since it was measured over a short time period and greatly varying number of man hours. The number of respondents from each business unit also varied significantly (from 3% to 30%) and it is recommended that at least 20 respondents are selected for each business unit. The incident rate was obtained by adding the number of first aid and recordable cases together. Other types of incidents could also be included in determining an incident rate.

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DEVELOPMENT OF A CONDITION MONITORING INFORMATION SYSTEM FOR DEEP LEVEL MINES

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ABSTRACT

Gold and platinum mines are under pressure to remain profitable. Therefore, the conditions and performance of equipment must be assessed continuously to ensure the systems are available and efficient. This however, results in a vast amount of data that needs to be translated into information. Automated monitoring and reporting processes are essential when considering the implementation of a condition based maintenance strategy on deep level mines. Machine and process data need to be analysed on a regular basis to identify operational risks and prevent breakdowns. Thus, an innovative methodology was developed to evaluate the operational condition of mining machinery. Several parameters were analysed individually, before being combined to provide a holistic assessment of each mining system. Systems that were evaluated include water reticulation, cooling and ventilation. Existing mining infrastructure was used to acquire the raw data. An information system was developed to automatically monitor these mining systems and generate notifications regarding operational risks. The information system provides maintenance engineers with a simplified view exhibiting the current state of the various mining systems. Summarised information is facilitated in the form of automated reports, while an online interface is used to provide more detail. Only relevant information is presented to selected stakeholders, making condition based maintenance possible.

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1. INTRODUCTION

Market related pressures have forced the South African mining industry to consider alternative approaches regarding energy usage, maintenance strategies and asset management [1-4]. If they are to remain profitable, gold and platinum mines need innovative solutions to avoid unnecessary operational and capital expenditures. One example of such a solution is a condition based maintenance (CBM) strategy [5]. There are, however, limiting factors that need to be considered before a CBM strategy can be implemented on deep level mines.

Deep level mines have limited access to installed equipment which makes the maintenance and monitoring thereof a challenge. Some mining systems are located on the surface, while others are a few kilometres underground with substantial distances between the equipment [6]. Underground entry is also restricted during blasting shifts [7]. It would therefore be beneficial to obtain machine and process data to identify operational risks before they develop into serious problems.

By making use of existing infrastructure, it was possible to obtain the required input data without additional expenditures. Several parameters were analysed on water reticulation, compressed air, cooling and ventilation systems. Figure 1 shows some key parameters indicated on a pump diagram. These are only some of the measurements that are available for a single pump. A vast number of measurements are available when considering an entire mining operation [8]. This equates to a vast amount of data to be translated into information.

Thus, an information system capable of automatic operation was designed and developed. The main objective of this system is to make CBM possible, by providing condition monitoring related information. A methodology was developed to analyse large amounts of data and provide simplified results regarding the operational condition of mining equipment. The methodology compares the input data with four regions of operation namely, safe, caution, risk and failure (SCRF). The automated system was therefore designed to collect data, perform an SCRF analysis and generate exception reports.

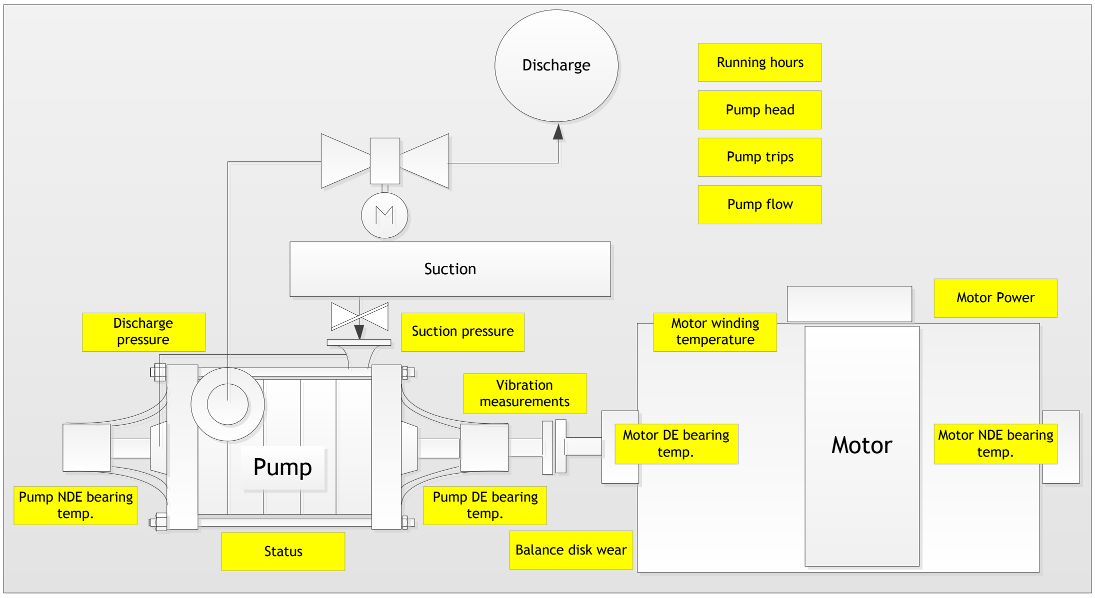


Figure 1: Pump monitoring parameters

2. BACKGROUND AND SYSTEM OVERVIEW

The field of condition monitoring consists of specialised instrumentation and advanced measurement methods. Moubray discusses several types of monitoring categories and techniques such as motor current signature analysis, LiDAR, infrared thermography and thin-layer activation [9]. These methods require specialist knowledge and equipment [10]. The use thereof can deliver valuable insights, presuming that a system defect was previously identified. It is, however, not feasible to perform these types of analyses on a regular basis. A solution was therefore needed to continuously analyse various parameters across multiple types of mining systems. This can be regarded as a first pass assessment which would indicate where an in-depth analysis is required.

Existing condition monitoring systems typically require the procurement and installation of additional hardware [11, 12]. These implementations result in large capital expenditures, and considering the current economic climate of the South African mining industry, solutions that require capital investment are, in general, not a viable option [13–15]. Other solutions are not compatible with multiple mining systems and require manual effort to perform the analyses [16, 17]. There exists a need, especially in South Africa, for an automated solution that can not only lower operational and maintenance costs, but also increase the efficiency and effectiveness of the equipment [18].

Dunn is an experienced maintenance professional and lists several business needs that relate to the asset effectiveness of equipment [10]. The information system and methodology that have been developed, aim to fulfil three of those business needs, namely:

- The need for a holistic view of equipment conditions;
- The need to reduce the cost of condition monitoring; and
- The need to optimise equipment performance.

The system was designed to monitor and assess multiple types of mining systems. Each system, e.g. a water reticulation system, consists of several subsystems, e.g. dewatering pumps. There are, in general, instrumentation equipment fitted to each subsystem that can measure various parameter types. These sensors and their related data, are customarily used to prevent unsafe operations. Measurements taken on site are linked to data tags which are made available on the site's Supervisory Control and Data Acquisition (SCADA) system. In this regard, data loggers were configured to collect, aggregate and send data from remote servers (located on site) to a localised server.

The monitoring process comprises three main elements: data acquisition, data analysis and information reporting (see Figure 2). Data acquisition refers to the process of data collection, transfer and storage. The data analysis procedure is based on the newly developed SCRF methodology and will be the focus of this research paper. The operational risks that were identified with the analysis are compiled into automated reports. In addition to the reports, an online platform provides users with access to the respective mining systems' operational data (e.g. temperature, vibration etc.). The online platform makes use of health indicators and colour formatting to indicate where attention is needed.

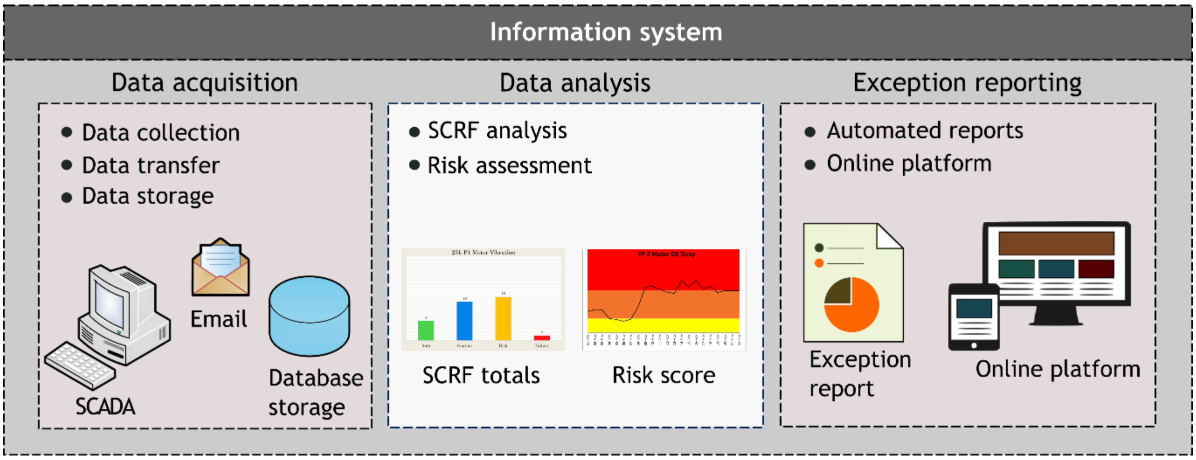


Figure 2: Information system design elements

3. DESIGN SPECIFICATION

A condition monitoring process is synonymous with data processing. Data can be obtained from various types of instrumentation and sensors. Input data needs to be continuously analysed to identify an unsafe or inefficient operation. It is not feasible to manually inspect or conduct in-depth analyses on the entirety of the mine's asset inventory on a regular basis. A prognosis can therefore be very beneficial when planning and conducting a comprehensive analysis. In some cases, only minor adjustments are necessary to prevent significant damage. Other cases require major repairs, which need to be scheduled in advance to minimise the effect of the maintenance intervention.

A methodology, to be used in an automated process, was developed to identify operational risks. Four regions of operation are used to characterise the parameters selected for analysis. These regions are labelled as safe, caution, risk and failure (see Figure 3), and can be configured for each individual parameter, based on its operating limits. The failure region would typically range from the parameter's trip value to a percentage value below it. The remaining regions can be determined by using normal operating levels. Parameter specific boundary levels (B_S, B_C, B_R and B_F) are therefore used to assess the relevant input signal.

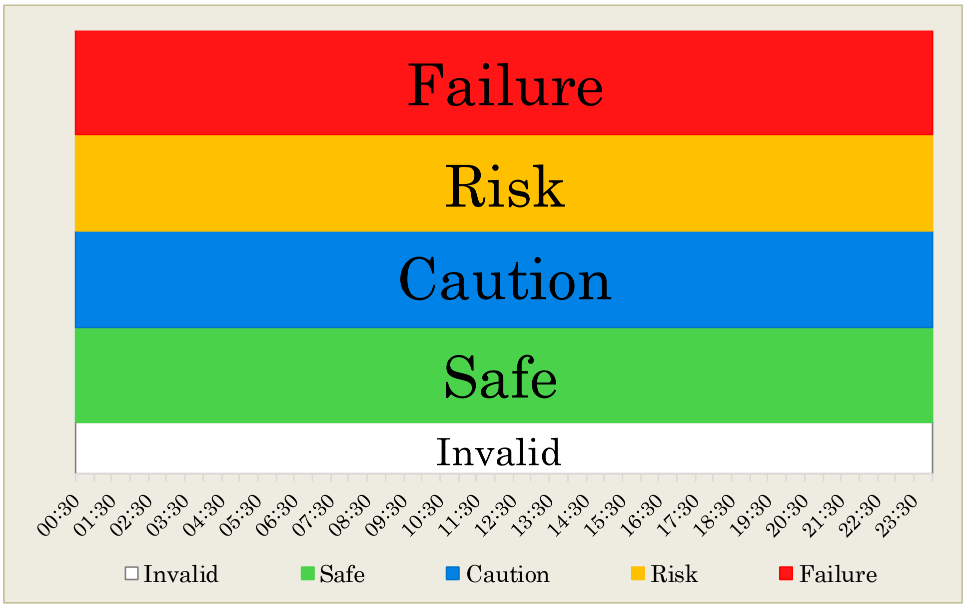


Figure 3: SCRF regions design

A fifth region namely, the invalid region, is also used in the assessment. The purpose of the invalid region is to identify suspect inputs. Measured values that are below a predefined maximum often go unnoticed as the system's trips or warnings only compare the value with a high limit. A bearing temperature measurement of 25°C does not exceed the limit of 75°C and may therefore be overlooked. The absence of an alarm gives a false sense of safe operation and could potentially be dangerous. The accuracy, or correct installation, of instrumentation should therefore be verified when a parameter evaluation exhibits a high invalid region count during periods of equipment operation.

Figure 4 below illustrates how the analysis is performed. Each of the 48 vibration values (P1 vibration) is compared with the respective boundary limits. The four region totals (T_S, T_C, T_R and T_F) represent the number of data points that lie within the relevant region. The region totals for this example can be seen in Figure 5 (B). The same procedure can be followed for the remaining pump parameters. Parameter totals can then be added together to obtain a holistic pump analysis.

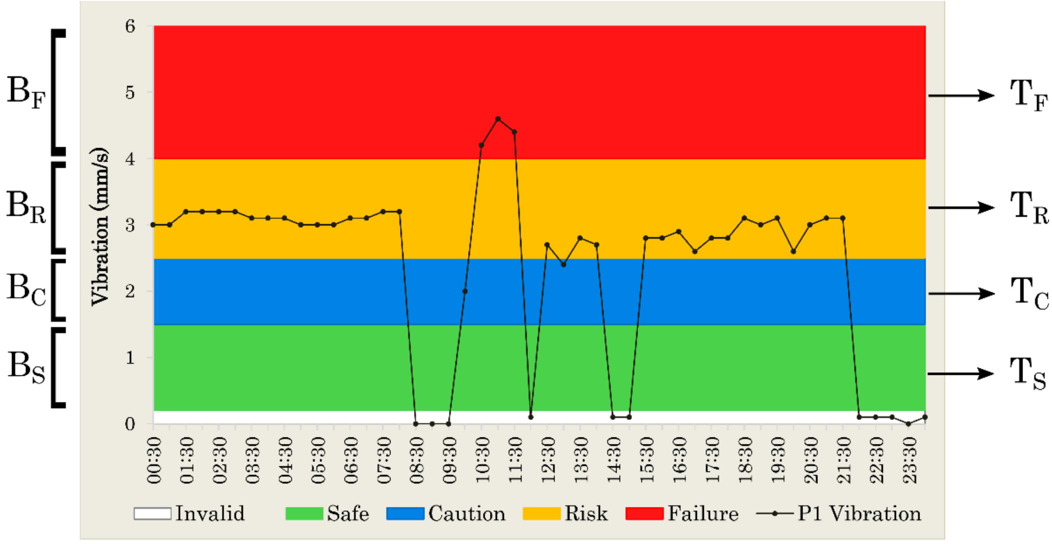


Figure 4: SCRF analysis example

Several pump, compressor, fan or fridge plant parameters can be included in the analysis. The following example demonstrates the analysis process of four pumps, each consisting of four parameters. Figure 5 shows the daily totals of the four parameters belonging to Pump 1. This type of graphic display makes it easy to identify parameters that are exceeding their safe region limits.

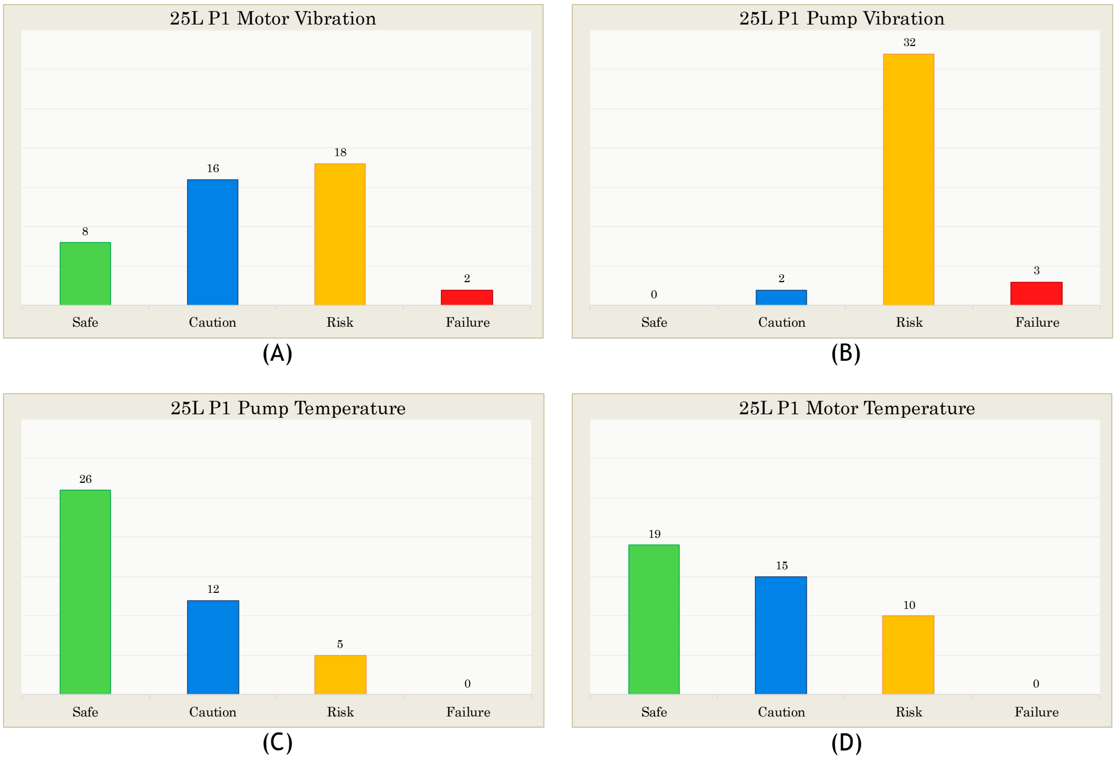


Figure 5: Individual parameter totals

The results from a system or level analysis can be summarised by displaying the risk and failure region totals of the respective components. This gives the user an overview of the components' operating regions. Figure 6 shows the risk and failure region totals of the four example pumps. The figure clearly shows that Pump 1 and Pump 4 are exhibiting operational risk symptoms, which require further investigation.

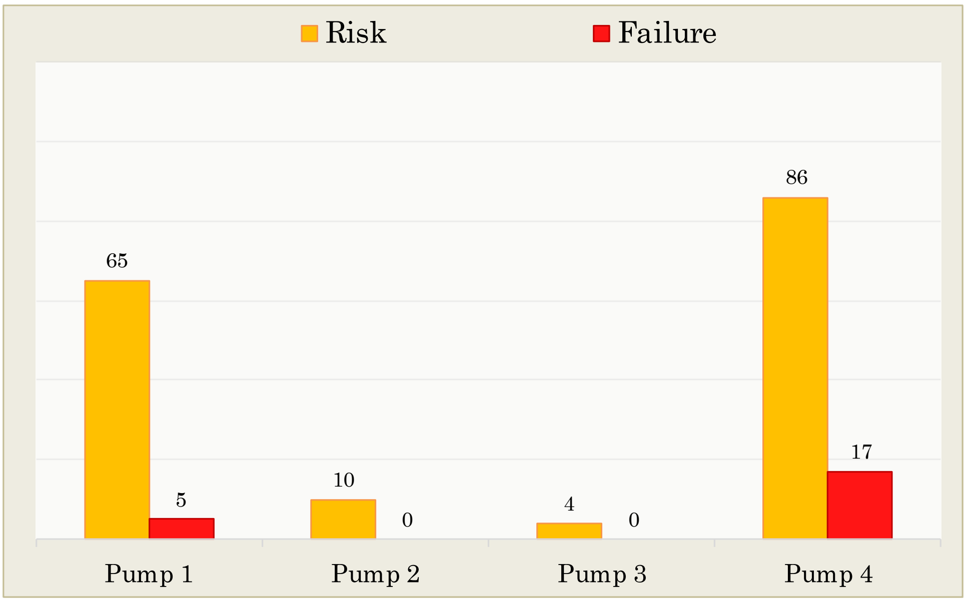


Figure 6: Risk and failure region totals

The final step in the analysis process is to determine where attention is needed. The aim is to minimise the time it takes for the user to interpret the analysis results. This can be accomplished by firstly compiling a 30-day profile of the four region totals for each parameter. Figure 7 illustrates such a profile for a selected parameter. The region totals shown in Figure 5 (C) are the daily totals of 12 February, as indicated on the profile plot.

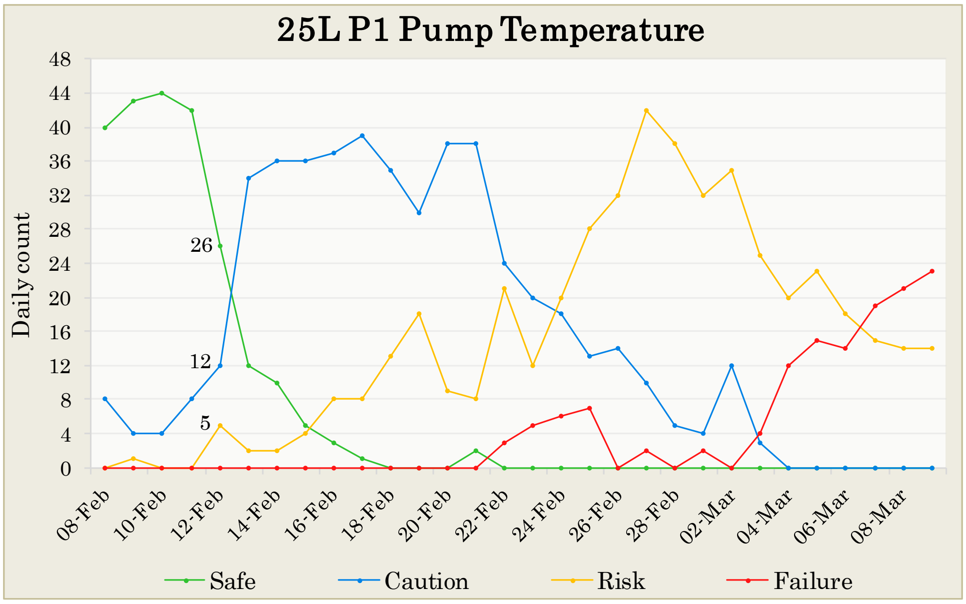


Figure 7: 30-day region total profile

From the profile plot, it can be observed that the parameter is exhibiting signs of deterioration. During the first week, the bulk of the operation took place within the safe region. The safe region operation then started to decline and an increase in the caution and risk regions can be observed. The risk region operation continued to increase and during the last week a large portion of the temperature measurements were in the failure region.

