The effects of waste management on profitability in a flexible packaging company

Zakhele Myeza

Supervisor: Ms. B.P. Sunjka

University of the Witswatersrand

Email: bernadette.sunjka@wits.ac.za

A research report submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Master of Science in Engineering.

Johannesburg 2017

DECLARATION

I declare that this Research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

…………………………………………………………………………………

Zakhele Myeza

Signed on ………...... day of ………….............................….., 20………

ABSTRACT

Waste results in material loss and cascades to production processes, affecting a company's profitability. This research sought to answer to what extent the implementation of a solid waste management protocol in a flexible packaging company (FPC) improves profitability.

The research focused on reducing waste from the gravure printing process, which was analysed using a Lean Six Sigma tool, DMAIC, that has been shown to increase productivity, reduce cost, reduce defects and standardise operations. Processes were implemented to ensure that quality substrate was input at the correct levels and transformed efficiently into sellable product. Additionally, new protocols were employed to control and manage waste, further increasing the FPC's savings.

These modifications reduced waiting down time by 78%, rework by 53%, and job-specific waste by 6%, which translated into a 17% improvement in profit on average. Thus, the research effectively demonstrates that a waste management protocol increases the profitability of a FPC.

DEDICATION

I'd like to dedicate this research to my grandmother; she was a wise, strong and tough woman. She always believed in me and taught me many lessons and principles, which I never followed as a youngster, but today I live by. She never lived to see my accomplishments and the man I have become, but I know she would be proud. I would also like to dedicate this to my family, Zakes (Dad), Phiwe (Mom), Nana (Sister) and Ayanda (Sister). Your support and sacrifice for me and each other is the motivation I used to achieve this. Thank you.

ACKNOWLEDGEMENTS

I would like to thank the following people and organisations for their contribution to my research:

- Bernadette Sunjka, my supervisor, for all the assistance and academic guidance during the research. The in-depth reviews you provided motivated me to ask the right questions and critically analyse any information obtained through this investigation.
- My employer for the financial assistance and time off to conduct my research and write up my findings.
- Fiona and Kirsty, for your assistance in reviewing the different revisions of my investigation.
- Nicole, Kim, Brittany, Rebecca and Nana for their assistance in adding an outsider's perspective to my investigation, questioning my motivations and explanations, and proofing my work.
- The case company for permission to go through confidential documents and for access to employees and operations.
- All the respondents to my questionnaires and interviews for freely giving their time and assistance.

Table of Contents

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

Table **Page**

NOMENCLATURE - ACRONYMS

BOPP	Biaxially Oriented Polypropylene
BRC	British Retail Consortium
C&D	Construction and Demolition
CE	Concurrent Engineering
COC	Certificate of Compliance
CTQ	Critical to Quality
DMAIC	Define, Measure, Analyse, Improve, Control
DPMO	Defects Per Million Opportunities
EPHA	Environmental Public Health Act
ERP	Enterprise Resource Planning
FEFO	First Expired First Out
FIFO	First In First Out
FMEA	Failure Mode Effect and Analysis
FMECA	Failure Mode Effects and Critical Analysis
FPC	Flexible Packaging Company
GM	General Manager
GSM	Grams per Square Metre
JIT	Just in Time
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory

Lm	Linear metres
MSPC	Multivariate Statistical Process Control
OEE	Overall Equipment Effectiveness
OEM	Original Equipment Manufacturer
OTIF	On Time in Full
P&L	Profit and Loss
PDCA	Plan Do Check Act
PET	Polyethylene terephthalate
PO	Purchase Order
Poly	Polypropylene
PP	Polypropylene
PVC	Polyvinyl Chloride
QC	Quality Controller
R&D	Research and Development
ROI	Return on Investment
RPM	Revolutions per Minute
RTS	Return to Stores
S.M.A.R.T.	Specific, Measurable, Achievable, Relevant, Time bound
SIPOC	Suppliers, Inputs, Process, Outputs, Customers
SIT	Systematic Inventive Thinking
SMED	Single Minutes Exchange of Die
SOP	Standard Operating Procedure

SPC	Statistical Process Control
SWM	Solid Waste Management
TPM	Total Productive Maintenance
TPS	Toyota Production System
TRIZ	Theory of Inventive Problem Solving
TQM	Total Quality Management
VOB	Voice of the Business
VOC	Voice of the Customer
VOP	Voice of the Process
VSM	Value Stream Map
WIP	Work-in-Progress

1. CHAPTER 1

INTRODUCTION

Flexible packing is a fast growing sector, growing by 6.2% annually and projected to be worth $37.3 billion globally by 2018. [1] Increasingly, products are shifting from rigid packaging to flexible packaging. This is due to changes in consumer behaviour–such as the rate at which products are consumed, which is driven by availability of excess funds– technological advancements– such as advancements in materials– and the practicality that flexible packaging provides– such as ease of storage and transportation. [2] As the global market expands, competition is created, resulting in pressure to produce at a lower cost. In the production of flexible packaging, there are various non-value adding processes, which affect profitability. In Lean principles, these processes are identified as waste. The waste is categorised into eight types: defects, over production, waiting, transportation, inventory, motion, over processing and underutilised talent. [3] For the purpose of this research study, two main categories of waste are defined below:

- Process waste: waste that indirectly affects the quality of the final product. In total, seven of the eight identified Lean wastes are classified as process wastes. The process wastes will be referred to as 'Muda' for the remainder of this research report. Muda is a Japanese word meaning 'waste' and is a key concept of the Toyota Production System (TPS). [4] Muda, as Taiichi Ohno describes in TPS, refers to the seven Lean wastes: namely defects, over production, waiting, transportation, inventory, motion and over processing. [4]
- Production waste: any form of raw material which could not be converted into a sellable finished product as intended i.e. damaged substrate, defective material, etc. This is physical or solid waste and will be referred to as 'waste' for the remainder of this research report.

Both process and production waste result in a loss of profit for the company. They decrease efficiencies and utilisation, thus limiting the productivity of the plant. This has a knock-on effect on the quality of the product, which ultimately gets transferred to the customer. The true cost of both waste types, their origins, how they influence each other and the effect they have on companies, is better understood through waste management. Waste management encompasses all of the actions required to manage waste from creation to disposal. This includes, but is not limited to, the collection, treatment, transportation, prevention, monitoring and disposal of waste. [5]

There are two main streams of waste management namely; liquid and solid. Within solid waste types, there is a further distinction between hazardous and non-hazardous. [6] The research focuses on non-hazardous solid waste produced in the industrial sector. This classification reflects the type of materials that are used in the production of flexible packaging. A flexible packaging company (FPC) is studied to see how it deals with profitability pressures and waste management. The case company is introduced in the following section.

1.1. Case Company

The case company requested anonymity due to the competitiveness of the industry and the sensitive nature of some of the research data. The case company is a leader in design, development and the manufacturing of flexible packaging, with a market value of $35 million. [7] The company has a global presence. Its head office is located in South Africa, and it has additional branches in Kenya, Zimbabwe, Mauritius, Malawi and Nigeria. These are all strategic placements to service the fast growing African markets. The company supplies flexible packaging to the food, beverage, pharmaceutical and confectionery markets. The company is accredited by the British Retail Consortium (BRC), which is a standard for food safety and quality. [8] The specific branch studied is in South Africa and has over 300 employees. Printing, lamination and slitting are the services offered at the branch. Finished goods can also be pouched at their sister company. Their average monthly production output in 2014 was 500 tonnes. The annual turnover for the 2014 financial year was R1.5 billion. [7]

1.2. Problem Statement

The case company was not realising the theoretical profit margins estimated in the quotes to the customers per job. Internal losses increased the selling price of the finished product, but these losses could not be recovered from customers. Purchasing agreements and selling prices were reviewed annually with customers. Changing these agreed upon prices would put pressure on customer relationships and force customers to look for stability in another supplier. The case company realised that there were internal problems and these included:

- increased raw material usage;
- long lead times;

- reduced production efficiencies;
- over- or short-produced orders being delivered;
- defective and inconsistent product quality being delivered to customers;
- a reduction in cash flow;
- an increase in labour expenditure through overtime;
- reduced efficiency in the customers' production facilities due to downtime caused by the delivery of defective products;
- the delivery of defective packaging to customers' client bases resulting in customers receiving rejections. These rejections further affect the customers' profitability. And since the root of the problem is the FPC, the FPC would then be required to compensate for the losses experienced by its customers downstream.

The case company has tried implementing solutions through trial and error. These solutions include:

- employing staff to increase in-process checks;
- including reworking processes to ensure product quality;
- changing input raw materials;
- reducing machine speeds to compensate for quality defects.

The solutions implemented successfully increased product quality, but at an increased cost for the case company and an increase in lead times. This was the price the company paid to repair and maintain good customer relations. Thus far, no solution has been implemented that has presented a sustainable option for the case company. Therefore, an investigation was required to determine where the biggest opportunity was for the case company to realise profit.

The unit of measure for a customer order is a kilogram. In order to get the rate at which each kilogram is sold, the case company considers the raw material required and the time it will take to produce the required product. The time incorporates fixed and variable expenses. If the variable expenses can be isolated for a single job, the behaviour of the variable expenses with regard to increases can be obtained. The base case considered was where the variable expenses were within the expectable range. Refer to Table 1 for a breakdown of how the selling price is reached for a single job.

Table 1: Pricing composition of a single job [7]

Expense	Composition of selling price
Fixed Cost	R 4.80
Direct Materials	R 28.00
Staff wages	R 12.00
Utilities – based on drying requirements (Gas/paraffin/diesel/electricity)	R 1.60
Machine time	R 18.00
Consumables	R 1.10
Waste	R 2.40
Storage	R 0.10
Profit	R 12.00
Total (selling price/kg)	**R 80.00**

Due to the nature of flexible packaging, a certain percentage of waste is provided for, which the customer agrees to pay. The selling price is constant as this is contractually agreed upon with the customer prior to production. Removing all complexities of production and assuming a directly proportional relationship between output and cost, each variable expense can be gradually increased by a certain percentage to monitor its behaviour and effect on profitability. Figure 1 displays how variable expenses behave as a result of their increase.

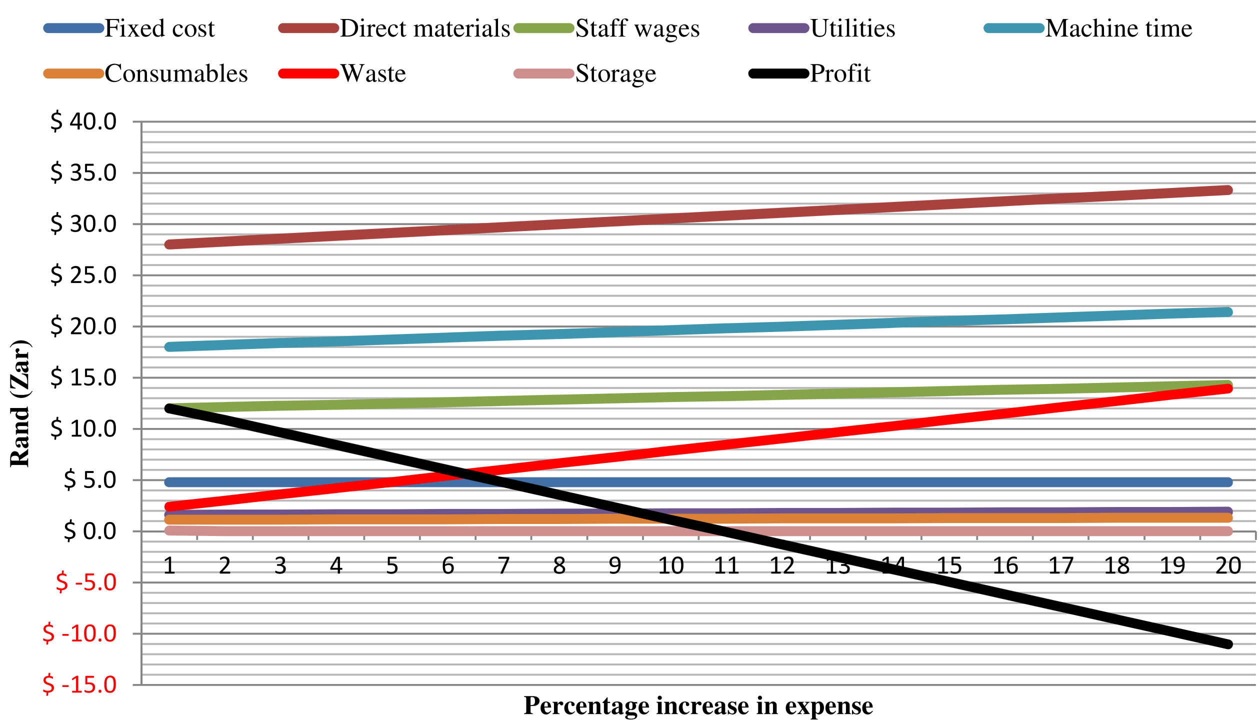


Figure 1: Graph showing changes in variable expenses with increased percentage variation [9]

From Figure 1, it is clear that the most financially demanding variable expenses, in order of severity, are direct material cost, machine time and staff wages. Initially as these expenses increase, the sum of their cost equals the greatest contribution to the decrease in profit. It is for this reason that most companies choose a quick fix. Examples of quick fixes could be finding cheaper alternative material or reducing the staff head count. While quick fixes have the biggest financial impact, based on the trends from Figure 1, they may not be the most sustainable option without an in-depth investigation and analysis. There is an imminent risk of compromising quality and creating labour unrest, which can result from saving on direct material or reduction in wage overheads. If all expenses' slopes (gradient of each series) are considered, the expenses with the biggest change per percentage increase are:

- waste (70c/kg);
- direct material (22c/kg);
- machine time (20c/kg).

The above values detail the impact of each expense on the selling price of the finished product. Thus, waste has the biggest impact on the selling price. As this increase cannot be passed to the customer, all excess cost is absorbed by the manufacturer. Excess waste is the sum of all the other variable expenses. A defective product goes through all the value adding processes using direct material, machine time, utilities, etc. and yields no profit. The finished product produced is what the customers pay for. Figure 2 illustrates the composition of the produced product. The weight composition is described by the percentages. The split further enforces importance of the substrate to the profitability of the company.

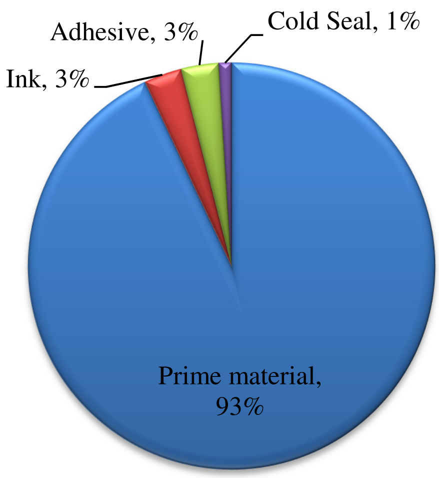


Figure 2: Composition of finished product [9]

The simplified analysis done assumes proportionality within all expenses in the manufacturing process, but in reality this is not true. It is for this reason that waste is investigated above all other possible impacts on profit. In order to understand the true cost of waste and gain an understanding of its source and true effects on profitability within flexible packaging manufacturing, research in waste management is required. The company's requirement for profitability has led to the critical research question in Section 1.3.

1.3. Critical Research Question

To what extent does the implementation of a solid waste management protocol in a FPC improve profitability?

1.4. Research Objectives

The primary objective of the research was to determine if the implementation of a solid waste management protocol at the FPC had an effect on the profitability of the company. This was achieved through the following specific objectives:

- determining the magnitude of loss or gain in profitability due to the current state of waste management;
- implementing specific solid waste management protocols;
- evaluating the impact of the protocols on profitability.

1.5. Limitations

The research took place in a FPC in a developing country. Some of the challenges that were documented would not be experienced ordinarily in a developed country. Therefore, the analysis and solutions are specific to the environment. The flexible packaging market is still growing in South Africa and jobs are scarce. The employees might meet the management of waste with resistance, as this was not previously done at the company and the outcomes might clearly expose under-performance or incompetence. Operator skill and competency play a large role in the creation and eradication of waste. The implementation of the systems and the results obtained could lead to unfavourable outcomes for individuals, but result in an improvement for the company. The success of the system development depends heavily on getting operators' buy-in whilst ensuring their job security. The most favourable outcome is full co-operation. The other limiting factor is cost. Due to the financial situation the FPC is in, supporting some of the Lean Six Sigma initiatives might be put on hold until the following financial year. This could impact greatly on the expected results as well as the investigation timeline.

1.6. Scope of Work

The scope of work was limited to within the flexible packaging company. Figure 3 shows a high level process flow for a flexible packaging company.

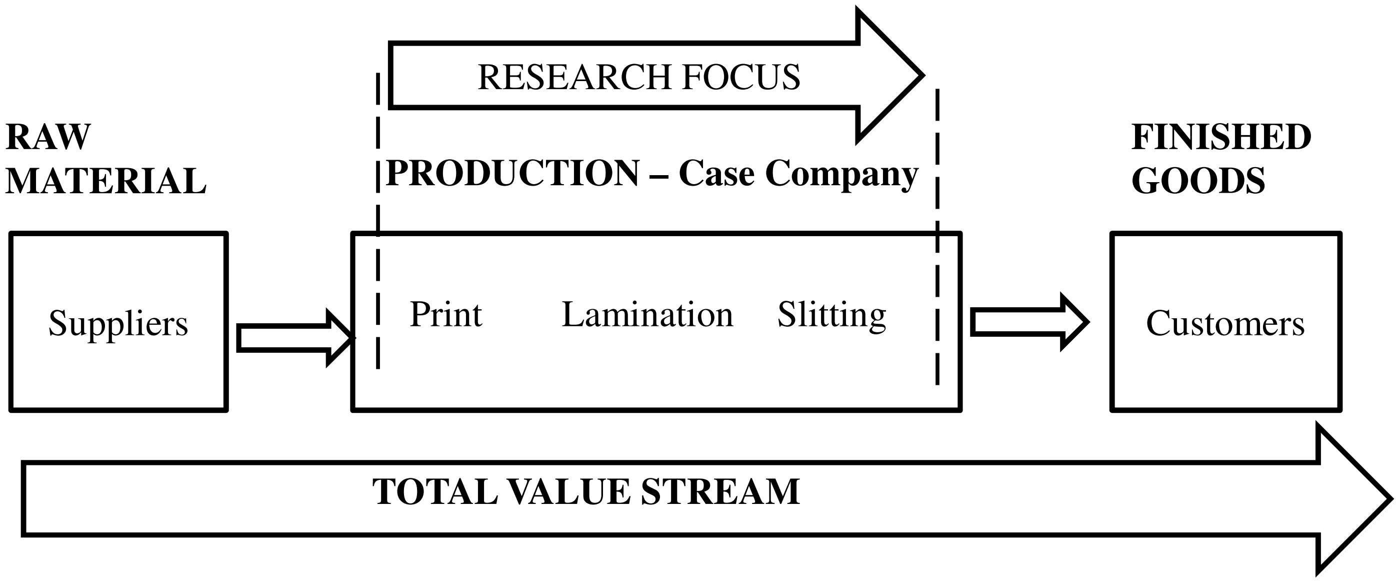


Figure 3: Research focus (created by author)

Waste was considered from the receipt of the purchased raw material, through the printing, lamination and slitting processes, and to the cataloguing and disposal from the manufacturing facility. The main process analysed was the printing process, namely the gravure printing process, as it potentially had the biggest opportunity for financial gain or loss. The lamination and slitting processes were not considered in great detail but they are included in certain analysis as printing waste affected their processes.

1.7. Outline of Chapters –

The structure of this investigation was focused on the problem statement (Section 1.2) and ultimately provided an answer to the research question (Section 1.3), These are provided in Chapter 1.

Chapter 2 contains a literature review covering the topics of waste management, Lean manufacturing, Six Sigma and Lean Six Sigma. Reference to previous cases and theses are also included to acknowledge similar investigations and identify where there was a gap in the literature.

Chapter 3 discusses the research methodology used to gather and analyse the data. It also covers the purpose of the data gathered and its validity and reliability.

Chapter 4 introduces the case company and provides a more focused outline of the processes that contribute to the problem statement. Measurable factors that provide indications of the success of the investigation are established, and their initial conditions are recorded. Further problems that influence the problem statement are discussed.

Chapter 5 provides a breakdown of how the problem statement is solved. It is here where the Lean Six Sigma tools are utilised. The solutions implemented, data analysed and results of each are discussed.

Chapter 6 contains the results and data analysis of the initial conditions that were introduced in Chapter 4. These results were obtained after the investigation and implementation.

Chapter 7 discusses the key performance indicators and how they relate to the problem statement. The successes and failures of the investigation are critiqued.

Chapter 8 concludes the investigation; an answer to the critical review question is obtained and recommendations for further research are provided.

1.8. Ethics Clearance

Ethics clearance is obtained through the University of the Witwatersrand, School of Mechanical, Industrial and Aeronautical Engineering Ethics Committee. The ethics clearance number is MIAEC 049/15. Refer to Appendix A for additional information.

2. CHAPTER 2

LITERATURE REVIEW

The purpose of this literature review is to: introduce the manufacturing process classification of the case company, discuss similar research that has already been conducted and the tools or methodologies that exist and can be utilised in the research, identify gaps that exist in the literature for the topic under investigation, motivate the direction taken in the research and elucidate the contribution that the research aims to make in manufacturing profitability and waste management. The review begins with the classification of the type of production process practised at a flexible packaging manufacturer. A background on flexible packaging is provided, which then looks more closely at the printing process. Profitability in manufacturing is discussed, which then provides the reasoning behind investigating waste. An exploration into waste management is provided. The tools available to achieve waste management are reviewed. The literature review concludes with a justification of the tools chosen to achieve solid waste management.

2.1. Manufacturing Type

The manufacturing type describes the processes employed by the manufacturer to produce their required product. Identifying the manufacturing type of the case company provided the necessary background for understanding the production processes when they were detailed. Certain characteristics of the manufacturing type allow for added benefits or provide limitations. These benefits or limitations guide problem solving due to the applicability of solutions. A process, as defined by Harrington, [10] is any activity or group of activities that take an input, add value and provide an output to an internal or external customer. [10] The process type is largely dictated by how raw material is transformed into a finished product. The raw material goes through a variety of value-adding processes during the transformation. The linking of these processes is classified into three main categories: job, batch and flow production. [11] The distinguishing features of each category were reviewed and the case company classified in the summary in Section 2.1.4

2.1.1. Job Production

Job production is used for the production of single, unique or one-off products. To be classified as job production, each individual product must be completed before the next product is started. [12] This production method tends to involve specialised tasks. An example of such is the production of high-end wristwatches. [12]

Characteristics

Job production is characterised by:

- a large number of general purpose machines;
- a large inventory of parts, materials and tools;
- a large number of employees with different tasks;
- flexibility in the production process as well the financing. [13]

Table 2: Pros and cons for job production [11], [12], [13]

Pros	Cons
Ability to customise products for customers even during the production process.	Highly skilled work forces required. Can be labour intensive.
Increased customer satisfaction due to uniqueness of product.	Long lead times limit output volume.
	Product cost can be high due to nature of production (machines set-up for specific job) and expense of highly skilled labour.

2.1.2. Batch Production

Batch production is the production of a limited quantity of identical products. To be classified as batch production, a group of products or parts must pass through a single process or operation together before being moved to the next process or operation in the production life cycle. [12] Examples of batch production are the production of different types of baked goods, sweets or medicines.

Characteristics

Batch production is characterised by:

- a more functional layout, due to the same types of machines being grouped together;
- one process or operation being performed on a whole batch before the batch is moved onto the next process or operation;
- the repetitive nature of the work;
- the type of usage, as it is generally chosen for seasonal production or where a greater variety of known goods is required. [13]

Table 3: Pros and cons for batch production [11] [13] [14]

Pros	Cons
Can take advantage of bulk purchases of raw material thus lowering material cost.	Usually have high set-up times between batches thus limiting flexibility.
Allows for machines to be more optimally used as there are fewer changes.	Productivity is gained through larger batch sizes.
Allows for workers to focus on a certain skill. Due to the repetition, workers become better at their task and thus can produce more.	Requires very good planning to respond quickly to customer orders.
Products produced are generally of a discrete nature making it easy to isolate defective batches or products	Can reduce cash flow and increase storage costs through the high levels of work in progress.
	A defective product in a batch could result in the whole batch being waste product. Money and time are then both wasted.

2.1.3. Flow Production

Flow production, also known as mass production, is used for the production of large volumes of standardised products. To be classified as flow production, products move between processes or operations as soon as they are ready, without waiting for other products. [12] This means the product is continuously in motion through the production process until completion. [11] Examples of industries using flow production are car manufacturing, bottling plants or sugar refineries.

Characteristics

Flow production is characterised by:

- production done in anticipation of continuous demand;
- the work flow, equipment and materials all being standardised;
- high production volume;
- machine set-ups remaining unchanged for long periods;
- the product flowing from one operation to the next until the whole process is complete;
- the operation generally running 24/7 and therefore requiring shift work;
- faults during production requiring immediate attention otherwise, the whole production process is stopped. [13]

Table 4: Pros and cons for flow production [11] [13] [14]

Pros	Cons
Can take advantage of bulk purchases of raw material thus lowering material cost.	Capital intensive due to machinery (automation, high technology and sometimes uses robotics).
Reduced direct labour content but more skilled labour required as process is more complex and highly automated.	Production is inflexible. Therefore, products cannot easily be customised for individual customer requirements.
Minimal physical handling of product therefore less probability of damage.	Switching off and starting up is usually costly and results in product variations.
Product quality tends to be consistent due to automation of processes.	Cost of the skilled labour required.
Low unit cost of product can be achieved.	Expensive to purchase tools and replace machine parts. The whole production process is stopped for this activity.
Infrequent maintenance shut downs.	The cost of undetected defective product that passes through the production process is very high.

2.1.4. Summary of Manufacturing Type

Flexible packaging is typically batch production. It contains all the characteristics of a batch production process. Thus at a macro level all the characteristics mentioned in Section 2.1.2 are shared. What makes flexible packaging unique is that the product produced is continuous, not discrete. Therefore, flexible packaging cannot share some of the advantages of a discrete manufacturing system. Examples of these advantages are easily identifying defects, isolating and removing defective product within the production process, isolating and removing or correcting defective processes, singling out one unit of finished product and stopping and starting the production process.

At a micro level (within each process individually, specifically printing and lamination) flexible packaging has characteristics of flow production. However, some characteristics are not shared, which are listed below.

- Materials are not standardised. There are hundreds of different materials. Materials are dictated by customer product application. Each different thickness, width and material type requires a different setting and behaves differently on the machine.
- Consistent quality is achievable, but it is not due to automation. The operator is very hands on in compensating for variations in the process. These variations can be due

to: atmospheric conditions, material quality, solvent blends and the misalignment of rollers, among others.

- Machine set-ups do not remain unchanged for long periods. In printing and lamination, machine set-ups are more frequent.
- Infrequent maintenance shutdown is not possible. Flexible packaging machinery requires constant cleaning. The machines themselves have many rotating parts that are subject to temperature extremes, vibrations and corrosive chemicals.

As such, it can be said that flexible packaging manufacturing is batch production with flow production properties. This classification will aid in understanding the flexible packaging manufacturing process, the problems experienced and the problem solving techniques that can be adopted. To a large degree, the classification defines which tools and techniques can be implemented during problem solving. With this understanding, a background in flexible packaging and its processes is provided in Section 2.2.

2.2. Flexible Packaging Background

Rigid packaging is packaging made from paper, corrugated fibre or paper board. This can be seen in stores as boxes, cartons or trays. [14] The first commercial corrugated boxes were made in England in 1817. From 1850, corrugated boxes were the preferred packaging option, which replaced handmade paper sacks or wooden crates. [15] The invention of commercially usable rigid packaging came in the form of cardboard cartons in 1870. Cardboard cartons continued to be the choice packaging container well into the 20th century. [15]

Paper is thought to be the first "flexible packaging" as used by the Chinese in the first or second century to wrap food. [16] Flexible packaging today is made from plastic film and/or foil and paper laminates. The packaging functions as both protection from external elements and as the container housing the product. [14] The development of plastic films and resulting packaging technology, as outlined below, has guided the development of flexible packaging.

- 1927 – Polyvinyl Chloride (PVC). Popular (at the time) due to its heat seal, barrier and clinging properties. This plastic was commonly used in meat packaging. PVC is used less today due to its environmental impact.
- 1933 – Polyethylene (PE). This plastic was further developed into three variants: high, low and linear low density. PE is flexible, durable, has a high moisture barrier

and has the ability to seal to itself without added adhesive. PE is the most commonly used film in flexible packaging.

- 1941 – Polyethylene Terephthalate (PET). PET has high temperature applicability and high oxygen and carbon dioxide barrier properties. These properties have increased the use of this plastic in the medical and food industries.
- 1950 – Polypropylene (PP). PP has low moisture absorption and permeability and a high resistance to chemicals. PP is used in the pharmaceuticals industry and in applications that require moisture proofing and/or fat resistance. [15], [17]

The film characteristics resulted in more applications for flexible packaging. Flexible packaging can be seen in growing quantities and is replacing rigid packaging in many instances. An example of this is refill packaging. [14] The final product is seen by the consumer in stores. The flexible packaging value stream is presented in the subsequent section. The value stream presented, while describing the flexible packaging value stream in general, may contain vast differences based on the internal processes of that manufacturer. Some technologies and processes can be outsourced for more focused specialisation on core processes.

2.2.1. Flexible Packaging Value Chain

Flexible packaging manufacturing follows the value chain shown in Figure 4.

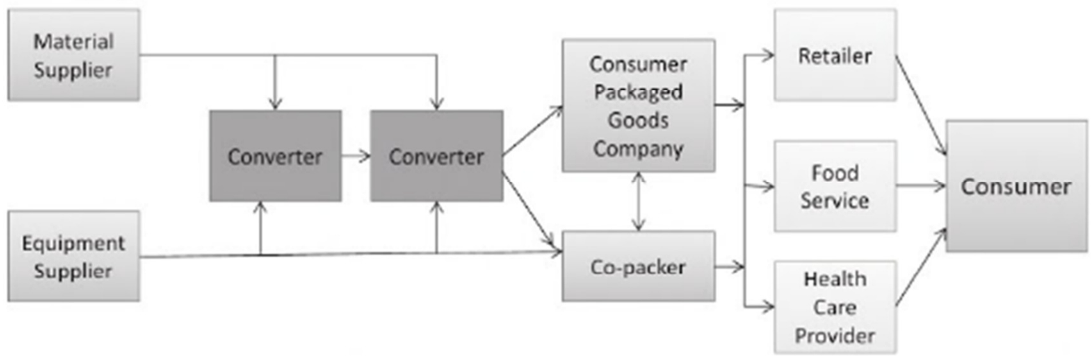


Figure 4: Flexible packaging value chain [18]

The material supplier can be a single entity or a variety of different entities whose function is to supply the materials required by the converters. The material supplier converts raw material such as PP, PE, PET pellets, paper and aluminium foil into wound roll. The raw material will be called substrate from here on as this includes all the various forms of film, paper and laminates. The material supplier is also responsible for providing all the wet ingredients (inks, adhesives, solvents). Each of these materials has their own value chain. [18] The equipment supplier supplies the required machinery and technology used by the converters. That technology will be reviewed later in this section. The material in raw form is provided to converters. Converter one will provide the required artwork to the substrate and output a wound roll as a finished product. [18] Converter two will provide any additional modifications to the wound roll (for example, pouching or tubing) required by the packaging process. The packaging process provides the content of the flexible packaging before it is shipped to various industries (food and beverage, industrial, health care etc.) to be made available to the consumer. [18]

The key process functions of any Converter one-type manufacturer are printing, lamination and slitting. These core functions make up the flexible packaging company (FPC) that is researched. A typical process map of a cascaded Converter one and two configuration is represented in Figure 5.

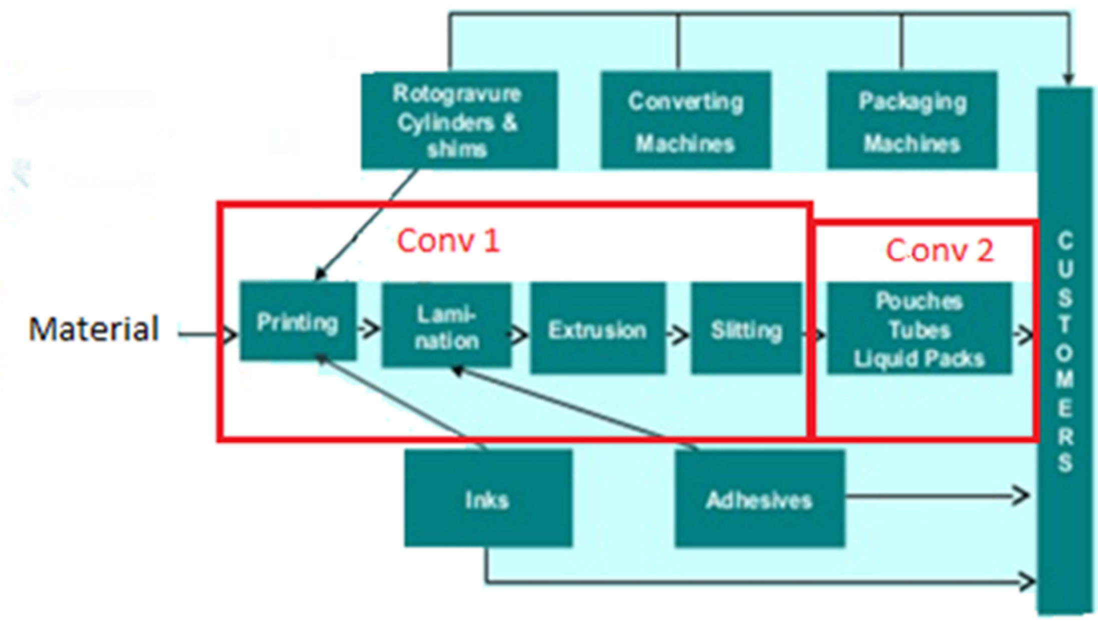


Figure 5: Converter process map. [19] **Modified by author to highlight functional areas**

On receipt of an order, the raw material is delivered to printing. Printing is the process where the artwork is applied to the substrate. Depending on the order requirements, the substrate is then taken to lamination and/or cold seal. Lamination is the process where a secondary and/or tertiary substrate is laminated to the primary printed substrate. The lamination process is either done with solvent or solvent-free adhesives (also known as dry lamination), or extrusion (the use of a molten polymer for adhesion). Lamination is done such that substrates with different characteristics may be bonded. In some cases, the same flexible film is laminated to make it thicker to increase the strength. [20]

The cold seal process is when a wet adhesive is applied to the substrate and remains uncured or “dry” unless exposed to temperatures above room temperature. [20] In this state, the dry adhesive does not bond to anything, and thus, the substrate can be rewound. Cold seal is used in many applications where the flexible packaging needs to be bonded together to hold the contents, for example: chocolate wrappers, condiment sachets, chip packets and the like. [21] All orders go through slitting, where the substrate is slit into wound reels. The reel specification (width, weight, core size) is provided by the customer, as these reels will be loaded into their machines to be filled with product.

The greatest value add to the customer can be gained by improvements in this converter process. In order to fully understand the problems experienced within this sector, the printing process must be understood down to the internal mechanisms. Sections 2.2.2 to 2.2.4 provide the required understanding.

2.2.2. Printing Techniques

There are different flexible packaging printing techniques available. The most prevalent types of consumer flexible printing are flexographic (flexo) and rotogravure (gravure). The main difference between the two is the way the ink is transferred to the substrate. The case company has flexo and gravure printing processes. In flexo printing, the design is cut into a soft polymer plate, stuck onto a sleeve (cylindrical hard polymer roller), rolled over an ink tray containing fast drying ink and applied to the substrate. The concept is similar to the operations of an inkpad and rubber stamp. The resolution of the final image is a limiting factor. The gravure process and ink transfer method (the reason for gravure being able to achieve a higher resolution) will be further explained in Section 2.2.3 and 2.2.4 respectively. Gravure printing is commonly used for high quality images and large production batches. This is due to the costly nature of the machine, the consumables required and the cylinders used to produce the image. [22] Gravure printing will be the focus of this research because the product it produces has the most financial value.

2.2.3. Gravure Printing Process

The gravure printing process is fundamentally the same, independent of the machine or substrate used. Figure 6 shows a process schematic. The substrate is loaded in ‘the unwind’ by operators, depicted by 'paper roll' in the schematic. The substrate is driven through the colour station process where a portion of the image is transferred. The transfer process is discussed in Section 2.2.4. The substrate is then passed through heated dryer hoods. The substrate passes through a series of buffer rollers, which provide time for the ink to dry. The substrate must be completely dry before the next colour station. Drying is dependent on atmospheric conditions, ventilation and the chemical composition of the ink. [20] Variations to any of these conditions require manual intervention from the operator. The number of stations the substrate passes through is determined by the customer design i.e. the number of colours required to produce the customer's artwork. Each colour station transfers a partial of the complete artwork until the image is complete. The substrate is then packaged in a form that is suitable for the next process (laminating or slitting). In the case company, the substrate is rewound. [22]

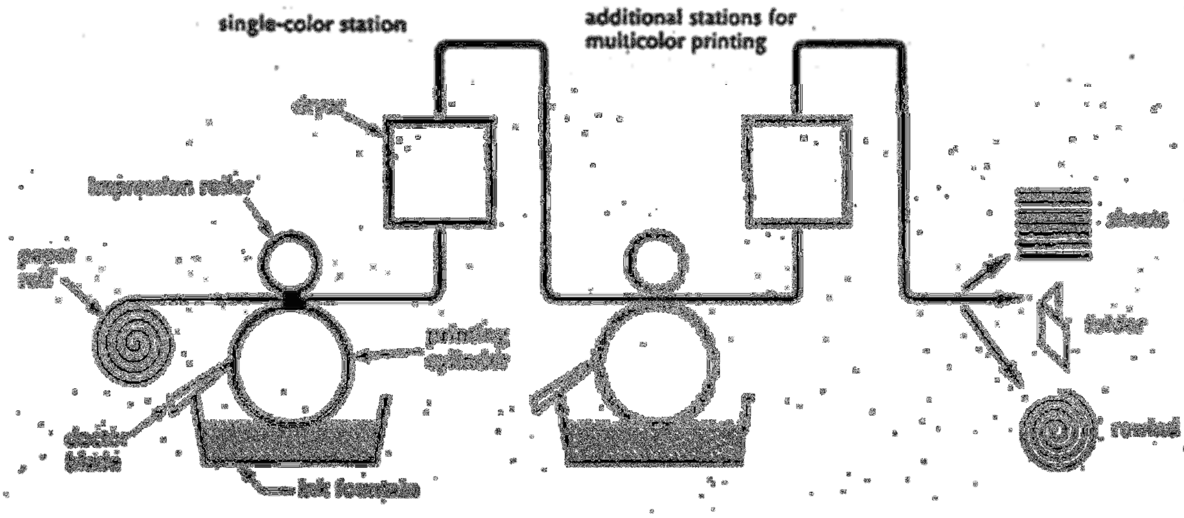


Figure 6: Rotogravure printing process schematic [22]

A number of variables regarding the print image determine which ink is used. The ink transfer process provides the mechanics of how the ink is applied to the substrate. A strong understanding of the ink transfer process (Section 2.2.4) will provide a greater understanding of the potential variables, which could dramatically affect the quality of the product.

2.2.4. Gravure Ink Transfer Process

The case company uses a solvent-based ink. The inks play a vital role in the printing process. Examples of variables that the operator must compensate for include: solvent saturation of the air, viscosity of the ink, atmospheric conditions, age of the ink and the ratio of agents in the ink. [20] These variables affect the quality of the finished product; i.e. how clearly ink is transferred onto the substrate. The gravure ink transfer method differs from flexo, beginning with the printing cylinder. A schematic is provided, refer to Figure 7.

The cylinders are made from zinc or copper that is chrome-plated and buffed. [23] On the cylinder, images are laser engraved or etched. These image areas contain sunken honeycombed patterns called 'cells'. [22] The cylinders are rotated in an ink pan, and ink is then trapped in the cells. The non-image areas are wiped clean using a flexible steel blade called the 'doctor blade'. The ink and the substrate are of opposite polarity due to an electron gun aimed at the substrate before the cylinders in each station. The difference in polarity helps the ink bond to the substrate. The electron charged substrate is passed over the cells and the ink is attracted onto the substrate. The rubber impression roller aids the transfer of the image to the substrate. This method of ink transfer allows for a higher resolution image. For these reasons, gravure provides a better quality of image than flexo printing. The impression roller also pinches the substrate against the cylinder so that it may be driven forward to the next process. [22], [23]

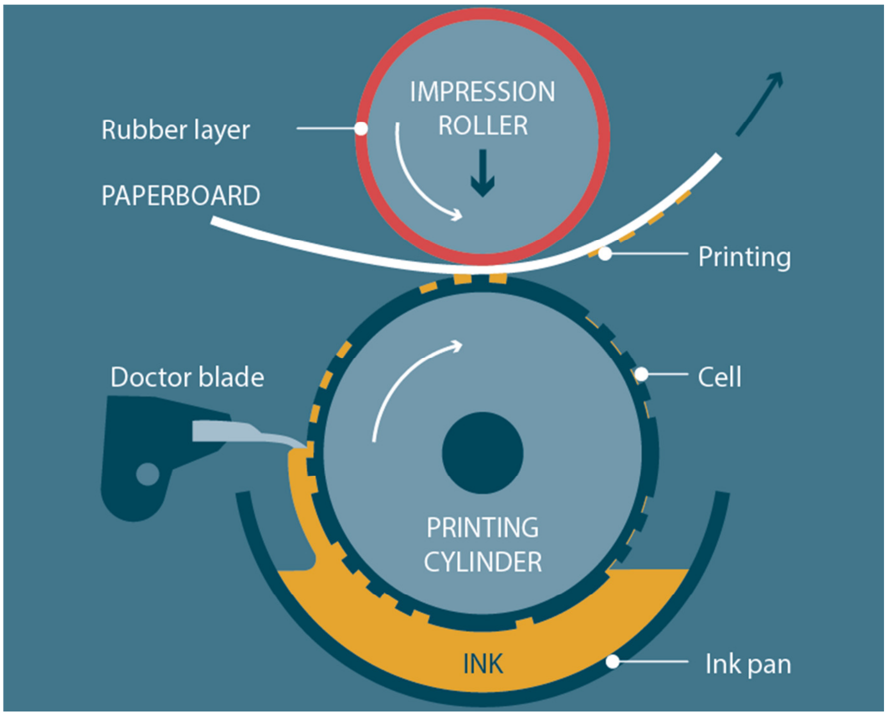


Figure 7: Rotogravure ink transfer schematic [23]

The gravure ink transfer process is complex. A sound knowledge will help in identifying potential risk areas where production waste could be produced and will better aid in the management thereof. Now that the production process is better understood, clarity on what constitutes profitability within a manufacturing environment is required. This clarity aims to justify the area of focus– waste management– explored in the research.

2.3. Profitability in Manufacturing

The reason a company trades and operates is to make profit. Profit is the positive result from the total income a company generates from its customers minus the cost of the goods/services sold and other running expenses over the same period in time. [24] Profitability, on the other hand, is the ability for a company to make a profit from all business activities. It shows how efficiently management can make a profit with the resources available. [25] From these definitions, we see how closely related profit and profitability are. Profit is an absolute value and the outcome that drives profitability. [25] In order to determine the increase or decrease of profitability, an evaluation of profit is required. An increase in profit suggests an increase in profitability. A decrease in profit suggests a decrease in profitability. The gross profit ratio provides a good indication of this relationship. The gross profit ratio is defined by Equation 1. [25]

$$Gross\ Profit\ Ratio = Gross\ profit / Net\ revenue \times 100 \quad (1)$$

Net revenue or net sales is the total income gained by a company from sales or services rendered to its customers. Gross profit is equal to the net revenue minus the operating expenses. [25] From Equation 1, we see the gross profit ratio changes through the increase or decrease in revenue or operating expense. If revenue is considered a constant, the gross profit ratio and thus profitability is inversely proportional to operating expenses. It is for this reason that the operating expenses of the case company are of interest.

Expenses are all of the factors that cause a decrease in company equity. [26]. Operating expenses are expenses that the business incurs through its day-to-day operations. Operating expenses can be fixed, and fixed expenses do not fluctuate with production outputs (rent, salaries, insurance etc.). [27] Operating expenses can also be variable. These fluctuate with production outputs (direct labour, materials, utilities, consumables etc.). Gross profit only considers variable costs in its computation. [27]

A list of the operating expenses experienced at the case company is provided below:

- direct materials;
- staff wages;
- utilities;
- machine time;
- consumables;
- waste;
- storage;
- transportation. [27]

For a company to be profitable, income must exceed expenses. There are many ways in which companies can reduce expenses such as a reduction in labour, a reduction in expenses and sourcing cheaper raw materials. Watts [28] suggests that material and labour should be the first to be considered when reducing factory costs. [28] Companies often hastily turn to these strategies. Watts goes on to classify two types of labour– productive and non-productive– and emphasises that time should be spent analysing labour functions to establish these two groups. It is from the non-productive group where reductions should be focused. [28] In most cases, the mentioned cost-reduction strategies are not sustainable, can affect the quality of the product if executed incorrectly, do not address the source of high expenses or waste, and could lead to labour unrest. The aforementioned views are shared by McCally. [29] With an understanding of how operating expenses vary in flexible packaging (See Section 1.2) and the justification provided, the need to focus on waste management is evident.

2.4. Waste Management

In order to manage waste, waste must first be defined. The Waste Framework directive from the European Union defines waste as: "any substance which the holder discards or intends or is required to discard". [30] This definition is not concise, as it leaves too much interpretation to the reader. What defines when waste is discarded, or when it is intended to be discarded, is arguable. [31] A more suitable definition is required.