Each parameter's daily totals are subsequently translated into a risk score. The risk scores are divided into three risk categories: low risk, medium risk and high risk. Medium and high risk parameters are included in the condition monitoring reports. This enables the user to evaluate the risk parameters, over a period of 30 days, with ease. Figure 8 shows the corresponding risk score profile for the pump temperature evaluation shown in Figure 7. The risk score profile indicates that a negative (upward) trend started to develop and continued to do so due to lack of maintenance. A condition based maintenance strategy can therefore be configured to generate a service request when a parameter's risk score continues to increase for a selected number of days.

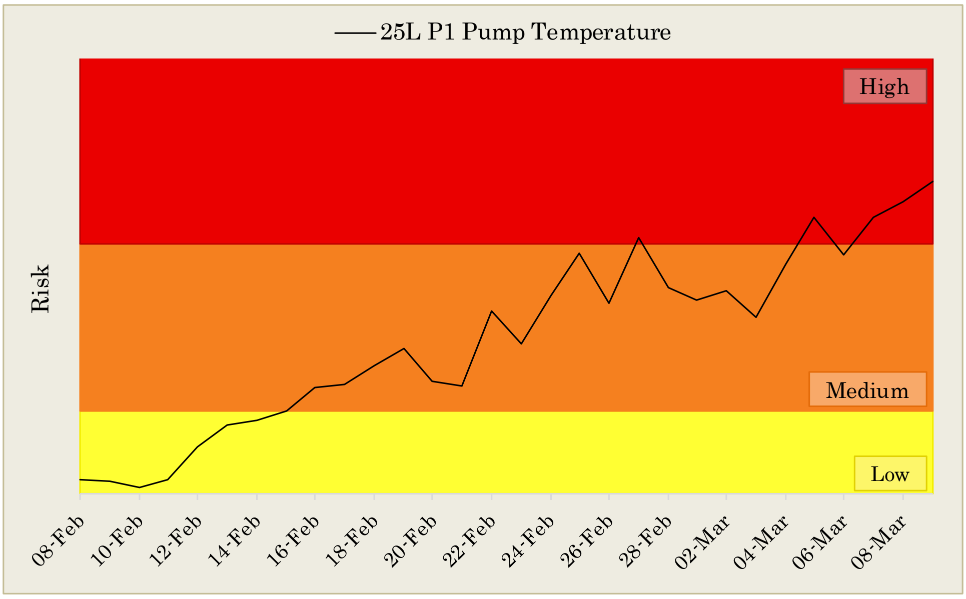


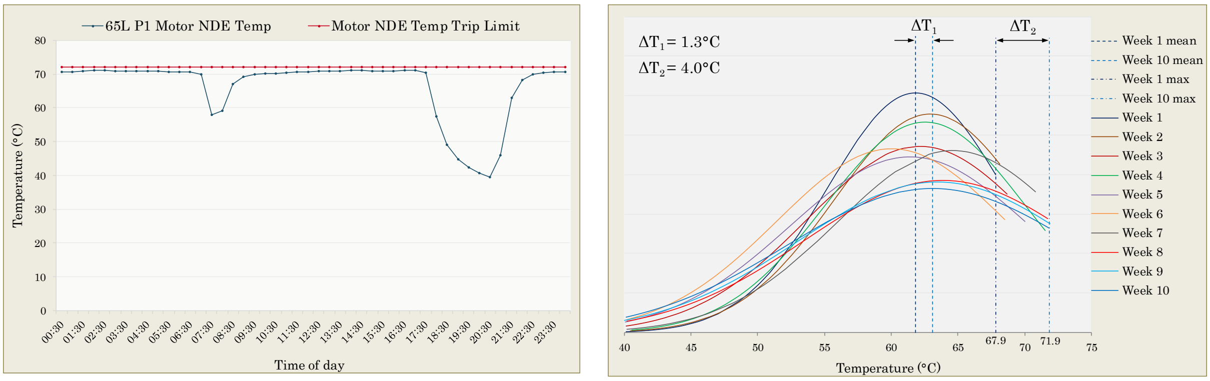
Figure 8: 30-day risk score profile

The results from the risk analyses, together with the four region total profiles, make it possible to identify and evaluate possible operational risks. Instead of having to monitor several systems, each with their own list of parameters, maintenance personnel can focus on these risk notifications.

4. SYSTEM VERIFICATION

Various verification tests were performed to prove that the system functionality complied with the requirements and specifications. One of these verification tests was selected to be discussed here. The selected parameter mainly operated in the failure (unsafe) region which is a cause for concern. Historical data was obtained to compare the measured values with the results obtained from the analysis.

Figure 9 (A) shows a daily profile of the motor non-drive end (NDE) bearing temperature which was identified and analysed. The relevant trip limit is also inidicated on the graph. During periods of operation, the bearing temperature approached the trip limit of 72°C. Figure 9 (B) displays a temperature distribution plot for a period of 10 weeks. The mean and the maximum temperatures of week 1 and week 10 are shown on the distribution plot.

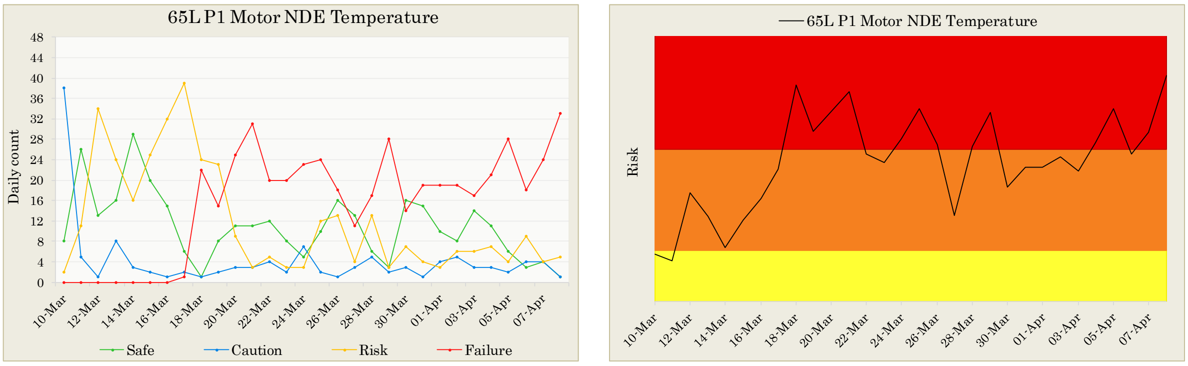


(A) (B)

Figure 9: Motor bearing temperature measurements

The ΔT calculations demonstrate that there was an increase in the average and maximum bearing temperatures. ΔT_1 and ΔT_2 represent the average and maximum temperature differences respectively. ΔT_1 was 1.3˚C while ΔT_2 was 4˚C. This indicates that there was a change in the operational condition of the pump.

The temperature measurements were subsequently used to perform an SCRF analysis. Results for a 30-day period can be seen in Figure 10. It was during this period that the bearing temperatures moved from the safe and caution region into the risk and failure region. The region total profile is shown in Figure 10 (A) and the corresponding risk score profile is shown in Figure 10 (B). The risk score profile demonstrates that the parameter progressed from the low risk to the high risk category.



(A) (B)

Figure 10: Motor bearing temperature analysis

The results from the analysis therefore coincide with a standard method of evaluation. The risk analysis illustrated that the pump was no longer operating within a safe temperature region. This example was used to demonstrate how the SCRF methodology was verified.

5. SYSTEM VALIDATION

The system was designed to be integrated with the daily operations on a mine. Once the system functionality was verified, it was implemented on a gold mine. The mining systems that were evaluated include water reticulation, compressed air, ventilation and cooling. Each of these systems comprise different types of equipment such as pumps, compressors, fans and refrigeration plants.

A similar approach was followed on each of the four systems to monitor the operational condition of the equipment. The water reticulation system will be used here to illustrate the validation process. Eight dewatering pumps, located on two different mining levels, were added to the available equipment configuration. Each pump is evaluated according to the nine parameters shown in

Table 1.

Table 1: Pump monitoring parameters

Dewatering pump parameters		
Motor power	Motor DE bearing temperature	Motor NDE bearing temperature
Pump DE bearing temperature	Pump NDE bearing temperature	Motor DE bearing vibration
Motor NDE bearing vibration	Pump DE bearing vibration	Pump NDE bearing vibration

Alarms were configured to send notifications to relevant personnel when a parameter exceeded its maximum allowable limit. Machine and process data were made available on the online platform, which is updated every 30 minutes. The data analysis procedure was performed on a daily basis. System specific reports provided information regarding the relevant system's operational risks. An exception report summarised the risks from all four mining systems. The online platform's overview page indicated where medium or high risk parameters were identified.

More than 20 alarms were triggered during the month of May 2017. One of these alarms was received on the 29th of May 2017 at 12:56. The screenshot shown in Figure 11 was taken at 13:05. It shows the real-time profile of the motor drive end (DE) temperature which was was responsible for triggering the alarm. For this illustration, it will be refered to as the alarm parameter.

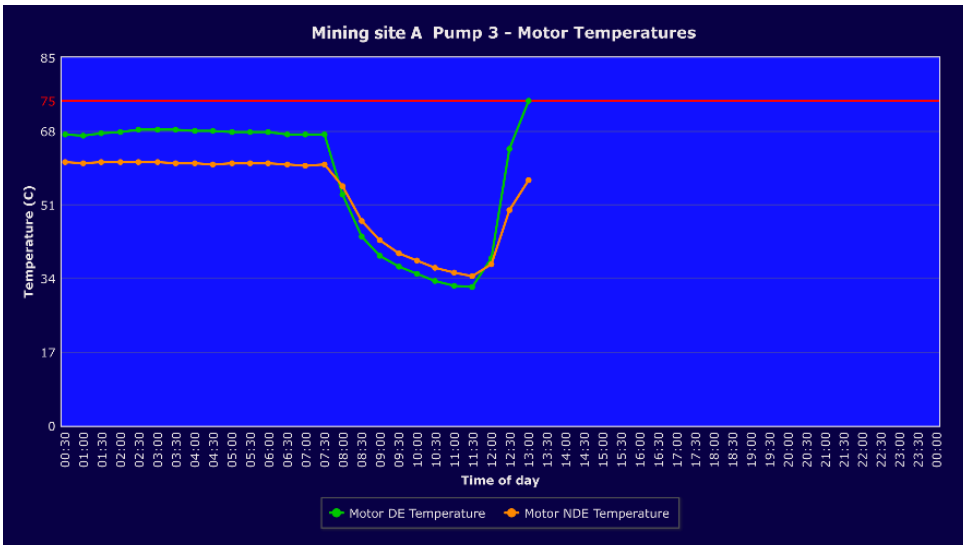


Figure 11: Live view screenshot of the alarm parameter

In Figure 12, a screenshot of the pumping system's overview page is shown. Critical exceptions (parameters in the high risk category) were identified on three separate pumps and are indicated by the red coloured markers. These exceptions are all related to temperature measurements. The orange coloured markers indicate that warnings (parameters in the medium risk category) were identified.

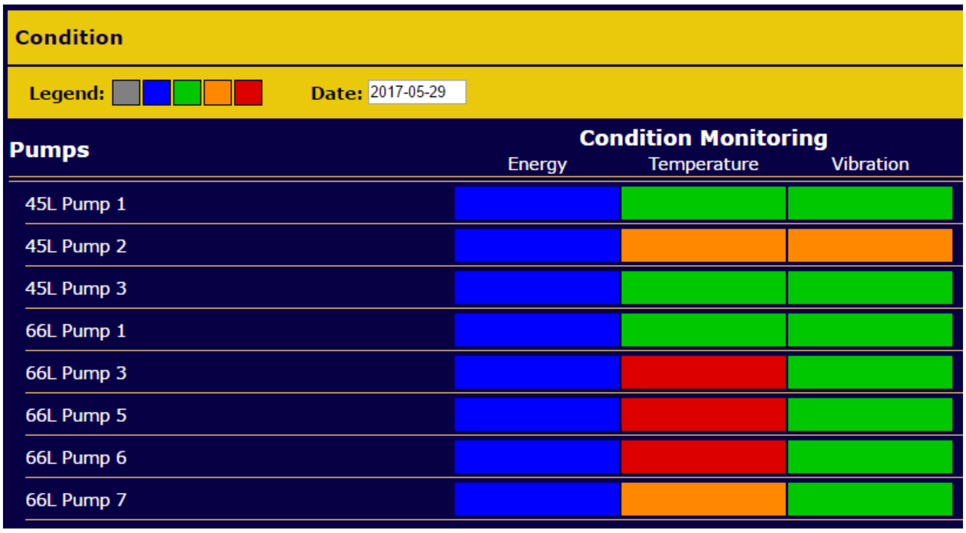


Figure 12: Online platform overview page of pumping system

The daily exception and system specific reports are generated automatically. Figure 13 shows an excerpt from the relevant exception report. The table lists the critical exceptions that were identified on the respective day. The motor bearing temperature which triggered the alarm is the first entry in the table. It exceeded the limit of 75˚C for a period of 6.5 hours.

Summary of critical exceptions **2017-05-29**

Exception level: Critical			
Parameter	Critical limit	Violation duration (hours)	Violation period average
66L P3 Motor DE Bearing Temp	75 °C	6.5	78.58
66L P6 Motor DE Bearing Temp	75 °C	4	77.26
Compressor 1 Comp NDE Vibr	6.2 mm/s	2	6.57
66L P5 Motor DE Bearing Temp	75 °C	2	77.14

Figure 13: Excerpt from daily exception report

The exception report also contains the critical parameters' daily profiles. Figure 14 shows the profile plot of the alarm parameter.

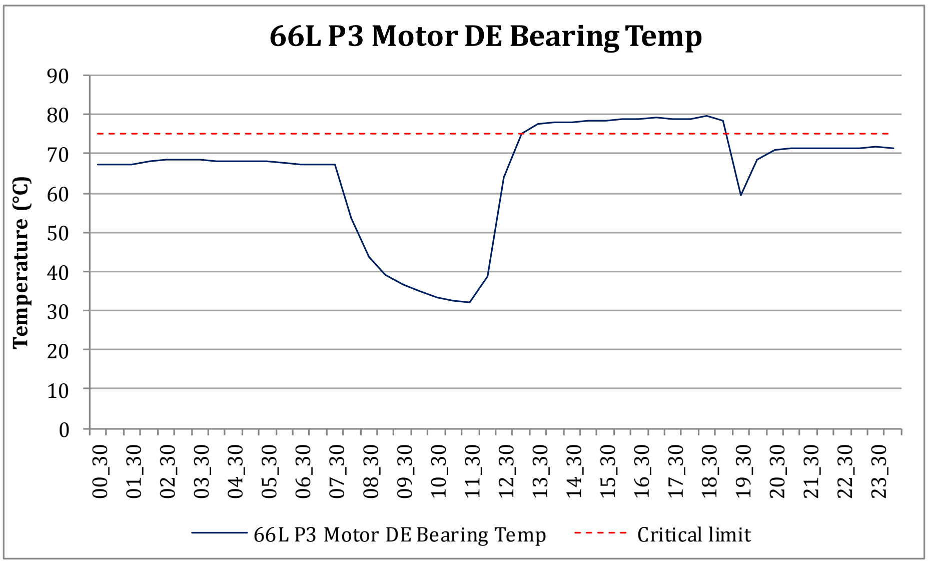


Figure 14: Critical exception parameter profile

The pump specific report provides more information regarding the risks that were identified. A 30-day risk score profile of all the medium and high risk parameters are added to the report. Figure 15 shows the corresponding risk profile of the alarm parameter.

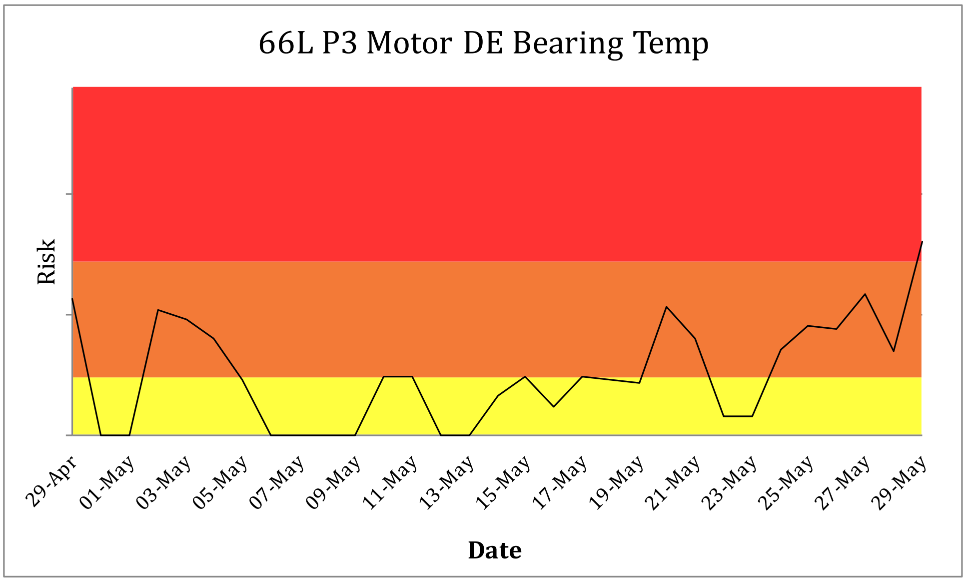


Figure 15: Critical exception risk analysis

Mining personnel were therefore made aware of operational risks on a continuous basis. The online platform indicated where risks were identified and provided access to the respective parameter values. The automated reports summarised information pertaining to the risks that were identified. This made the monitoring process much more efficient and facilitated the prevention of equipment failures.

Following the success of the initial implementation, the mine requested that the system be implemented on five additional sites. The additional implementations were completed effortlessly, due to the scalable design of the system. The calculation scripts were subsequently configured for each site according to the relevant alarm limits and available systems and parameters. Figure 16 illustrates the scope of the implementation on the six mining sites.

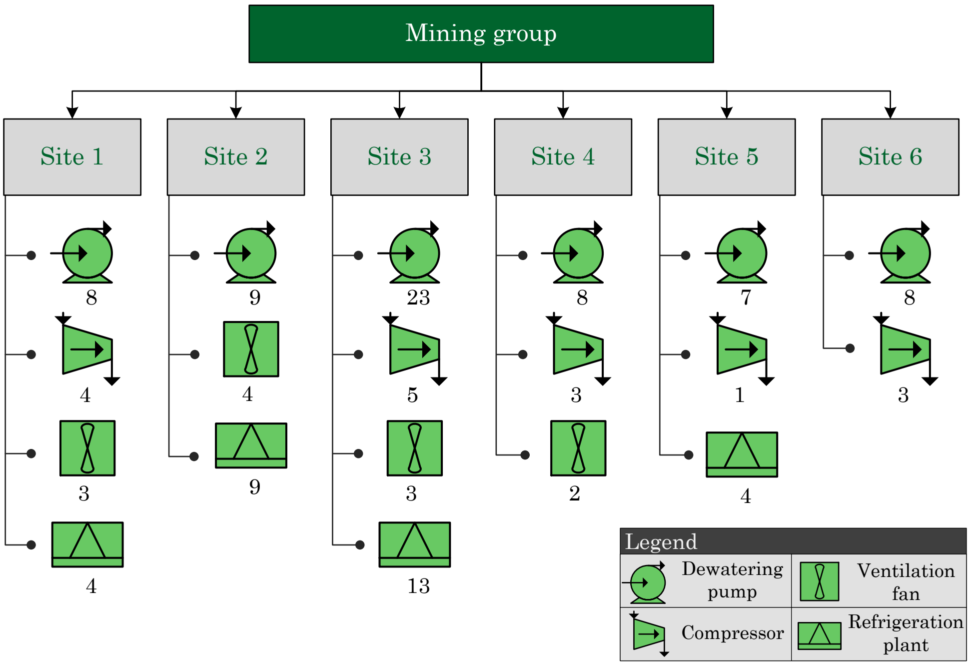


Figure 16: Scope of the implementation

6. CONCLUSION

Deep level mines depend on the availability of different types of systems to ensure that operations are uninterrupted and comply with safety regulations. These systems are expensive to procure and maintain. However, mines are under pressure to reduce operational costs due to budget constraints. It is therefore vital that the mining systems are continuously monitored to avoid unneccessary expenditures.

A condition monitoring process on deep mines requires the collection and analysis of a vast amount of data. Several parameters need to be evaluated on multiple types of systems. An information system was therefore developed to automatically identify operational risks and generate exception reports. Existing infrastructure is used to obtain machine and process data. An innovative methodology is used to analyse the data and provide simplified information on a daily basis. This enables maintenance personnel to be proactive when planning and scheduling service interventions.

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PROPOSING A COMPUTATIONAL SYSTEM PROJECT (COSYP) FRAMEWORK FOR GOVERNMENT SERVICE DELIVERY PROJECTS

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ABSTRACT

The deepest fear for almost every project personnel is project failure. Most computers and computational system projects fail completely or partially because of requirements (i.e. scope, time, cost, quality, objectives, etc); since a very small number of projects meet requirements. Different constraints affect government service delivery computational system projects. In this context, project failure could create unnecessary expenditure, affect project quality, scope, and turn-around-time of addressing citizen's service delivery issues. The Limpopo provincial government has over the years implemented different computers and computational system projects throughout its different departments. Some of these projects have been a success, others failed and some were delayed. In this regard, the main research question guiding this paper is phrased as follows: "which project development and implementation framework could be effective in avoiding project failure and delays but results in successful projects for the government?" To answer this question, this paper uses the Iron Triangle Model, the Lewin's Model and the three dimensions of Requirements Engineering to propose a Computational System Project (CoSyP) Framework. A case study of a computational system development and implementation project was used to corroborate the fact that CoSyP Framework is a project development and implementation framework for producing successful projects for the government.

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1 INTRODUCTION

Computer Science is described as the study of computers and computational systems; unlike electrical and computer engineers, computer scientists deal mostly with software and software systems; this includes their theory, design, development, and application.

In real-life scenarios, most of the Computer Science work is implemented as projects comprising of different phases. In this regard, a computer scientist or technician, as the project manager will have to at least understand (if not to have) project management and change management skills for successfully implementing the computers and computational system projects.

With the dawn and growth of the study of technology, literature turns to refer to information technology projects or information and communication technology (ICT) or e-government projects rather than computers and computational systems projects or computing projects.

The development and implementation of the computational systems projects in a government sector offer a real-life scenario. The South African government in all its spheres (national, provincial and municipal) frequently initiate computer and computational systems projects that could aid both officials (to do their work efficiently) and members of the community (to easily access and be serviced by the government).

The South African Provincial government has over the years implemented different computer and computational system projects throughout its different departments for the development and implementation of service delivery. Some of these projects have been a success, others failed and some were delayed.