The Environmental Public Health Act (EPHA) defines waste as:

> …any substance which constitutes a scrap material or an effluent or other unwanted surplus substance arising from the application of any process; and any substance or article which requires to be disposed of as being broken, worn out, contaminated or otherwise spoiled, and anything which is discarded or otherwise dealt with as if it were waste shall be presumed to be waste unless the contrary is proved. [32]

The EPHA definition assumes everything is waste unless proven otherwise. In the flexible packaging industry, the only way to prove otherwise is if the substance has financial value to the customer. It is for this reason the EPHA definition is acceptable. Waste can therefore be further classified into different streams. The classification can be found in Section 2.4.1.

2.4.1. Classification of Waste

There are two main streams of waste management, namely liquid and solid. [6] At the FPC liquid waste is in the form of used solvent, residual adhesive/cold seal/release lacquer and inks that could not be reused due to contamination. Only 3-7% of liquid is transferred to the final product, therefore the financial impact on profitability is very low. [9] The research focuses on solid waste, due to the category of waste produced within the focus area at the FPC, and the financial opportunity when compared to liquid waste. Management principles vary depending on the type of waste produced, and these will be further explored in the literature Section 2.4.6. There are two types of solid waste, hazardous and non-hazardous. Non-hazardous waste is then split between agricultural, municipal and industrial waste. The waste of interest is non-hazardous industrial solid waste stream. Industrial waste comprises a further four categories. [6] These can be seen in the deployment chart, refer to Figure 8:

- C & D – construction and demolition (C & D) waste: concrete, rubble, steel, wood etc. Can be in a commercial or residential setting.
- Medical – waste generated in the diagnosis, testing and treatment of people or animals.
- Process/special – waste consists of sludge, by-product and chemical waste from the process or treatment thereof.
- Manufacturing – waste from any industrial manufacturing process. This can be from housekeeping, packaging, plastics, chemical, scrap material, etc. [6]

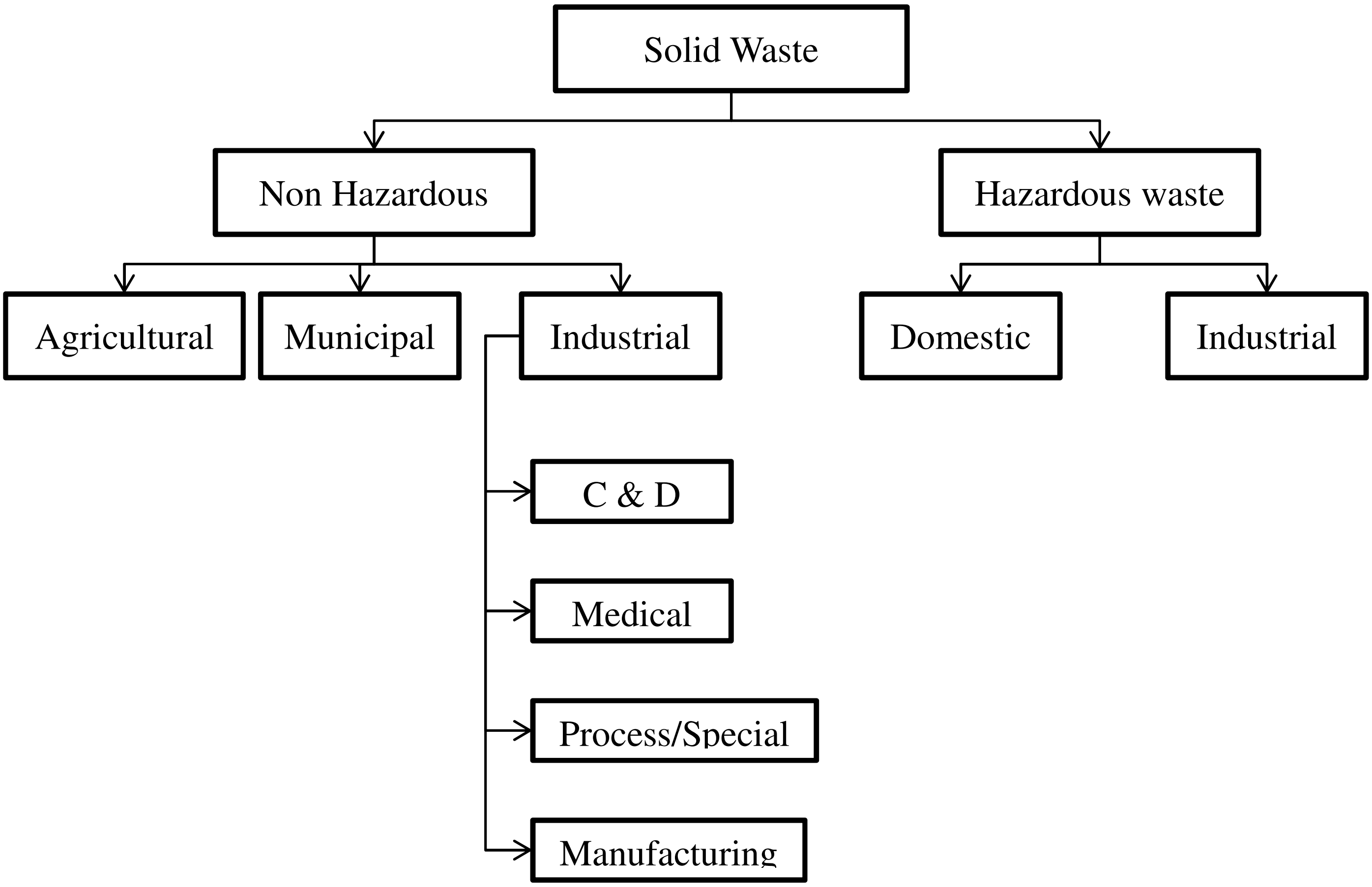


Figure 8: Deployment of Solid Waste (created by author using information from [6])

The FPC waste to be managed falls within the category of non-hazardous industrial manufacturing waste. This classification sets the boundaries of operation and determines which processes are applicable to the research.

2.4.2. Waste Management Principle

Management principles vary depending on the type of waste produced. Not all waste can follow all of the management principles. Waste management is all the actions required to manage waste. This includes but is not limited to the collection, treatment, transportation, prevention, monitoring and disposal of waste. [5] The priority at which waste management should be approached is given by the waste hierarchy (See Figure 9). The waste hierarchy was first accepted into policy by the European community in the 1975 framework directive and is now internationally accepted. [30] The hierarchy is aimed at: preventing waste where possible, reusing, recovering and recycling waste, treating the waste such that it is less hazardous or harmful to the environment and as a last resort, disposing the waste into landfills. [31]

Cleaner production	Prevention
	Minimisation
Recycling	Re-use
	Recovery/Reclamation
	Composting
Treatment	Physical
	Chemical
	Biological
Disposal	Landfill

Figure 9: Hierarchy of waste management [30]

The waste hierarchy is in line with the ‘4 R’ principle, which is to Reduce, Reuse, Recycle and Recover. [33] The hierarchy is broken down and further explained as follows.

Cleaner production

The hierarchy of waste management emphasises that the most desirable result for waste management is to prevent waste from being created. The rationale behind this is that if waste is prevented or reduced at the source there is less waste that filters down to the lower levels. [34]

Recycling

To recycle is to convert waste into reusable material. [35] Reuse is defined as “any operation by which end-of-life products and equipment (such as electrical and electronic goods) and its components are used for the same purpose for which they are conceived”. Generally, reuse is the process where an item can be used over and over again for the same purpose. [36] Recovery is the process of obtaining energy from waste. The energy can be used for heating, direct combustion or incineration, secondary derived fuel (i.e. obtaining oils from waste) and the generation of electricity. [37] Reclamation is the act of restoring or returning an item to its former or better state. [35] Composting is the process of turning waste in fertilizer. Composting is not a method that could be applied to the waste created at the FPC currently as it is more commonly used with biodegradable waste. [37] Advances in material science could potentially produce compostable materials and inks in the future that could then be implemented in the industry.

Treatment

Treatment is a process whereby waste goes through another operation so that the waste becomes less hazardous or harmful to the environment. [31] The treatment operation uses either physical, chemical or biological means to break down the waste. [37]

Disposal

If waste cannot be converted in any of the other processing techniques, disposal is then the action considered. Disposal is the least desired state, considering that the most commonly used disposal method is landfill. Disposal has a negative effect on the environment, as material being broken down releases methane and carbon dioxide. [37] Landfill sites are visually unattractive and contribute to air pollution.

The purpose of the waste management hierarchy is to provide a prioritisation framework for waste management. The higher up in the waste management hierarchy a strategy is, the more desirable and sustainable it is. [37] Adherence to the waste hierarchy requires education of employees as well as an adoption into company policies. Based on the hierarchy, it is clear that a sustainable long-term solution that complements and incorporates the hierarchy is required. An integrated approach to waste management consisting of a "hierarchical and coordinated set of actions" [33] is obtainable through integrated waste management. Section 2.4.3 further explores integrated waste management.

2.4.3. Integrated Waste Management

Flexible packaging is either recyclable or non-recyclable. With each stream, there are requirements and protocols to follow for effective waste management. Integrated waste management is defined by McDougal [38] as "an overall approach to waste management, it combines a range of collection and treatment methods to handle all materials in the waste stream in an environmentally effective, economically affordable and socially acceptable way". [38] An integrated waste management solution must incorporate economic and environmental concerns. McDougal identifies three sustainability factors that an integrated waste management philosophy should ultimately satisfy. He goes on to mention that it is idealistic to believe that a philosophy can satisfy them all. [38]

The sustainability factors are listed in the three steps below:

1. waste management dealing with public health issues which it then extended;
2. to optimise the waste management practises known as integrated waste management;
3. to optimise the resources included to form the integrated resource management process. [38]

The research seeks to satisfy step two as step one and three will shift the focus of the research from the scope identified. According to Zerboc [39] "Integrated waste management aims to be socially desirable, economically viable and environmentally sound". Zerboc [39] further lists a series of questions which need to be asked when developing and evaluating an integrated solid waste management plan or framework.

- Is the proposed technology likely to accomplish its goals given the financial and human resources available?
- What option is the most cost-effective in financial terms?
- What are the environmental costs and benefits?
- Is the project feasible given administrative capabilities?
- Is the practise appropriate in the current social and cultural environment?
- What sectors of society are likely to be impacted, and in what way are these impacts consistent with overall societal goals? [39]

The answers to these questions are critical to obtaining the correct framework. The answers contribute to understanding the existing problems and will allow the author to derive the appropriate solutions using the waste hierarchy as a guide.

Tools such as life cycle inventory (LCI) are used to measure waste management progress. LCI is useful in waste management for assessing environmental efficiency with progress. The LCI of solid waste begins at the source of waste creation and ends when the waste is disposed, recycled or reused. [38] LCI is part of life cycle assessment (LCA), which is further explained in Section 2.4.4.

2.4.4. Life Cycle Assessment

The life of a product starts from obtaining raw material, through all the value adding processes, to being bought and used by the consumer until it is disposed of. [40] LCA is a quantitative method for examining the total environmental impact of a product through every step of its life. [40] LCA informs product decisions to reduce the environmental impact from the design phase. It allows for a focus on the most significant environmental impacts and further allows the engagement of the consumer. [41] A typical LCA goes through the steps below.

- Goal and scope definition: selecting the product or activity, defining the purpose of the study and fixing the boundaries.
- Life Cycle Inventory analysis: identifying all the inputs and outputs about energy, resources use and emissions through the product life. Figure 10 shows the elements required to conduct a LCI.
- Determining the potential environmental impacts based on the inputs and outputs.
- Using the values obtained to measure up against the objectives of the study. [41]

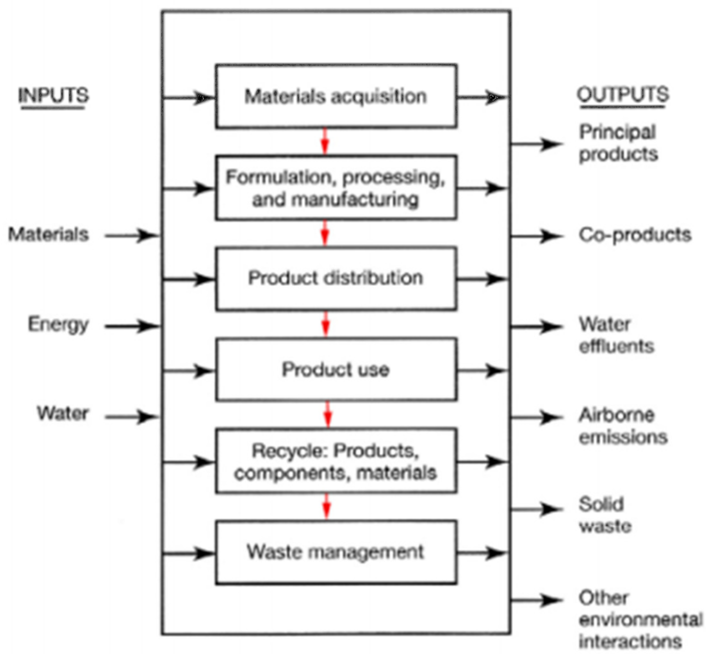


Figure 10: The elements of Life Cycle Inventory (LCI) [42]

LCA is merely an indicator, and should not be understood as a complete or comprehensive assessment. LCA uses subjective judgement and lacks scientific and technical data. LCA seldom includes social and economic factors; hence, it should be used in conjunction with other techniques. [41] A possible technique– concurrent engineering– is discussed in Section 2.4.5

2.4.5. Concurrent Engineering

Concurrent engineering (CE) is a design technique that involves parallel product development. All life cycle phases are considered simultaneously including cost, quality and user requirements. [43] CE uses a cross-functional team in order to identify potential risks in the design phase and reduce components as much as functionally possible. Being cross functional, the design process benefits from:

- teams being in sync with the design goals and objectives;
- teams understanding the interrelationships between processes;
- a reduction in redesign or reworking, resulting in faster decision-making;
- improved communication. [43]

As a development philosophy, CE allows users to design for the environment. CE contains three major elements of design for environment that are critical to its success.

- Design for environmental manufacturing requires using:
    - minimum waste, scraps and by-products;
    - minimum energy utilisation;
    - non-toxic processes and production materials.
- Design for environmental packaging requires using:
    - minimum packaging materials;
    - reusable pallets and wrapping materials;
    - bio-degradable packaging materials;
    - recyclable packaging materials.
- Design for disposal and recyclability requires:
    - minimising the number of materials and colours to facilitate the separation of material to recycle and allow for reuse;
    - avoiding filler materials that cause the product to be non-recyclable i.e. fibreglass or graphite;
    - limiting additives, coatings, adhesives, metal laminates;
    - designing for serviceability to minimise disposal of non-working products or to allow for refurbishment and reuse. [44]

The mentioned major elements are considered for the complete life cycle of the product, which includes design, manufacture, use and disposal. Although CE is a philosophy that is aimed at the design phase of a product, the methodologies can be applied to existing systems and product improvements to minimise waste and the impact on the environment. The FPC will consider the elements of CE that can be applied to the manufacturing phase within a product life cycle. Concurrent engineering waste management technique is more closely associated with the objectives of this research, as it concentrates more on the economic factors within the product life. A review of the previous research in solid waste management follows in the subsequent section.

2.4.6. Previous Research on Solid Waste Management

Waste management literature was reviewed to identify which tools and techniques have previously been utilised to achieve an effective waste management system. If applicable, any correlation with profitability was considered. Developing countries' waste management was considered, as developed countries do not face the same problems. These problems include inadequate education, poor infrastructure, a lack of funding and underdeveloped legislative regulations. An example from a developed country was also considered in order to highlight the difference between the two and to provide the author with a goal for waste management. Different waste management strategies are reviewed, the overview provided and then summarised in the subsequent sections.

Solid waste management in Polokwane (municipal waste). [45] The objective of the research was to compare how households and the municipality store, collect, transport, treat and dispose of solid waste and to make recommendations for improvement. It was found that the majority of waste is mixed into 20L refuse bags and collected by a service provider in trucks and sent to landfill. The different waste streams (batteries, electronic appliances, hazardous, etc.) have the same fate (landfill) with only 27% being disposed by other methods. The other methods include burning the waste in the back garden or burying it. No sorting is done at the source. Only once the waste gets to landfill does the Polokwane municipality have reclaiming activities. The waste hierarchy is neglected within this municipality. Without the reclaiming activities at the disposal site, little to no consideration is given to the 4 Rs principle. A lack of community education and resources were highlighted as reasons for poor reduction, recycling and reusing rates. The areas that were identified as lacking were suggested as future recommendations to investigate. [45]

Solid waste management in Lagos, Nigeria (municipal waste). [46] The objective of the research was to identify how households handle waste and how the municipality then handles this waste. A framework was developed to encourage reduction, recycling and reuse. Waste was collected from households using wheelie bins and truck transportation. These trucks are a mix of private operators and the municipality. Private operators aim to sort the waste at the source, pick waste that can be resold and leave the rest dumped in the street. The waste arrives at the municipality as a mix of organic and non-organic waste. This waste is then sorted. Organic waste is converted into compost. Non-organic waste is divided into metal, PET and paper. The rest is lumped together and disposed.

Lagos has very little recycling, and the municipality has invested in larger landfills. Education and a lack of resources are given as the contributing factors to why the waste hierarchy is so poorly pursued. An attempt was made to reduce plastic waste (second highest stream after organic waste) through promoting the use of biodegradable packaging. The government incentivised consumers and manufacturers alike. Nigeria has a high reuse rate for plastic containers, and these are even traded as a currency. It is noted that the economic standing of households is the biggest contributing factor to the rate of reuse. Recycling plants were in the process of being developed, and waste would be diverted from landfill after a sorting stage. The waste process followed was collection, sorting, processing and then disposing. The framework developed for waste management used the waste hierarchy as the backbone. At each tier, the challenges experienced were discussed and solutions to overcome these were proposed. The solutions proposed directly addressed the problems raised, but there is no evidence of tools used to get to the proposed solutions. [46]

Site waste management in The UK (construction and demolition waste). [47] The purpose of the investigation was to assess waste management practises in the construction sector following a policy document published by the government in 2004. The policy provides a framework, the persons responsible and the steps that should be taken in order to achieve solid waste management (SWM) for a construction project. Figure 11 provides a schematic of the persons responsible and the stages as indicated in the policy.

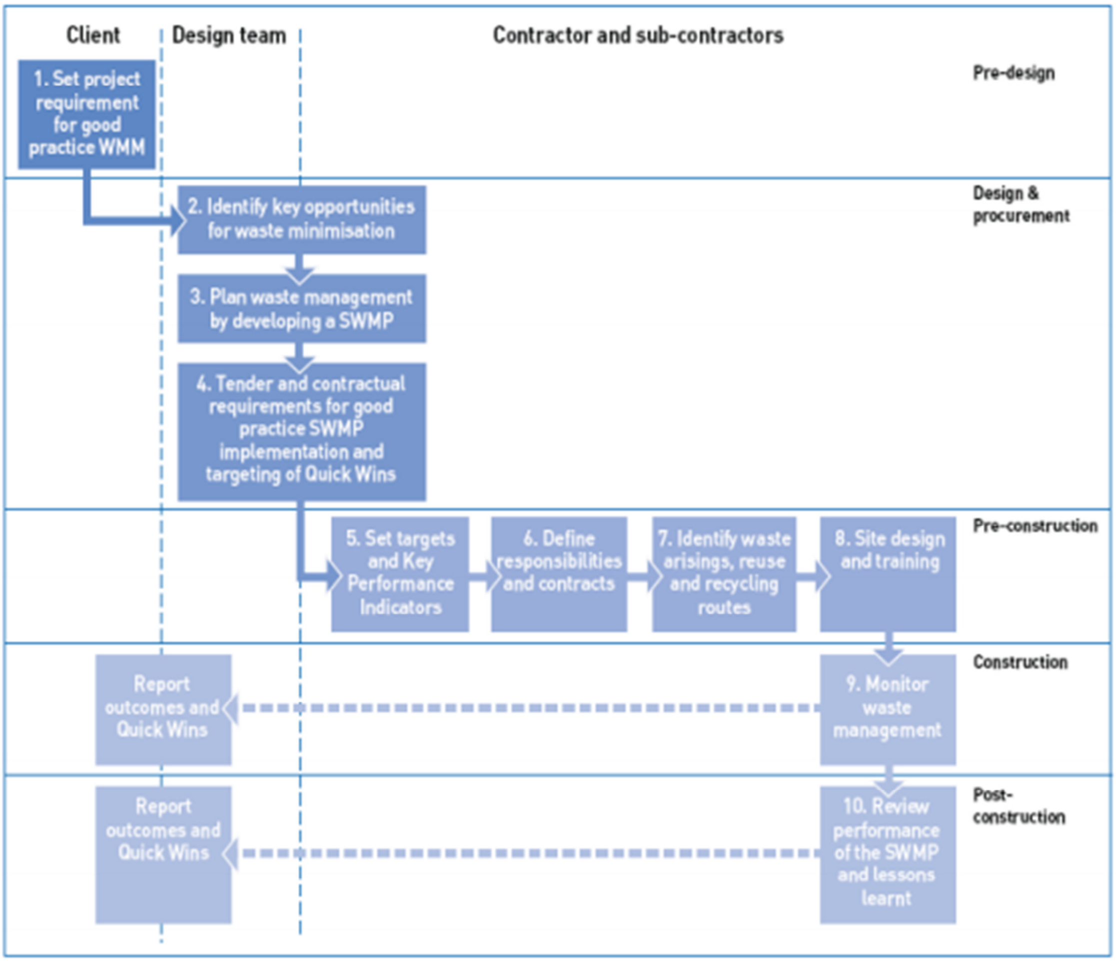


Figure 11: Policy stages from the solid waste management policy 2004 [47]

The policy was made mandatory for all projects commencing after 1 July 2008 in the United Kingdom. Eight case studies were considered to assess the implementation of the policy. The case companies used varying initiatives and Lean tools to achieve SWM. Some examples are listed below.

- Just-in-Time (JIT) was used to reduce the waste created from storage and double handling.
- 5S was used to ensure the correct tools were being used for each job and that these were readily available. 5S also ensure the materials were properly stored on the construction site to reduce damage and waste.
- Visual management was implemented in the form of labelled different coloured bins for the different waste streams. Sorting waste at the source was achieved.
- Rubble was crushed and used as aggregate, reducing the amount of virgin aggregates bought as well as the waste to be disposed.

- The use of pre-fabricated parts was increased as this reduces site waste (mainly plaster boards).
- Raw materials were redesigned such that they were reusable and recyclable i.e. plaster reduced from double skin to single skin, material delivery pallets were modified and used as plaster boards, flooring changed to recyclable material with less maintenance, thus requiring less replacement. [47]

Further literature regarding solid waste management in the medical, construction and municipal services was reviewed. The literature [46], [47], [48], [49], [50] uncovered similar processes which were followed, these are described. At the source the waste is classified and categorised, except with municipal services where a secondary processing stage is required to achieve the same result. The classification is industry specific, but the commonality is that waste of similar classification is stored together waiting further processing. Waste is stored in refuse bags, wheelie bins and buckets. The waste is then transported via the most appropriate means (truck, vans or skips) and weighed. After the weighing, the waste is disposed in the appropriate manner dictated by the category. Disposal methods include incineration, landfill and delivery to recyclers for further processing. [48], [49], [50]

Non-hazardous solid waste consists of three categories– agricultural, municipal and industrial– [6] of which the latter two contain information applicable to this research. The scope of municipal waste that was researched began at the collection of the waste and covered until it was disposed in the appropriate manner. The framework used for SWM was to collect the waste, transport the waste, sort the waste (through third parties), recycle that which is recyclable and dispose the rest to landfill. [48], [49], [50] Although no formal tool usage was explicitly mentioned in the literature, waste management was achieved through transfer batching [51]. Transfer batching occurs when all processes wait until a certain quantity is met and then the batch is moved to the next process; i.e. trucks must be full before they go to secondary sorting. At sorting, a certain quantity of like material is collected before it is sent to recycling etc. The use of Lean tools (i.e. problem solving, visual management, 5S) is used to overcome problems experienced and to achieve a waste management system.

2.4.7. Waste management summary

Industrial waste consists of four distinctions; C&D, process/special, medical and manufacturing. [6] Process/special waste was not considered in the review due to its lack of relevance to this research. Literature on C&D and medical waste contained similar frameworks to achieve waste management. [49], [50], [52] Lean tools such as problem solving, standardisation, visual management, Poka Yoke and Kaizen are used to reduce and, in the case of C&D waste, reuse and recycle. [49], [50], [52] The waste management hierarchy in developing countries, according to the literature reviewed, is recognised ideologically, but does not effectively translate into the methods practised. There is very little integrated waste management, as the economic impact of waste outweighs the environmental aspect. This is evident from the lack of landfill diversion strategies and practises. The literature highlighted two methodologies life cycle assessment and concurrent engineering. These will be used together to address this insufficiently addressed area within developing countries. Concurrent engineering provides a more holistic approach as an assessment tool and provides a better guide to make strategic decisions that influence the integrated waste management. [43]

The framework used for SWM is as follows: use Lean tools to identify opportunities, classify, separate and sort waste at the source, store in the appropriate container or manner, recycle and reuse at the source, transport the waste via trucks, and dispose via incineration or landfill. [45], [46], [47] From the literature, it is clear that waste management has three main benefits to consider:

- Environmental: there is less requirement of space for landfills and reduced air, noise and environmental pollution.
- Financial: waste management initiatives improve product development and increase financial gains through waste recycling, recovery and reuse.
- Social: waste management improves safety, has increased health benefits, can provide communities with skills and development and can potentially provide jobs.

These benefits cannot be considered in isolation, as they share a symbiotic relationship. The life cycle of a product is from raw material extraction until disposal. The literature reviewed considered the life of the product from the consumer to disposal. The top tier of the waste management hierarchy (Figure 9) is neglected for the most part, except in the case of C&D waste. The FPC is in a position to dictate the end of the life cycle of a product based on the input raw materials used. As consumer behaviour cannot be controlled through flexible packaging, the manufacturing process is the area of focus where the waste management hierarchy can be addressed. There was little relevant literature found about the implementation of methodologies to fulfil the waste hierarchy that covers the manufacturing phase of the product life cycle. Most of the research was centred on the environmental and social impact of manufacturing waste and the importance thereof. For flexible packaging manufacturing, to address this gap in the literature and due to the nature of the process, continuous improvement methodologies must be considered. Continuous improvement methodologies have been used in production environments for process and quality improvements. In order to understand their application to waste management, the supporting theory must be reviewed.

2.5. Lean Manufacturing

The purpose of this section is to provide a theoretical understanding of Lean, Lean principles and Lean tools, which affect profitability with regards to waste management. Lean manufacturing looks at removing different types of Muda (waste), which make processes inefficient. Lean is a tool used to reduce Muda within processes. [53]

2.5.1. The 3 Ms

Liker [54] writes about the "The Toyota way", an account of how TPS has been implemented successfully at Toyota. The Toyota way describes TPS as a system that eliminates three types of waste: Muda (Japanese meaning non value adding work), Muri (Japanese meaning overburdening people or equipment) and Mura (Japanese meaning unevenness). [54] These are the wastes observed by Ohno, which he did not want in the Toyota plant. [4]

<u>MUDA</u>

Muda as mentioned previously, refers to non-value adding work. These wasteful activities require more parts, more time, cause extra movements, create excess inventory and result in waiting, which increases lead times. [4] Ohno described these Muda as follows:

- over production – producing more than the internal or external customer requires;
- waiting – people waiting for machinery, tooling, maintenance, raw materials, etc.;
- transportation – moving of material or people over long distances;
- inappropriate processing – non-value-adding operations or inefficient processing;
- work in progress (WIP) – process inventory requires extra work, space, cost, etc.;
- excessive motion – motion by people or machine that does not add value to product;
- defective products – scrap, rework, customer returns or customer dissatisfaction. [55], [56]

The list above mentions seven Lean wastes. Through developments, an eighth waste has been identified as the underutilisation of talent (people). [3]

MURI

Muri is the over burdening of people or equipment. Muri is overloading people or machines beyond their capacity. The results can be poor quality, stress on workers, safety hazards and lengthy breakdowns. [4] The main causes of Muri are:

- lack of standardised work;
- lack of maintenance standards and over utilisation;
- poor process or factory layout;
- sudden increases in production volumes;
- absenteeism, putting pressure on remaining workers;
- underperformance or underutilisation of workers and machines. [57]

MURA

Mura is unevenness. In production there are periods where there are more resources available than production requirements and sometimes the opposite is true. These irregular occurrences or fluctuating production volumes are unevenness. [4] Mura can cause both Muda and Muri:

- Muda, because over production could result in order to buffer variations. This in turn could result in high levels of inventory. [57]
- Muri, because the production requirements could result in production periods where people are over worked and machines are pushed to their limits. It can also result in troughs where machines and workers are underutilised. [57]

Mura is typically seen in companies that practise batch production (like the FPC). Companies will build up buffer stock (producing more than the requirements) to compensate for the variation. Unintentionally, they increase production variations. A phenomenon called the "Bullwhip" effect can result. This is when small changes at the end of the value stream (customer) result in big changes in the production volume of earlier stages. [57]

Lean wastes result in inefficient operations, increased costs, reduction of cash flow, delays in lead times and a reduction in customer satisfaction. [56] All three Lean wastes are connected to each other. Mura creates Muri and the two together create Muda. It can be said that Mura and Muri are the root causes of Muda. And thus, focusing on all three Lean wastes is the only way to absolutely eliminate waste. [4]

2.5.2. Lean Concept

Hines, Holwe and Rich [58] have proposed a model covering the Lean concept. The Lean concept model distinguishes between two levels: the strategic level (Lean thinking) and the operational level (Lean production, performed physically on the production floor) [58] as shown in Figure 12. Hines, Holwe and Rich [58] believe identifying this distinction will give organisations the understanding required to apply the correct tools and strategies.

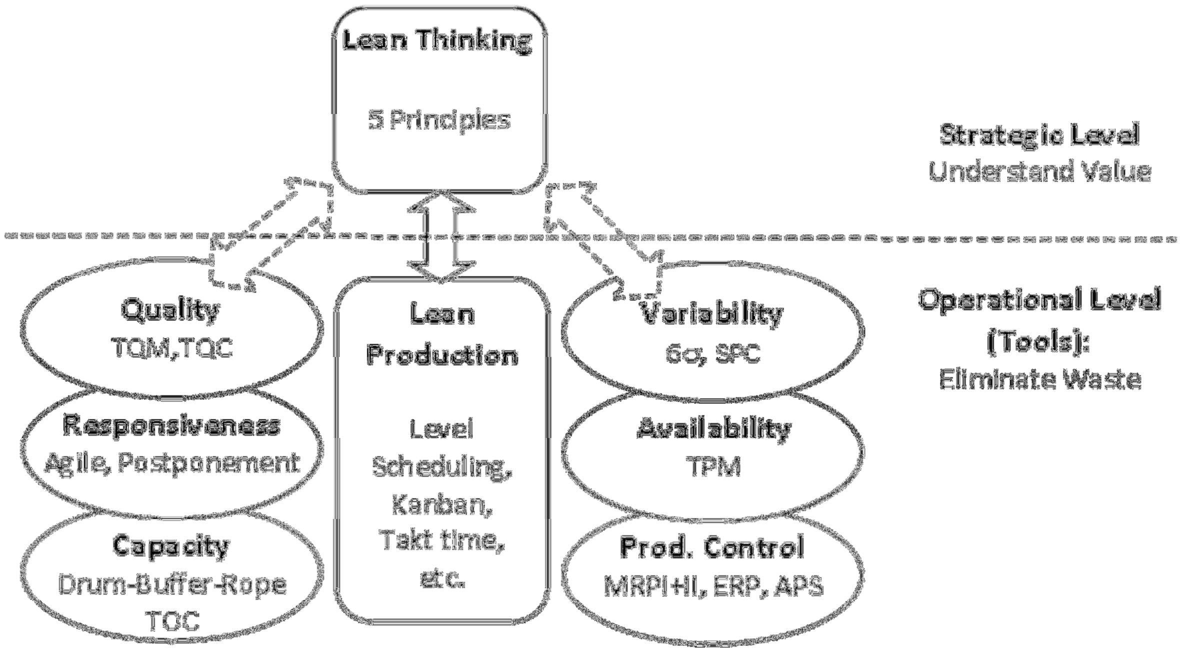


Figure 12: The Lean concept model [58]

If the operational level is addressed and the strategic level neglected, the lack of a holistic view might result in a decrease in value from the customer perspective. This is a common mistake made by organisations that implement Lean. [54] It is vital to understand that it is possible to increase customer value without reducing waste. It then becomes the organisations decision to provide a customer-centred strategic approach to the application of Lean. [58] This approach can be provided through Lean thinking. Womack and Jones [59] describe the five Lean principles of the strategic level as:

1. Specifying value. According to Womack and Jones, [59] 'value' is defined as a capability provided to the customer at the right time and at an appropriate price. In each case, the customer defines both parameters.
2. Identifying the value stream for each product. Value stream is defined as the specific activities necessary to design, order and provide a specific product to the customer. This is considered from design to launch, order to delivery and raw materials to complete product.
3. Smoothing the process flow. 'Flow' is defined as the progressive achievements of tasks along the value stream without interruptions, backflow, waiting or scrap.
4. Producing based on pull. According to Womack and Jones, [59] 'pull' is defined as a system of cascading production and delivery instructions from downstream to upstream in which nothing is produced by the upstream supplier until the customer downstream signals for its requirement.
5. Perfection through elimination of Muda. Eliminate Muda such that all activities along the value stream create value. [59]

There are only two strategic principles that are applicable to the scope of this research, namely specification of value and perfection through the elimination of Muda. Lean thinking is always a desired outcome. At a strategic level, it is necessary for the decision maker and participants of the research in the case company to put these first in order to achieve waste management and affect profitability. The two specific principles that have been chosen focus on the operational level while providing consideration for the customer. And therefore, a complete holistic view was obtained.

<u>Value</u>

Value is the cornerstone of Lean thinking. Value is created by the producer and needs to be defined in terms of the customer's expectation of the product. [59] There may be more than one ultimate customer. Therefore, it becomes critical to consider their collective value system. [54] The customer can be internal (downstream process) or external (clients) and their expectation may vary. Specifying value correctly is the first step in Lean thinking. [59] In flexible packaging, internal customers are downstream processes that require the product delivered to be within specifications to operate on their machines optimally.

Since flexible packaging is a time-based manufacturing process, external customers provide their design and pay for the time taken to print, laminate and slit to obtain their final product.

The time is provided by standards based on the complexity of their product. The target cost is based on the amount of resources and effort required to provide a product within the given specifications, provided all Muda is removed from the process. [59] The target cost becomes a value expectation for both internal and external customers. It can be concluded that value to the external customer encompasses performing the processes they pay for within target cost, replicating their desired print exactly according to the specification they provide, and producing material that has the properties required by the contents of the flexible package.

From the definition of value to the customer, we see that principle five forms a big part of the value to all customers. Muda is discussed in Section 2.5.1, and it has consistently been mentioned that it needs to be eliminated. This is the second Lean thinking principle to be considered and forms a functional aspect of the operational level. Section 2.5.3 describes what Lean tools are available to achieve waste elimination, and which of these are applicable to the research.

2.5.3. Lean Tools

The operational level of the Lean concept (See Figure 12) is about elimination of Lean wastes. This coincides with the strategic level which encourages a methodical approach to operation. Lean wastes are eliminated using Lean tools and techniques. Not all tools will be applicable to all industries. Therefore, understanding the Lean principles will guide companies as to which are the correct tools to implement. The following sections contain a topic-by-topic description of such tools. The tools summarised are specific to the research performed.

<u>Value Stream Mapping (VSM)</u>

As defined by Womack and Jones, [59]

> … A value stream map identifies every action required to design, order, and make a specific product. The actions are sorted into three categories: (1) those that actually create value as perceived by the customer; (2) those which create no value but are currently required by the product development, order filing, or production systems; and (3) those actions which don’t create value as perceived by the customer and can be eliminated immediately. [59]

Value stream map (VSM) is one of the five Lean principles in Lean thinking, and for the scope of this research, it is an important Lean tool to eliminate waste. A VSM is a visual representation of processes, tasks, steps or activities in sequence from start to finish. [60] The level of detail on a VSM is dependent on the application. The first step of a VSM is mapping out the current state. The current state map will highlight non-value adding activities that add cost. The current state is analysed to develop the future state, which is the target state. [61] A VSM is usually the starting point in waste identification and understanding the flow of the current state. Further tools are then used to eliminate the waste.

Visual Process Control

Visual process control is a process of providing simple clear indicators or markers in the workplace. The markers or indicators allow for quick identification of:

- a machine status;
- locations and quantities;
- production information, i.e. plan adherence;
- information critical to safety;
- operating standards and methods used;
- feedback to team members and/or supervisors. [61]

Visual process control provides a better work environment and reduces the need for meetings. [61] An example of a common visual control is the use of the Andon cord above workstations. When a defect is identified, the cord is pulled stopping the production line. The team then gather to diagnose the problem, find the root cause and prevent the problem from occurring again. [4] The use and application of similar visual control will need to be customised for flexible packaging.

5S

5S is form of visual control. It is also considered the first step towards a Lean company and waste reduction. [54] 5S is the discipline required for good housekeeping. 5S is derived from five Japanese words Seiri, Seiton, Seiso, Seiketsu, Shitsuke. [54] Refer to Table 5 which describes the meaning of the Japanese words in 5S, how 5S is applied and the benefits of each stage.

Table 5: 5S definition and description [54], [61]

Japanese	English	Description	Benefit
Seiri	Sort (Organise)	Sort through items (tools and materials in work area) and keep what is essential and needed. Dispose what is not required.	Removing unutilised items clears up space; this will allow material to flow smoothly and workers to move freely without obstructions. Waste reduction is realised. An increase in safety and productivity is gained.
Seiton	Set in order (Simplify)	"A place for everything and everything in its place" This means having the right items in the right area for functional use.	This will allow for easy location and management of resources. A great saving in time and motion can be realised. A reduction in variation is achieved.
Seiso	Shine (Cleanliness)	Cleaning the workspace and leaving it tidy daily. All tools/resources need to be returned to their place.	This serves as an inspection for missing tools. It reduces the risk of accidents. A clean workspace shift-after-shift boosts worker moral and promotes a healthy work environment.
Seiketsu	Standardise	Developing a system, standards and procedures to ensure the first three S's are maintained.	Workers have responsibility and accountability. Everybody operates within the same confines. This allows optimisation of other processes and increased productivity
Shitsuke	Sustain (Discipline)	An on-going process of continuous improvement such that people follow the housekeeping rules. It is a management responsibility not to give instruction but to obtain worker acceptance	This promotes interaction between management and workers and encourages continuous improvement.

<u>Standardisation</u>

Standardisation is the best way to get a job done right, the first time, every time and within the available time. [59] In order to stabilize the process, standardisation must be achieved. Once that is achieved, continuous improvement can be made. Toyota believes standardisation is the basis for empowering workers and innovation in the workplace. [54] Quality cannot be guaranteed without standard operating procedures (SOP) for ensuring consistency. The Lean philosophy is to empower the workers (those doing the work) to design and build in quality by producing their own SOP's. SOP's should be simple and usable every day. [54] When workers are encouraged to produce standards and innovate for improvements, the traditional bureaucratic approach of instruction giving is not practised. Extensive employee involvement, a lot of communication and flexibility can build worker morale and result in a strong customer focus. [54] A strong balance between rigid procedures and freedom to innovate is still required in order to meet customer demands, production targets, produce consistent quality and drive costs down.

The Toyota way describes three elements of standardised work:

- the time required to complete a job at the pace of customer demand;
- the sequence of doing the work or completing processes;
- the amount of inventory that is on hand to accomplish the standardised work. [54]

In flexible packaging there are many complex processes, variables and procedures required to deliver the customers' products. Variations in any of these will result in varying quality and could result in waste. Standardisation will form a critical part of the analysis and implementation performed in this research.

Poka Yoke

Poka Yoke translated from Japanese means "mistake-proofing". Mistake proofing uses a device or procedure to prevent defects or equipment malfunction during normal operation. The Poka Yoke enforces correct execution of activity by eliminating choices that could lead to incorrect actions (mistakes), possibly creating waste (defects) or damage to equipment. [62] According to Shingo, [62] mistakes are inevitable–humans cannot be expected to provide 100% concentration and to execute instructions given exactly as provided for 100% of their working time. When mistakes are not picked up and reach the customer they are then defined as defects. Defects result from neglecting human error, and these are completely avoidable. [62] Human error as defined by Shimbun [63] is shown in Table 6.

Table 6: Classification of human errors. [63]

Type of Human error	Example
Forgetfulness	Sometimes we forget things when we are not concentrating.
Errors due to misunderstanding	Sometimes we make mistakes when we jump to the wrong conclusions before we are familiar with the situation.
Errors in identification	Sometimes we misjudge a situation because we view it too quickly or are too far away to see it clearly.
Errors made by amateurs	Sometimes we make mistakes through lack of experience.
Wilful errors	Sometimes errors occur when we decide that we can ignore rules under certain circumstances.
Inadvertent errors	Sometimes we are absentminded and make mistakes without knowing how they happened.
Errors due to slowness	Sometimes we make mistakes when our actions are slowed down by delays in judgement.
Errors due to lack of standards	Some errors occur when there are no suitable instructions or work standards. For example, a machine might malfunction without warning.
Surprise errors	Sometimes errors occur when equipment runs differently than expected.
Intentional errors	Some people make mistakes deliberately.

Poka Yoke implementations can perform three useful functions when these errors occur.

- A mistake is about to occur. The Poka Yoke implemented must provide a warning. The warning may be in the form of a sound, a light or a visual display. Employee intervention is required [62]
- A mistake has occurred, but not yet resulted in a deviation from customer specification. The Poka Yoke implemented must provide control. Control prevents mistakes or defective products from moving through to the next process. Control may be autonomous or require employee intervention. [64]
- The mistake has become a defect, The Poka Yoke implemented must shut down the process. Shutting down the process prevents any more defects from being created and allows for troubleshooting before proceeding. [62]

Poka Yoke improves quality by preventing defects. This is the most desirable outcome for the application to the research.

Jidoka

Jidoka is a Japanese word, that can be translated as "automation with a human touch". Jidoka is the ability for a machine to automatically detect a defect and to stop, preventing the defective product from further processing. [57] Stopping of the production line is fundamental to Jidoka, as it forms part of the problem-solving process. Stopping the product line allows for more effective root cause analysis, as the problem is still fresh and it creates a sense of urgency to solve the problem as fast as possible. [65] Jidoka is key to building quality into the process by preventing defects from occurring and highlighting issues for problem solving. [57]

Tools such as Poka Yoke form part of Jidoka. The ability to apply Jidoka removes workers from doing those tasks, which in high-speed mass production they previously could not do effectively. In flexible packaging, Jidoka is built into the process, but the handling of the defect is different. It would not be economical to stop the line for every defect, as more waste would be created stopping and starting the line to solve the problem. [20] Problem solving is not addressed by a team, but by the operator and/or assistant. The majority of the time, problems are solved while the machines are in operation. Only major defects require the machines to stop. [20] Jidoka implemented was customised to suit the specific manufacturing environment.

Just-in-Time

Just-in-time (JIT) is a key tool strongly associated with Lean manufacturing. JIT is a management concept that attempts to eliminate the source of Muda by producing only that which is required. The right parts, produced at the right place, providing only the quantities required at the right time will achieve a reduction in raw material, work-in-process (WIP), defects and poor scheduling. [54] Customer demand is the driving force behind the system. In the ideal case, JIT systems are purely pull systems, where products are only produced to fulfil actual customer orders. Such operation can often be unfeasible as the total lead time of products is often longer than the demand lead time from the customer. [65]

The customer creates the order, which initiates the production process. The complete process then works back starting from the finished product required. The process preceding pulls the necessary parts and quantities at the required time. This process is replicated per process until the initial raw material required is pulled into the first process. The whole process uses a communication medium to co-ordinate it called "Kanbans". [66] Kanbans are further discussed in the subsequent section. JIT subsequently manages external activities feeding into the production process. These external processes are purchasing and distribution, and they also follow the JIT principles. [66] The scope of the research limits further exploration of JIT purchasing and JIT distribution. The use of JIT in the research will still have a customer-driven demand, i.e. the process upstream from printing, which is laminating or slitting.

Kanban

Kanban is a Japanese term meaning "card". It is a type of visual control process used to replenish inventory and is associated with pull systems such as those required for JIT. [67] The Kanban triggers the pull action of the correct quantity of raw material or WIP for the next process. There are two types of Kanban cards, single and dual cards. [67] Single Kanban cards are used between two work areas as a pull signal. The single Kanban authorises the movement of product from one location or work area to the next. A type of single card Kanban is a product Kanban. Whenever a product is pulled, another product should automatically replace it. If there is no pull request, there is no authorisation, and there should be no actions taken. [67]

Dual Kanban cards would use a product Kanban for the supplier and a conveyance Kanban for the customer. The conveyance Kanban is used for any process where raw material is converted to finished product. It ensures the correct levels of raw materials are supplied and maintained for the conversion process. The raw materials supplied have product Kanbans either at a staging area or the stores. [68] The product Kanban works exactly like previously described. Kanbans do not have to be physical cards. Nowadays they can be electronic, a physical bin (Kanban container) or a demarcated floor area (Kanban square) in the production hall. [68]

Utilisation of Kanbans simplifies processes and allows for visibility. Kanbans are easy to understand and, to a certain extent, easy to implement. [67] The use of Kanban in the research will force the author to explore outside the scope of the research. In order to achieve waste management, the raw material supplied to the printing process must be explored.