It is important to study the success or failure of computational systems projects, because according to Nkohkwo, and Islam, [2], in government such projects provide the capability of promoting better governance, transparency, raising service performance and eliminating bottlenecks in the service delivery process. The literature identifies that in Sub-Saharan Africa (SSA) the success or failure of ICT infrastructure dominates the research, and this is followed by human resources, legal framework, Internet access and connectivity, language, illiteracy, awareness and the digital divide amongst others [2].

Against this backdrop, this paper proposes a Computational System Project (CoSyP) Framework to answer the research question: "*Which project development and implementation framework could be effective in avoiding project failure and delays but result in successful projects for the government*?" A Logistic Information Systems (LOGIS) project was used to corroborate the fact that CoSyP Framework is a conducive framework for project and change management.

Except for this introduction, other sections of this paper briefly discusses the literature on Iron Triangle Model (i.e. project management), Lewin's Model (i.e. change management) and requirements engineering. This is followed by a brief discussion on the use of a case study method in which LOGIS is mapped into CoSyP Framework to determine whether it satisfies the framework. The paper then concludes by providing some key principles on achieving project success.

2 IRON TRIANGLE MODEL

A project is a temporary endeavour undertaken to create a unique product, service, or result (Reynolds, [3]). According to [3], five highly interrelated parameters (illustrated in Figure 1) define a project: (i) scope, (ii) cost, (iii) time, (iv) quality, and (v) user expectations. If anyone of these parameters changes for a project, there must be a corresponding change in one or more of the other parameters.

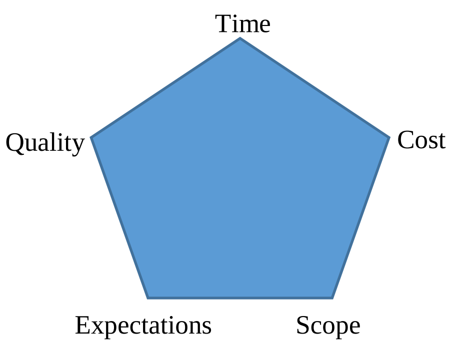


Figure 1: Interrelated project parameters (Source: Adapted from [3])

Project management helps to effectively manage the interrelated project parameters. Project management is the use of knowledge, skills, and techniques to interrelated project parameters (i.e. time, cost, scope) to meet the project expectations (i.e. quality and expectations). In comparison to Figure 1, the model created by Dr Martin Barnes which was known as "Iron Triangle Model" identifies the time, cost and scope as the three major constraints to be managed very well for achieving quality user expectations and deliver successful project outcomes [3].

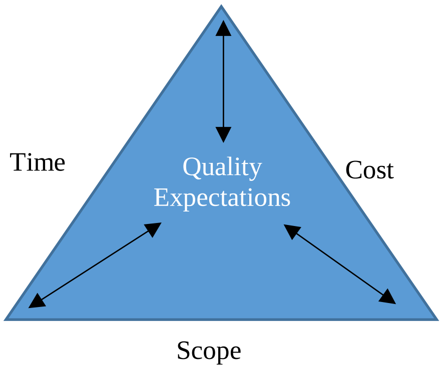


Figure 2: The Iron Triangle Model (Source: Authors adaptation).

The factors in the Iron Triangle Model (Figure 2) are interlinked in such a way that any change on one, will cause an impact on the other two (Lock, [4]). Despite the factors identified by Dr Barnes much more derivations of the triangle have since been developed. For example, Kliem, Ludin and Robertson [5] modified the triangle of objectives to show people at the centre and they called this the Four Variables of Project Success. They believed that if people are not considered as the crucial element, the project will fail, even in the presence of good plans, organizational structure, and proper controls. Lock [4] proposed a combination of Barnes' and Kliem's triangle of objectives but replaced quality with a level of a specification; arguing that if the quality is defined as fit for purpose it can never be negotiable but performance or level of specification is more appropriate as it could be negotiated. Together with cost and time, these derivations replaced the scope with quality or performance or people.

The deepest fear for almost every project manager is project failure. Having inspired by actual mistakes encountered in real world of computers and computational systems projects, Rajkumar and Alagarsamy [6] suggests that there are 12 most common reasons for project failure: (i) lack of customer or user involvement; (ii) unclear goals and objectives; (iii) poor requirement set; (iv) lack of resources; (v) failure to communicate and act as a team; (vi) project planning & scheduling; (vii) cost estimation; (viii) inappropriate estimation methodology; (ix) cost estimation tools; (x) poor testing; (xi) risk management; and (xii) unrealistic expectations.

Rajkumar and Alagarsamy [6] recommended the following four principles for project success: (i) monitor the project; (ii) effective software process can be used to increase accuracy in cost estimation in a number of ways; (iii) do not depend on a single cost or schedule estimate; and (iv) fully satisfied the user requirements.

To fully satisfy the user requirements the principles of Change Management (CM) and Requirements Engineering (RE) should be applied and used to address the following project failure indicators: (i) lack of customer or user involvement; (ii) unclear goals and objectives; (iii) poor requirement set; (vi) failure to communicate (v) poor testing; (vi) risk management; and (vii) unrealistic expectations.

3 CHANGE MANAGEMENT

In this paper, change means to modify or alter the users' work platform in order to provide them with a transformed users' expectation and experience. To accomplish this modification, a change should be viewed not as an event but a process that could be managed.

Change management is the process, tools and techniques used to manage the people side of change to achieve the required outcomes (Creasey, [7]). Change management on the personal and organizational level requires thinking, models or framework for change and tools to enable the smooth implementation of the desired change.

One of the cornerstone models for understanding change was developed by Kurt Lewin, a physicist and also a social scientist, back in the 1940s. Despite all other models, just like Einstein theory, Lewin theory is still relevant. The Lewin's Model (Lewin, [8]) refers to the three-stage process of change: (i) unfreeze, (ii) change and (iii) freeze or refreeze. To explain the model, [8] used the analogy of changing the shape of a block of ice.

In this regard, to obtain a cone of ice from a (freeze) cube of ice, one must (i) melt the ice to make it amenable to change (unfreeze); (ii) then mold the iced water into the shape one wants (change); and (iii) finally, solidify the new shape (refreeze).

In a project context: (i) the understanding of why the change must take place leads to the beginning of the unfreezing stage. Unfreeze stage is the current status core of one's life or users' work platform or organization/government's existing product and/or service which needs to be changed (i.e. the crux of this paper is to the users). Lewin [8] advised that in this stage the motivation for change must first be generated before change can occur; (ii) Change stage follows after understanding why change should take place and examining the need for change (i.e. tasks of the freeze stage), then the project team or developers begin with the steps to modify users' work platform. These modifications result in a transformed workplace, and (iii) Freeze (also known as re-freeze) stage takes over once the changes have been made as a result of the new user work platform or modified workplace. This should have reached the users' expectation. This stage is also concerned with establishing stability on the users' expectations and experience for the users to effectively accept their new workplace. Once the users' expectations and experience are affected the change process is initiated from the beginning.

4 REQUIREMENTS ENGINEERING

Computer and computational system project are considered as a branch of Systems Science with a strong contribution of Engineering; the reason is that it follows the System Engineering life cycle. Computer and computational system project result in a field devoted to the creative application of engineering principles to the design and development of systems (Ramos, Ferreira, and Barcelo, [9]).

Every computer and computational systems project requires the project manager and the team to have some skills and techniques of obtaining project requirements and specifications from the client and also work at understanding those specifications. Requirements Engineering (RE) is the process of developing a requirements specification. It is defined as the systematic process of developing requirements through an iterative co-operative process of analysing the problem, documenting the resulting observations in a variety of representation formats and checking the accuracy of the understanding gained (Loucopoulos and Karakostas, [10]).

The aim of RE is to introduce engineering principles to the practice of traditional systems analysis (Martin, Aurum, Jeffery, and Paech, [11]). RE is about establishing the ‘connection’ between the need for some change and the system that could bring about such a change.

Martin, et. al. [11] analysed different RE process models and suggested that a RE process consists of structured and repeatable activities. Furthermore, RE process models are either linear, linear with iterations between activities, and iterative.

Loucopoulos and Karakostas [10] said RE process is constructed by considering three fundamental concerns, namely: (i) the concern of *understanding* a problem ('what the problem is'); (ii) the concern of formally *describing* a problem; and (iii) the concern of attaining an *agreement* on the nature of the problem. To address this concerns, they proposed a framework that comprised of three major interacting, concurrent (sub)processes which could also be linked to managing change, namely: (i) Requirements Elicitation – an understanding at a conceptual level of the current status, (ii) Requirements Specification – a definition of the change in terms of the transition from the ‘old’ conceptual situation to a ‘new’ target conceptual situation; and (iii) Requirements Validation – the implementation of the change in terms of the new components of the system.

Evidently, the RE process has important ramifications for the overall success or failure of the project. It is this paper’s hypothesis that when RE process model is linked to activities of other models (such as Iron Triangle Model and Lewin’s Model), it will yield an overall project success. In this regard, this paper argues and proposes CoSyP Framework as the integration of Iron Triangle Model, Lewin’s Model and RE process model to validate projects successes or failures.

5 A COMPUTATIONAL SYSTEM PROJECT (COSYP) FRAMEWORK

It is this paper’s view that for a project to be successful it should be of quality and satisfy user’s expectations. In this regard, this paper proposes a Computational System Project (CoSyP) Framework for the development and implementation of service delivery projects (see, Figure 3).

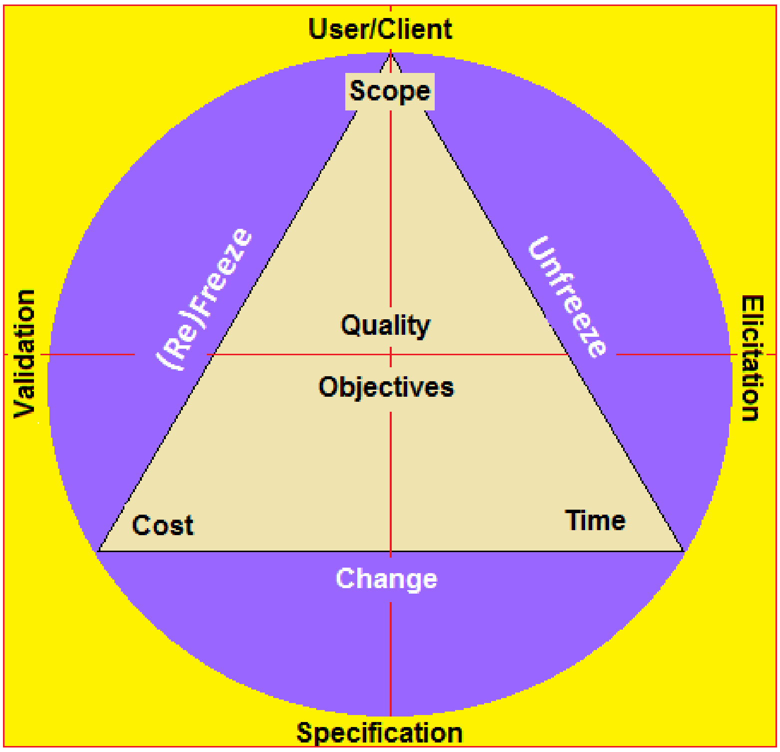
The CoSyP framework integrates PM model with both CM model and RE process model. It is viewed as the quadratic, triangular and cyclic framework. The process of the framework is structured as follows:

(i). *Elicitation:* it begins when the system user/client initiate the process, by providing the requirements to the project manager and the team. This is an exercise of unfreezing the existing status core by determining why the project or system change must take place (as suggested by Lewin's model), setting a scope and timeframe for completing the project (this is a scope and time wing in the Iron Triangle model);

(ii). *Specifications:* followed by using the provided requirements to setup different milestones and budget/cost for achieving the milestones. This is an exercise of changing the status core (i.e. change - in Lewin's model) to begin a process of achieving project's objectives at a given cost (this is a time and cost wing in the Iron Triangle model);

(iii). *Validation:* the furthering of the process by re-aligning the project cost to the scope, for the purpose of achieving the necessary quality needed for new or changed systems (this is a cost and scope wing in the Iron Triangle model). Then testing the alignment of the project objectives with quality. This is an exercise of refreezing the status core (as suggested by Lewin's model); and

(iv). User Satisfaction: then complete the process by validating the requirements by testing them against the users need in order to satisfy the quality and objective checklist which is at the centre of the system projects.



Figures 3. The CoSyP Framework (Author's Adaptation).

It should be noted that Figure 3 illustrates the fact that some segments of (i) and (ii) above are within the quadrant, User - Elicitation; while some segments of (ii) and (iii) are within the quadrant, Elicitation - Specification; and some segments of (iii) and (i) are within the quadrant, Specification - Validation; and then Validation - User, leads to the user being satisfied and accepting that the requirements are at 99% achieved (see Table 1). The combination of all these tasks should lead to reaching project quality and objectives which are the qualities of an achieved user system requirements.

Table 1: CoSyP Quadrants and relating description.

Quadrants	Elements	Description
1	User - Elicitation	In this quadrant, several questions are asked to unfreeze the existing project status core, e.g.: Why was the project requested or needed? How big and long should the project take?
2	Elicitation - Specification	In this quadrant, several questions are asked to continue unfreezing the existing project status core and begin to provide the elements of change, e.g.: What is available, what should or could be done to achieve the project scope and purpose? What and when could the targets be implemented? What resources are available? Which and how should the phases be implemented?
3	Specification - Validation	In this quadrant, several questions are asked to continue providing change; and providing clarity of what and how to achieve the change (begin the refreezing stage), e.g.: How much will be needed to complete and achieve the change? Has this cost been attached adequately to the tasks of achieving the necessary quality needed for new/changed systems? Does the achieved change, certify and align to project objectives? Is the quality of change adequate?
4	Validation - User	In this quadrant, several questions are asked to refreeze the changes and provide a new project status, e.g.: Where the requirements successfully met? Are the users satisfied with the changed status and the requirements are reached? If not, the process begins back to quadrant 1.

To better understand why CoSyP Framework is a project development and implementation framework that could help to avoid project failure and delays resulting in successful system projects, the case of a government system projects to corroborate that fact is discussed below.

6 RESEARCH METHODS

Yin [12] provides the general fundamentals of when to use a case study method in a research. A case study could be used when: (i) the type of research question is typically phrased like "how" or "why"; (ii) an extent of control over behavioral events like when a researcher has a little/no possibility to control the events; and (iii) when general circumstances of the phenomenon to be studied is a contemporary phenomenon in a real-life context. The latter, set a scene for the development and implementation of a sphere of government to be a good case study.

Relying on theoretical propositions and developing case description are two general analytic strategies used in a case study method [12]. According to [12], these strategies rely on the following analytic techniques: (i) pattern matching (explanatory/descriptive); (ii) explanation-building (mainly explanatory); and (iii) time-series analysis.

In this study, developing case description strategy was adopted and the explanatory technique was used. The explanatory technique is a result of series of iterations and it allows for the analysis of a case study data by building an explanation about the case and identifying a set of causal links [12].

7 FINDINGS

In South Africa, there exist three spheres of government (i) the National Government (comprising of at least 35 Ministries), (ii) nine Provincial Governments, and (iii) the Local Government (comprising of at least 205 local municipalities). The South African Parliamentary Cabinet is responsible for an overall management of all these spheres.

The case for this study was the project of developing and implementing the LOGIS for the government of Limpopo Province. In this regard, the data that was used emanated from the project documents.

7.1 CoSyP Quadrant 1: User – Elicitation

In December 2011, five Departments (Provincial Treasury, Education, Transport and Roads, Health, and Public Works) of the Limpopo Provincial Government were put under national executive administration following Section 100 (1) (b) of the Constitution, 1996. This was due to provincial government's challenges with their supply chain management and irregular financial expenditure (i.e. underspending and overspending).

As part of the intervention, the Executive Administrators (EAs) made a decision to develop and implement a computational project (LOGIS) in order to solve the provincial challenges and irregular expenditure. LOGIS is a transversal financial information system used by supply chain, asset and inventory management units. In this regard, the project team was formed and comprised of members of the: (i) project management office, (ii) asset management office, and (iii) steering committee. The project management office included the project manager, project administrators and office administrators. The asset management included asset specialist, manager, data captures and asset data collectors. While the steering committee comprised of the senior members of the province including the chief financial officer (CFO).

Several project scoping, timing, costing, objective and quality meetings were held by different project stakeholders (EA, staff members as system project users, and the project team). The resolutions of the meetings were documented through minutes and project documents.

The brief discussion provided above, illustrates the process of unfreezing the status core which was provided by the project or system sponsor (EA), who allowed the project to resume by setting the project scope, time and cost; the system user (staff members of the five provincial departments), who provided the requirements for the project scope; and the project team for elicitation of the details and boundaries from both the system sponsor and system user.

7.2 CoSyP Quadrant 2: Elicitation – Specification

During the project requirements elicitation stage, when a question "what is available, what should or could be done to achieve the project scope and purpose", the answer revealed that Limpopo provincial government has been operating without a procurement system, since 2007/08 financial years. In that period, Financial Efficiency System (FINEST) was the system used to issue orders and recapture the order BAS system in order to process invoices. The problem with FINEST was the fact that the system was decentralized. For example, one provincial department had six decentralized supply chain structures, operating from different locations (head office and five district offices, with each serving the entire supply chain operation with all its related functions.

It followed that in order to bring stability in the financial management process of the Limpopo provincial government supply chain environment, it was necessary to develop and implement LOGIS. This was because an absence of an appropriate system in the government's supply chain management makes management of procurement, assets and inventories a challenge. For example, most departments struggle or fail to come out of the disclaimer or qualified audit outcomes because of the inability to enforce procurement and inventory management prescripts.

The project team continued to gather requirements and concluded the elicitation stage with two major outputs being the fact that the project (i) would be considered complete once the LOGIS system has been successfully implemented and has been demonstrated to be operationally useable, including the availability of the necessary support functions; and (ii) end goal was to ensure successful implementation of LOGIS in five departments (highlighted in par. 7.1).

7.3 CoSyP Quadrant 3: Specification – Validation

As a form of implementing the project, the project team determined the way of decommissioning the legacy processes and systems (FINEST). The intention of the project team was not to bring a complete system overhaul but to utilise some of the good modules of the legacy system (FINEST) on the new system (LOGIS). In this regard, the project team gathered (from the FINEST users) usable information about what was good and bad before they decommission the legacy system. This helped the project team to gather information and draft clear specifications for the new system.

The LOGIS project was kicked-off with workshops that were conducted by the project team with all departments. LOGIS modules were programmed and tested. A phased approach was used to phase-out the old system and to introduce the new system. The system modules were validated with a practical usage in which users would use the system for conducting their daily duties and the project team would solve system problems at a go.

If a problem was found, the module would be altered to produce a new version. This could be done until the module satisfies the users and the project objectives. However, this changes on the already deployed modules extended the cost with a budget of acquiring other tools necessary for achieving users' expectations and requirements; and for paying an overtime of some of the project team members.

Ultimately, all the modules were integrated and centralised to form a provincial system (LOGIS) for managing the province's finances. This was a necessary change needed by the EAs but further validation had to be done to determine whether or not the system have mapped the project objectives and quality. Given the CoSyP framework, this could be mapped to quadrant 4.

7.4 CoSyP Quadrant 4: Validation – User

Table 2: Achievements against the project objectives (Source: extracted from project documents).

Project objectives as defined in Project Charter	Status of achievement against objectives
Objective 1: Shared data and process Cooperation with the central support team from on the Preparation of the common data elements and any other matters that can be done centrally before the implementation at department can commence.	Achieve
Objective 2: Solution implementation Execution of the business processes, as defined and adopted for Limpopo.	Achieved
Objective 3: Business processes Adoption of the business processes that support the operation of LOGIS.	Introduced. To be adopted by the Limpopo.
Objective 4: Go Live Activate the system, with all of its processes, as well as any interfaces to external systems and processes, in a fully operational state, on the as determined by the Project Plan, and Operate the system productively and stabilise the process for a defined period with the support of the project team, while also processing any backlogs that might have accrued during the project.	Achieved
Objective 5: Ongoing support Ensure that arrangements for ongoing operation, support and maintenance of the system in its broadest sense, is in place and is activated before the implementation project is closed.	Achieved

The LOGIS implementation project was completed within the agreed timeframe and scope (see, Table 2). The system was successfully activated with loaded reference data. It was tested and demonstrated to work. The maintenance and support procedures were put into place and there were no reported challenges thereafter.

Table 2 shows that the system was developed to satisfy users' requirements but did not fulfil certain project related principles. These were that LOGIS implementation process: (i) did not make any indication of how the project should be managed; (ii) focused only on activities that aimed at getting data into the new system, train the users and installation of individual systems; (iii) would be implemented concurrently through a programme management process; (iv) did not have any project management methodology to guide the implementation process; (v) did not cater for change management which was necessary for the implementation of a new system; (vi) did not cater for quality management.

To mitigate the above-mentioned risks, the following activities were executed: (i) the new project plan was developed to guide the new activities; (ii) the project management methodology was customized to cater for the effective programme management (made up of project and change management principles); (iii) risks mitigation strategy per department was put into place, and (iv) redefine the project cost model. Through these activities the next iteration of the LOGIS process took place.

The activities of not meeting the project principles could have been resolved if the development and implementation of LOGIS could have been done following the CoSyP Framework. This is because CoSyP has the capability of managing uncontrollable factors.

8 RECOMMENDATIONS

The CoSyP framework is recommended for achieving a successful project because it factors in the following principles: (i) a risk management and monitoring and evaluation plans are done by the project team and approved by the steering committee (these leads to avoiding crisis and should be frequently done); (ii) time and cost management plans are put into place and frequently updated, with initial funds budgeted for the completion of the whole project; (iii) people (users, sponsors and project team) are considered as crucial elements of the framework and should always be consulted as there is no project without people; and project quality is determined by the people; (iv) through interviews or workshop users are involved in the project development and implementation. Users are used to clarifying the unclear goals and objectives; (v) team dynamics that facilitates good communication and acting as a team; (vi) clear cost and estimation methodology conducted through the use of tools; (vii) apply change management process throughout the stages of project management and check that requirements are always satisfied; and (viii) the repetition of (i) to (vii) which should always be done to achieve a high probability of success.

The CoSyP framework through its integration of PM, CM and RE could help reduce project failure or delay. To achieve project success, use the above CoSyP principles.

9 CONCLUSION

Time, scope, cost, quality, objectives, and user requirements are crucial factors used in a CoSyP Framework. If these factors are not controlled, they could either delay the project or cause it to fail. As an example, failure to meet the deadlines could create adverse effects that could lead to the need for an increase in budget.

If well used in a service delivery projects, CoSyP Framework could help to avoid the project failure and delays; thereby, produce a successful project. This is because in a CoSyP Framework a project scope is well planned and clearly defined based on the user requirements.