Summary of Lean Tools

The reviewed tools are applicable to this research and were utilised. Other Lean tools that aid in achieving– perfection through elimination of Muda– were discovered. These include:

- Single Piece flow: In an ideal manufacturing environment, production is organised for a single piece flow. A single piece flow means semi-finished product moves from process to process to completion, a single piece at a time. The advantages are reduced inventory, short lead times, very high flexibility to customer demand and hence reduced cost. [69] This tool is not applicable due to the quantity of orders and the production lead time versus customer demand lead-time.
- Heijunka (production smoothing): Lean and TPS have a goal to build to customer order. As this is not practically feasible due to variations in customer orders, Heijunka is used to stabilise production. Heijunka takes the whole volume of orders in a period and levels them out to the same amount/mix to be made per day. [65] The most economical production method eliminates high fluctuations of quantity and, product mix and contains low WIP. Production smoothing achieves these outcomes. Production smoothing allows for the best utilisation of resources, as a result it is better suited for implementation in the complete value stream and not just a single process. Heijunka for a single process focuses on Muda elimination through production planning. The key focus area of the research would be too broad, if production planning were considered.
- Takt Time: Takt is German for rhythm or meter. Takt in production translates to the rate of customer demand. In Lean, customer demand drives the rate of production. If production is over the Takt time, the result will be over production. If production is below the Takt time, then bottlenecks occur. Takt time sets the pace of production. [54] The concept of Takt time changes when applied to flexible packaging. The customer who drives the demand is volatile. The margins are never fixed, are based on consumer purchasing habits in the real world, and are dependent on the state of the economy. In each production process, there are internal customers who also have unpredictable behaviours. The cascaded variability makes it difficult to stick to a Takt time, as well as to judge its effectiveness with respect to waste.
- Single-Minute-Exchange of Die (SMED): SMED is the time taken to change over between jobs. It is a measure of the time from the last good piece produced to the first

good piece of the next job. SMED is very good with lead time; it increases profitability and creates availability, but does not control or influence waste. SMED contributes largely to Muda.

2.5.4. Lean Techniques

The *Oxford Dictionary* describes a technique as, “A way of carrying out a particular task, especially the execution or performance of an artistic work or scientific procedure.” [35] With Lean literature, the use of the terms “Lean tools” and “Lean techniques” seem to be intertwined. To distinguish between the two, it can be said that, a Lean technique is used to determine the correct Lean tool to implement. The Lean techniques researched are detailed in the subsequent sections.

Pareto Principle

Attempting to solve every possible problem can be an impossible task. There are many different factors that have varying impacts and consequences. A requirement exists to identify a problem group, classify the problem group and use a model to determine which problem or problem groups will result in the greatest benefit.

Vilfredo Pareto noted that 20% of the population was receiving 80% of the income (hence the more commonly used name the 80/20 rule). The general principle is that a large proportion of results come from a small number of causes, types or circumstances. This is the most important observation and not the exact 80/20 proportion. [70] The visual representation of the rule is displayed on a histogram or bar chart named “Pareto Charts”. [71] Figure 13 displays an example of a Pareto Chart for paint defect frequency.

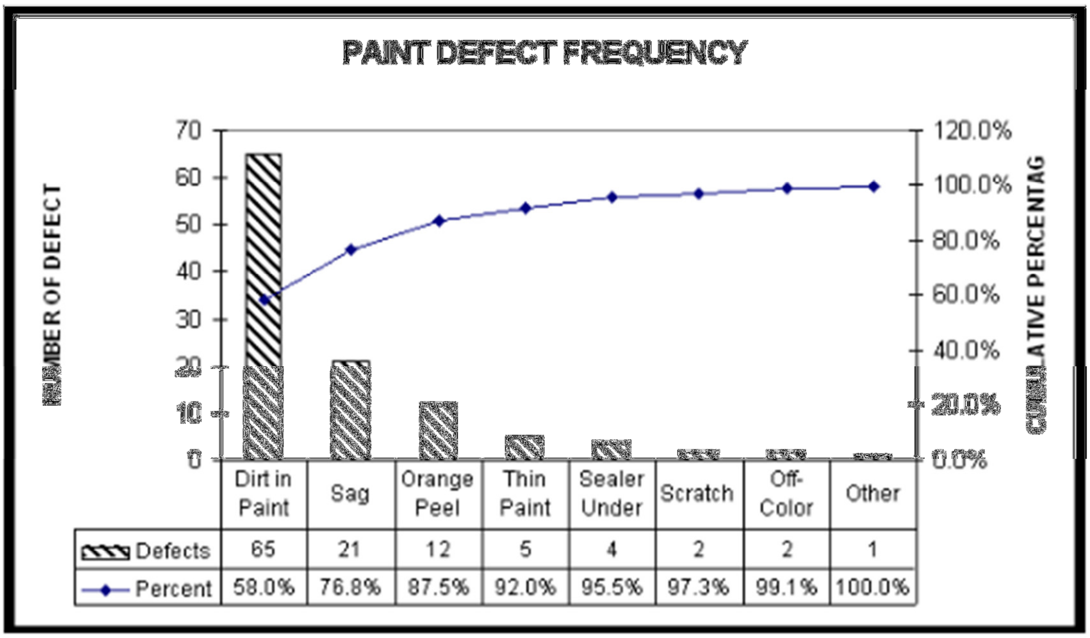


Figure 13: Example Pareto of paint defect [71]

From the chart it is clear which defect should be addressed first. It is important to note that a Pareto Chart should not be taken in a single dimension. The single dimension provides a good starting point but not a holistic view of the problem. The above example shows dirt in the paint as the most frequent defect. If the cost of the defect is considered, orange peel and sag could be a higher priority. [71] The cause, type or circumstance that has the highest financial implication or represents a constraint to the entire process should always be a higher priority. In the research, the Pareto Principle and Pareto Charts will be used to provide the initial focus required to be in line with the research objectives.

Hansei

Hansei is Japanese for "Relentless Reflection" an action required in the pursuit of perfection. Hansei was practised by Taiichi Ohno, and one of the results is a technique called the "5 ways". [59] Ohno asked the question "Why?" five times when a problem was encountered in order to discern the root cause of the problem. Effective counter measures are then developed using further tools and techniques, and these counter measures are implemented. [59] With all actions, there is always a requirement for Hansei. Lean encourages teamwork, but with every action or process, there still needs to be individual accountability. Individual accountability is not to punish or bestow blame, but provides an opportunity to grow and learn to avoid repetition. [54]

Kaizen

No process can be perfect, and in the pursuit of perfection another action required is Kaizen. "Kaizen" is a Japanese word. 'Kai' meaning continuous and 'Zen' meaning improvement and as such, Kaizen is continuous improvement. [67] Kaizen is implemented through formal events known as Kaizen events. The events seek to clearly identify the problem area, implement improvements and monitor their outcome to standardise that which is successful or have another Kaizen event for unsuccessful implementation. There are two levels of Kaizen [54]:

1. System or Flow Kaizen, which focuses on the overall value stream
2. Process Kaizen, which focuses on individual processes.

This research utilised the second– Process Kaizen. The principle behind Kaizen is that small improvements, continuously made in a process, will lead to significant positive change over time. [67] Kaizen will be used during problem solving. It is expected that Kaizen could potentially lead to "Kaikaku". Kaikaku is radical or revolutionary change to the process or value stream, as opposed to Kaizen, which uses incremental changes. [67]

Brainstorming

Brainstorming is a technique that is used to generate as many creative solutions to a given problem as possible. The ideologies behind the technique are listed below.

- Working in a group allows for more ideas to be created than thinking individually. The chain reaction of thoughts created in a group leads to more ideas, i.e. a single idea can stimulate other people's thoughts through association.
- Idea creation is greatest in a criticism-free environment. Criticism leads to conservative ideas and people withholding information out of fear of criticism. [72]

For a brainstorming activity the following should be considered.

- Facilitator: This is the person who will lead the brainstorming activity, ensure participation by all, clarify the rules and ensure they are kept, clearly define the problem for all to understand and ensure people do not wander off topic and start discussing unrelated topics.
- Group: The number of people attending should be between five and ten people. This will ensure the most efficient participation. The members of the group should be as diverse as possible as this will lead to greater idea creation.

- Tools: A white board, flip chart or any device appropriate to accurately record each member's ideas should be used.
- The set of rules: A set of rules will enable clear structured communication channels. The rules must encourage as many ideas as possible and the expansion and/or improvement of other people's ideas.
- A time frame: The brainstorming activity should not carry on too long without beaks. Breaks should be kept short so that momentum is not lost and should take place at regular intervals to keep the mind and body fresh. [72]

The research encountered situations where brainstorming activities was required. The ideas and solutions generated during these activities were not necessarily correct and further analysis tools were used to evaluate the legitimacy of the ideas.

Causal Map

A causal map is a diagram that shows the cause and effect relationships in a system. Casual maps may have outcomes that organisations can extract value from such as those listed below:

- Problem solving and process improvements: Casual maps identify causes that result in goals not being achieved. The effects of removing those causes results in process improvement.
- Provide training and teaching aids: Causal maps are visual and can therefore reduce time required to understand complex relationships.
- Support risk mitigation efforts: Identifying possible causes of problems allows for the development of risk mitigation efforts.
- Identify the critical metric: A causal map will visually show which critical variables organisations should focus on to drive performance. [73]

An example of a casual diagram was developed in the 1960s by Dr. Kaoru Ishikawa. It is named after him, and the Ishikawa diagram is often also referred to as a cause-and-effect diagram or Fishbone diagram due to its function and shape. [73] Figure 14 provides an example of an Ishikawa diagram.

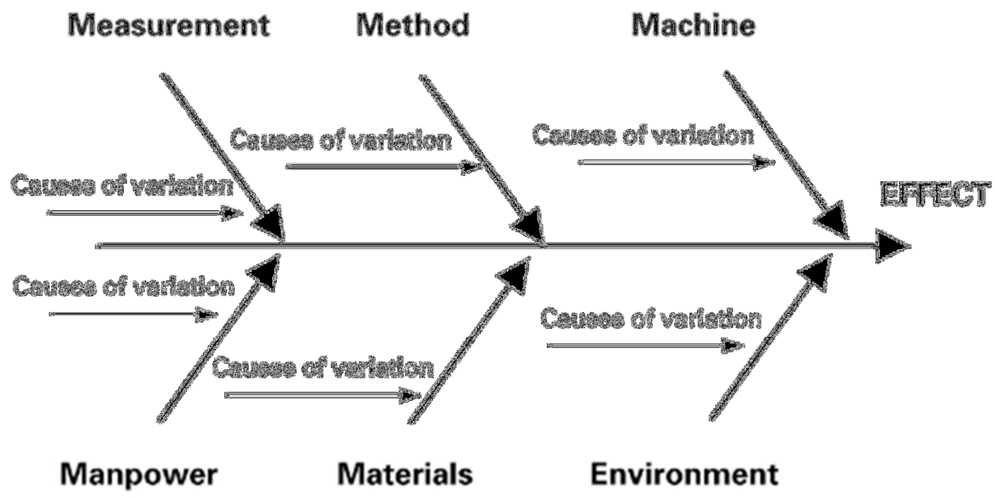


Figure 14: Example of Cause and Effect diagram or Ishikawa diagram [74]

The diagram starts with placing the problem or effect at the head of the main back bone of the fish. The main causes of the effect are drawn as bones off the main back-bone. In manufacturing these main causes are called the 6M's Machine (Equipment) Method, Measurement, Materials, Manpower (Labour) and Mother Nature (Environment). The secondary causes branch off from the primary causes. These are populated using tools such as brainstorming. Further evaluation of the causes can be carried out using other tools such as Pareto to provide a focus area. [73]

Ishikawa diagrams are easy to understand, use a structured approach to determine the root cause of a problem and consider all possible causes within the confines of the primary causes due to group participation. The Ishikawa diagram is limiting as any causes outside of the primary causes are not considered. If the problem is complex, the diagram can get messy and only one variable can be evaluated at a time. [73] Single variable analysis can be challenging but this attribute was desired for and used in the research as it removed complexity.

<u>Benchmarking</u>

"A standard or point of reference against which things may be compared" is the definition of 'benchmark' as given by the *Oxford Dictionary*. [35] Womack and Jones [59] believe an organisation that practises Lean thinking is wasting its time benchmarking against other organisations. The reasoning behind this belief is if the organisation finds itself to be of superior performance to its competitor, it tends to relax and become comfortable with their operation. [59] The benchmarks will not be taken as the absolute goal, as this would go against the principles of Kaizen and Hansei.

FMEA

Failure Mode Effects Analysis (FMEA) is a method to accomplish the following tasks:

- Identify and understand potential failure modes. A failure mode is a way in which a system, component, product or process could fail to perform its designed or intended function.
- Explore the causes of the failure mode. Techniques such as the 5 Why, Ishikawa diagram or brainstorming can be used.
- Obtain the effects of the failure. The effects are the consequences of the failures on the system or end user of a product or process.
- Assess the risk. Determine the risk, frequency or occurrence rate and the severity of each cause based on a ranking scale, where 1 is insignificant/highly unlikely and 10 is catastrophic/inevitable
- Identify and implement corrective actions in the order of severity. [75]

There are 3 types of FMEA: these are listed and detailed below.

- Design FMEA: These are focused on product design at component or subsystem level.
- System FMEA: System FMEA encapsulates the entire value chain or system. They focus on system-related deficiencies, safety, system integration, human interaction and services, the overall system functionality, interfaces and interaction. Nothing low level is included except where single component failure can result in complete system failure.
- Process FMEA: Process FMEA focuses on the manufacturing process to ensure the product is built to specification in a safe manner with minimal downtime, scrap and rework. Process FMEA assumes the design is perfect. [75]

Within process FMEA there is also an approach called Failure Mode Effects and Critical Analysis (FMECA). The added step involves a more formal critical analysis requiring objective data and calculations. Although FMECA would provide a more complete solution, it will not be used as the author feels it will draw out and disrupt the brainstorming activities. Most of the people participating in these sessions are not at a level that will allow for seamless analysis. Process FMEA will be used during brainstorming activities, and other tools such as Pareto, Severity Rating and/or financial value will be used to refine the causes list. Only those causes chosen were further investigated and supporting data gathered. Analysing and gathering data for all causes would be too time consuming and not financially viable.

Summary of Lean Techniques

The Lean techniques mentioned in the previous sections will be utilised in the investigation. Other Lean techniques were discovered during the literature review. These are detailed briefly and a justification to their exclusion provided.

- Plan Do Check Act (PDCA) – This is an improvement cycle used for problem solving. When the area of concern is not within the boundaries of optimal operation the cycle is initiated. "Plan" is the development of a hypothesis with the end customer requirements as the benchmark. A timeline is also developed. "Do" is the implementation of the planned improvement. "Check" is where the implemented solution is checked against the planned solution. If there is a deviation from the plan or the optimal operations boundaries, further investigation into why is conducted. "Act" is based on the outcomes of "check" and will detail the necessary action required based on the checked results before the cycle repeats itself. [67] This improvement cycle though achieving results in many spheres, was not applicable to the area of focus. There are too many dynamic variables and a large, erratic product mix to allow for the cycle to be accurately completed. Planning, doing and checking can all happen under differing conditions. The conditions play a big part in the manufacturing process, and therefore there is no guarantee of uniformity. Additionally, changes in the process need to be successful at high running speeds (200-300m/min) and following the cycle and using the Lean tools available without measured numeric results (current and historic) will create a large amount of waste. The impact means that this method is not financially viable.
- Total Productive Maintenance (TPM) – TPM is a proactive progressive maintenance methodology that requires everyone on the shop floor to contribute by doing basic maintenance work. Operators are trained to do minor fixes, lubrications, inspections and cleaning while the maintenance team focuses on root cause analysis to prevent similar breakdowns. The objective is to extend equipment life, lower maintenance costs, improve utilisation and quality and have a factory full of reliable equipment. [76]

Although TPM does contribute to achieving the objective of this research, its implementation falls outside the scope defined in Section 1.6.

2.5.5. Implementations of Lean

Lean has been implemented in different ways across different industries and has achieved different results based on the tools and techniques used. Table 7 shows a summary of some of the literature on Lean.

Table 7: Literature reviewed using Lean (created by author)

Title	Author(s)	Aim	Tools & Techniques	Outcomes Achieved	Ref
Increasing competitiveness of service companies developing conceptual models for implementing Lean management in service companies	Damrath, Felix	Apply Lean in service companies and investigate whether a similar outcome to that of manufacturing can be achieved	-VSM, 5S -Standardisation -Heijunka, -Jidoka -Single piece flow -PDCA Kaizen	-Lean implementation framework -Understanding of current and target processes -Identification of weaknesses, errors and shortfalls -Ability to improve on identified problems -Reduced service time -Improved workflow -Even distribution of work load -Problem solving methodology	[77]
Waste in Lean Construction - A case study of a PEAB Construction site and the development of a Lean Construction Tool	Arleroth, Jens; Kristen, Hendrik	Bridge the gap between theory and practise in Lean construction. Implement Lean and monitor potential consequences	-VSM, -Flow, -Pareto, -Ishikawa diagram, -5 Whys, -JIT, Kaizen, Standardisation, Reduction of Muda.	-Measurement and classification of waste -Reduced building time -Safer working environment -Reduced inventory -Improved SOP -Continuous improvement ideology -Reduced lead times, defects, and workforce -Increased construction capacity	[50]
The application of Lean manufacturing principles in a high-mix low-volume environment.	Dudley, Amber N	Apply Lean manufacturing principles in a highly complex environment, process flow improvement and understanding the results of team involvement in production improvement initiatives	-VSM -Pareto -5S -Standardisation	-Current state of process -Identification of key problem areas -Task prioritisation -Improved work flow -Safe and clean working environment -Reduced variation in parts and working procedure -Employee morale boost -Future state analysis -Increased output	[78]
The application of Lean Principles in the Fast Moving Consumer Goods (FMCG) Industry	Aljunaidi, Alaa; Ankrah, Samuel	Investigate if Lean is applicable in FMCG industry, identify the applicable tools, develop a framework for implementation and determine potential benefits of Lean implementation	-Reduction of Muda, -JIT, Kanban -Jidoka -Heijunka, SMED, 5S -Visual management, Poka Yoke, VSM, Kaizen, Standardisation	-Improved performance efficiency -Reduced waste, cost, and inventory -A safer and cleaner work environment -Better work flow -More modernisation through automation -Development of best practise	[79]

Although Lean manufacturing started in the automotive industry, its principles have been adapted and successfully implemented across a broad spectrum of industries. The literature reviewed in Table 7 shows some of the benefits of Lean implementation, which include:

- reduction of lead time;
- increased safety;
- increased production efficiency;
- reduction of waste;
- reduction of inventory;
- cleaner work environment;
- satisfied employees;
- improved quality and reduced defects;
- increased and better utilisation of production lines;
- increased staff competence and problem solving skills;
- reduction of staff headcount;
- reduction of operating errors;
- ultimately a better product and/or service at a reduced cost with a reduction in resources. [77], [50], [78], [79]

2.5.6. Shortcomings of Lean

Lean is a great tool and has been proven time and time again to be successful. However, it does have shortcomings. According to Chen et al., [80] Lean does not look after the work force. A Lean organisation will have redundant employees, as the focus is on multi-skilled employees doing multiple tasks. The best employees are kept and will have to work hard, but they can become highly stressed due to the pressure of always improving and the pressure to keep their job, as more is demanded with fewer employees. [80] Another shortcoming of Lean is the reduction of inventories to reduce waste. In some cases having a bigger inventory lot is desirable as the raw material might have long lead times (as is the case with the FPC) or there could be supplier inconsistencies (defects, delay in deliveries, etc.). [80] In flexible packaging, stoppages on the machine are undesired. Stoppages result in waste of raw material and reduce production efficiencies and profitability. Lean calls for stopping the line to solve problems, but this is not always feasible in flexible packaging.

With Lean, most of the analysis and improvement is focused on the supporting services to the process but little is covered that focuses on statistically controlling the process itself. There needs to be a focus on the measurement and verification within the process and the systems in place, in order to evaluate variations. [81] In the complex process of flexible packaging manufacturing, the process has a large dependence on data. Due to high product mixes, the volume of production and the nature of the operation in a FPC, a singular Lean approach to reduce production and process waste, manage it and gain the maximum contribution towards profitability is insufficient. [56] For this reason, the Six Sigma strategy will be reviewed in Section 2.6.

2.6. Six Sigma

Six Sigma is an improvement strategy that aims to eliminate defects in the manufacturing process through the reduction of variation. This results in optimised operation and improved quality. [56], [82] The term "Sigma" comes from the Greek letter 'σ', which is also used as a symbol in statistical mathematics to represent standard deviation. Standard deviation is a unit of measure that expresses the distribution or spread about the mean (μ) of a process. [83] Six Sigma is thus six deviations from the mean or customer specification. The mean in question is the mean of defects per million opportunities (DPMO), where an opportunity is every time a process is run. DPMO is calculated by taking the number of defects dividing by the number of units produced then multiplied by 1 million. [67] The value obtained corresponds to the sigma level achieved. Refer to Table 8 which displays the Sigma performance scale.

Table 8: Sigma performance scale [84]

Sigma Performance Level	Defects per Million Opportunities	Process Yield	Estimated Cost or Poor Quality (% Revenue)
1.0σ	670 000	33%	>40%
2.0σ	308 537	69.2%	30-40%
3.0σ	66 807	93.32	20-30%
4.0σ	6 210	99.38%	15-20%
5.0σ	233	99.9767%	10-15%
6.0σ	3.4	99.99966%	<10%

Quantitatively, Six Sigma sets a goal of 3.4 defects per million good products. [84] Six Sigma is a newer methodology than TPS. It originated at Motorola in the 1980s to reduce process variation and to better compete with their Japanese counterparts. The CEO at the time, Bob Gavin, set a goal of 10-fold improvement across all products and in service quality for every two-year period. Motorola achieved an increase in quality, a reduction in operating cost, a decrease in cycle time and a resulting increase in customer satisfaction through employing this strategy. [85] Other companies including ABB, Nokia, Toyota, DuPont and AlliedSignal further developed and employed Six Sigma. One such success story was General Electric in 1995, who recorded $1-2 billion in savings as a result of Six Sigma implementation. [86] Six Sigma is a data driven philosophy with a high dependence on measurement and statistical analysis to improve processes. Six Sigma is best used for repetitive processes such that process variation can be eliminated. [87] In order to implement Six Sigma, a project team is required. Due to the analytic nature of the methodology, the project team will require certain skills and/or qualifications. These requirements are clarified in the subsequent section.

2.6.1. Six Sigma Project Team

A Six Sigma project follows a very systematic and methodical approach. The Six Sigma project team has a pyramid-type organisational structure and defined roles, which require a certain level of training. For implementation, this structure is needed, as it will deal with issues of resistance and allow factual decisions to be taken. The project team consists of the following roles: Executive Sponsor, Champion, Master Black Belt, Black Belt and Green Belts. [88] This section will introduce the project team roles in the order of the hierarchy.

The Executive Sponsor role should be occupied by someone from top management. This ensures the project gets the required resources since someone of authority is available to make decisions. The Executive Sponsor should be involved in project selection because they have a good understanding of which projects fall in line with the company's strategic direction. [88]

The Champions should be senior managers. These are managers who have the ability to: drive the financial results, achieve planned objectives, supervise the project, plan and keep the project aligned to the company's strategic objectives. The Champion reports to the Executive Sponsor. [88]

The Master Black Belt is the technical specialist, who provides support on data analysis and, mentoring and training for the downstream roles, namely the Black Belt and Green Belt. Master Black Belts ensure the Six Sigma improvement procedure (discussed in section 2.6.2) is adhered to. Master Black Belts have the same technical proficiency as Black Belts, but also possess the comparable managerial and leadership skills as Champions. [88]

The Black Belt is the full time Six Sigma project leader and manager and handles most of the detailed work. They are also very technically proficient in Six Sigma methodology and tools as well as statistical analysis. They are the cornerstone to the successful implementation of a Six Sigma project and provide mentorship to Green Belts. To qualify as a Black Belt, the individual is required to do Six Sigma training (four to five weeks spread over a period of four to five months) and complete a project within six months with a yearly saving to the bottom line of at least 175 000 – 250 000€ (at the time of compiling, roughly a minimum of R2.7 million). [88]

Green Belts work with Black Belts through the problem solving phases, and their involvement is usually part time. They should possess strong analytical skills and have sufficient knowledge of Six Sigma tools and methodologies. Their knowledge grows through interaction with and training from Black Belts during projects. To qualify as a Green Belt the individual is required to do a couple of weeks of Six Sigma training and deliver a project with a yearly saving to the bottom line of at least €50 000 – €75 000 (at the time of compiling, roughly a minimum of R 775 000). [88]

The project team is not rigid in its composition. Master Black Belts are uncommon, the role of a Master Black Belt can be satisfied with a Champion and a Black Belt. Where Black Belts are not available, Green Belts under the supervision of Champions, can lead projects. The roles are decided by an individual's expertise. The whole project relies on teamwork. Process owners should also be included in the project team as they can provide technical knowledge of the process as well as ensure sustainable improvement. [88] Now that the project team roles are clarified, the methodology to be used by the project team to implement Six Sigma is discussed (Section 2.6.2)

2.6.2. Six Sigma Improvement Procedure

In the 1980s, Six Sigma used a process improvement methodology of measure, analyse, improve and control (MAIC)· [86] By the 21st century the improvement methodology had evolved to include an additional step of "Define". Inspired by Demining's Plan, Do, Check, Act (PDCA), MAIC became what is commonly known today as "DMAIC" (Define, Measure, Analyse, Improve and Control). [86] DMAIC is used to achieve successful implementation. The DMAIC methodology is explained below. Some of the tools and techniques mentioned below have already been explained in Lean, Section 2.5.3 or section 2.5.4. New tools and techniques are further explained in Section 2.6.3.

"Define" is used to clearly identify the problem statement, set-up the project, goals, targets, and project teams and prepare timelines and schedules for the Six Sigma initiative. Focus should be put on process mapping and identifying the related stakeholders. Supplier, Input, Process, Output and Customer (SIPOC) diagrams and voice of the customer (VOC) can assist in determining the customer's requirements. [56], [87], [82], [88]

The "Measure" process is then followed to attain the current state of the project (data collection) to allow for benchmarking. In order to benchmark, the critical-to-quality (CTQ) parameters (process factors or critical X's and customers' opinion) of the study need to be selected. In addition, graphical analysis of the data can be carried out in this section such as Pareto charts. The target can then be defined. [56], [87], [82], [88]

"Analyse" uses various techniques such as Fishbone Diagrams, Process Maps, Failure Mode and Effect Analysis (FMEA) and Root Cause Analysis (RCA) to identify the sources of variability in the process. [56], [87], [82], [88]

The next step, "Improve" is geared towards obtaining potential solutions that are low cost with the highest effectiveness to address the root cause of the problem. Validating these solutions is carried out through some sort of testing. The source of the information and knowledge to aid the "Improve" phase is from the "Measure" and "Analyse" phase. [56], [87], [82], [88]

Finally, the "Control" phase is used to verify the process improvements and stability. The critical X's need to be under statistical control and outputs must be monitored. The ultimate goal of the control phase is to ensure the improvements are sustained and become a standard operating practise. Commonly used tools in the Control phase include: Poka Yoke, Standardisation and Statistical Process Control (SPC). [56], [87], [82], [88]

Further improvement has led to a new methodology called Design For Six Sigma (DFSS). This methodology was shaped around the principles of basic Six Sigma. DFSS focuses on new product and process design rather than on improving existing products and processes, which differentiates it from Six Sigma. DFSS has its own improvement methodology - Define, Measure, Analyse, Design and Verify (DMADV). [86] DMADV methodology will not be further explored due to the application of DFSS, the problem statement provided and the objective of the research.

2.6.3. Six Sigma Tools and Techniques

Six Sigma uses various concepts, tools and techniques to achieve statistically controllable inputs. As Six Sigma is newer than Lean, some of the tools used are the same as previously described in Lean Section 2.5.3 i.e. Standardisation and Poka Yoke. Similarly, techniques such as Pareto, Causal Maps and Benchmarking are shared. Tools and techniques shared will not be repeated, but those specific to Six Sigma are further elaborated on. The subsequent section contains a topic-by-topic break down of the tools and techniques available to Six Sigma, with a focus on those applicable to the research.

Six Sigma Fundamental Equation

The Fundamental Six Sigma equation is $Y=f(x)$, where Y represents the output variable to satisfy the customer requirements and X_p are process inputs ($_p$ is an integer) that are identified (See Figure 15 showing a model of a process). Noise (n_n) are factors that cannot be controlled within the Six Sigma equation such as: unexpected customer demand or environment, etc. The equation describes that the output (Y) is a function of inputs (X_p). Optimising these process inputs (critical X's) results in satisfying customer requirements and leads to; yield improvements, cycle time reduction, resource reduction or a reduction in variability. [89]

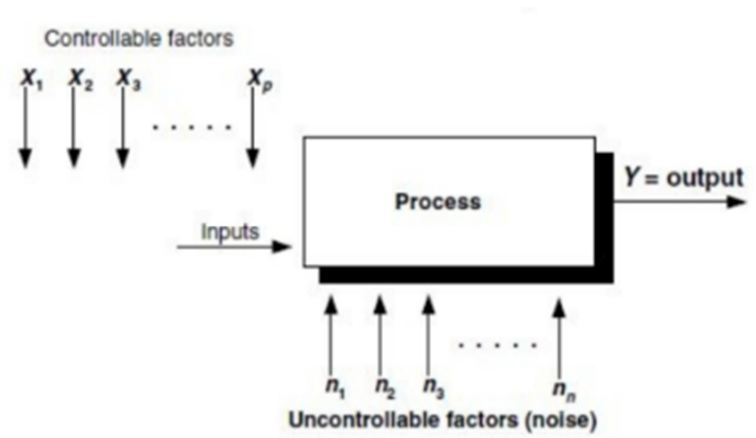


Figure 15: General model of a process [89]

The fundamental equation contains X's in order to produce Y's. X's are the drivers of Y's, and the fundamental equation is the building block of the DMAIC improvement process. Each phase can be described in the form of the fundamental equation to show the X-Y relationship through the DMAIC process as demonstrated below. [90]

Define: Using SIPOC, potential X's and Y's are obtained. To obtain a clear and measureable Y that is in line with the company's objectives, VOC is used. The outcome achieved is the main project Y (referred to as Y' from this point on) and how to measure it. [90]

Measure: The potential X's that have the most influence on Y' are reduced to the critical and measureable few. A prioritisation matrix or multi-voting technique during brainstorming can be used to achieve this. At this point the critical X's are based on process expertise not facts and data. The collection of data through measurement for critical X's and Y' is planned and executed. The outcome achieved is the prioritization of X's and the measurement of X's and Y'. [90]

Analyse: Graphical and statistical tools (histograms, causal maps) are used to identify cause and effect or test X-Y relationships. X-Y relationships are verified and quantified. The previous qualitative analysis now has supporting quantitative data. The critical few X's with the greatest impact on Y' are known. The achieved outcome is to test X-Y relationships and to verify and quantify the critical X's. [90]

Improve: Potential solutions are obtained (using various tools previously discussed) that improve Y' by addressing the critical few X's. FMEA can be used to analyse how Y' could fail based on potential causes –X's that are new or previously identified. Data is gathered again to illustrate if the identified solution really has improved Y'. The outcome achieved is to address the critical few X's and implement solutions to improve Y'. [90]

Control: The control phase is to ensure the improvement in Y's performance is sustained over time. Tools such as control charts can be used. The outcome achieved is to monitor the X's and Y' over time. [90]

Critical-to-Quality

Critical-to-quality (CTQ) is a performance indicator. It is a localised quality parameter that aligns the wants and needs of the customer with key output characteristics of a process. CTQ's are measurable elements or attributes that are critical in the eyes of the customer. [91]

KPI

For the successful implementation of a Six Sigma project, well defined Key Performance Indicators (KPI) are required. KPI's are required to drive operational improvements and set targets and aspired outcomes of projects. KPI's can take on many forms and are specific to the objectives of the company. Robert S. Kaplan and David P. Norton [92] in the early 1990s developed a KPI metric that considers four perspectives. KPI's can be defined by the financial perspective, customer perspective, internal business process perspective and the learning and growth perspective. The four perspectives are called "the balanced score card".

- The financial perspective provides shareholders with information of how well the objectives of the project contribute to the bottom line such as return on Investment (ROI), economic value added or return on capital. [92]
- The customer perspective provides a measure of how effectively the objectives of the project create value for the customer. This is not easily obtained as multiple approaches and consultations with the customer are required to ensure their stated and unstated expectations are delivered i.e. customer satisfaction levels, quality, retention rates or on-time delivery rate. [92]
- The internal business process perspective includes all the organisation's processes that were intended to provide value to the customer. These include cycle time, defects rate, quality, throughput rates or on-time delivery rates. Organisations that excel in this aspect have high levels of customer satisfaction and strong customer relationships. [92]
- The learning and growth perspective include the organisations skills and capabilities to support the internal processes that deliver value to the customer, such as absenteeism, employee satisfaction, employee turnover rate or percentage of internal promotions. [92]

The balanced score card provides financial and non-financial measurement categories to achieve operational excellence. KPI's should follow suit and can also be built into the framework of the balanced score card.

Choosing the correct KPIs can be defined by the acronym SMART which is outlined below.

- Specific – KPI's should be focused and process based.
- Measurable – KPI's must be quantitative and easily determined.
- Achievable – KPI's should be set within benchmark levels yet still remain reachable. KPI's set at unreachable targets demoralise employees and subsequently can have a negative effect on organisational performance.
- Relevant – KPI's should be in-line with the organisation's objectives.
- Time bound – KPI's should never be open ended, as this creates no urgency to reach the set target. A specific time period should be chosen. [92]

SIPOC

Supplier, Inputs, Processes, Outputs and Customer, which has the acronym SIPOC, establishes the boundaries of a business process and shows how these entities interact around these boundaries. SIPOC models illustrate clearly the beginning of the process (resource and suppliers) and the end points of the process (outputs and customer). SIPOC models divide the entire scope of the Six Sigma project into manageable sub-sections through a process-driven approach. [93] Below is a simple example to illustrate how SIPOC can be used in the define stage. The example is the process of making a photocopy. (See Figure 16)

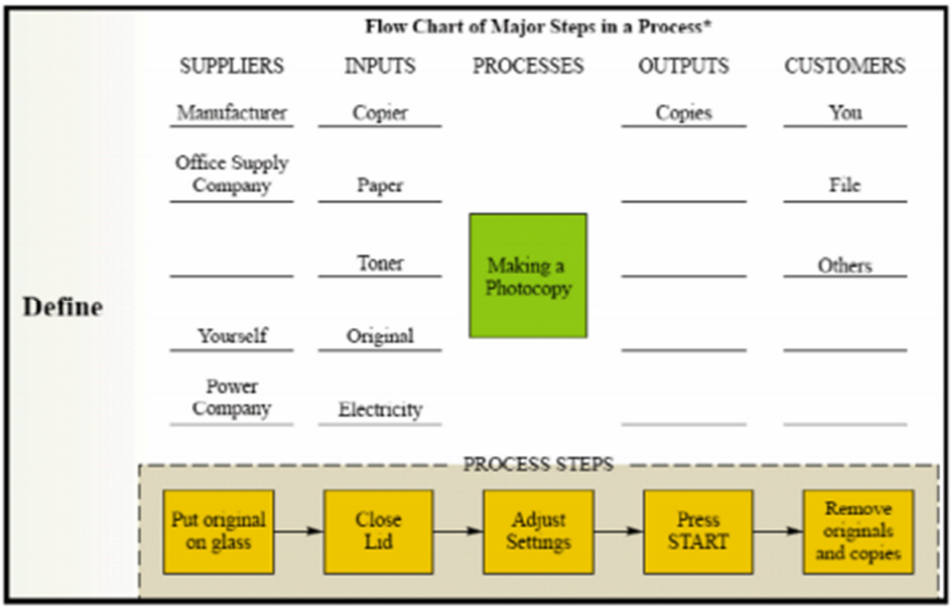


Figure 16: An example of SIPOC implementation [94]

The steps followed while developing the chart in Figure 16 are listed below. The same steps are used to develop any other chart for any process. With the project team the SIPOC chart can be developed interactively using a flip chart using the chronological steps below.

1. Start by listing the process. The process map should be a high level process map with four to five steps.
2. Identify the outputs of the process.
3. Identify the customers who will receive the outputs from the process.
4. Identify the inputs required for the process to be functional.
5. Identify the suppliers of those inputs. [94]

Root Cause Analysis

The *Oxford Dictionary* describes a problem as, "a matter or situation regarded as unwelcome or harmful and needing to be dealt with and overcome". [35] From this definition, a problem represents an unwanted state, and the definition encourages the elimination of this unwanted state. Behind every problem there is an underlying cause or causes that resulted in the problem. Clearly establishing the cause or causes will make eliminating the problem easier. [95] Root cause analysis (RCA) is a structured methodology used to identify the true cause of a problem and propose the actions required to eliminate it. [95] The methodology does not represent a singular approach, but rather a collection of tools and techniques where the appropriate tool or technique must be used to uncover the true cause of a problem. The group of tools are chosen based on the desired outcome. The proposed outcomes and the tools relevant for the RCA as described below. These tools are often used together, sequentially or applied at different points in the RCA. [95] Only the tools that will be utilised in the research will be expanded upon.

Problem understanding focuses on understanding the problem and is the first step before starting the analysis. Tools to achieve this are flowcharts, critical incidents and spider charts. [95] Flowcharts provide complete details and an understanding of the process or processes. Flowcharts map the process to visually illustrate where problems occur and which problems to address. [95] Flowcharts that simply depict the sequence of events will be used.

Critical incidents help to understand the nature of the problem and its consequences. They aid in understanding the problem to be solved. They are best utilised in group environments where the most critical incidents are obtained through ranking. These provide a starting point to RCA. [95] Spider diagrams provide an external comparison of processes. They provide a graphical representation that compares the seriousness of the problem and the business' performance of the process with other organisations. In the competitive industry of flexible packaging, such information for comparison could not be obtained ethically. Therefore, this tool is not used. [95]

Problem cause brainstorming involves tools that can be applied throughout the different stages of the RCA. The expected outcome is the generation of many ideas about possible causes. The techniques used are mainly group work orientated, for example, brainstorming, Is-Is Not matrix and paired comparisons. [95] The brainstorming technique was discussed in Section 2.5.4.

Is-Is Not matrix is a technique where a group separates factors in a problem which are relevant from those which are not. It helps the group focus on the true causes and remain within the boundaries of the problem. The Is-Is Not analysis is used early in the analysis and is then followed with a probing method such as 5 Whys, Ishikawa, etc. [95] Paired comparisons is a technique where participants choose between pairs of competing alternatives. By comparing pairs of alternatives to the objectives, tasks are moved up or down on the priority list of cause. This technique will form part of the RCA within the research scope. [95]

Problem cause data collection uses tools to systematically collect data that relates to the problem and the cause. Tools used for collecting data include sampling, surveys and check sheets. [95] Sampling is a tool whereby data on a large population is summarised by collecting a small sample size. This method is practical, saves time and money and is easier to manage. Choosing the correct sample type and/or sample size becomes of utmost importance, as misleading conclusions can be reached if the wrong sample is chosen. [95] The FPC is a high-mix, high-volume manufacturer. Therefore, sampling must be used since realistically not all variants can be analysed. Sample size will be determined using either the table in Figure 17 or logical selection.

Required Sample Size†

Population Size	Confidence = 95%				Confidence = 99%			
	Margin of Error				Margin of Error			
	5.0%	3.5%	2.5%	1.0%	5.0%	3.5%	2.5%	1.0%
10	10	10	10	10	10	10	10	10
20	19	20	20	20	19	20	20	20
30	28	29	29	30	29	29	30	30
50	44	47	48	50	47	48	49	50
75	63	69	72	74	67	71	73	75
100	80	89	94	99	87	93	96	99
150	108	126	137	148	122	135	142	149
200	132	160	177	196	154	174	186	198
250	152	190	215	244	182	211	229	246
300	169	217	251	291	207	246	270	295
400	196	265	318	384	250	309	348	391
500	217	306	377	475	285	365	421	485
600	234	340	432	565	315	416	490	579
700	248	370	481	653	341	462	554	672
800	260	396	526	739	363	503	615	763

Figure 17: Table for determining sample size [96]

Surveys can be used to collect qualitative data and opinions, but their uses and applicability can vary. Check sheets use predetermined questions to systematically collect data. Check sheets are used when data can be observed and collected repeatedly. However, with check sheets there is the potential to misrepresent information, as the external conditions are not considered. [95] Flexible packaging parameters vary greatly with atmospheric conditions. There are multiple approaches and/or solutions to address this variation. Therefore, check sheet data is likely to yield incorrect conclusions, and check sheets will not be utilised based on this potential for misrepresentation.

Problem cause data analysis contains tools used to make sense of the data collected. Different approaches can be used on the same data with varying outcomes, but these all ultimately converge to a common conclusion. These tools include histograms (discussed in Section 2.5.3), Pareto Charts (discussed in Section 2.5.3), scatter charts, relations diagrams and affinity diagrams. [95] The tools not previously discussed are described below.

- Scatter charts plot the relationship between two variables, X and Y. [95]
- Relations diagrams are a tool to help identify logical relationships in a complex system. They are used for cause-effect relations where a network of causes and effects

are linked with arrows pointing from cause to effect. Arrows only flowing out of the cause show a root cause, which should be eliminated. [95]

- Affinity diagrams are charts that help correlate apparently unrelated causes, ideas or concepts such that they may be explored together more closely. [95]

Root cause identification is the ultimate desired outcome. Tools are used to more deeply analyse the problem's root cause. These tools include cause-and-effect charts (discussed in Section 2.5.3), the 5 Whys (discussed in Section 2.5.3), matrix diagrams and fault tree analysis. [95] The previously un-described tools are outlined below.

- Matrix diagram is a visual aid used to spot relationships between factors and analyse the causal relationship between them. The diagram can be used to determine which different causes contribute the most to the problem. [95]
- Fault tree analysis is used to traverse forward in time to foresee any problems that could occur in a system or process.

Root cause elimination is an outcome that is made possible through root cause identification. Once the root cause is known, solutions can be devised to remove it. The techniques used include six thinking hats, theory of inventive problem solving (TRIZ) and systematic inventive thinking (SIT). [95]

- Six thinking hats is a technique that forces people to think laterally and consider different situations by assuming different roles. [95]
- TRIZ is a technique where the problem is broken down into smaller, more manageable and recognisable engineering problems. This process allows for better problem solving, as the small problems usually have known solutions. [95] This is a desired technique because FPC systems are complex. It will be used with further supporting tools to eliminate root causes.
- SIT is a technique built upon TRIZ. It uses four principles that require a changed mind-set in the process of approaching a problem. [95]

Solution implementation contains techniques used to aid in successfully making changes during the process of implementing the devised solution. RCA uses multiple tools and involves drilling down into the problem. The analysis phase and the application of the above-mentioned tools require a skilled person.

Statistical Process Control (SPC)

The extent to which a product meets the customer specification or satisfies the customer's intended use is deemed the product quality. In simple terms, a product of the highest quality meets all the requirements defined by the customer. Statistical Process Control (SPC) is an effective technique that when used correctly, can help achieve high product quality. [97] According to Dr. Walter A. Shewhart, [98] variation of a process results from the following two sources:

1. Common causes are inherent in the production system and include setting up methods, atmospheric conditions, machining operations and measurement systems. Common cause variability can be non-controllable or controllable. Controllable variability often cannot be reduced or eliminated economically. [98]
2. Special causes result from particular operational reasons such as operator mistakes, machine failure, defective material and tool wear. These can lead to serious quality problems and are all, to some extent, preventable, controllable or correctable. [98]

Dr. Shewhart developed a tool, the control chart, which is critical to SPC, as it monitors industrial processes such that product quality can be controlled. Once the common causes have been quantified, the control charts are used to determine whether the special causes are affecting the process. If the special causes can be detected and eliminated, the process and product quality can be improved. A process is under statistical control if special causes are within upper and lower limits determined for the data collected to achieve the customer specification. If process parameters such as standard deviation and mean are constant in most applications this is considered sufficient. [98] Shewhart's control charts offer single variable control. In complex processes there is usually a correlation or interaction between variables. A singular shift in the mean and standard deviation is insufficient for analysis because changes in individual variables must be analysed with respect to each other. This is achieved using Multivariate Statistical Process Control (MSPC). [97] For the scope of this research, MSPC is not required and therefore it will not be explored further.

2.6.4. Application of Six Sigma

Six Sigma has been implemented across many different industries, achieving similar results based on the tools and techniques used. Table 9 shows a summary of some of the literature on Six Sigma.