In this study, a development and implementation of a LOGIS project were investigated to view whether or not it corroborates the CoSyP Framework. In general, it was found that LOGIS project was delivered on time and also developed to satisfy users' requirements. The latter was shown in Table 2 which shown that Project Objective 4 (Go Live) was actually achieved. However, it did not fulfil certain project related principles. For example, there was no project management methodology to guide its implementation process, did not cater for change management or quality management (as discussed in par. 7.4). The litigation of these neglected principles set into the process the next iteration of the LOGIS process.

It should be noted that the three management principles - project management, change management and quality management (or requirement management) are effective factors to yield a successful project. In this regard, when they are combined they form a basis for CoSyP.

Future studies should focus on investigating how CoSyP could foster a development and implementation of a project with a limited resource but achieve more than the required outputs.

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A CONDITION MONITORING SYSTEM USING BASIC EQUIPMENT PROTECTION MEASUREMENTS

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ABSTRACT

Condition monitoring on equipment reduces maintenance costs and aim to ensure minimum downtime on sites. Traditional condition monitoring measurements usually consist of multiple accurate vibration and temperature sensors. Mines have basic vibration and temperature sensors that are installed to safeguard the equipment against excessive vibration and overheating. These sensors typically only measure vibration in one plane. This study investigates the effectiveness of utilising these basic sensors to do condition monitoring on mine compressors, refrigeration machines, pumps and ventilation fans.

Typically, notifying plant personnel when vibrations and temperatures exceed critical limits is standard practise. In cases where these limits exceed safe working conditions, the machines are stopped by initiating tripping protection procedures by the time the notification is actioned. This study therefore focusses on identifying systematic equipment deterioration in the long term and developing an effective notification strategy for ensuring efficient maintenance strategies. This includes adjusting limits to ensure that high temperatures and vibrations are identified early with timeously actioned notifications.

Condition monitoring using basic equipment protection sensors are not only cost effective but also reliable. These protection sensors are widely available since they are lawfully required on larger machines. Alarms are triggered based on these critical measurements, which successfully identify equipment that need maintenance.

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1. INTRODUCTION

1.1 Background

In our modern world machines perform tasks that increase our productivity and output and is a great resource that is increasingly utilised. One of the drawbacks of machines is that they require maintenance to keep them functional. Unmaintained machines can become unreliable and fail without warning. Replacements of these machines are costly in terms of production losses, breakdown failures and other financial expenses.

There are mainly three types of maintenance, which can be categorised according to their scheduling. Forced maintenance or breakdown maintenance might be the most expensive type of maintenance. This type of maintenance is only done when a machine fails, and is commonly used on machines that don't impact production. Corrective maintenance is applied to increase machine or component reliability by upgrading components with more reliable or efficient ones. Preventative maintenance, which is used to keep equipment in a good running condition and keep them from failing, includes condition monitoring. [1]

It is thus important to have a maintenance strategy in place to avoid unnecessary and unexpected expenses.

There are two condition monitoring strategies used in the mining industry. Machines' condition can be manually monitored by using hand operated instrumentation to determine the condition of machines. This is time consuming and labour intensive, since machines must be studied individually and on a regular basis. A team of technicians are sent underground on a regular basis to take measurements on various machines, using different instruments.

Secondly, condition monitoring is applied using specialised equipment to constantly monitor the condition of machines. This equipment is highly accurate and measures very specific machine condition parameters. These specialised condition monitoring systems are very expensive to implement and requires specialist personnel to utilise.

1.2 Condition monitoring in the South African mining industry

Most of South African gold mines do not have proper condition monitoring strategies in place. Most gold mines do not prioritise condition monitoring, thus neglecting the current condition and deterioration of machine components. Other mines do not do condition monitoring and only does maintenance on machines when failure occurs. This creates large maintenance expenses and in some cases production losses. Rotating machines are required by law to have basic protection sensors installed and maintained. [2] These basic protection sensors prevent machines from running outside of their safe operating parameters. As an example, if a machine's bearing temperatures exceed a predetermined limit, or the rotating shaft vibrates beyond a certain point, the machine will be forced to shut down by the protection sensors. This protects the machine from possible damage and reduces safety risk to nearby workers. There is therefore a need for an inexpensive simplified condition monitoring strategy in the South African mining industry. Specialised condition monitoring systems must endure extreme conditions in the mining areas and cannot be operated and maintained by untrained personnel. Although protection sensors are not as accurate as dedicated condition monitoring sensors, they are an alternative system that is more religiously maintained in the mining industry.

2. SPECIALISED CONDITION MONITORING SYSTEMS

2.1 Vibration monitoring

Vibration monitoring is applied by using vibration transducers to measure radial or axial displacement, velocity or acceleration of the rotating shaft of an electric motor. The resulting frequency or vibration spectrum is compared to that of a new machine or machine in a known condition to determine the current condition of the machine. This frequency can also be processed statistically as an alternative to the signal analysis of the vibration spectrum. [3] Certain frequencies in the vibration spectrum can be linked to specific mechanical components. Condition monitoring specialists can even use these frequencies to determine the location and cause of the problem. Vibration analysis is very data intensive and the signal processing must be done individually for each machine, since their frequencies are unique, to provide accurate results.

2.2 Acoustic emission (AE) monitoring

It is known that load conditions on certain materials can cause them to produce sound waves due to material specific damage. Acoustic emission monitoring makes use of piezoelectric transducers which converts sound waves into electric current to detect material faults. This type of monitoring is also used for bridge condition monitoring. Deformation of a material causes energy to be released by the material in bursts of elastic waves, which is then detected and recorded by transducers or sensors. [4] Faulty bearings will generate a repetitive sound when moving due to roller elements striking cracks, which can also be monitored by acoustic emission monitoring. This makes it very effective for monitoring bearings, but can also pick up interference generated by external sources. [3]

2.3 Visual Monitoring

Visual monitoring can be done by using a remote camera to inspect a machine or doing it in person. It is also not limited to visual aspects like suggested by the name, but can include sounds and smells. In the railway industry, visual inspection of railway sleepers is done manually, which is both expensive and time consuming. This process can be automated so that a patented Visual Inspection System for Railway maintenance (VISyR) can do visual inspection of the railway. This is an on-the-fly analysis by analysing a video sequence of the tracks acquired at up to 190 km/h with an accuracy of 98.5%. [5] The big drawback of this type of monitoring is that by the time a visual inspection identifies a possible fault on rotating machines, it might already be too late to repair without replacement. [3] This process cannot be automated in the mining industry, and will not predict failures efficiently.

2.4 Oil particle analysis

Oil particle analysis focuses on analysing the chemical composition of the bearing lubricant in a circulatory system to identify the presence of metal particles and other impurities. This is unfortunately limited to circulatory lubrication systems, which is not very common and it has to be done manually. [3]

2.5 Infrared thermography

Infrared thermography is a novel approach to condition monitoring and can visualise the temperature of a machine without the need to have direct contact with it. Thermal cameras are available as portable devices and mountable cameras. They are highly accurate and can be widely used for condition monitoring. [6] Thermal cameras are still expensive and the maintenance costs of such a condition monitoring system in the mining industry may not justify the benefits. The operating environments of machines in the mining industry are also quite hot and might decrease the practicality of such a monitoring strategy.

2.6 Requirements for mining industry

The system must have a low implementation cost and should function with as little extra maintenance requirements as possible. This is because mining personnel are already under heavy workloads, and an increased workload can cause the cost of condition monitoring to outweigh the benefit. The operation of such a monitoring system should not have specialist skill requirements, as dedicating certain personnel to condition monitoring is not economically justifiable. This system must be able to endure the harsh operating environment of machines and should provide accurate predictions of machine failures. This makes the basic protection sensors that are already installed and maintained on these machines an ideal solution.

2.7 Basic protection systems

In paragraph 1.2 it is mentioned that all rotating machines must be equipped with basic protection sensors by law. These sensors must be able to stop running machines if they pose a risk to mine workers or cause damage to their immediate operating environment. These sensors generally measure machine vibrations and the temperatures of both the bearing elements of rotating machines. The machines are designed in such a way that protection sensors can be factory fitted by the manufacturer. This eliminates the need for the user to make modifications to install protection sensors. This also makes basic protection sensors an ideal solution to machine condition monitoring in the mining industry.

3. METHODOLOGY

3.1 Limit analysis of protection system

It is important to analyse the trip limits of these protection sensors, or to determine under what conditions the machines will be stopped or tripped by the protection sensors. It is important to capture these values for individual components, since two identical pumps installed next to each other can have different limits for the same measurements. The values for these key parameters must be included in the scope of the condition monitoring system and should be evaluated and recorded.

3.2 Data analysis of key parameters

The next step is to determine which condition monitoring parameters are being measured for the machines and at what resolution or intervals their readings are available. Such parameters can include temperatures, vibrations, pressures, and energy consumption on running machines. The frequency at which these parameters are recorded should not be too high, as this might negatively impact the performance of the mine's central control system. If the frequency is too low, critical changes in the system condition might not be detected in time. These values can be recorded to study their behaviour over a short time. From this behaviour analysis, the critical measurements must be identified. Critical measurements are typically those that are relevant to machine trips that were observed. The limits of these identified measurements can be obtained by using statistical methods to determine normal operating boundaries or by studying the original equipment manufacturer's provided documentation for the relevant machines. The documentation would provide more accurate limits, but this information is not always available.

3.3 Data management and interpretation

The recorded data should be centrally managed and processed. The critical measurements can be visually represented in graphs to provide feedback at a glance for all the components. It is also important to develop a notification strategy, so that the necessary people can be notified in time of a possible machine failure. An alarm must be sent out before the machine is shut down. This will provide them with information about problematic machines without having to constantly monitor the recorded data.

It is important to test the entire system before implementation. The measurements taken by the protection sensors must be validated to ensure that they are functioning correctly. The recording of essential measurements should not impact the performance of the mine's central control system. It is important to ensure the mine personnel confirm the trip limits as well as the warning limits, or measurements at which alarm messages will be sent out.

4. CASE STUDY

4.1 Description

The developed model was implemented on a South African gold mine. The mine has three pumping stations that are used to pump excess water from mine activities and underground sources to the surface of the mine. All the pumps in the dewatering system is included in the condition monitoring model.

4.2 Implementation

The warning limits were initially set at 85% of the trip limits. After a test period, it was decided to increase these limits to 95% of the trip limits, because alarms were triggered in events where machines did not trip. This yielded a much more accurate prediction of machine failures. There were occurrences where alarms were triggered for some measurements when machines were not operating. It was decided that the machine must be running before any alarms can be triggered. The alarms were also triggered too frequently and an adjustment was made so that alarms could only be triggered every six hours instead of every three hours.
A report was developed that would be sent out if an alarm was triggered more than 10 times. This report would indicate current operating conditions as well as normal operating conditions of the machine involved, and a recommendation would be made towards correcting the problem.

5. RESULTS

5.1 Outputs

During a period of one week, one of the pumps caused an alarm to be triggered 10 times because of the high temperature of the non-drive end bearing on the pump. A report was generated and sent to the shaft engineer on the mine. The report highlighted that there is a problem that will significantly shorten the life time of the pump if it was not corrected urgently. It illustrated the current operating conditions of the pump as shown in Figure 1.

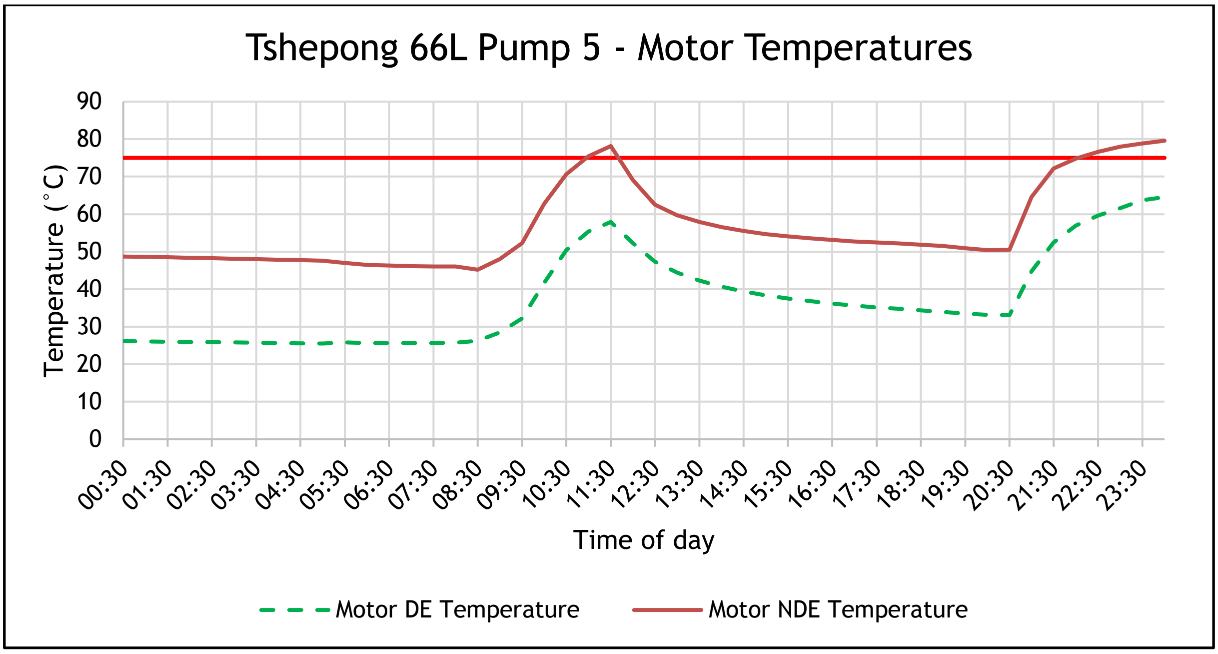

Figure 1: Motor bearing temperatures on 15 March 2017

As illustrated by these graphs after an alarm message was triggered at 76 °C, the bearing temperature kept increasing until the pump was tripped by the protection sensors at 80 °C.

5.2 Outcome

After the report was sent out, a technician was sent underground to investigate possible problems on the pump. The technician found that the motor was installed incorrectly and the motor alignment, coupling gap and magnetic centre was not correctly determined. This was fixed by moving the motor, adjusting the bearing and re-establishing the magnetic centre. After the adjustments were done, the pump was restarted and the bearing temperature settled at 73 °C. The operating temperatures of both bearing were nearly equal and stayed this way. The resulting bearing temperatures are shown in Figure 3.

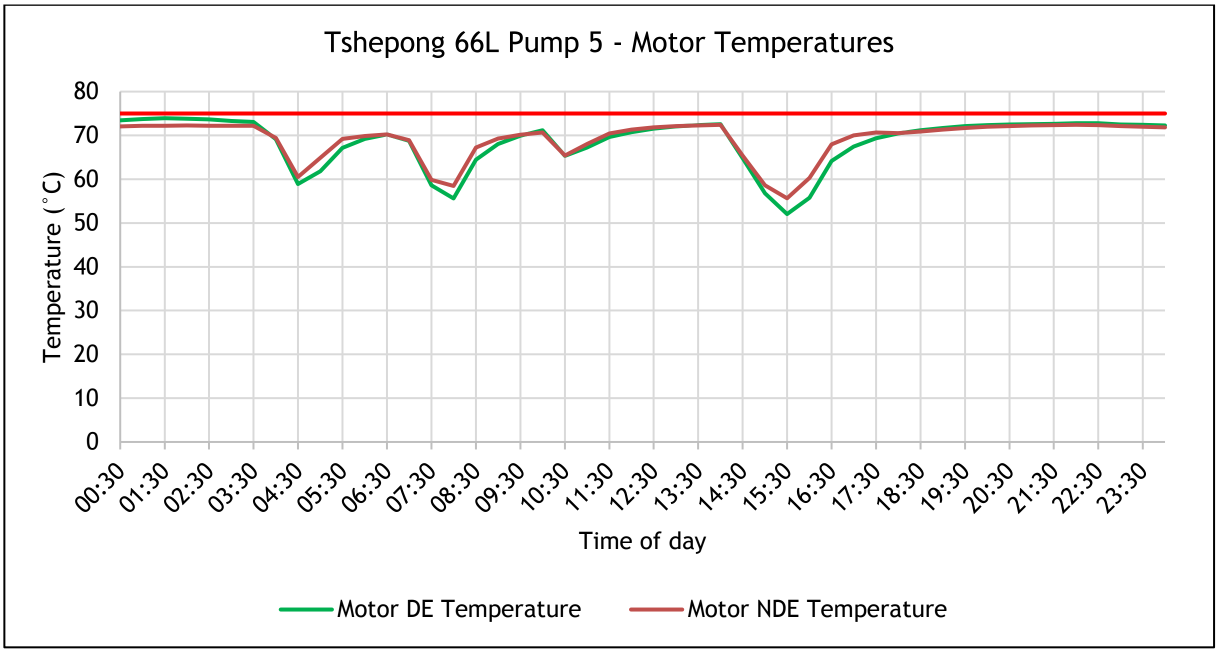

Figure 2: Motor bearing temperatures after adjustments

6. CONCLUSION AND RECOMENDATIONS

6.1 In summary

This study determined that condition monitoring can be implemented using various methods, which are applicable to various industries and environments. There is a unique requirement for simplified, non-complex and inexpensive condition monitoring strategy in the mining industry. Since basic protection sensors are lawfully required on these machines, it can be utilised as basic condition monitoring instrumentation. A notification strategy was developed based on key parameters to ensure that potential failures are communicated to mine personnel timeously.
The case study proved that this method accurately predicted machine trips and notifications were generated and sent out accordingly. Action was taken upon recommendation and it was found that there was a problem as indicated by the condition monitoring system. This resulted in the pump running with lower bearing temperatures which in turn resulted in an increased bearing life expectancy.

6.2 Future development and recommendations

This condition monitoring system can be developed in the future to take more measurements into account that are less important. More measurements can aid in improving the accuracy and prediction of this condition monitoring system. This same strategy can also be applied to performance monitoring and in this way, keep well maintained machines running at better efficiency rates as well.

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APPLYING FLEXIBLE MANUFACTURING AS A WAY OF REDUCING MUSCULOSKELETAL DISORDERS AND MAINTAIN PRODUCTIVITY IN POULTRY PROCESSING INDUSTRY

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ABSTRACT

Productivity is the effectiveness of constructive effort, as measured in terms of the rate of output per unit of input, and is strongly associated to the quality of output. Quality can be compromised from time to time by occupational injuries, one being Musculoskeletal Disorders (MSD). Musculoskeletal disorder's problems are rampant in many manufacturing sectors including poultry industry. This paper aims to demonstrate that flexible manufacturing techniques can be employed as a means to reduce work MSD and subsequently maintain organization productivity. Production process flows were studied to identify the "Critical Operations" (CO) that subjected employees more to MSD. Cycle time was used to determine process cycle efficiency which assisted in determining the time that employees should be subjected to CO so as to flexibly switch to other operations. Results indicated that there was productivity improvement as a result of applying job switching techniques (switching from one operation to another) which created room for the body part that was affected in previous CO to rest in subsequent CO and hence not compromising organizations productivity and their health. This system yielded positive results as the rate of absenteeism resulting from MSD was reduced and company cost resulting from compensation requests also reduced.

Keywords: Poultry industry, productivity, musculoskeletal disorders, performance, flexible manufacturing

OPSOMMING

Produktiwiteit is die effektiwiteit van konstruktiewe poging, soos gemeet in terme van die koers van opbrengs per eenheid van insette, en word sterk gekoppel aan die kwaliteit van uitset. Kwaliteit kan van tyd tot tyd deur beroepsbeserings opgedoen word, een is Muskuloskeletale Disorders (MSD). Muskuloskeletale siektetoestande se probleme is opvallend in baie vervaardigingsektore, insluitend pluimvee. Hierdie referaat het ten doel om te demonstreer dat buigsame vervaardigingstegnieke gebruik kan word as 'n manier om werk-MSD te verminder en daarna organisasieproduktiwiteit te handhaaf. Produksie proses vloei is bestudeer om die "Kritieke Operasies" (KO) te identifiseer wat werknemers meer aan MSD onderwerp het. Siklus tyd is gebruik om te siklus doeltreffendheid wat bygestaan in die bepaling van die tyd wat werknemers moet onderwerp word aan so KO as om buigsaam te skakel na ander bedrywighede te bepaal. Resultate dui daarop dat daar 'produktiwiteit verbetering as gevolg van die toepassing van werk te skakel tegnieke (oorskakeling van een operasie na 'n ander) wat ruimte vir die deel van die liggaam wat geraak is in die vorige KO rus in die daaropvolgende KO en dus nie in gevaar organisasies produktiwiteit en hul gesondheid geskep . Hierdie stelsel het positiewe resultate opgelewer aangesien die afwesigheidsrisiko as gevolg van MSD verminder is en maatskappykoste as gevolg van vergoedingsversoeke ook verminder is.

Sleutelwoorde: Pluimveebedryf, produktiwiteit, muskuloskeletale afwykings, prestasie, buigsame

1. INTRODUCTION

1.1 Occupational injuries and MSD

Musculoskeletal disorders (MSD) are the greatest causes resulting to lost workdays and medical bed days. Thirty thousand South Africans suffer from neck or back pains annually, with 10% of them becoming chronic sufferers [1]. In Great Britain, MSD remains to be an ill health related condition that places significant burdens on employers and employees accounting to 41% of all work related ill-health [2]. The disorder has been found to be the leading cause of work disability [3]. Musculoskeletal disorders are very common and are major causes of sick leave, disability and reduced productivity while at work [4-6]. The leading users of disability pensions, sick leave and compensation claims are people with musculoskeletal pains [7-8]. Earlier studies have shown that approximately a quarter of all sick leave applications are related to MSD [7]. In France, work-related MSDs of the upper limb account for two-thirds of all occupational disorders [8]. Long term sick leave increased in Sweden during the 1990s with forty percent of all sick leave related to MSDs [9]. In 1988, it was reported that, on average, approximately 300,000 work-related accidents were reported annually in South Africa, with 2000 fatalities occurring in industry and agriculture, and a further 500 in the mines [10]. Deviation from upright posture generates increased force on the lumbar spine, with the disc fibre layers being most heavily loaded [11]. Any work situation requiring repetitive flexion and/or twisting for long periods, or sustained bending, is therefore at risk of causing lower back pain in workers [12].

One-third to half of all disability claims in poultry industries are related to hand, wrist or upper extremity cumulative trauma [13] which are prominent due to the nature of poultry processing. Based on this nature the underlying questions are “Which of these task performed in poultry processing are more pining (critical) operations “CO” to the development of MSD? How often, and for how long are rest pauses to be structured for these operations?” Therefore, seeing that MSD still prevails in other industries as well as in poultry processing industry, it is necessary for interventions to be made such that employee’s well-being is cared for and that the employer’s interests are considered. As a result the purpose of this paper is to present how the techniques of flexible manufacturing can be employed to reduce work MSD and subsequently maintain organization productivity and employee health and safety.

A variety of direct costs (compensation of victims, medical care, etc.) and indirect costs (loss of production, replacement costs, absenteeism, etc.) are associated with MSD, which considerable impacts on productivity, since it drives up costs for workers, companies, and society in general.