Table 9: Literature reviewed using Six Sigma (created by author)[1]

Title	Author(s)	Aim	Tools & Techniques	Outcomes Achieved	Ref
Applying Six Sigma to manufacturing processes in the food industry to reduce quality cost	Hung, Hsiang-Chin; Sung, Ming Hsien	To reduce operational cost and improve financial performance in order to better face an increasingly competitive market.	-DMAIC -Process flow diagram -Pareto chart -Tree diagram -Benchmarking -KPI -Sampling -Ishikawa diagram, -Brainstorming -FMEA -SOP -SPC.	-Identification and prioritisation of source of variation and wasteful expenditure -The ability for the case company to execute a Six Sigma project -A reduction in shrinkage defect from 0.40% to less than 0.14% and a more than 70% reduction in shrinkage defect in 6 months -Sustainment of the reduction for a further three months, which was the verification period	[99]
Using Six Sigma to achieve sustainable manufacturing - A case study in aviation company	Zhang, Min	To use Six Sigma tools and principles to provide a systematic framework that can be adapted and implemented by organisations to achieve sustainable manufacturing.	-DMAIC -Process mapping -Ishikawa diagram -RCA -Benchmarking -Statistical analysis -KPI	-A sustainability framework focused on data-driven decision making -Validation of the merits of the framework through implementation at a case company -Improvement in social, environmental and economic factors that influence sustainability	[100]
A Six Sigma project at Ericsson Network Technologies	Nyren, Gustav	To use Six Sigma methodologies and tools to manufacture thinner cables without compromising on insulation, electrical and mechanical properties.	-DMAIC -Benchmarking -Process mapping -Pareto diagrams -SPC -Control chart -Ishikawa diagram -Critical-to-Quality	-Identification of influencing variables -Optimisation to achieve a stable, repeatable process	[101]

[1] The table continues over two pages

Title	Author(s)	Aim	Tools & Techniques	Outcomes Achieved	Ref
Implementation of the Six Sigma methodology in the maintenance process of Crown Hellas Can.	Zaparta, Zaeiriou	To apply the Six Sigma technique of problem solving to achieve higher efficiency from maintenance operations.	-DMAIC -VOC -CTQ -Process mapping -SIPOC -KPIs -Affinity diagrams -Fault trees -Histograms -Pareto charts -Scatter Plots -Brainstorming -FMEA -SPC	-Establishment of a numeric relationship between defects and breakdown duration and frequency -A finding that 7.3% of the defects were due to employee skill -Implementation of a programme to educate all employees from the top management down to the floor on Six Sigma -Improvement of the maintenance effectiveness and viability of having a Computerised Maintenance Management System (CMMS) -Improved results in terms of change of company culture and systems approach, as Total Quality Management (TQM) formed the backbone of the CMMS operation -Achievement of statistically driven maintenance	[102]

Six Sigma has been proven to have many benefits across different industries through the application of the DMAIC methodology. DMAIC forms the cornerstone of Six Sigma. The literature reviewed in Table 9 describes, the many benefits that can be achieved using this methodology such as:

- a methodical approach to problem solving;
- an ability to prioritise problems and address those with the biggest impact first;
- data driven decision making, no guess work;
- increased understanding of process;
- reduced process variability;
- increase in quality;
- sustainable and measurable improvements;
- increase in profit margin;
- improved customer satisfaction (internal and external)
- increased employee empowerment and education;
- positive change in company culture. [99], [100], [101], [102]

2.6.5. Shortfalls of Six sigma

Six Sigma is a great methodology and contains many helpful tools which when implemented correctly yield good results. Its power lies in data driven statistical analysis. At the same time, this requirement is a limitation. Six Sigma requires an educational level of competency from the project team as well as the shop floor. The project team requires training, which can be too expensive for companies requiring project implementation. [103] Six Sigma training is further criticised by Antony [102] as being non-standardised for the different belt rankings. Antony further mentions that the system could easily evolve into a bureaucratic menace where companies are chasing “belt” qualifications, with the same people being afforded the opportunities and the company losing focus on the issue on hand. [102]

As previously mentioned, the case company has a shortage of skilled, educated shop floor employees. Mika [104] believes Six Sigma does not cater for the “average” worker on the floor due to its highly technical nature, and could result in rejection from the work force. [104] According to the problem statement, the Six Sigma methodology does not achieve some desirable outcomes required. These are described below.

- There is no direct focus on improving the speed of the process. Six Sigma focuses on reducing waste. And by reducing waste, it assumes that Muda is taken care of.
- There is no focus on support services to the production process. For example there is no consideration for reducing inventory. Inventory ties up cash flow.
- Financial gains take time due to the training required and the project implementation process. Time is required to ensure accurate data collection and analysis. [81]

Six Sigma is better suited to address the production waste (defects or waste), but not the process waste (Muda). Waste management of solely production waste is a costly exercise and the FPC is already struggling financially. Waste management considers the complete spectrum, so neglect of one type of waste would not be fulfilling the requirements of the research. Some quick wins are required if the profitability of the FPC is to be considered along with sustainable solutions. The FPC requires short to medium length projects in order to quickly realise the value of waste management. The realisations from the short projects can be used to fund the lengthier ones. Six Sigma outcomes are desirable in part but a combination of Six Sigma and Lean principles would provide the best fit solution. The two methodologies complement one another in areas where they are deficient individually. Section 2.7 looks at this combination

2.7. Lean Six Sigma

Lean Six Sigma is a combination of the Lean (TPS) and Six Sigma concepts. The two concepts complement each other and achieve greater results when used to collectively improve overall equipment effectiveness (OEE), reduce cost and eliminate waste. [56], [82] Breyfogle *et al.* [105] believe "In a system that combines the two philosophies, Lean creates the standard and Six Sigma investigates and resolves any variation from the standard". If the objective is to increase productivity and reduce cost, then Lean principles should be adopted first. Six Sigma is then used to solve the remaining complex problem of producing consistent quality that meets the customer's demands in a timely manner. [56]

Lean Six Sigma as an improvement methodology was not conceived in isolation. Inputs were required from existing methodologies. Upton and Cox [106] break down the historical development of Lean Six Sigma in Figure 18. The figure is a static snapshot of what was a continuous improvement process to obtain Lean Six Sigma as we know it today.

The influences of Ohno through TPS, Shewart's statistical methods and quality engineering efforts of Demming, Juran and Taguchi can be seen. [106]

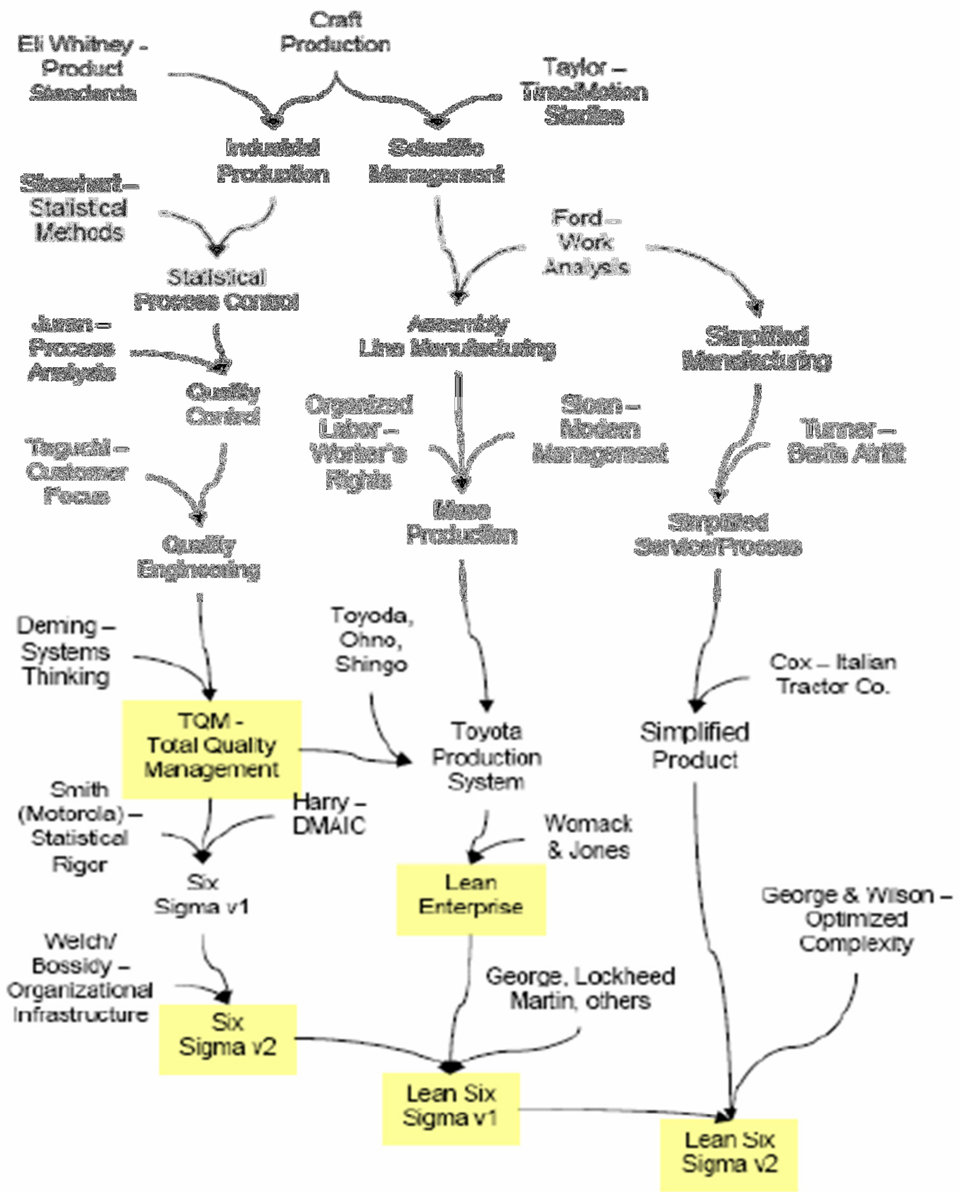


Figure 18: Development History of Lean Six sigma [106]

Six Sigma did not eliminate the use of Total Quality Management (TQM) or SPC (See Figure 18). Instead it combined the two with a structured problem solving method DMAIC and achieved greater results. Lean was developed through the TPS and made accessible to the world by Womack and Jones [4]. Contributions from George *et al,* [61] leading Lean Six Sigma advocates, contributed to the development of Lean Six Sigma and to its further improvements. It is apparent that Lean Six Sigma is a merging of two independently functional, continuous improvement methodologies.

The principle of Lean Six Sigma as outlined by George [60] is "the activities that cause the customer's critical-to-quality issues and create the longest time delays in any process offer the greatest opportunity for improvement in cost, quality, capital, and lead time." Lean provides a reduction of Muda, and Six Sigma brings the process under statistical control by the elimination of variation. The correlation between Lean and Six Sigma is summarised in Table 10.

Table 10: Correlation between Lean and Six Sigma [87]

Lean	**Six Sigma**
Efficiency focused (productivity)	Effectiveness focused ('zero defects')
Waste reduction	Variation reduction
Experience driven/intuitive	Data driven/statistical
Implements known solution	Implements creative or innovative solution
Reduction in the number of steps in the process	Reduction of the variation in the process
Reduction of inventory	Reduction of rework
Targets low hanging fruit (short projects)	Targets lengthy project achievements
Continuous improvement	Breakthrough improvement
Volume/output increase	Quality increase

2.7.1. Lean Six Sigma Project Deployment and Project Implementation

In order for companies to align their strategies to their operation plan, according to George, [61] a Lean Six Sigma initiative is deployed following three streams of activities.

1. Initiation – the initiation activity includes all the steps to fully execute the Lean Six Sigma project, and these activities lay the foundation for a successful implementation. At the cornerstone of the activities is CEO involvement. George [60] states "Over the past dozen years in working with both successful and failed continuous improvement initiatives, my colleagues and I have learned one hard-and-fast lesson: the Lean Six Sigma effort will succeed or fail based on the engagement and buy-in of the CEO and executives with Profit and Loss (P&L) responsibility". [60]
   The success or failure lies with the CEO's engagement. The CEO must decide that Lean Six Sigma is the correct strategy to address the company's needs and then wholly commit to it. The CEO should then set the performance goals, expected gains in operating profit expected, revenue growth and intrinsic shareholder value to be aligned with the business strategic goals. [61] The final act is to commission a design

team that will champion the deployment plan. According to George [60] the deployment plan should include the following.

- Process: Designing the critical Lean Six Sigma sustaining process to be a part of the company culture.
- Organisation: Determining which individuals require training, their roles and reporting structure.
- Measure: What factors will determine the success of the project.
- Rewards: Establishing a mechanism for obtaining information, feeding it back to the company and providing reward and recognition.
- Tools: Determining what supporting tools are required for successful implementation. These could require further financial investment. [61]

2. Resource and project selection – this stage of deployment takes place just before the implementation phase. The project team is selected and the people requiring training are selected. Naturally, a top performer will be the best candidate for selection as a Black Belt. The selection efforts should be multilevel collaboration between process owners, management and the Lean Six Sigma champion. [60] Project selection is critical, the project needs to align with the business' strategic objectives. The company should also consider firstly, the VOC, the Voice of the Process (VOP – linking company process requirements for better perspective of projects) and the Voice of the Business (VOB – identifying the financial gaps to generate projects). [61]
3. Implementation, sustainability and evolution – The purpose of this stream is to adopt Lean Six Sigma into the company culture and produce transformational change in the organization. The ability for an organisation to successfully achieve change is linked to the visible commitment from the CEO and management and to the company's ability to overcome barriers during the deployment and implementation phase. [60]

2.7.2. Previous Research on Lean Six Sigma

In the literature reviewed, emphasis was placed on the application of Lean Six Sigma in a manufacturing environment to increase production efficiency. [107] The manufacturing environments reviewed cover a broad spectrum of industries. The tools and techniques used and their outcomes are tabulated in Table 11.

Table 11: Literature reviewed on Lean Six Sigma (created by author)

Title	Author(s)	Aim	Tools & Techniques	Outcomes Achieved	Ref
Use of Lean Six Sigma methodology to reduce defects in a high volume unit-of-use dispensing in a mail order pharmacy system	Brueckneranď, Rita; Siehr, Kenneth	To reduce defective script output by 50% in 9 months	Process Map, DMAIC, VOC, SIPOC, VSM, Benchmarking, RCA, Pareto Charts, FMEA, Control Charts,	-Reduced defective prescription scripts by 57% -Realised an annual cost saving of $355 404 with a return of investment of 41 days	[108]
Lean Six Sigma application in Aircraft Assembly	Ramamoorthy, Siddhartan	To reduce the defect rate and lead time of the upper main entry door of a business jet	VSM, DMAIC, SIPOC, Pareto Charts, Cause and Effect diagram, 5S, Poka Yoke, Kaizen, statistical analysis (mean, standard deviation), control charts	-Reduced lead time from 26 to 10 days -Reduced the non-conformance occurrence by 30%. -Subsequently reduced the rework time of three hours per aircraft with a value of $6000	[109]
Implementing Lean Six Sigma: A case study in concrete panel production	Yong-Woo, Kim; Hutchison, John	To implement Lean Six Sigma in construction based production and to demonstrate its application through eliminating variation in concrete panel production	CTQ, Y=f(x), VSM, DMAIC, Kaizen, Work Balancing, VOC, Control charts, Standardisation, Process flow, visual control	-Increased concrete panel production rate from 18 to 75 panels per day -Reduced lead time for the delivery of panels by 25% -Obtained a production process under statistical control	[52]
The Implementation of Lean Six Sigma Methodology in the wine sector: Analysis of a wine bottling line in Trentino	De Gracia, Sergio	To demonstrate the use of Lean Six Sigma in the wine sector with a focus on the bottling phase due to high rejection rate and high financial value for defective products since the manufacturer requires consistent quality wine to be produced	CTQ, Y=f(x), SIPOC, DMAIC, VSM, 5S, SPC, Cause and Effect diagrams, JIT, Kanban, Standardisation, time and motion studies.	-Improved lead time by 56% -Reduced raw material inventory -Reduced filling variation by 1ml -Changed the company culture	[110]
An application of customised Lean Six Sigma to enhance productivity in a paper mill company	AL Hedeethi, Rami, Obeidat, Suleiman; Mandahawi, Nabeel	To streamline the process and to enhance productivity at a paper manufacturing company	DMAIC, Brainstorming, 5S, process mapping, Benchmarking, Pareto analysis, Statistical analysis, SOP, Cause and Effect diagram.	-Increased production rate of printing machines by 5% -Increased production rate of cutting machine by 10% -Increased the OEE for printing and slitting by 21.6% and 48.5% respectively -Decreased solid waste by 0.78% in the printing department -Changed the company culture	[82]

The literature reviewed addresses how Lean Six Sigma can be used to achieve measurable financial gains in a short time. This was one of the desired outcomes for this research. The similar research reviewed in the different manufacturing sectors all contained concepts that could be transferred to the current research. A common framework is recognised in the literature to solving problems, which is outlined below.

1. A problem is recognised by the company, either through investigation and justification or a management request motivated by financial loss or a desire to maximise financial gains.
2. A tool is used to describe the affected process in its current state. The tool can be a VSM, flow diagram, SIPOC or process map.
3. The current state exposes Muda and/or deviations within the current state when compared against a standard. The standard could be CTQ, VOC, a benchmark or a management-defined strategic position.
4. A measurable desired outcome is set. The outcome is defined using KPI's, benchmarking or a management-defined goal.
5. The DMAIC methodology is used to structure the problem solving phase required to address each Muda and/or deviation identified.
6. The DMAIC methodology then highlights which tools or techniques in Lean and/or Six Sigma, are best suited for the application.
7. The success of the problem solving phase is determined through comparison to the desired outcomes set in point 4 above. [108], [109], [52], [110] , [82]

All the literature that adapted the above framework achieved: results which were measurable, an increase in productivity, a measurable reduction in cost, an increase in customer-focused production substantiated by a decrease in quality defects, a reduction in process and product variability and a reduction in lead time. All the outcomes achieved affected the profitability of the company.

2.7.3. Challenges of Lean Six Sigma

The combination of the two methodologies Lean and Six Sigma functionally, as discussed, can produce more desirable results for the company that implements it. The methodologies combine well to complement one another in areas where they are deficient individually. The same cannot be said about the flaws in each methodology. Lean Six Sigma still requires the strong support of upper management. Management needs to fully adopt the methodology and be willing to accept active roles in changing the company culture. Six Sigma uses a structured top down approach while Lean puts an emphasis on the shop floor and empowering the staff. The two opposing approaches have their drawbacks for implementation in the case company.

The author intends to overcome these by, taking on multiple roles in the Lean Six Sigma team. As a facilitator and participant, the author can encourage employee participation and contribute where there is a knowledge gap. Top management will be presented financial justifications of "low hanging fruit". These are easy wins that are used to demonstrate the effectiveness of the methodology and obtain management support. The low hanging fruit might not be in line with this research, but it will be used to justify any expenditure required for this research. The foundation will be management support. Liker and Chio [111] believe challenges faced for continuous improvement programmes like Lean Six Sigma include:

- managers' inability to manage production as well as continuous improvement efforts;
- internal political tensions;
- management not allowing active worker participation;
- employee resistance. [111]

Employees have knowledge of their trade through years of experience, during which people pick up good and bad habits and short cuts to execute tasks. This could be the greatest risk resulting in employee resistance to change. Another challenge could be a resistance to change due to a lack of knowledge or relevant education. The author intends to combat both these employee-related problems through: educating the employees through workshops, interesting topics of the day discussed at daily production meetings, visual aids, open discussions and as part of the management strategy, introducing a rewards or incentive scheme. The roll out was carried out in small focused groups as visible success and changes spark interest in those around and motivates those participating. The small groups allowed for more focused teaching for those employees who do not easily learn or require special attention. Overcoming these challenges will lead to successful implementation.

2.8. Methodical Frame: Lean Six Sigma

Continuous improvement methodologies contain tools and techniques that can be utilised to achieve waste management. Continuous improvement methodologies all have a common outcome which ultimately results in increased profitability. Increasing profitability can be in the form of: increased quality through defect reduction, improved product design, reduction in Muda, improvement in processes, overhead cost reduction or increased output. Based on the requirement of the research, TQM as a methodology is not considered due on the following reasons:

- It has a very vague definition. This makes it hard for companies to succeed in their implementation and further development. [112]
- It is very focused on increasing internal and external customer satisfaction with reduced resources, this potentially could result in job loss. [113]
- TQM is designed to deliver long term results and can involve high implementation and process costs. The case company would like to achieve sustainable results but due to financial constraints requires a methodology that can offer short term results as well. [113]

Lean as a methodology falls short as described below:

- Lean does not look after the work force. Lean focuses on a multi skilled workforce thus resulting in redundant employees. [80]
- Lean encourages a reduction in inventory, which is not always a desired outcome. [80]
- Lean focuses on known solutions and does not put emphasis on measurement and verification to evaluate variation. [81]

Six Sigma as a methodology falls short because:

- Six Sigma does not have any focus on process efficiency and production flow. [81]
- Six Sigma initiatives require lengthy training due to the analytical nature of methodology. Financial gains are thus delayed. [81]

Waste management aims to reduce defects as its highest priority. Increased profitability is a result of maximising the difference between the selling price and the cost of sales. In flexible packaging, selling price is market related therefore to be competitive, the cost of sales is where the manufacturer has control. The case company is in financial difficulty and seeks to sustainably increase process flow and reduce defects while maintaining a stable workforce. A results-driven methodology with a focus on savings was required. The choice is therefore to use Lean Six Sigma as a continuous improvement methodology.

The theory reviewed contained tools, definitions and concepts used and referenced in similar research and will be used to better answer the research question. From the reviewed literature it is clear there is abundant research available on Lean Six Sigma, its application and the effects that result from its implementation. There seems to be minimal published research identifying Lean Six Sigma as a methodology to achieving solid waste management . Six Sigma was emphasised for the application in continuous systems to achieve the most desired state of waste management. The suggested application is to prevent defects from occurring in the production line by the use of 100% inspection systems. [114] These 100% inspection systems are industry and application specific. No further detail on these systems or the management of the waste they detect was explored in the literature.

The literature review shows the versatility of Lean Six Sigma across different sectors and further reinforces the choice of using this methodology for the case company's research. Brainstorming, failure mode effect analysis (FMEA), KPI's, benchmarking, process flowcharts, SIPOC, Pareto Charts, trend charts, statistical process control (SPC), Ishikawa diagrams, 5S, error proofing, standardisation of work and Kaizen are all tools from Lean Six Sigma that were used in the research.

The research aims to contribute to waste management literature by providing more insight to the application of Lean Six Sigma to achieve Lean waste management in a high-volume production operation. The waste that will be managed is produced during the production phase in the form of defects. These defects result in solid waste, as a mix of raw material and processed material. A management protocol from the point of origin to the disposal point within the defined scope will be developed. The waste management protocol will include a reduction in process and production waste.

In this report, a waste management protocol was developed using Lean Six Sigma to achieve process improvements, huge cost savings, quality improvements and a change in profitability.

3. CHAPTER 3

RESEARCH METHOD

The scientific method was used to address the research questions. The scientific method is a process whereby scientists, collectively and over time, endeavour to construct an accurate representation of the world that is reliable, consistent and non-arbitrary. [115] The scientific method thus rules out bias by the researcher and the ability for them to influence the outcome of an experiment. There are many variants of the scientific method and each researcher can customise the process to suit their working. [115] Common to all are four main components.

- Observation
  - Observing and describing some phenomenon initiated by the researcher's curiosity, scepticism or misunderstanding of variables.
- Hypothesis
  - Conceptualising the problem in the form of a hypothesis to explain the phenomenon.
  - A hypothesis is a statement that proposes a relationship between functions, factors or variables. It can also be described as an assumption that can be tested for correctness.
  - The hypothesis used in a scientific method must be clear, specific, observable and measurable.
- Testing
  - These are experimental tests done with the aim to disprove the hypothesis but that may lead to the confirmation of the hypothesis.
  - The experiments require the gathering of data. Important to the data collection is determining the appropriate sample size to increase the ability to generalise.
  - The data gathered must be analysed using the appropriate methods, tools and procedures.
- Drawing a conclusion
  - Based on the results of the analysed data, explanations can be provided, conclusions can be drawn and if the results are unfavourable, direction for further investigation should be provided. [115]

The scientific method was used through the application of DMAIC. DMAIC qualifies as a variant of the scientific method as it contains all four attributes mentioned above. "Define" is obtained through observation, which allows one to hypothesise. “Measure” and “Analyse” form part of testing, but they are two separate processes. “Improve” is a process where the value-add is observed with the Lean Six Sigma. The observed phenomenon is altered to achieve the desired result. Normally, with the scientific method, when the hypothesis is not supported by the analysis, the hypothesis is rejected, refined, expanded or altered before testing is repeated. “Control” is where a conclusion is drawn. [115]

The DMAIC method was then applied to the case company, a producer of flexible packaging servicing the pharmaceutical and food and beverage industries. The use of the DMAIC procedure based on scientific research results in research that is objective, systematic, testable and reliable. [115] Central to the DMAIC process and to fulfilling the requirements of the scientific method is data. The subsequent section describes how data was acquired.