1.2 Multiple facets resulting to MSD in poultry processing industry

Poultry processing involves a combination of highly repetitive and forceful movements that place the employees at increased risks for MSDs [14, 15]. Much of the work on a poultry processing line involves the use of hand and wrist, from which workers may be particularly at risk for MSD. The table below indicates common poultry processing MSDs and their causes.

Table 1: Common work-related musculoskeletal disorders that affect workers in poultry industry

Disorder	Symptoms	Causes
Carpal tunnel syndrome	Numbness of middle fingers, especially at night	Repetitive wrist flexion
Myofascial pain of the neck	Heaviness and aching in the shoulders, upper back and neck	Overhead work and work with extended arms
Shoulder bursitis	Shoulder pain and stiffness	Repetitive shoulder movements
Rotator cuff tendinosis	Shoulder pain and stiffness	Repetitive shoulder movements with twisting and overhead activities
Lateral epicondylitis	Lateral elbow pain, especially with extended wrist	Lateral elbow pain, especially with extended wrist
Trigger finger	Locking of fingers in flexion	Repetitive hand grip

Based on the literature mentioned with the statistics from various countries in terms of the prevalence rate of MSD, costs affecting all stakeholders within the industry, the underlying questions are “which of these task performed in poultry processing are more pining (critical operations) “CO” to the development of MSD? How often, and for how long should pauses be structured for these operations?”

1.3 Musculoskeletal disorder (MSD)

Musculoskeletal disorder is an umbrella term encompassing overuse and repetitive disorders and injuries of muscles, and is characterized by pain in muscles, nerve, and joints. This disorder is also known as Repetitive Strain Injury (RSI) which is a pain felt in muscles and joints stemming from prolonged repetitive movement. This disorder mostly affects parts of the body such as forearms and elbows, wrists and hands, and necks and shoulders. The disorder has various symptoms ranging from weakness in the forearm, numbness, lack of control and fatigue [17].

The underlying reasons to these MSDs are mostly due to lack of enough rest pauses for worker's bodies to recover from the pains and discomforts experienced during work activities [1]. MSDs result from overuse of musculoskeletal system. Overuse of these systems leads to situations where MSDs generally develop gradually and occur because a structure is abused repetitively [1]. Due to the nature of operations in poultry processing pertaining industry, which may be repeated movements and postural stress, static work, continuous loading, this sector is commonly classed as high risk occupational sector with increased risk of developing MSD [16]

2. METHOD

MSD is due to repetitive or prolonged stressing and straining of muscles and tendons because of repetitive tasks. As such, MDS can be viewed as a cumulative effect of the repeated or prolonged straining on human muscles. The straining of a muscle normally leads to fatigue, which has been generally identified as one of the symptoms of MSD. As such fatigue was used in this paper as the indicator of (mild) MSD, with the understanding that prolonged or repeated fatigue will lead to (chronic) MSD in the long run. Fatigue can be easily identified by the extension in the time in which individuals take to perform a task. Thus, a change in production cycle after certain number of repetitive tasks was used as an indicator of fatigue by the workers and hence the development of mild MSD.

Secondly, productivity is commonly defined as the amount of output produced per given input [18]. This input might be raw materials, labour-hour and/or other capital investment. Thus, productivity was measured in this report as the amount of chicken parts produced per unit (or given) time. The given time in our particular case was the amount of time spent by the poultry worker per shift. Thus, the number of chicken parts processed by a worker per shift was a measure of the worker's productivity.

3. RESULTS AND DISCUSSIONS

3.1 Participants and process description

Participants were workers from a small poultry processing enterprise in the Vaal region. All jobs were considered and observed but since the study was more focused on the critical operations that subject employees more to MSD, not all departments were included in the study. The plant operates a two eight-hour shift. The plant does not operate with a fully automated system as a result several of its tasks are performed manually. The birds averaged a weight of between 1.8 – 2 kg a bird. Ten employees worked at the plant on an eight-hour shift with one sixty - minute break per shift and with occasional overtime depending on customer's demand.

Tasks monitored for selection of CO

Workers were observed and timed as they performed their normal day-to-day tasks. This exercise took 2 weeks so as to find accuracy and to leave no opportunity for any overlook of crucial information. After a series of observations, cutting and packing operations, among others were found to be the prominent critical operations. These critical operations with their operational requirements and impacts are given in Table 2 below

Critical Operations (CO)	Normal Cycle time	Common risk factors	Health problems caused
Class 1: Packaging	5 min	Repetitive task High work pace	Injuries MSD
Class 2: Production line: (cutting and deboning)	10 min	MSD loads Repetitive tasks	Accidents and injuries MSD Cut injuries

Table 2: Critical operations, cycle time, risk factors and health problems.

The Cycle time was measured per output, which for the purpose of this study is known as worker output per cycle. The time taken to complete an operation was measured to determine how long it took to complete a cycle. This step was conducted to determine the pace of each worker performing a task. Having measured the cycle time on each day there were output variations from employee to employee, but the common observation was that these variations (i.e. number of units produced) occurred approximately equal on the same interval. After every five hours of work the production time per operation started to increase indicating that the pace with which the worker worked had reduced gradually. The time reduced from five to seven minutes for packaging operations and 10 to 13 minutes for cutting operations. This was therefore used as an indicator to allow them to switch to other tasks so as to alleviate MSD onset on the tired muscles that slowed down their performance on the production line. A test was done to demonstrate the results that the proposed (flexible manufacturing) method would present. The impacts of using job switching (i.e. flexibility to change job types) as compared to staying fixed on specific job type (i.e. traditional method) are discussed in the two scenarios below.

The application of rating technique was profoundly used to eliminate the Hawthorne effect as it was carefully maintained by the study person not to take readings when the following occurred:

1) worker was worried and looks hurried;
2) worker was being over careful;
3) worker does not pause to think when it is expected;
4) the study person was tired;
5) the worker was working very fast.

3.2 Scenario 1: (Traditional method)

3.2.1 Cutting operation

Knives and scissors were the tools used in cutting and deboning chicken, and knives were used to cut chickens into pieces. In the deboning process, the chicken carcass was placed on a cone on a conveyor line. A worker had to cut into different pieces by removing the legs, wings, skin, breast meat and thighs. These cutting operations were comprised of either flexion or extension and sometimes both as illustrated on figure 1.

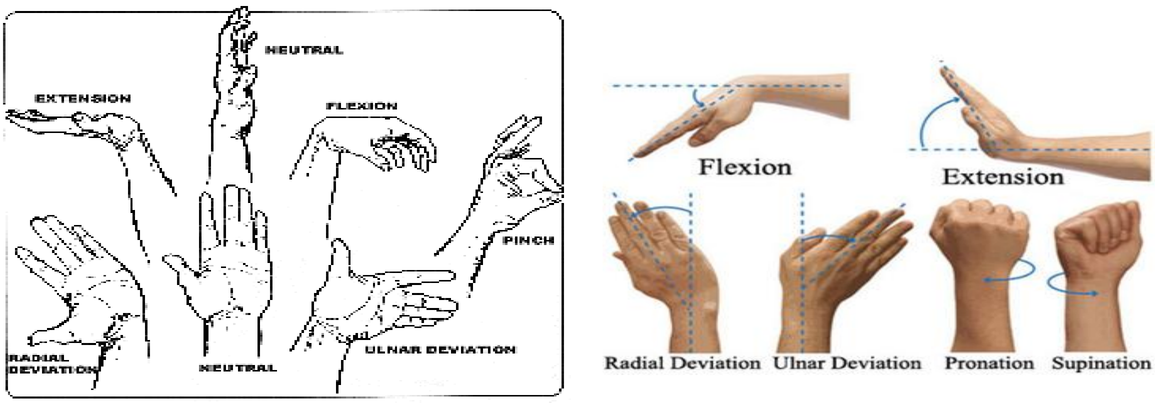

Fig 1: neutral, flexion and extension postures

Each operator on the line performed one or more cuts with sharp knives to remove specific portion of meat. Scissors were used to trim bone, cartilage and fat from the meat. Due to the nature of operations in this industry, workers hand and arm motions included grasping, turning, applying pressure and pinching so as to achieve cutting out wings, thighs, and tender meats to ultimately removing all the meat from the bones. Therefore these movements frequently resulted in stressful hand and wrist positions as the worker's arm, hand and wrist were subjected to flexion or exertions repeatedly. See fig 2:

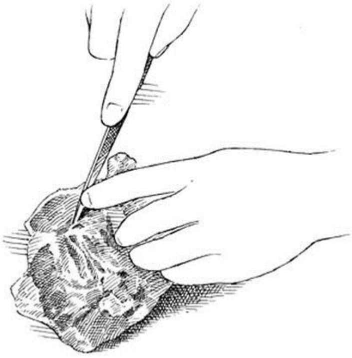

Fig 2: cutting operations stressful to hand and wrist

The force that was required to make the particular cut, either by knife or scissors, could also contribute to MSD. Increasing the applied force increases muscle effort, decreases circulation to the muscles and causes greater muscle fatigue [7]. Awkward hand motions were equally performed to separate meat from chicken bones. One hand held meat while the other hand held the knife to make a specific cut. Scissors rubbed the sides of the fingers, causing pressure and discomfort to fingers muscles.

As it has been stated above, the normal cycle time for this cutting operation was supposed to be 10 minutes, and therefore 6 units were supposed to be produced in an hour. Observational and time study methods indicated that although it was expected for the worker to produce same amount of units per hour throughout the shift, that was not normally the case because the body muscle experienced discomfort which led to longer time to produce than expected or set standard of performance. This ultimately resulted into reduced number of units produced within allocated time as a result of pain and discomfort.

The cost to company increased in this scenario mainly because the company's two input resources, which are manpower and labour hour, increased. Labour hour was increased so that the demand could be met, as a result workers had to work overtime. Again absenteeism rate resulting from MSD increased as workers needed to recover from the disorder.

3.3 Scenario 2: (Flexible manufacturing method)

3.3.1 Cutting operation and other operations

Flexible manufacturing is a system that allows for an amount of flexibility and the ability to do different tasks by the same resources. Job rotation is process of shifting an employee from job to job and a change in the scope of a job so as to provide greater variety to an employee [19]. The purposes of these two techniques are the same. In this scenario a worker was asked to perform a specific task at hand (cutting and deboning) for a four hours and stop just before the onset of fatigue (i.e. when it takes them longer than prescribed standard time/cycle time to produce a unit). As a result the worker's muscles were not allowed time to experience fatigue and because the state of the muscles was not compromised, a worker then switched to the other tasks (such as packaging) not involving the same body muscle when operating.

It turned out that workers produced for further three hours before on set of next MSD as indicated by increase cycle time. They were then asked to switch to a third type of task after 6 hours 30 minute of work in the plant to complete the rest of the shift. Since all the different types of tasks were performed before the onset of fatigue, complaints about fatigue lessened and productivity increased since the workers did not carry on doing the same task when their paces were to reduce that could have resulted in them taking long to produce and yet producing less quantity at a compromised quality.

It was observed that there was a reduction in absenteeism rate since worker's body parts were freed from prolonged activities which resulted to them being absent from work. These absenteeism rates affected productivity of the organization since it caused production process to carry on with members under staffed. Based on the system of flexible manufacturing allowing frequent rest pauses for worker's body parts, then there was an approximate 2.5 - 5% daily increment in productivity as all workers could be available to execute their activities without any fatigue complaint.

4. CONCLUSION

Musculoskeletal disorder has been found to be, for most countries and industries, a source of reduced productivity and an element compromising employee's health. To reduce this state this paper has shown that an approach of production like flexible manufacturing can yield good results that save costs and eliminate ill health as compared to traditional production methods. Of course, employers should train their employees to be able to perform different types of operations or this ability should be a requirement before employment.

The proposed use of flexible manufacturing approach to operations yielded improved process cycle efficiency as it allowed workers to flexibly switch the operations before the eruption of MSD, which ultimately increased productivity by having more units produced by a worker per shift with and reduced company cost.

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AGRICULTURAL INNOVATION PLATFORMS ESTABLISHMENT AND FUNCTIONING: A SYSTEMATIC REVIEW

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ABSTRACT

The use of agricultural innovation platforms has become recognised as a key mechanism through which to stimulate inclusive growth by serving as a space for agricultural stakeholders to engage, improve and develop new agricultural products and services.

A vast body of literature has been produced in the agricultural innovation platforms domain. This study presents a systematic review of the agricultural innovation platform concept. The aim of the study is to determine a) the core theoretical foundations and theoretical concepts that have been utilised in studies of agricultural innovation platforms; b) develop a conceptual framework on the process of developing and managing agricultural innovation platforms c) identify potential areas of further research.

The fundamental principles (theoretical foundations) identified in this study include value chains, multi-stakeholder environments, social networks, diffusion theory and resource assembly & organisational economics. Theoretical concepts explored focused on stakeholder management, innovation process management and agricultural production management. The study concludes by identifying research gaps within the agricultural innovation platforms domain.

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1. INTRODUCTION AND PROBLEM STATEMENT

Agricultural research development is focused on improving the livelihoods of poor farmers through effective technology and knowledge dissemination mechanisms. The evolution of agricultural research for development is best described in three phases shown in Figure 1 which shows that it has evolved from a linear approach to a holistic approach and finally an innovation platforms approach (Nederlof, Wongtschowski, and Van Der Lee 2011).

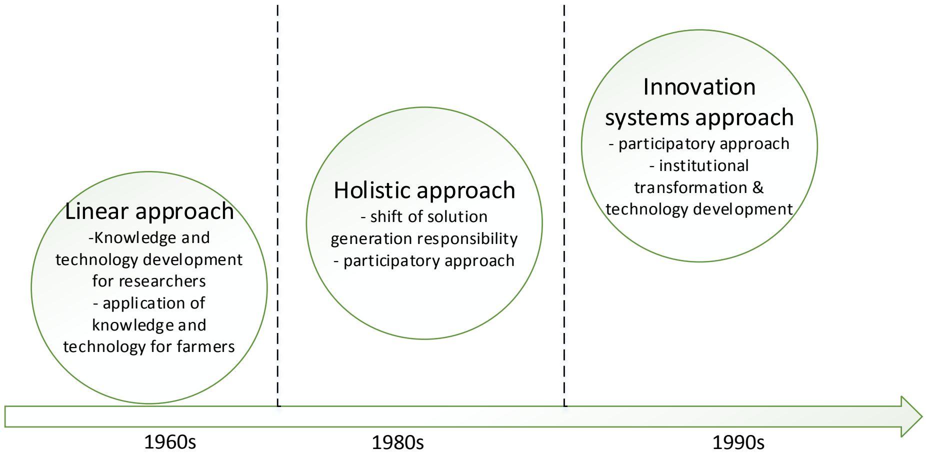

Figure 1: Transformation of agricultural research for development

The original linear approach was the dominant mode of innovation over the period 1960s to 1970s (Nederlof, Wongtschowski, and Van Der Lee 2011) in which development of knowledge and technology by researchers was considered a separate activity from the application and adoption of knowledge by farmers. Farmers were considered as only as receivers/beneficiaries of new technology and knowledge which led to the approach not to produce the anticipated results. Failure of uptake of new knowledge and technology was due to a lack of interest in the solutions, little flexibility for adaptation and a lack of proactivity (Barrantes and Yag e 2015). It became clear that technology was not the only bottleneck for effective transformation of farming methods and social development but institutional constraints hampered intended recipients from properly receiving and implementing technologies (Abate et al. 2011).

The failure of the linear approach led to the acknowledgement that farmers' engagement and inputs are crucial for problem identification and adaptable solution generation. The shared responsibility of problem identification and solution generation between other stakeholders and farmers introduced a participatory approach which marked the beginning of the holistic approach era (Nederlof, Wongtschowski, and Van Der Lee 2011). Despite the participatory approach towards problem solving between farmers and researchers, sectoral fragmentation between different stakeholders in various agricultural sub-sectors existed (Mango et al. 2015). Each sub-sector would individually collaborate with farmers and advance its objectives but there was no coherence. And this did hamper proper transformation and successful agricultural enterprise during the holistic era. The era was a transformation phase towards agricultural institutional change and the era was mainly characterised by recognition of farmers' responsibility towards sustainable production.

From policy discussions on the appropriate nature and analytical frameworks for industrial growth in the 1980s, emerged the innovation system approach (Adekunle and Fatunbi 2012; Anandajayasekeram 2011). The innovation system approach is a dynamic network of different actors interacting in a specified structure which have networks and institutions as structural components (Bergek et al. 2008). The functions of structural elements supported through innovation platforms are inter alia to develop knowledge, assemble resources, gather market formation, influence research, advocacy and economic development. The approach found prominence amongst policy makers and in the 1990s was introduced to achieve sustainable agriculture and rural development (Nederlof, Wongtschowski, and Van Der Lee 2011). Agricultural Innovation Platform Systems (AIPS) focus on institutional transformation and technological development. Technology development may for instance consist of new pesticides, new breeds of animals, new seeds and new production techniques whilst institutional transformation encompass effective organisational setups, market establishment, partnerships and policies (Nederlof, Wongtschowski, and Van Der Lee 2011; Klerkx, Aarts, and Leeuwis 2010). AIPs increase support and facilitate interactions between stakeholders by providing an action arena for collective problem identification and solution generation (Kambalame and Cleene 2006).

A significant body of literature has been produced on the setup and functioning of agricultural innovation platforms in various development contexts. The transformation of agricultural research for development over the years has also been supported by the evolution of theoretical foundations and concepts within innovation studies. Through the examination of literature on the establishment and operation of agricultural innovation platforms (AIPs) this study seeks to conceptualise how such platforms operate. The core objectives for this research article therefore are:

a) To identify theoretical foundations and theoretical concepts implemented in agricultural innovation platforms literature;

b) To develop a conceptual framework on establishment and operations of agricultural innovation platforms;

c) To identify potential areas of further research.

2. RESEARCH METHODOLOGY

The research methodology is shown in **Figure 2, the problem statem statement forms the first stage and outlines the need for this research study. The study is a sytematic literature review through which the authors collected and analysed the literature on agricultural innovation platforms. The systematic literature review approach was selected as the systematic review allows for an in-depth literature review and is transparent and minimi es bias (Bryman and Bell 2 11). The method was selected because the results of the search are reproducible if the same procedures and search terms are used. A conceptual framework was developed to organise agricultural innovation platforms concepts identified.**

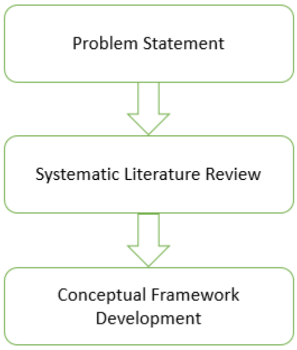

Figure 2: Research structure

The problem statement is presented in Section 1 and Section 3 is the agricultural innovation platforms systematic review. Section 4 contains the results and analysis of the review, development of a conceptual framework is in Section 4 with the conclusion and gap analysis in Section 5.

3. SYSTEMATIC LITERATURE REVIEW OF AGRICULTURAL INNOVATION PLATFORMS

A summary of the stages and steps towards completing the review is shown in Table 1. The first stage undertaken was to plan how the collection of various literature sources was to be conducted. This included the development of research questions, formulating the search terms and identifying data sources. Stage B of conducting the review was completed by identifying literature that focus on the agricultural innovation platforms concept and to select relevant studies for the review. The evaluation stage included the in-depth analysis of the selected studies to determine theoretical foundations and theoretical concepts with the development of the framework that was completed as the final stage.

Table 1: Systematic Literature Review Methodology

Stage	Steps	Accomplished objective	How was it accomplished	Where it is presented
A) Planning the review	a) Review specification	a) Research questions development b) Selection of data sources c) Search term definition	Determined the objectives of the study. Studies were identified using key terms.	Research questions presented in section 1 and literature search in section 2.1
B) Conducting the Review	a) Identification of the research	a) Identify studies that describe agricultural innovation platforms	A total of +1000 publications were harvested from the search engines	Forms the basis of section 2.1
	b) Study selection	a) Analysis of studies to understand the categories in agricultural innovation platforms literature	45 publications qualified for the study.	Forms the basis of section 2.2
C) Evaluation	a) Data extraction and analysis	a) Determine the trends of publications and theoretical foundations and concepts of Agricultural innovation platforms	An evaluation template was developed by the authors and each paper was rigorously examined.	Evaluation criterion is included in table 3. And the results in section 3
D) Conceptual Framework Development	a) Development	a) To give a theoretical explanation of agricultural innovation platforms operate	Through identification of different theoretical foundations and concepts and then deduce how the structure operates	Section 4

3.1 Data Collection

The study employed the phrases "Agricultural Innovation platforms" and "Agriculture Innovation Platforms" as the search terms on three academic databases namely Scopus, Web of Science, Science Direct and the Google Scholar search engine. The search was filtered for papers published over the 2000-2015 period with search fields that included article title, abstract and keywords. The resultant yield for each search term and each database is shown in Table 2.

Table 2: Search Terms and Search Yield

Search Term	Scopus	Web of Science	Google Scholar	Science Direct
Agricultural Innovation Platforms	153	68	143	+500
Agriculture Innovation Platforms	125	54	6	+500

3.2 Study Selection and Inclusion Criterion

The initial search yielded over a 1000 publications as shown by the document progression vine in Figure 3. The preliminary vetting phase was based on the title of the document and if any doubt arose regarding relevance, the abstract was examined. Here 271 publications were still included in the database as publications that could be identified to be related to the topic of the study. The final inclusion decision was made based on an in-depth examination of the 271 publications to determine if they focused on either the establishment of AIP or on the operations of an AIP. Finally, a total of 48 publications were found to be within the scope of the study (See Figure 3).

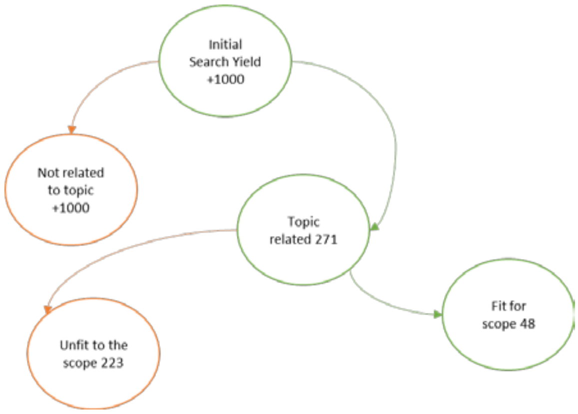

Figure 3: Documents Progression

A systematic analysis process of each of the publication was undertaken with the data from the papers categorised into three data categories namely, descriptive data, conceptual aspects and empirical aspects. The paper analysis and evaluation criteria for each category is shown in Table 3.

Table 3: Publication Analysis and Evaluation Criteria

Descriptive Data	Empirical Aspects	Conceptual Aspects
• Document file name • Title of the document • Type of document (e.g. Journal, working paper, conference) • Phase of analysis (five year periods, e.g. 2000-2004 and so on) • Year published • Published in (e.g. Journal name, conference name, University name) • Authors • Geography of authors (country of affiliation) • Affiliations Citations (from Google Scholar)	• Focus of study • Data collection and validation • Abstract • Geographic focus of the empirical work • Application area (e.g. Geographic, sector, national)	• Foundational Principles (e.g. value chain, multi stakeholder) • Theoretical concepts (e.g. Supply Chain Management, Network Intermediaries) • Goals • Future issues for study identified in the document • Conclusion drawn by authors of the document

3.3 RESULTS AND ANALYSIS

The 48 publications reviewed were all individually coded by the authors to have a standard representation of information, this enhanced easy observation of trends within the literature. This section consists of the trends and themes in the publications as per the analysis and evaluation criteria shown in Table 3. The results section is presented in three main sub sections which consist of the descriptive statistics, empirical aspects and conceptual aspects.

3.3.1 Descriptive Statistics

This section focuses on the bibliometric trends of the 48 papers evaluated, by type of paper is shown in Figure 4. The period of analysis is divided into three phases and the paper type includes journal articles, conference papers, books and book chapters.

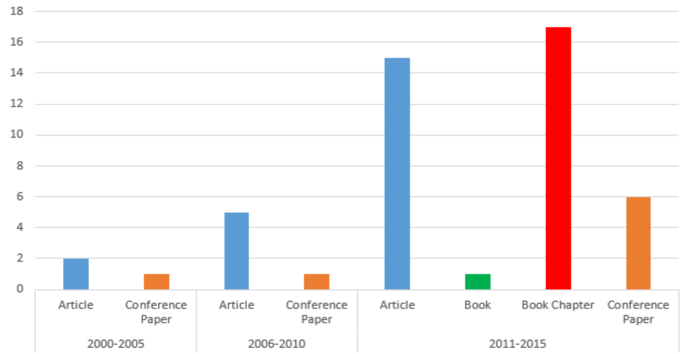

Figure 4: Timeline of publications and Publication Types

With closer inspection, the collection includes 22 journal articles, 17 case study reports as book chapters, 1 book, and 8 conference papers. The details of distribution and publication names can be found in the Appendix in Table 2. Citations statistics shown in Figure 5 were based on google scholar statistics and suggest that journal articles and books collected have proven to be much more highly cited than to conference papers.

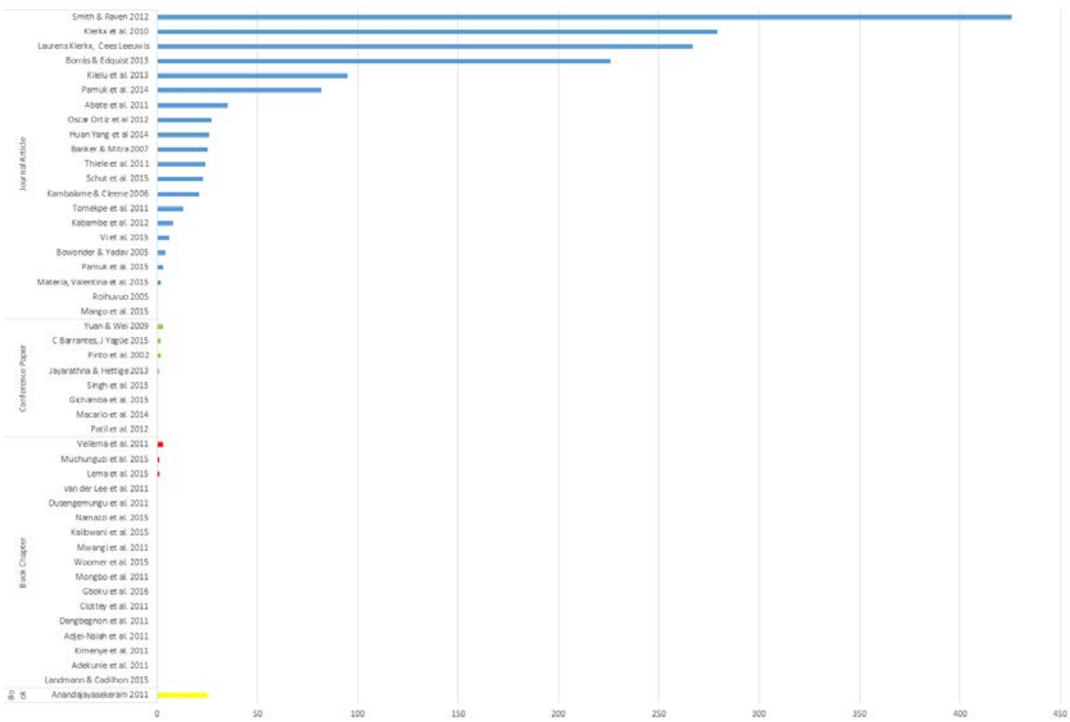

Figure 5: Publication Citations

3.3.2 Empirical Aspects

This sub-section interprets patterns and trends concerning themes identified in the reviewed papers. The geographical location of platforms identified in the papers is shown in Figure 6 and 71% of the papers focused on platforms in Africa and 29% of the papers focused on platforms in Asia, Europe and South America.

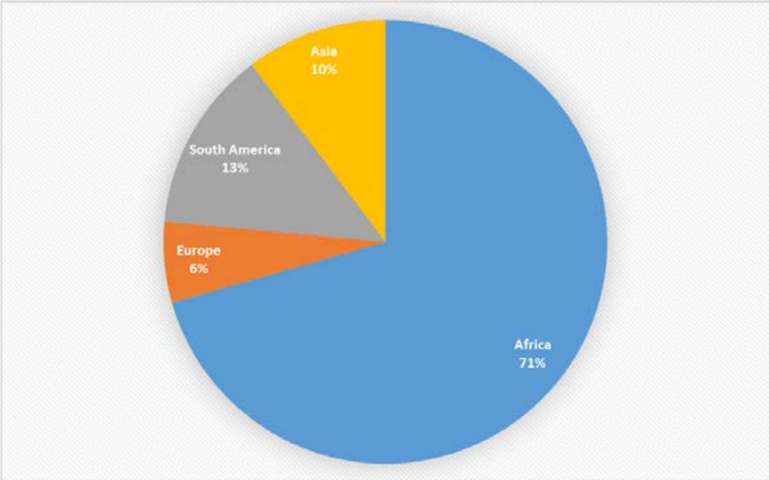

Figure 6: Geographical location of Empirical Work

With closer inspection, various categories or types of platforms can be been identified from our sample. These include platforms to enhance the creation and spreading of new technology and information (technology dissemination platforms), research labs, online marketing platforms, charted value chains platforms with multiple stakeholders, farmer advisory platforms and community of practice platforms (Explained in Table 4).

Table 4: Types of platforms

Type of platform	Description	References
Technology Dissemination	Technology dissemination platforms are focused on the distribution of new or improved agricultural methods and improved breeds. Platform facilitators concentrate on how improved products and methods will reach the end-user (farmer) to improve agricultural production.	(Kabambe et al. 2012; Schut et al. 2015; Pamuk, Bulte, and Adekunle 2014; Mango et al. 2015; Gboku, Modise, and Bebeley 2015; Oladele 2013; Bowonder and Yadav 2005; Dror et al. 2015; Nederlof, Wongtschowski, and Van Der Lee 2011; Yang, Klerkx, and Leeuwis 2014; Ortiz et al. 2013; Barrantes and Yag e 2015)
Research lab	This type of platform integrates farmers and researchers through information communication technologies (ICT) and extensive field demonstrations as part of knowledge generation and knowledge extension.	(Singh et al. 2015)
Online marketing & auctions	Links agricultural producers and consumers using mobile phones and information technology. The platforms have eliminated the need of product brokers (middle merchants) thus farmers' sale their products to the consumers at reasonable prices.	(Banker and Mitra 2007; Jayarathna and Hettige 2013; Yuan and Wei 2009)
Community of practice	These platforms enhance knowledge sharing between researchers and advisors that makes innovation repository. Through ICT infrastructure, fragmentation between researchers and advisors has been bridged despite different geographical locations.	(Materia, Valentina, Giare, and Klerkx 2015; Macario et al. 2014; Kliment et al. 2015; Pinto et al. 2002; Patil et al. 2012)
Farmer Advisory	Advisory platforms are established to give farmers advice on specific challenges and warnings on disease outbreaks and weather updates. Modern ICT infrastructure plays a critical role in offering two-way communication channels between experts and farmers. This have seen the development of mAgriculture (mobile agriculture) and eAgriculture (online agriculture) systems.	(Gichamba, Waiganjo, and Orwa 2015)
Multi-stakeholder value chain	A multi-stakeholder value chain is focused on linking stakeholders within a specific agricultural value chain to identify value chain constraints	(Thiele et al. 2011; Kilelu, Klerkx, and Leeuwis 2013; Tomekpe et al. 2011; Adekunle and Fatunbi 2012; Abate et al. 2011; Dror et al. 2015;

	and generation of solutions that remove inefficiencies.	Nederlof, Wongtschowski, and Van Der Lee 2011; Klerkx and Leeuwis 2008)

3.3.3 Conceptual Aspects

Conceptual aspects cover the fundamental principles and concepts that moulds and facilitate the development and running of platforms. Focus in this section is on platform operational structure, theoretical foundations, theoretical concepts and goals.

Theoretical Foundations

Theoretical foundations are abstract principles that describe the architecture of the platform from which theoretical concepts emanate from. The purpose of exploring the theoretical foundations of the AIP literature is to provide a framework to guide identification of potential stakeholders and provides a framework of how the platform is expected to function.

The study managed to identify five theoretical foundations which consist of the value chains, the multi stakeholder concept, social networks, innovation diffusion theory and resource assembly and organisational economics. The full list of papers and corresponding theoretical foundations is listed in Appendix Table 1.

a) Value chains focus on the interrelations of actors along the production chain of agricultural products and analysis of the relationships between value chain actors and their participation to identify driving constraints to higher efficiency and productivity (Banker and Mitra 2007). Due to the informal relationship between farmers and markets (Thiele et al. 2011), operations are characterised by higher transactional costs and may lead to innovations to be unsuccessful. To overcome challenges around developing relations between farmers and other agricultural stakeholders within the value chain, facilitators have developed innovation platforms which acts as a structure to govern trade and synchronize business activities. Combining value chain stakeholders through such structures facilitate learning, joint innovation and can be used for advocacy roles to secure policy transformation.

b) The Multi-stakeholder principle had been regarded vital for sustainable agricultural development. Defining agricultural challenges is a complex task and combining heterogenous stakeholders in agricultural innovation platforms has eased and often enables the process of problem identification and solution generation. The role of platform facilitators is then to ensure and facilitate the involvement of all stakeholders in exploring, implementing and monitoring agricultural innovations for effective solution generation. A platform should seek to promote innovation by facilitating interactions between farmers with indigenous knowledge, agricultural merchants, researchers and national policy makers. Actor engagement should focus on identifying problems and providing insights on the biophysical, technological and institutional dimensions of the problem (Esparcia 2014). Generation of economically, culturally and politically viable solutions is eased and this fosters interdependence and collective action in problem solving.

c) Social network theoretical principles focus on the linkage between members in a network were resources flow freely and effectively (Rogers 1995). The concept is based upon the framework that an idea is possessed by an individual but can be transmitted through social groups, networks and practice (King, Chung, and Haney 2009). Network formation consists of network brokering in which platform facilitators identify and link relevant actors (Miller and Jones 2010; Thiele et al. 2011). Interlinking different stakeholders within a platform facilitates the free flow of ideas and solutions to native problems. Knowledge gained by different farmers within the platform through observations, practice or interactions can be transmitted to other farmers within a similar social setup.

d) The Resource assembly and organisational economics theory seeks to exploit the advantage of combining farmers resources and share the fixed expenses incurred on procurement of raw metals and marketing products (Banker and Mitra 2007; Dror et al. 2015). Combining resources expands capacity of stakeholders involved and offers a variety of options within the platform. A variety options means a range alternatives which means agricultural production is accomplished with the most effective and efficient method available. The principle of sharing expenses amongst farmers reduce individual production costs thus increasing net earnings.

e) Diffusion theory seeks to examine factors influencing the dissemination of new ideas within a social structure (Kilelu, Klerkx, and Leeuwis 2013; Rogers 1995). Dissemination of new technologies can be hindered by cultural settings, disseminating channel and the product itself. Identification of possible hurdles in distributing new ideas and agricultural methods is crucial for meaningful transformation of targeted group. Platform facilitators and technology developers should consider religious and social norms of the targeted farmers, choose channels that have a provision of feedback from the recipients of technology. It is critical to develop products based on recipient needs for successful adoption and a product or method that is alien to targeted farmers have high chances of rejection.

Theoretical Concepts

Theoretical concepts drive and govern platforms towards attainment of its objectives. These concepts originate from foundational principles (theoretical foundations) and are coalesced to form a complex function that facilitates agricultural production through promotion of new or improved agricultural products and practices. This study managed to identify 19 theoretical concepts and depending on the concept objective, the study grouped these concepts into three groups with concepts that relate to stakeholder management, innovation & knowledge management and production management (See Table 5). The list of papers corresponding with theoretical concepts is shown in Appendix Table 1.

Table 5: Core platform categories and functions

Category	Core platform functions
Stakeholder Management	• Network Brokering (Thiele et al. 2011; Klerkx, Aarts, and Leeuwis 2010; Bowonder and Yadav 2005; Roihuvuo 2005; Klerkx and Leeuwis 2008), • Intermediaries (Anandajayasekeram 2011; Yang, Klerkx, and Leeuwis 2014; Klerkx and Leeuwis 2008) • Structuration Theory (Klerkx, Aarts, and Leeuwis 2010) • Stakeholder Engagement (Abate et al. 2011) • Interaction & Learning (Materia, Valentina, Giare, and Klerkx 2015; Mango et al. 2015; Gboku, Modise, and Bebeley 2015; Adekunle and Fatunbi 2012; Oladele 2013; Dror et al. 2015; Barrantes and Yag e 2015) • Organisational Development (Klerkx, Aarts, and Leeuwis 2010)
Innovation and Knowledge Management	• Decentralized Innovation (Pamuk, Bulte, and Adekunle 2014) • Innovation Ecology (Anandajayasekeram 2011) • Evolution (Smith and Raven 2012) • Open Innovations (Anandajayasekeram 2011) • Policy Instruments (Borrás and Edquist 2013) • Demand Articulation (Kabambe et al. 2012; Kilelu, Klerkx, and Leeuwis 2013; Klerkx and Leeuwis 2008) • Niche Formulation (Schut et al. 2015; Smith and Raven 2012), • Knowledge Management (Macario et al. 2014; Singh et al. 2015; Kliment et al. 2015) • Knowledge co-construction (Materia, Valentina, Giare, and Klerkx 2015; Patil et al. 2012) • Co-evolution (Kilelu, Klerkx, and Leeuwis 2013; Schut et al. 2015)
Production Management	• Demand and Supply Coherence (Tomekpe et al. 2011; Mango et al. 2015) • Sustainable Production (Adekunle and Fatunbi 2012) • Supply Chain Management (Banker and Mitra 2007; Gichamba, Waiganjo, and Orwa 2015; Jayarathna and Hettige 2013; Yuan and Wei 2009; Abate et al. 2011; Dror et al. 2015)

Stakeholder Management consists of concepts that focus on building and managing networks which include, actor addition, managing power dynamics and conflict resolution. Stakeholder networks are held together by mutual customs of reciprocity thus establishing trust through continuous exchange of goods and services. Learning and interaction structures amongst platform actors should be clearly stipulated to entice maximum participation of stakeholders. Stakeholder participation determines the fate of the platform thus platform structures should be proactive towards inhibiting environment.

Innovation & Knowledge Management include the idea that different innovation intermediaries (brokers) must facilitate the creation of new methods and technologies within the platform. Key brokerage functions include demand articulation which facilitates the process of identifying innovative solutions to overcome perceived challenges and innovation management. Universities, non-governmental organisations and other research institutes make up the innovation ecology as the repositories of existing knowledge and generators of new knowledge. Niche operations within platforms are established to operate independently from the main regime thus allowing experimentation and exploration which facilitates path breaking innovation.

Production Management focuses on improving constraints associated with production, transformation, marketing and consumption of the agricultural products. The objective is to bridge production and consumption to avoid the waste of over production. This can be accomplished by observing the status of the current market and use post-harvest records to forecast demand. This facilitates proper production planning within the platform and the platform facilitators can mobilise the required inputs and other necessary resources to all stakeholders within the value chain at appropriate time.

Platform Operational Levels

A platform can have more than one operating structure (Dror et al. 2015; Adekunle and Fatunbi 2012) and these structures served three sole purposes which are: strategic management, operational management and grassroots operations. Strategic structure is often established at a national level as shown in Table 6. The purpose of strategic management is to set objectives for focused research (Kabambe et al. 2012), advocacy and policy development and interact with other platforms.

The purpose of operational management level in agricultural innovation platform system is to translate the objectives of strategic management level into an action plan that will be implemented at the grassroots operational level by farmers (Kabambe et al. 2012). This is accomplished by identifying current challenges and perceived challenges within the grassroots action arena and develop solutions to facilitate smooth agricultural production.

Problem identification is achieved through a participatory approach which include farmers, extension officers, agricultural dealers, input suppliers and processors. Innovation outcome of this process include new markets, working capital for farmers, new farming methods, new animal breeds and new plant seeds (Tomekpe et al. 2011; Mango et al. 2015). The grassroots operational level is where actual agricultural production is achieved (Kabambe et al. 2012). New farming methods are expected to diffuse through the farming community during local meetings, field days and field demonstration by interaction, observations and doing (Ortiz et al. 2013; Rogers 1995; Barrantes and Yag e 2015). This will empower the farmers and improve their methods thus capitalising on innovation to improve agricultural yield.

Table 6: Platform Operational levels

	Strategic Management level	Operational Management level	Grassroots Operations level
Application Area	National	Provincial	Local districts
Functions	• Develop objectives for focused research (Kabambe et al. 2012; Tomekpe et al. 2011) • advocacy, formulate policy (Nederlof, Wongtschowski, and Van Der Lee 2011; Abate et al. 2011; Gboku, Modise, and Bebeley 2015) • Interact with other regional platform (Mango et al. 2015; Tomekpe et al. 2011)	• Facilitates implementation of strategic management objectives (Kabambe et al. 2012; Abate et al. 2011; Mango et al. 2015), • identifying & promotion of new methods, new plants & new animal breeds to farmers (Ortiz et al. 2013; Abate et al. 2011; Mango et al. 2015) • monitors evaluates grassroots operations (Kabambe et al. 2012; Abate et al. 2011; Mango et al. 2015) • market identification (Nederlof, Wongtschowski, and Van Der Lee 2011) • meshing farmers (Thiele et al.	• Learning by interaction, doing & observation (Kabambe et al. 2012; Barrantes and Yag e 2015) • agricultural production (Gichamba, Waiganjo, and Orwa 2015; Tomekpe et al. 2011)

		2011; Abate et al. 2011)	
Actors	• University researchers (Abate et al. 2011; Gboku, Modise, and Bebeley 2015) • Government Representatives (Adekunle and Fatunbi 2012; Abate et al. 2011) • Non-Governmental Organisations (NGO) (Kabambe et al. 2012; Tomekpe et al. 2011), • Private Business (Abate et al. 2011) • Farmer's Representatives and Farmer's Associations (Adekunle and Fatunbi 2012)	• Agronomists (Kabambe et al. 2012) • Agricultural economists (Kabambe et al. 2012) • Land resource extension managers (Kabambe et al. 2012) • Researchers (Mango et al. 2015; Barrantes and Yag e 2015; Abate et al. 2011), • Traders & Agro-processors (Thiele et al. 2011; Banker and Mitra 2007; Abate et al. 2011)	• Farmers (Nederlof, Wongtschowski, and Van Der Lee 2011; Mango et al. 2015; Kabambe et al. 2012; Abate et al. 2011) • Extension Workers (Abate et al. 2011; Kambalame and Cleene 2006; Mango et al. 2015) • NGO personnel (Ortiz et al. 2013; Mango et al. 2015) • Researchers (Barrantes and Yag e 2015; Kabambe et al. 2012; Adekunle and Fatunbi 2012)

Platform Goals

Goals are measurable targets and objects of platform efforts which participants desire to attain. Despite different types of platforms, goals were identified and classified per anticipated period of attaining that goal. The goals of participating in the platform are set in three time frames as immediate goals, intermediary goals and the long term (impact) goals as shown in Figure 7.

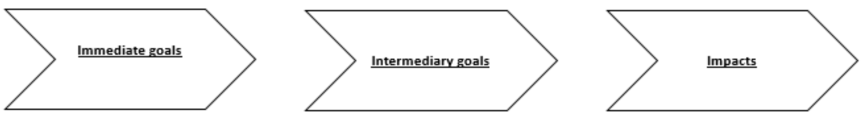

Figure 7: Platforms goals

During platform establishment, it is critical that facilitators highlight the expected immediate benefits for participating in the platform. Immediate benefits stimulate participation of platform actors, however without a clear long-term vision the platform might lose track and lose relevance amongst actors resulting in actor withdrawal. Immediate benefits should be incremental towards meaningful transformation of livelihoods of platform participants and have sustainable revenue for other commercial stakeholders. Immediate goals shown in Table 7 include new revenue streams identification, conflict resolution, advocating for new policies, combined problem solving and low agricultural transactional costs.

Intermediate goals act as a framework that sustains continuous realisation of immediate benefits and these include improvement in research, better policies, enterprise growth, increased agricultural productivity and empowerment of platform stakeholders. Platform impacts are the long-term effects that platform participants realise and these include capacity building, macro-economic gains and improved food security and livelihoods as shown in Table 7.

Table 7: Platform Goals

Immediate	Intermediate	Impacts
• Identification of opportunities (Thiele et al. 2011) • Conflict resolution (Adekunle and Fatunbi 2012; Pamuk, Bulte, and Adekunle 2014) • Policy advocacy(Abate et al. 2011) • Needs articulation (Abate et al. 2011; Mango et al. 2015; Kabambe et al. 2012) • Problem solving (Abate et al. 2011; Mango et al. 2015; Kilelu, Klerkx, and Leeuwis 2013; Materia, Valentina, Giare, and Klerkx 2015; Ortiz et al. 2013) • Stakeholder organisation (Ortiz et al. 2013; Yang, Klerkx, and Leeuwis 2014; Dror et al. 2015), • Entrepreneurship (Nederlof, Wongtschowski, and Van Der Lee 2011) • Lowering transaction costs (Banker and Mitra 2007)	• Improvement in research & development (Barrantes and Yag e 2015; Jayarathna and Hettige 2013; Patil et al. 2012), • Improved policies & decision making (Abate et al. 2011) • Agricultural enterprise growth (Mango et al. 2015) • Improved agricultural productivity & management practices (Abate et al. 2011), • Stakeholder empowerment (Nederlof, Wongtschowski, and Van Der Lee 2011)	• Capacity building (Gboku, Modise, and Bebeley 2015; Pamuk, Bulte, and Adekunle 2014) • Macro-economic gains (Adekunle and Fatunbi 2012) • Improved food security and livelihoods (Dror et al. 2015; Tomekpe et al. 2011)

4. CONCEPTUAL FRAMEWORK

Theoretical foundations are the anchor that defines platform geometry, during the scoping phase displayed in Figure 8 platform facilitators need to determine the trajectory to follow. This trajectory is based upon identified needs on why to initiate the platform and the objectives to be satisfied. The theoretical notion that points the route to follow in solving these challenges and satisfying demands are foundational principles (theoretical foundation) of the platform. The scoping phase therefore involves narrowing down the platform objectives to be aligned with the context of targeted group. Issues of concern include mapping out the framework on how the intended objectives will be achieved.

Guided by the theoretical foundations, facilitators might identify the need to engage multiple partners (multi stakeholders) within the agricultural value chains to build trust and expand the agricultural enterprise. In some instances, platform facilitators will adopt farmer collaborations in networks approach to identify challenges, produce grassroots solutions and learn from one another (social networks). This boosts the intellectual input from the community and allows for complex problems to be better defined through a collective search for solutions. For profitable operations, facilitators might combine farmers' resources thereby sharing purchasing and marketing costs. Agricultural production systems exist in a globalised context and the need to link different research programmes across continents or sharing research outputs amongst the inclusive innovation community is crucial. This however adds to the complexity of technology transfer of improved agricultural methods and improved products, which necessitates facilitators to map out clearly how generated solutions will diffuse within the community. Factors that affect dissemination of new technologies include cultural settings, broadcasting mediums and nature of the new technology. Platform facilitators should clear any barriers for effective technology transmission within the platform.

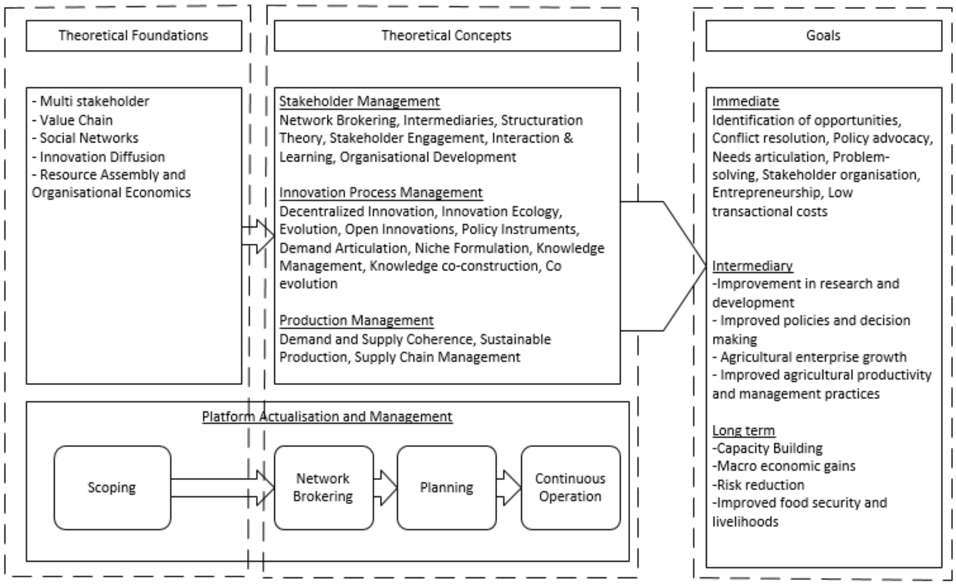

Figure 8: Conceptual Framework

During network brokering facilitators need to identify relevant stakeholders and assigning stakeholder responsibilities. Regulations to govern the platform should be developed during this stage and focus should be directed on member addition, existing member termination, handling conflict between members and establish how stakeholders should engage and interact. If the stakeholder engagement regulations are clearly defined and disciplined, unity is more likely to prevail amongst platform participants. Innovation process management concepts are implemented to facilitate knowledge construction, problem identification and solving. The choice of platform regulations and policies (instruments) implemented have an impact on the demand articulation (Borrás and Edquist 2013) process which is concerned on identifying perceived platform challenges and generating solutions. Depending on the context of the targeted group facilitators might opt for a decentralised innovation approach or foster path breaking solutions through niche operations (Smith and Raven 2012). Knowledge sharing and technology dissemination channels should be designed such that new products and methods will reach intended platform participants.

Production management focus on forecasting consumer demand and producing what is enough to satisfy consumer demand. Supply chain management is focused on mobilizing and utilising resources efficiently within a specified agricultural supply chain (Danreid and Sanders 2007). Goals are desired outcomes for participating in the platform and facilitators should set goals that are specific, measurable, attainable, realistic in a specific timeframe. The time frame for goals should be categorised into three frames which are immediate, intermediary and long term. The immediate goals as shown in Figure 8 include identifying new business opportunities, conflict resolution, advocating for better policies and low transactional cost. If these goals are attained on a continuous basis this will bring proper transformation of livelihoods and macro-economic gains. To support continuous reaping of immediate goals, intermediary goals should aim at research & organisational improvement and enterprise growth to improve agricultural productivity and management practices. The overall impact on the long-term basis include capacity building, macro-economic gains, agricultural risk reduction, improved food security and livelihoods.

5. CONCLUSION

The study identified the core trends of the extant research in establishing and operating AIPs. Concerning the types of platforms established, the evidence provided by this research indicates limited research output on research labs. Other agricultural innovation platforms identified in this study include multi-stakeholder value chain platforms, technology dissemination platforms, farmer advisory platforms, online marketing & auctioning platforms and community of practice platforms.

The study has managed to identify five theoretical foundations on establishing agricultural innovation platforms which consist of value chain, multi stakeholder, diffusion theory, social networks and organisational economics & resource assembly. These principles are supported by theoretical concepts divided into three groups which include stakeholder management, innovation process management and production management. The study recommends grouping platform goals into three groups for successful operations. These groups include immediate goals, intermediate gaols and long term goals and there should be coherence between these goals for inclusive growth and livelihood transformation.

The study identifies coordination of platform production activities focusing on demand and supply coherence as a gap for future study. The study proposes analysis of platform production activities and delivering of goods to the consumer within the value chain from a production line perspective. Issues of concern include demand forecasting, farmer skill improvement (capacity building) and supply chain activities. Successful integration of operations management and supply chain principles into agricultural production will bring significant transformation and inclusive growth.

6. APPENDICES

Appendix Table 1: Survey publication list

Title	Theoretical Foundations	Theoretical Concepts	Reference
Multi-stakeholder platforms for linking small farmers to value chains: evidence from the Andes	Multi stakeholder platforms, Social networks, Value chains	Supply chain management, Network brokering	(Thiele et al. 2011)
Partnership building as an approach to addressing corporate social responsibility in the agriculture sector in Malawi. (Special issue: Is business coming to the table? Corporate citizenship in Africa.)	Social networks, Resource assembly & organisational economics	Innovation process management	(Kabambe et al. 2012)
Procurement models in the agricultural supply chain: A case study of online coffee auctions in India	Resource assembly & organisational economics	Supply chain management	(Banker and Mitra 2007)
Unravelling the role of innovation platforms in supporting co-evolution of innovation: Contributions and tensions in a smallholder dairy development programme		Demand articulation, Co evolution	(Kilelu, Klerkx, and Leeuwis 2013)
Increasing Knowledge Flows between the Agricultural Research and Advisory System in Italy: Combining Virtual and Non-Virtual Interaction in Communities of Practice	Social networks	Social learning, Knowledge sharing, Knowledge co-construction	(Materia, Valentina, Giare, and Klerkx 2015)
Innovation Platforms: Experiences with Their Institutional Embedding in Agricultural Research for Development		Niche formation, Co evolution	(Schut et al. 2015)
Do decentralized innovation systems promote agricultural technology adoptionα Experimental evidence from Africa	Multi stakeholder platforms, Social networks, Innovation diffusion	Innovation decentralization	(Pamuk, Bulte, and Adekunle 2014)
CARBAP and innovation on the plantain banana in Western and Central Africa. (Special Issue: Sustainable intensification: increasing productivity in African food and agricultural systems.)	Value chains	Value chain management, Demand & Supply coherence	(Tomekpe et al. 2011)
Kenya: Challenges and Lessons	Social networks, Value chains	Supply chain management	(Gichamba, Waiganjo, and Orwa 2015)
AgriCom: A communication platform for agriculture sector	Multi stakeholder platforms, Value chains	Supply chain management	(Jayarathna and Hettige 2013)
NatData: A platform to integrate geospatial data from natural resources of the Brazilian biomes		Knowledge sharing, Knowledge co construction	(Macario et al. 2014)
The impact of integrated agricultural research for development on food security among smallholder farmers of southern Africa.	Social networks, value chain	Social learning, Demand & supply coherence	(Mango et al. 2015)

ICT platform for climate change adaptation in agriculture	Innovation diffusion	Knowledge sharing,	(Singh et al. 2015)
Agris on-line Papers in Economics and Informatics Supporting a Regional Agricultural Sector with Geo & Mainstream ICT – the Case Study of Space4Agri Project Key words		Knowledge sharing, Knowledge co construction	(Kliment et al. 2015)
Design and Implementation of Agriculture Product Supply Chain Information Sharing System Based on Web Service	Value Chain	Supply chain management	(Yuan and Wei 2009)
A Case Study of Innovation Platforms for Agricultural Research, Extension, and Development:	Social networks	Social learning, policy instruments	(Gboku, Modise, and Bebeley 2015)
Approaches for setting-up multi-stakeholder platforms for agricultural research and development	Multi stakeholder, Social networks	Social learning, demand supply coherence, sustainable production	(Adekunle and Fatunbi 2012)
Approaches for setting-up multi-stakeholder platforms for agricultural research and development	Multi stakeholder, Innovation diffusion	Social learning, Knowledge construction	(Oladele 2013)
What is protective space? Reconsidering niches in transitions to sustainability		Niche pathways, Co evolution	(Smith and Raven 2012)
A Framework to Support Scientific Knowledge Management: A Case Study in Agro-meteorology	Innovation diffusion	Knowledge co-construction, knowledge sharing.	(Pinto et al. 2002)
A systems and partnership approach to agricultural research for development: Lessons from Ethiopia	Multi stakeholder, Value chain	Stakeholder engagement, supply chain management	(Abate et al. 2011)
Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment		Structuration theory, innovation configuration	(Klerkx, Aarts, and Leeuwis 2010)
Developing an ICT platform for enhancing agricultural productivity: The case study of EID Parry	Multi stakeholder platforms, Social networks, Innovation diffusion	Network brokering	(Bowonder and Yadav 2005)
Information and Communication Technologies for Agriculture Knowledge Management in India	Social networks,	Knowledge co-construction, knowledge sharing.	(Patil et al. 2012)
The sky is the limit.	Multi stakeholder, Value chain	Network Brokering	(Roihuvuo 2005)
The choice of innovation policy instruments		Policy Instruments	(Borrás and Edquist 2013)
The role of agricultural r&d within the agricultural innovation systems framework	Value chain	Eco systems, Open innovation, intermediaries	(Anandajayasekeram 2011)
With trust and a little help from our friends: how the Nicaragua Learning Alliance scaled up training in agribusiness	Social networks, resource assembly & organisational economics, Value chain	Supply chain management, Social learning	(Dror et al. 2015)
Overcoming challenges for crops, people and policies in Central Africa: the story of CIALCA stakeholder engagement	Multi stakeholder platforms, Innovation diffusion	Social learning	(Dror et al. 2015)
Can an innovation platform succeed as a cooperative society? The story of Bubaare Innovation Platform Multipurpose Cooperative Society Ltd	Value chain	Supply chain management	(Dror et al. 2015)

Crop-livestock-tree integration in Uganda: the case of Mukono-Wakiso innovation platform	Multi stakeholder, Value chain, Innovation diffusion	supply chain management	(Dror et al. 2015)
Humidtropics innovation platform case study: WeRATE operations in West Kenya	Multi stakeholder, Innovation diffusion		(Dror et al. 2015)
Innovation platforms for improved natural resource management and sustainable intensification in the Ethiopian Highlands	Multi stakeholder, Innovation diffusion		(Dror et al. 2015)
Soybean cluster in Ghana	Resource assembly and organisational economics, Value chain	Supply chain management	(Nederlof, Wongtschowski, and Van Der Lee 2011)
Improved maize-legume production systems in Nigeria	Multi stakeholder, Value chain, Innovation diffusion and	Supply chain management	(Nederlof, Wongtschowski, and Van Der Lee 2011)
Oil palm in Ghana	Multi stakeholder, Value chain	Demand Supply coherence, Entrepreneurship	(Nederlof, Wongtschowski, and Van Der Lee 2011)
The national innovation platform for the agricultural sector in Benin	Multi stakeholder, Value chain	Demand Supply coherence, Entrepreneurship	(Nederlof, Wongtschowski, and Van Der Lee 2011)
The Ugandan Oilseed Sub-Sector Platform	Multi stakeholder, Value chain, Innovation diffusion	Supply Chain management	(Nederlof, Wongtschowski, and Van Der Lee 2011)
Maize in Rwanda	Multi stakeholder, Value chain	Innovation diffusion, Supply Chain management	(Nederlof, Wongtschowski, and Van Der Lee 2011)
Agricultural innovation platforms: The ASARECA experience	Multi stakeholder, Value chain	Innovation diffusion, Supply Chain management	(Nederlof, Wongtschowski, and Van Der Lee 2011)
Putting my fruit with yours: Organising the mango value chain in Kenya	Value chain	Demand Supply coherence, Entrepreneurship	(Nederlof, Wongtschowski, and Van Der Lee 2011)
Conservation agriculture in Zambia	Multi stakeholder, Innovation diffusion		(Nederlof, Wongtschowski, and Van Der Lee 2011)
Vegetable production in the Thyolo District of Malawi	Social networks, Value chains	Social learning, Supply chain management	(Nederlof, Wongtschowski, and Van Der Lee 2011)
Functions and limitations of farmer cooperatives as innovation intermediaries: Findings from China		Innovation intermediaries	(Yang, Klerkx, and Leeuwis 2014)
Insights into potato innovation systems in Bolivia, Ethiopia, Peru and Uganda	Diffusion of innovation	Dissemination of technologies	(Ortiz et al. 2013)
Adults' Education and Agricultural Innovation: A Social Learning Approach	Social networks	Social learning	(Barrantes and Yag e 2015)
Matching demand and supply in the agricultural knowledge infrastructure: Experiences with innovation intermediaries		Demand articulation, innovation intermediaries, Knowledge construction	(Klerkx and Leeuwis 2008)

Appendix Table 2: Publication List

Publish	Number of Publications
Article	**22**
Agricultural Economics Research, Policy and Practice in Southern Africa	1
Agricultural Systems	4
Agris on-line Papers in Economics and Informatics	1
Development Southern Africa	1
Electronic Commerce Research and Applications	1
Experimental Agriculture	1
Food Policy	2
International Journal of Agricultural Sustainability	2
International Journal of Services Technology and Management	1
Journal of Agricultural Education and Extension	1
Life Science Journal	1
Outlook on Agriculture	1
Research Policy	1
Technological Forecasting & Social Change	1
World Applied Sciences Journal	1
African Journal of Biotechnology	1
EFI News	1
Book	**1**
FARA	1
Book Chapter and Case study reports	**17**
Cases on Leadership in Adult Education	1
Development, Policy & Practice	10
Innovation Platforms for Agricultural Development: Evaluating the Mature Innovation Platforms Landscape	6
Conference Title	**8**
2014 IEEE 10th International Conference on eScience	1
12th IEEE AFRICON International Conference	1
2013 IEEE 8th International Conference on Industrial and Information Systems	1
2015 7th International Conference on Communication Systems and Networks, COMSNETS 2015 – Proceedings	1
First International Workshop on Education Technology and Computer Science	1
Proceedings of the International Conference on Computer Supported Cooperative Work in Design	1
World Applied Sciences Journal	1
Procedia - Social and Behavioural Sciences	1
Grand Total	**48**

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HUMAN FACTORS INTEGRATION FOR SUSTAINABLE MANUFACTURING

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ABSTRACT

In the current global market dynamics, the functional requirements of manufacturing technologies are increasingly constrained to deliver a higher operational performance, while minimizing the use of resources. Today's development of industrial products and their associated manufacturing systems is more oriented toward profit margins than before, allowing little or no room for defects and rework. In this globally competitive environment, concurrent approaches to designing products and their manufacturing processes require a better analysis and an integration of the systems' operations with the relative functionality of the systems' features and accompanying fixtures. From a review of the literature around the causality that decisions made on the selection of operational processes have effects on the output performance, this paper explores several components in the science of human integration for the design of sustainable labour solutions in manufacturing operations. Based on the dynamic trends of the current conversation on the design of manufacturing systems and a discussion on human factors in manufacturing, a suggestion is made for an interaction model that places ergonomics at the center of the design and implementation process for inclusive solutions, that can sustain labour operations in manufacturing.

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1. INTRODUCTION

Product development defines a process in which a good preparation and a series of actions result in the introduction of new processes and or improved products. Manufacturing planning deals with the coordination between humans and machines to derive an appropriate set of sequences for performing tasks. In manufacturing, Boujut & Laureillard [1] report that the integration of various parameters in engineering design is interaction oriented rather than task oriented. In one domain, conceptual manufacturing parameters can be listed as: planning, system's design, systems' behavior simulation, prototyping. In another domain, operational manufacturing parameters can be listed as: cycle-time, machining, assembly balancing, maintenance, operating procedures, work allocation, inspection and so forth. The degree to which the design of processes, products and services reflect human's needs and limitations can be defined by the level of integration between the conceptual and operational domains before the introduction of new models and methods of industrial operations. Thus, iterations between the conceptual and the operational domains in systems design provides production engineers with the relevant means to investigate the design of systems and their outcome predictions.

In the product realization process through fabrication and assembly, Boothroyd [2] note that assembly operations make-up for the majority of the cost of manufacture of a product. In the present competitive operating margins, the need for operation design engineers to incorporate the desired level of the product's quality into the operational process and the work environment is particularly important in industrial operations. This requires models that can analyze the design process and its realization. When a manual operation is considered a sustainable method to run manufacturing activities; decisions in products and processes design must be made with the consideration of human limitations in terms of ergonomics constraints. These constraints may constitute setbacks in working conditions at the time of running operations, if not properly managed.

In the literature [3, 4], on generic concepts for products design, the product development process was traditionally defined as a sequential flow of activities and information across stages; which each stage preceded by a gate to check that the previous stage has been completed. As illustrated in Figure 1, the product development process is made of a succession of stages comprising: ideas generation, concept development, design specifications, prototype fabrication, testing and manufacturing ramp-up.

Figure 1: Generic product development [4].

As today's market conditions put users' needs and competitive requirements at the center of all decisions related to products, services and production systems' realization, the consideration of unforeseen circumstances and downstream constraints is somehow neglected in a sequential design approach. However, the right understanding of users' needs in a product and its realization through design and manufacture remains yet, neither a linear nor a rational decision-making exercise. This is primarily due to a lack of objective data for interpreting downstream manufacturing requirements, constraints and trade-offs.

This paper investigates the ergonomics' dimension of co-operative design as expressed in the theories of concurrent engineering. In placing the overall operational capabilities of labour-intensive manufacturing systems around human ergonomics, the paper puts emphasis on designing processes that consider the working conditions of users, for achieving systems' life-cycle efficiency. This paper is arranged as follows: Section 2, explores some works on concurrent engineering and the influence of ergonomics in the design for manufacture. Section 3, provides the motivation for the paper. Some components of the human factors consideration in design and operation of industrial systems is presented in section 4. Section 5, illustrates and discusses our proposed ergonomics model and section 6, talks of the benefits for an ergonomics' integrated system development and concludes the paper.

2. RELATED WORKS

Although manufacturing organizations have different methods for introducing new products and services, the ability of these organizations to quickly identify the opportunities for product realization, and to promptly quantify the necessary variables to attain a higher level of systems' functionality is critical to assure growth and sustain their operations in the long term. Traditionally, there was the common assumption that only upstream sharing of knowledge among designers is sufficient for better success in meeting customers and users' requirements. Scientists and engineers, in isolation from shop floor technicians have often developed products and their envisioned production systems. In this traditional approach to design, Das et al. [5] have reported that it is not always obvious to the product development team to determine how features in the new design could adversely affect the downstream elements of the operational cost. A lack of communication between engineers and operators working at the manufacturing shop floor can often result in an under-performing outcome, that privileged the early aspects of the design in terms of products' characteristics while depriving the downstream efficiency and the capability of the manufacturing process. To promote the co-operation between designers and operators, Nafisi et al. [6] report that manufacturing requirements can be well expressed by operators working in the manufacturing environment. Similar remarks by Fleischer & Liker [7] in manufacturing suggest that better manufacturability is highly associated with intensive engagement between designers and downstream operators.

The time where designers developed products, threw them beyond the '*Wall*' to the manufacturing personnel and expected they could just produce them is now a story of the past. In recent time, the theories of concurrent engineering have gained significant industry and academic relevance. The concurrent model of industrial development also known as simultaneous or integrated design, helps developers to lower the design flaws and achieve faster products realization lead-time and moreover, to improve the quality, the functionality and the safety of use of products [8]. Simultaneous design, through early iterations between the product and its process development is an approach in which design activities in various domains overlap and multiple departments collaborate from the beginning [9]. Closely linked to industrial development, Sagot et al. [10] define ergonomics as the compatibility of humans with products and processes in their co-operative environment. Mallane & Tengen [11] report that In the automotive industry, poor workplace ergonomics affect the sustainability of a company or even of an entire sector. They further note that inappropriate working conditions results in lost productivity and waste, increased costs to employers through workers' absenteeism and medical claim. Some other setbacks related to ergonomics, which are less tangible include human pain and discomfort.

Colledani et al. [12] point out that most shortcomings that eventually cause deficiency and waste are induced in the production phase, then early failure analysis can prevent the recall of products and a loss to a manufacturer's image and profits. In complex manual assembly tasks, studies conducted by Zhu et al. [13] revealed that operators are often confronted with conflicting decisions to make under strict time pressure, e.g. pick the right components, get the right orientation, use the right tools and so forth. As an answer to human deficiency; Ogbemhe et al. [14] have reported that there has been a worldwide push in robotics to sustain manufacturing operations. However, although automation can save time and cost for mass production, Wang et al. [15] recognized that automation can only be applied and cost justified for systems with simple configurations. To respond to increased competition to attract customers and retain their loyalty, many products now require multiple process variants due to numerous built options. The ability of human operators to quickly execute the multiple alternatives for delicate processes continues to give relevance to manual operations. Gonçalves-Coelho & Mourao [16], argue that today's design engineers can resort to a vast array of decision making tools for selecting solutions for product realization that easily define the manufacturing processes. Such decision support tools include, and not limited to: decision matrix (DM), robust design (RD), design for X (DFX) and process functions (PF) modelling. Under DFX, the principles behind ergonomics studies and their applications are well discussed in the paradigms of design for manufacture (DFM) and design for assembly (DFA) [17]. As described by Das et al. [18], design for manufacturability is a support for designing products that can easily be translated into fabrication, with minimal manufacturing cost and effort and that meet a desired level of quality.

Product design typically precedes manufacture and it is driven by the need to create new products in relatively complex and conflicting constraints characterized by low cost, shorter life cycle and delivery time, higher quality and a high degree of competitiveness [5, 18, 19]. In the design and realization of modern systems, the choice of fabrication and assembly technologies almost ultimately defines the return on investment in terms of the operational cost and efficiency, the quality and the market value of the final products. Nevertheless, the intelligent provision that early translates products' characteristics into manufacturing capabilities can often be omitted. This necessitates an understanding of manufacturing parameters that can best reduce production cost and improve performance.

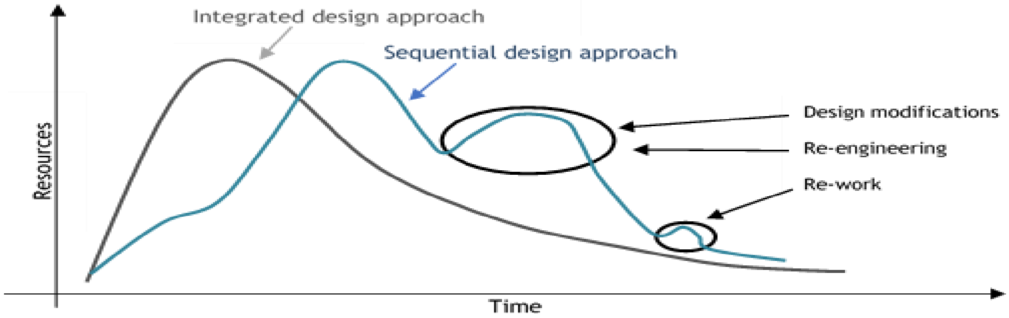

Figure 2: Integrated vs sequential design methods: modified from [20].

In a manufacturing context, the illustration in Figure 2, suggests that upstream design activities are tasked with enormous downstream manufacturing consequences (cost). In a sequential design, downstream repetitive and time-consuming iterations between the design and the manufacturing stages result in unforeseen changes to the initial design details, which eventually trade-off the customers' initial requirements and increase the cost of production. In concurrent engineering, efforts are made for quality to be instilled into products early in the development stages by focusing on the fabrication steps and the capability of the manufacturing technologies rather than the product's parts characteristics per se. In an assembly line, correcting inadequate ergonomic conditions would require subsequent capital to be invested to re-design the process, causing profits loss. With the bottom line on saving cost, reducing waste and attaining quick profitable returns; an early manufacturability analysis in new products development helps identify features and attributes that are susceptible to result in higher manufacturing cost [5].

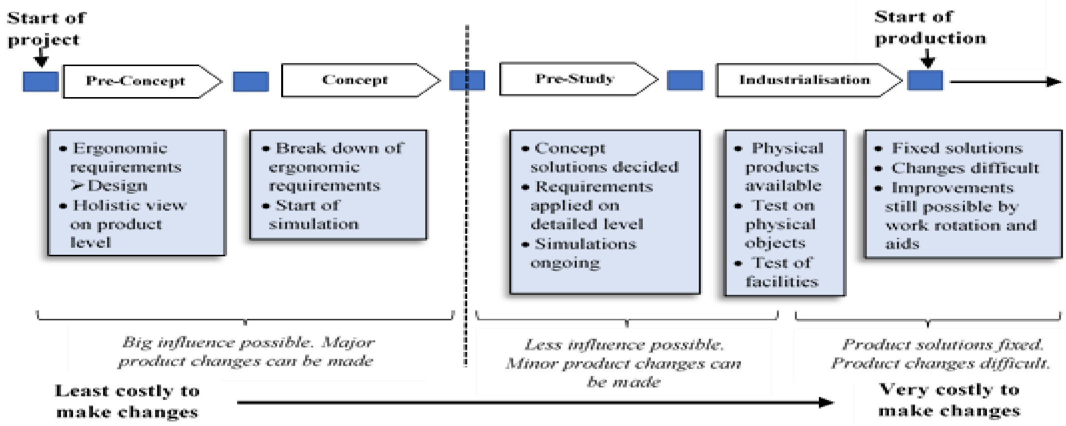

Figure 3: Ergonomics influence over project progression: adapted from [21].

In Figure 3, as developed by Falck et al. [21], it is a crucial requirement to establish ergonomics constraints and to apply an early holistic view at the product main assembly and the subcomponents assembly levels. They argue that; early in the development stages of new products and production systems, changes are less costly and easier to make than are late changes to the product, the work process, or the workplace design. Considering design as the fundamental step in the construction of a project or the manufacture of a product, design can also be described as a method for evaluating products or projects feasibility. Indeed, the selection of right solutions in industrial processes defines the degree of conformity of manufacturing operations and the end products.

There have been significant efforts over the past years to develop products and processes from a sustainable view point. Falck et al. [22] report that "managing complex products and installation conditions will result in distinct competitive advantages". Theko et al. [23] reported that in the *Industrial Engineering and Operation Management* fields, many companies are engaged in sustainable activities, by means of continuous improvement as a strategy to minimize operational cost. Most of the initiatives to attain sustainability in projects realization now give decision makers the tools to develop solutions that meet three dimensions of sustainability. These dimensions are defined by Clark et al. [24] as: social, economic and environmental. The influence of ergonomics has been well reported in productivity improvement efforts [25, 26]. According to Gladwin et al. [27], sustainability discusses and addresses present environmental degradation and violation of human rights such as occupational health. Improper occupational health and safety conditions contribute to operational set-backs in terms of medical claims and lost hour productivity. With the main industrial objective of achieving higher productivity quality targets, a question among academics and industry practitioners remains to find '*which tools can support the production design logistics in terms of joint consideration of process' operational capability and products' functionality for the efficiency of the downstream production system?*'. Products functionality and delivery reliability are critical factors for success in the manufacturing sector. Moreover, sustainable manufacturing requires lowering the utilization of resources along the product and the process design and the overall life-cycle.

3. ACADEMIC AND INDUSTRIAL RELEVANCE

3.1 Academic motivation

For improved functionality of manual systems, the ongoing research oriented towards users' integration is gaining more attention. Ergonomics studies can assist production design students to develop manually operated systems, analyse and optimize their associated features and mechanisms before their future commissioning. In this paper, an interpretation of prior empirical studies that have mainly described the relation between ergonomics and production quality is conducted to derive the proposed model. This paper falls alongside a primary research work on the effect of ergonomics on the performance of manual assembly operations. The objective in this paper is to suggest a descriptive tool that can assist production designers in 1) predict the operational complexity of a labour-intensive operation, and 2) provide characteristics for designing and integrating ergonomics for the overall productivity of a manufacturing system.

3.2 Industrial relevance

Some assembly operations cannot be automated or the cost for automating the system will fall higher beyond the market value of the product the system is to produce. It is somehow equivocal that much attention is now directed towards the improvement of manual operations only after the emergence of automation in manufacturing and the acknowledgement of the inherent operational limitations of robots. To a major extent, the dexterity of humans makes manual operations appropriate for fine manipulation and complex tasks. Although manual assembly has remained a preferred method of operations in several applications, the inconsistency in achieving repeatable processes and the lack of accuracy in manual operations continue to require increased levels of procedural standardization. The modelling of ergonomics features in designing manual operations can highlight the interactions amongst the main manufacturing features. These features related to manufacturing quality comprise: assembly tolerance, machining, maintenance efficiency, inspection and so forth. An ergonomics model can demonstrate some significant effects of ergonomics on the performance of manual operations for practical and industrial applications. Colledani et al. [12] point out that several studies have discussed the interactions among many parameters in manufacturing systems. They have reported that the complex dynamics of the interactions among these parameters require considerable engagement and discussion to be modelled and understood.

4. HUMAN FACTORS CONSIDERATION IN THE DESIGN AND OPERATIONAL PROCESS

4.1 Ergonomics influence on manufacturing productivity

Assembly methods can be grouped as: manual, semi-manual/automatic, flexible and dedicated. Nevertheless, all assembly methods have some elements of similarity. In manufacturing, Lotter [28] report that approximately 70% of operations performed are related to handling, insertion and joining of components. The remaining 30% are mainly comprised of in-process forming and inspection of processes. An assembly shop floor layout can significantly affect the efficiency of the subassemblies and main assembly sequences, as well as other activities related to maintenance and decommissioning [29]. The benefits of an appropriate ergonomics design include better production lead-time, reduced production cost and lowered human-machine faults. Some other benefits of ergonomics which cannot be easily quantified include reduced physical and mental load, improved motivation and better work satisfaction [30]. These factors indicate that ergonomics characteristics play an important role in the design for sustainable manufacturing operations.

4.2 Manual assembly design

Before commissioning a labour-intensive assembly operation, an assembly analysis should be considered at early conceptual stages and throughout the manoeuvre of the system. As defined by Boothroyd [2], an ease of assembly operation is achieved by providing assembly information at the conceptual stage of the design in a logical and organised fashion. In assembly, the execution process can be divided into two areas: Handling (acquiring, moving and aligning parts) and joining (insertion, mating of multiple parts). Although there has been an increase in robotic applications for manufacturing operations in the recent decades, the limitations of robots in terms of their access restrictions and their lack of ability for fine manipulation often does not justify the cost of their commissioning. Other difficulties associated with automation are listed by Bley et al. [31] as: lower investment, shorter product life cycle, decreasing lot size, higher flexibility of capability and so forth. For which, Alkan et al. [32] have observed that manual assembly is a preferred solution to support high product variety, low production systems, manufacturing in low wage areas and assembly operations that are 'too complex' to automate. Many authors have linked ergonomics in manufacturing with time studies [26, 33]. Some equations for manual assembly time efficiency from Boothroyd [2] design principles are expressed as follow:

$$E_m = \frac{3N_m}{T_m} \quad (1)$$

$$t_{pw} = 0.0125\,W + 0.011\,W_{th} \quad (2)$$

$$t_i = (-70\ln c + f\,(chamfers) + 3.7\,L + 0.75\,d\,)\,ms \quad (3)$$

- In (1), the overall manual assembly index is expressed by: E_m is the design efficiency for manual assembly; N_m is the minimum number of parts; T_m is the total assembly time.
- In (2), the effect of weight on handling time is expressed by: t_{pw} is the total adjustment to handling time; W is the weight of the part; *th* is the basic time for handling a light part.
- In (3), the insertion time is expressed by: t_i is the insertion time for plain cylindrical peg; c is the dimensionless diametric clearance; $f\,(chamfers)$ is the chamfers dimension; L is the insertion hole; d is the peg diameter.

4.3 Operators integration in the design of production systems

Considerable attention in the product development process is now directed towards processes that can familiarize the end users to the product. Recent arguments suggest that the operational processes highly determine the quality of the finished products. The degree of ergonomics constraints in industrial operations is associated with the rate of exposure to physical workload such as inappropriate working postures, lifting heavy weights, repetitive work sequence, as well as environmental factors such as noise, lighting and temperature. Human rely on perception, judgement and skills when performing manual operations. The implementation of industrial ergonomics looks at the performance of human workers in terms of physical and mental limitations. It is also referred to as an anthropocentric production system. In the design of such manufacturing systems, uncertainty and systems' constraints are recognized early. If for instance; operators' accessibility and visibility difficulties of the work area are increased, the process can then be redesigned to prevent the likelihood of a lowered downstream productivity. Therefore, the ability of human operators to perform effective manual tasks is determined by the degree to which the product and process design team integrate ergonomics standards in the development of the system, the product or the process.

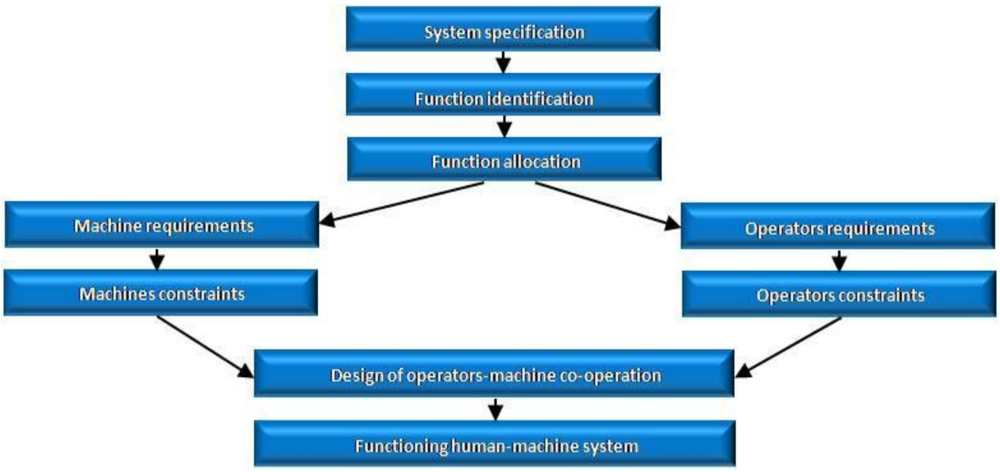

Figure 4: Man-machine system design: adapted from [34].

As illustrated by the '*Man-machine system design*' of Figure 4 [34], the design of a human centred production system is characterized by permitting a unification of planning '*how*' and doing '*what*'. Charles et al. [35] speak of healthy and socially interactive working environment by giving users the control of the work process and the technology as a means to ensure human competencies and safeguarding the quality of manual operations.

According to Jensen [36], a human centred design approach can be defined as a socio-technical design approach. In this approach, the development of new techniques is increasingly seen as a strategy to not only consider ergonomics from the perspectives of maintenance activities, but towards an integration into systems' design. However, ergonomics considerations are often traded-off when they are directly constrained by other highly ranked design requirements. In particular instances, ergonomics characteristics can be omitted when objective ergonomics data are missing, specifically during the design of new systems.

4.4 Human ability in customizing industrial systems

Since the introduction of automation in manufacturing, there still exists some challenges for which manual assembly has remained the preferred mode of assembly methods. The current varying consumers' habits and market conditions require manufacturing organizations to continuously look for appropriate processes that can promptly configure their production systems to meet their changing production targets. Koren & Ulsoy [37] have recognized 'customized flexibility' among the core characteristics of a reconfigurable manufacturing system. In achieving customized flexibility of systems, the ability of humans to quickly execute multiple process variants in manufacturing operations is often neglected. This in favour of artificial intelligence, digital manufacturing and automation components, as the main drivers of the fourth industrial revolution. Yet a manual operation is still considered a flexible support for non-repetitive operations, mixed models assembly and processes which necessitate fine manipulation. Pressure from rapidly changing customers' needs and markets conditions, the cost implication of automation and the quick realization of system customization by manual work are factors, which continue to make manual assembly a preferred mode of operations for certain production segments. This requires today's manufacturing companies to reconsider the traditional manual modes of production to meet their fast-changing production targets.

For responsive mining operations; Ramatsetse et al. [38] have proposed the reconfigurable vibrating screen (RVS) as a flexible beneficiation machine. Through an adjustment or geometric transformation of the screen structure, the RVS built-in option makes it capable of screening varying flow rate of mineral based on the customers' demands. An early analysis and search for solutions allow the process designers of reconfigurable production systems such as the RVS to identify the information required to quantify the key characteristics of the product and its associated operating features. In concurrent engineering, the initial step in developing the reconfigurable mechanism of a reconfigurable system and its associated realization process would first identifies the elements around which the reconfiguration process is centered. The following step translates the theoretical reconfiguration process into feasible engineering terms (functional requirements/FRs & design parameters/DPs) to which the product is to satisfy. Suh [39] defines Axiomatic Design as the making of synthesized solutions in the form of products and processes that suit apparent needs through zigzagging between FRs and DPs from the main level to the lower levels of the product and the process decomposition domains, as illustrated in Figure 5.

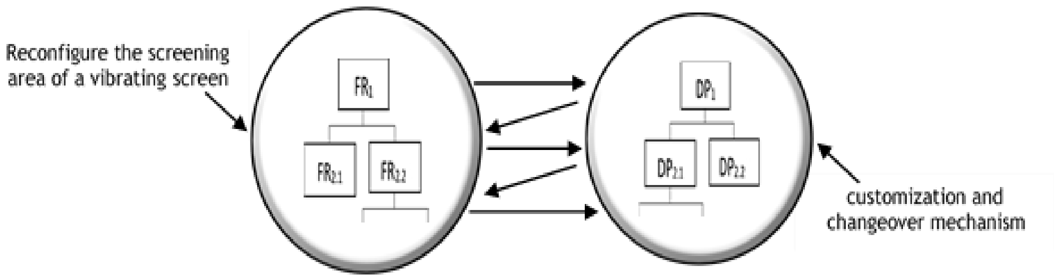

Figure 5: Domains integration in concurrent engineering for a RVS: adapted from [39].

For reconfiguring a production system like a RVS, an early iteration amongst the different design domains may give many suggestions to the product design team. As seen in Figure 5, at the first level of system's iteration, the initial FR_1 command could speak to a 'changeover in production set-up', to which the corresponding DP_1 could be 'how should the operations be performed?'. At the second level of the system decomposition, $FR_{2.1}$ and $FR_{2.2}$ could be 'expand in either width, breath or both' and 'increase screening meshes' respectively. To which the associated $DP_{2.1}$ and $DP_{2.2}$ could be 'what fixtures are needed to assist the operators in performing the command?' and 'which sequences must be followed to execute the required function?' respectively. In the instance of non-repetitive single-station reconfiguration operations for a RVS, the choice of manual customization methods is envisaged to be an efficient method. Good training may enable human operators to quickly identify the system's characteristics and make manual operation a technologically compliant answer to satisfy the various screening configurations and changeover needs.

5. DISCUSSION ON THE PROPOSED MODEL

While the interactions among the multiple variables that make-up for sustainable manufacturing are complex and difficult to manage, an ergonomics relationship in people-process-products can help model and reduce the difficulty of any labour-intensive activity in a manufacturing process. [25] presented a human factors triangle model which comprises health/safety, productivity and comfort at its three points. Figure 6, summarises our proposed model of an ergonomics centered system realization process. Our system's life-cycle model includes inception, implementation and production. The activities in the model can identify and help reduce many previously unknown trade-offs. In our model, there is some level of correlation in people designing safe and comfortable processes which would produce output products that meet the overall efficiency of the process.

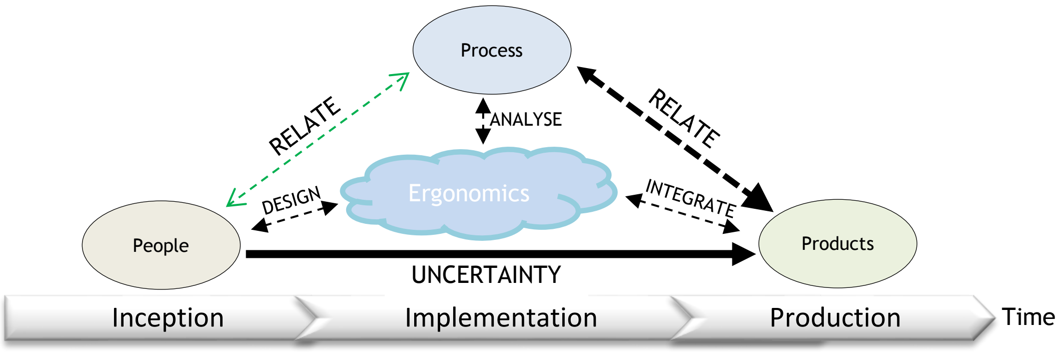

Figure 6: Ergonomics interaction model in systems' design.

In the model, the *design ergonomics* takes place in the inception phase. At this phase of interactions in the system, human concurrently generate the need (what) and its process realization (how). The Left-Right arrow between people and process suggests that iterations and design modifications can be easily done as the system's development is still in its early stage. This double-sided arrow between people and processes reflects the early iterations necessary to satisfy the idea in terms of '*how*' can the system be constructed? At this level of system inception, provisions for downstream design modifications should be emphasized as major design changes can be made on the process designed to make the product.

The next step is the *analyze ergonomics* specifications stage: here process implementation takes place. At this phase, there are two dimensions of system iterations, one across people-process and another across process-product. However, the iterations across process and product becomes increasingly unidirectional as the project progresses in time. As initial design requirements are applied on detail levels, only minor changes can now be made. It should be noted that the thickness of the arrows reflects the project rigidity in terms of time progression, and the dashed arrows indicate the level of flexibility of the system design.

As the project matures to the production phase, we reach the level where prior ergonomics analysis and evaluation need to be integrated into the end-product or output of the system. We are now at the *integrate ergonomics* phase. In this phase, the resulting single-sided continuous arrow between the people and the process means that it is highly impractical to reverse the design decisions towards the final product. This rigidity reflects the progression in the development of the system and its materialization into physical structures. To redesign the process to suit unforeseen product characteristics and constraints is now costlier. As in figure 2, as the idea is physically translated into realization in terms of processes commissioning, downstream design changes increase the cost of production. When omitting process constraints, the unidirectional arrow between people and product signifies an irreversible path. In this direct or sequential path to product realization, there is a high level of uncertainty and increased risk of products not meeting the necessitated level of manufacturing feasibility via assembly, with specific reference to manual operations.

6. CONCLUSION

There continues to be instances where products are manufactured and their specifications are only written after the design is completed and put to the test. Such activities of the traditional engineering method may not be an accurate reflection of the users and customers' needs in new products or processes. This requires substantial design changes to suit the initial intend of the designers. It is thus, important to analyze and evaluate the capability of the production processes that can guarantee the long-term sustainability of the operations. Ergonomics constraints are not just related to complex systems, yet there exists a strong correlation between ergonomics and production quality. Complex manual operations usually mean ergonomics difficulties and increased possibility for end process defects. The lack of integration between design and manufacture may lead to lower products' life cycle efficiency, because of an improper translation of users' requirements. This paper presented the merits for ergonomics analysis to be initiated at an early stage of the development of systems for an improved life-cycle operational efficiency. Ergonomics study and design do not necessarily fill the production quality gap, they instead open further boundaries by addressing conceptually weak labour-intensive operations and providing opportunities to improve their potential to be more robust in the use environment. Future engagements on ergonomics models should discuss the end-of-life management of production systems in terms of systems decommissioning or de-manufacture and recycling.

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