3.1. Data Gathering

Various forms of data collection were used to provide useful information for analysis.

Participant Observer

Observations cover real time events and provide another source of evidence. Observations can be made formally and included in the DMAIC process such as fieldwork gathering data - or less formally for example observations from a site walk through. [116] A participant observer is then an observer who actively participates in the events of the research project. They have a role to play within the DMAIC process and influence the outcome of results. [116] The author was a participant observer while conducting the research, he was also a key decision-maker within the business. Additional roles of the author are described below.

- Project lead – The author was the project lead in the implementation of the project, facilitated problem solving and ensured all work was executed timely within scope and budget. In this role, the author fulfilled the role of the Six Sigma team Black Belt.
- Design engineer – The author performed the analysis for machine and process specifications. Along with the project team, the author employed various problem solving techniques to address issues and consult on any designs required, mechanical and/or electrical.
- Project foreman – During the implementation phase, the author sourced suppliers and prices and supervised their work. Additional help was provided by employees in the purchasing and engineering departments.

The research protocol (Section 3.4) will better clarify the participant observer role, as details of task execution highlight the participant observer's function. The reason behind the multiple role allocation is that the case company did not have enough resources to fulfil all the roles. All efforts were made not to influence the outcomes of the results, as participant observation bias and manipulation of events is possible. [116] Where the observation of people was required for example recording the time taken to locate material detailed in Section 1 these recordings were done before any training workshops or operator involvement so that true behaviours were captured without the knowledge that observations were taking place.

Once the communication and workshops had begun, casual labour was used to record people's behaviour to achieve the same result. Taking on so many roles in the research and being the knowledge provider, the author ran the risk of imposing his thoughts and ideas on the participants. To avoid this possibility, the author rotated between being a facilitator and a participant in group discussions and/or brainstorming sessions. In one case, the author encouraged others to participate and led the discussion before making final rulings. In the other the author shared ideas and somebody else had the final ruling.

Documentation

Documents play a vital role in any data collection. They can be letters, email, personal notes, reports, formal studies or media articles to name a few. [116] Documents were used to provide data and corroborate the analysis. Production sheets, the electronic database found on the ERP software, personal written notes and online reports were all used. The production sheets were filled in by the operators and assistants on the production floor. They provide a written account of all the actions that have taken place on the production floor – performance, materials used and breakdowns among others– per machine, per operator and per job order. The ERP was updated with information captured by data capturers from the production sheets as well as supervisor reports. Supervisors reported on actions and performances from their respective shifts. This is a duplication of work, but in the absence of trusted data, it provides greater reliability. Personal notes were used from observations and informal interviews. Online reports were used as supporting material. The purpose of the documents is to provide the primary information for analysis. The documents provided quantitative data to support the problem statement and establish and measure the key performance indicators (KPI's). The KPI's are discussed in Chapter 4, but the information measured or provided from company records to obtain the KPI's includes the following:

- job input raw material weights (kg);
- job output WIP (kg and linear metres);
- job waste produced (kg and linear metres);
- job time utilisation (hours);
- material raw material cost (ZAR);
- machine rates (ZAR);
- labour rates (ZAR);
- overhead rates (ZAR).

Study Subjects

The global population is the entire group that the researcher wants to draw conclusions from. [117] Since the study generalised and drew conclusions about flexible packaging manufacturing in developing countries, the global population of the study is flexible packaging manufacturers in developing countries. Within this population, this research made use of a single flexible packaging manufacturer as the subject of a case study. A sample is a subset of the population chosen by the researcher for the study. [117] Considering the global population, the case company is the sample subset. The subset was picked using convenience sampling. Convenience sampling is a type of non-random sampling where the population meets certain practical criteria. [118] The case company was accessible and was willing to share confidential information.

The study made use of a questionnaire. Since the scope of the research focuses on gravure printing, the questionnaire population consisted of the workers of the flexible packaging company who dealt with gravure printed material. These were workers who:

- came into direct contact with gravure printed material;
- had gravure printed material as an input within separate value adding processes;
- offered support to the gravure printing process such as in maintenance, supervisory and technical support roles.

Profitability and waste are everybody's responsibility so, a random sample was drawn from within this subset of the workers. However, it is important that the views of managers as process owners were included as well as the random sample. As such, a stratified sample was used. Stratified sampling is used where groups share at least one common characteristic. These groups are called strata. Stratified sampling is considered superior to random sampling, because it reduces sampling error. [119] Due to the limited number of managers who are linked to the gravure printing process, all members of the management team that fell within the sampling subset were selected to take part in the questionnaire. There were significantly more factory floor workers who fell within the sampling subset. The factory floor workers were again stratified based on work shifts. Within these strata, the selection of participants was random. If participants fulfilled the criteria for a stratum, they had equal chance of participation to others within the same stratum. The respondents/participants chosen are tabulated in Table 12

Table 12: Participants and respondents of survey and interviews (created by author)

Number	Respondent position	Quantity
1	Quality manager	1
2	Print manager	1
3	Conversion manager	1
4	Quality controller	1
5	Cost analyst	1
6	Waste management contractor	1
7	Printing operator	3
8	Material handler	3

Questionnaires and Interviews

The sample groups were engaged with a structured questionnaire supplemented by some semi-structured interviews with key informants as necessary. The same sample group made up the project teams. The sample group was also used to gain more in-depth information on perceptions, insights, attitudes, ideas and beliefs within the factory. [120]

A questionnaire is a set of standardised questions used to collect data from a large group of people. [121] The data gathered would otherwise be difficult to observe. The purpose of this questionnaire was to gauge how much knowledge the employees had about Lean Six Sigma, waste management, the company's performance data, the company's waste statistics and to attempt to understand what accountability, if any, the employees had for waste and profitability.

Ackroyd and Hughes [122] describe three types of surveys.

1. Factual surveys – these are used to collect descriptive information.
2. Attitude surveys – these are used to measure people's opinions and attitude.
3. Explanatory surveys – these aim to test or produce new theories and/or hypotheses.

A mix of a factual and an attitude survey was used. The factual portion of the questionnaire gathered quantitative data using closed questions. [121] These answers were used for comparison with the initial conditions to gauge how informed the sample group was. The attitude portion of the questionnaire gathered qualitative data in the form of open-ended questions. [123] The gathered answers were used to draw conclusions on how much knowledge the participants have on the research topic and their attitude/opinions towards it. The questionnaire was conducted in the form of a self-completion questionnaire personally handed to the respondents. [123] This method was chosen to remove the author's bias which could result from assisting the participants. The questionnaire design was based on the outcomes expected from the purpose of the questionnaire. Drafts were given to a senior manager and an operator to review to scrutinise the length of the questionnaire and whether it was presented at an appropriate academic level for the respondents. The complete questionnaire can be found in Appendix C. The structure of the questionnaire was as follows:

- to provide information of the study and details of how to complete the questionnaires;
- to establish the respondent's role;
- to ask questions about Lean Six Sigma and then to gather quantitative data;
- to ask questions about waste-causing processes and then to gather quantitative data;
- to ask questions about waste management and then to gather quantitative data;
- to ask questions about profitability and then to gather quantitative data;
- depending on the answers provided, to gather qualitative data for each of the sub sections;
- to ask personal questions to gauge the respondent's opinions and attitude on the subjects discussed.

According to Kvale, [124] "Interviews are conversations where the outcome is a coproduction of the interviewer and the interviewee." Informal conversational interviews were used to engage members of the study group. Hand written notes were used to record the interviewees' responses. Two interviews were conducted. The purpose of the first was to highlight the current problems experienced by the employees in their respective positions with respect to waste. Where applicable, it was used to gather information about the processes. The resulting information was used in the formulation of the current state problems. The second, a more structured individual interview, [124] was only used with the respective process managers to obtain a critical analysis of the implementation of the Lean Six Sigma initiatives.

Ethical Considerations

Ethics play a big role in engineering. It is vital to respect and protect the privacy and intellectual property of individuals and companies. [125] The author included the following to ensure the research followed good ethical practise:

- A participant information sheet (See Appendix A) outlining the details of the author, the academic institution, the research supervisor and the intended research was given to the case company. Before pursuing further correspondence or information, a letter was received back granting permission to conduct the research and detailing any boundaries or limitations. These were respected by the author.
- Letters of consent (See Appendix A) were given to each individual in the subset as well as the most senior representative of the company giving the participants the option to agree or disagree to participate in the research. The letters were given in English and were explained or translated to any participant who did not fully understand. The letters protect the individuals as well as the company.

A draft of the questionnaire (See Appendix C) that was given to participants and the abovementioned documents were submitted to the School of Mechanical, Industrial and Aeronautical Engineering Ethics Committee for ethics clearance.

Summary

Table 13 provides a summary of the data sources and their purposes.

Table 13: Summary of data sources and purposes (created by author)

Data Source	Data Type	Data Utility	Purpose of Data
Documentary evidence	-Official records -Questionnaire -Historical data -ERP system	-Provided official information from case company -Data recorded from actual operations - Verified data collected from other sources	-Provide raw data for analysis -Provide error checking for validation -Provide information on processes -Provide point of reference -Provide benchmarking data
Semi-structured interviews	- Participant constructions	-Participants' own words, their interpretations, and understanding of the problem and issues in the case company - Verification of data collected from other sources	-Obtains people's personal opinions -Obtains feedback on implementation -Verify work
Participant observation	- Field notes - Observations, experience, events, activities and process executions	-Author's input from interpretations and understanding -Execution of tasks within study parameters	-Assisted in collecting descriptive details and processes of case company - Helped interpret data gathered from interviews, and meetings - Active involvement in solution implementation

The tools and instruments used in the study are detailed in the subsequent section.

3.2. Tools and Instruments

All the measurement instruments and tools used in the research are summarised in Table 14.

Table 14: Instruments and tools (created by author)

Instrument /tool	Function	Identification	Make and model	Usage	Unit of measurement
Scale	Obtain all weight measurements [126]	1.5x1.5m floor scale	Clover scale LD12-3	Measurement	Kilogram (kg)
Timer	Used to record elapsed time [127]	Wall mount digital display	Zenith 100mm, 7 segment display	Measurement	Hours or minutes
Production book	Record job information– time utilisation, raw material input and output and WIP output	100-page duplicate book, in identification sequence		Measurement	Hours or minutes, linear metres (Lm) and kilogram (kg)
Waste book	Record job-specific waste and classification of its origin	100-page duplicate book, in identification sequence		Measurement	Kilogram (kg), linear metres (Lm)
Microsoft Excel	Perform mathematical functions and arithmetic operations and allow for graphical displays of data [128]	Software program	Microsoft Office 2010	Analysis	N/A
Programmable Logic controller (PLC)	Monitors inputs (sensors, switches etc.); executes required action to outputs (motors, lights etc.); to control the process. Contains feedback circuitry [129]	A series of cards in an enclosure with connecting wires from inputs (encoder) to outputs (drive)	Siemens ET200SP	Analysis	N/A
Drive	Provide motor control using smart electronic equipment [130]	Power electronic component with smart logic connected to motor, fed from encoder	Siemens F24700059 84	Conditioning	N/A
Gravure Machine	Print images on substrate. This was the main machine being analysed [131]	Nine station gravure press with dedicated ventilation and automatic splice	Rotomec RS 4003 - 60530	Analysis	N/A
Rotary encoder	Measure distance [132]	Black rectangular instrument that is connected to PLC	Siemens AM 2048 S/R	Measurement	Revolutions per minute (RPM) and linear metres (Lm)

3.3. Data Analysis

This section details the data analysis techniques that were deployed for this investigation. Tools from the Lean Six Sigma methodology were used for analysis (See Chapter 2). Lean Six Sigma tools rely on statistical analysis. This sort of analysis supports the scientific method. For example, a general hypothesis about Muda of motion, through data gathering and analysis, can pinpoint whether there actually is Muda of motion or not. If the hypothesis is proven to be correct, the data will specifically expose the cause of the Muda of motion. This can allow for the implementation of processes to eliminate it. If the data disproves the hypothesis, the data will expose an opportunity to reanalyse.

The research contains quantitative and qualitative data. Quantitative data, such as that collected using the closed questions of the questionnaire, was analysed to test theories. The qualitative data, which was collected with the open-ended questions in the questionnaire, first required some patterns and associations to be made before interpreting the data by theorising. [133] The two together provided a greater understanding of the questionnaire results. With both methods, information was analysed using Microsoft Excel [128] to tabulate, categorise, examine and visually represent the data. Descriptive statistics such as the mean, range, standard deviation and variance were also used.

3.4. Research Protocol

The research protocol aims to provide a guide to an investigator such that data collection can occur in a reproducible way. [134] The aim of this research was to assess the effects of implementing a waste management system on profitability. Figure 19 is a graphical representation of the research protocol followed.

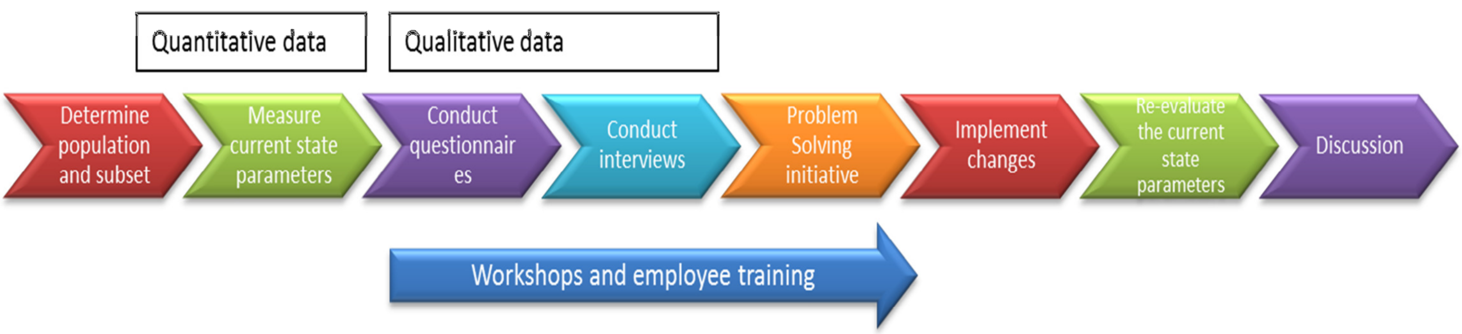


Figure 19: Research protocol mapping (created by author)

The analysis population and subset was determined. The current state parameters were quantified and linked to profitability. Questionnaires and interviews were then conducted. After the baseline had been established, changes were made to the processes following the problem solving initiatives conducted. The new case was analysed and the same current state parameters were measured for like comparison. The following section details the measurements taken and the subsequent analysis conducted.

3.4.1. Selecting the Job Subset

- The company customer list was obtained from the head of sales or equivalent personnel. The list was maintained in Microsoft Excel which allowed for arithmetic computations and data manipulation.
- All the customers who did not use gravure technology to print were filtered out. Only the customers who use gravure technology were considered thereafter.
- The top 10 customers- based solely on the financial sales value- were determined from that list. These figures were also obtained from a sales representative to cross-check.
- A wide array of customers was selected to display the different effects or characteristics associated with the customer account. It was understood that the highest sales value does not equate to the highest profitability. Of the list of 10 customers, the highest two, median two and the lowest two were chosen for further analysis.
- Thereafter, for each customer, the top 10 jobs were obtained based again on the sales value. If the customer had less than 10, all jobs were considered.
- The top two and the bottom two jobs for each customer were obtained. These were the jobs that the KPI's were measured against. The jobs were chosen this way to dilute the probability of obtaining jobs with similar construction. Jobs with similar construction were more likely to have the same production and waste characteristics; therefore the conclusions drawn would have not been a fair representation of the sample population. Figure 20 graphically represents how the study population and subset were chosen.

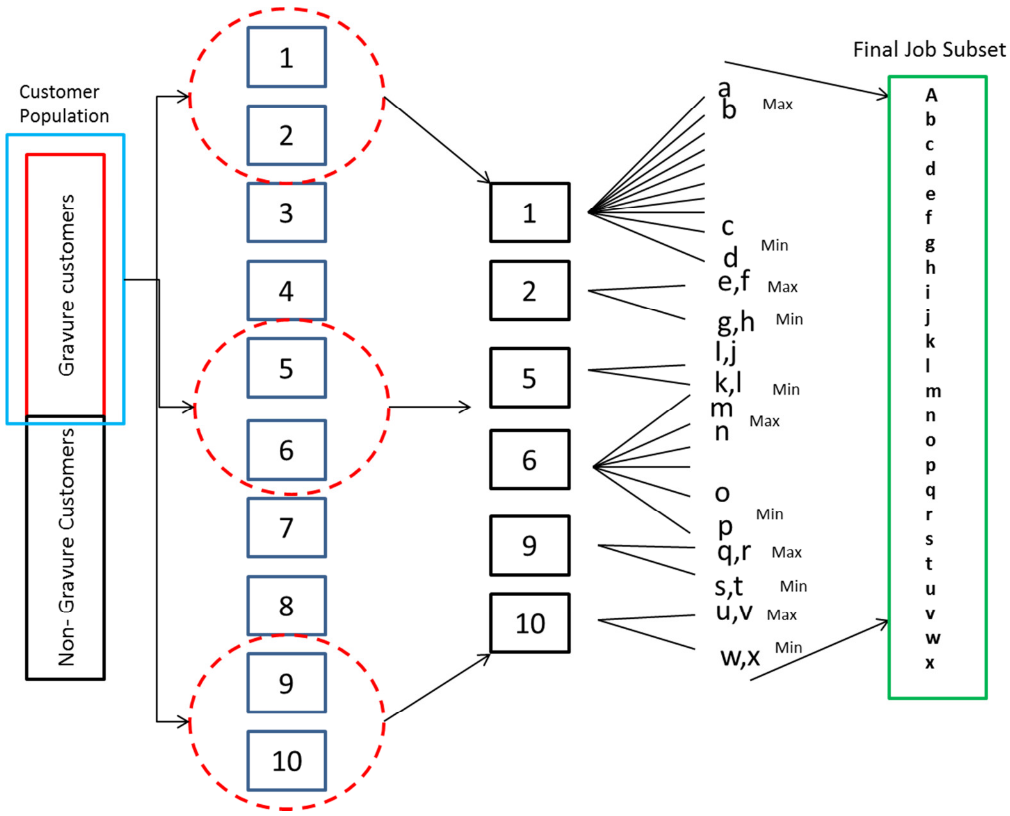


Figure 20: Job subset visualisation (created by author)

3.4.2. Measuring the current state

The current state was computed once the study subset had been obtained. Data on each job was required to calculate profitability and was obtained from the sales representative or the production manager. The data obtained follows.

- The standard costs per job from a costing model. These included the: order quantity, estimated machine time, machine rate (inclusive of fixed and variable overhead), required input materials, input material cost and the estimated waste.
- The selling price agreed with the customer.
- The actual job execution data. This included the time to complete the job, input materials usage, output WIP and waste.
  - The time to complete the job was defined and measured from the set-up of the job to when the machine was washed up for the next job. The time that elapsed was recorded via a timer.
  - The input material comes with a data specification from the manufacturer. The specifications include: weight, thickness, width, density and material classification.

The output WIP weight was estimated using the following formula:

$$Weight(kg) = density\left(\frac{kg}{m^3}\right) \times linear\ metre(m) \times \text{width of material (m)} \times thickness(micron, converted\ to\ metres)$$

The profitability of each job was then calculated. The profit percentage was then calculated with this formula:

$$profit\ margin\% = \frac{sales - cost}{sales}$$

The waste percentage was calculated using the waste weighed on the scale and the output from the process (WIP) using the following formula:

$$Waste\% = \frac{waste(kg)}{(sum\ total\ of\ waste\ and\ wip)}$$

Material variance is the deviation of a job from the standard that the customer is quoted on. The standard was obtained from the cost accountant and was based on the theoretical values, which ideally should be obtained given near perfect operation. Based on the requirements of the design, material properties, ink coverage, number of colours on the design, number of processes to create product, set-up waste allowance per process, material width and any allowances, the required raw material weight for each job was calculated. The complete workings of how the case company calculated the raw material requirements were deemed confidential. A variance was noted if the raw material used for a job exceeded the standard and no material was returned. A simplified example of this variance and how it was recorded is shown in Table 15. The material variance is a cost to the company. The variance was calculated using the following formula:

$$material\ variance\% = \frac{issued\ material - return\ material}{required\ material}$$

Table 15: Example of material variance log [135]

Order Quantity	Required material	Issued Raw Material	Used Raw Material	Returned Raw Material	Variance	Notes
800	600	784	700	84	16%	16% over
1500	800	1000	984	0	25%	25% due to no return

The initial state of waste management was also computed for the current state. The process in the production environment was observed. The objective was to follow and document how solid waste was managed. The substrate was the item of interest from the time it arrived at the raw material store to when it was disposed. Particular attention was paid to the documentation trail of the substrate. After a substrate 'changed hands' between processes or locations, a document acknowledged the transaction as complete. When the substrate moved between processes, an electronic confirmation documented the transaction. The information contained in the electronic transaction is the same information recorded for the physical movement of the substrate. Output information from the preceding process formed the input to the succeeding process. The changes at each location were documented as described below.

- The raw material store – all substrate attributes were obtained from the supplier information. The supplier information was the input and output information from this location.
- The printing process – this location had supplier information as an input. The good products' output kilograms were weighed and the linear metres were obtained from the digital display on the machine. This information was then recorded in a production book. At this point, any waste material that was created was removed from the process. The waste was weighed, put into plastic tubes and moved to the external disposal area.
- The lamination process – the input substrate information was obtained from both the supplier information (in the form of the laminate) and the good product output from the previous process. Waste again was created and removed in this process following the procedure described for the printing process.
- The slitting process – the substrate information came from the previous process output. Good product was sent to the customer. Waste was created and removed from the process following the same procedure described above.
- The disposal site – here, the waste was sorted into two streams; recyclable and non-recyclable. Each waste stream was weighed such that the skips were not over-filled, before being disposed of in a suitable location. The current state waste management was completed and reproduced in the form of a process flow map.

Once all this current state information was gathered, the current state as perceived by the employees was obtained using a structured questionnaire. When analysed, insights into the strengths and weakness of the employees were gained. The outcome provided a road map as to how to approach the human aspect of waste management.

3.4.3. The improvement methodology

Once the current state had been established, the methodology used to improve on the current state was implemented. A visualisation of this methodology is represented in Figure 21. The conceptual model shows that the main problem was broken into smaller segments, which were then solved independently. Each of these solutions contributed to the overall solution.

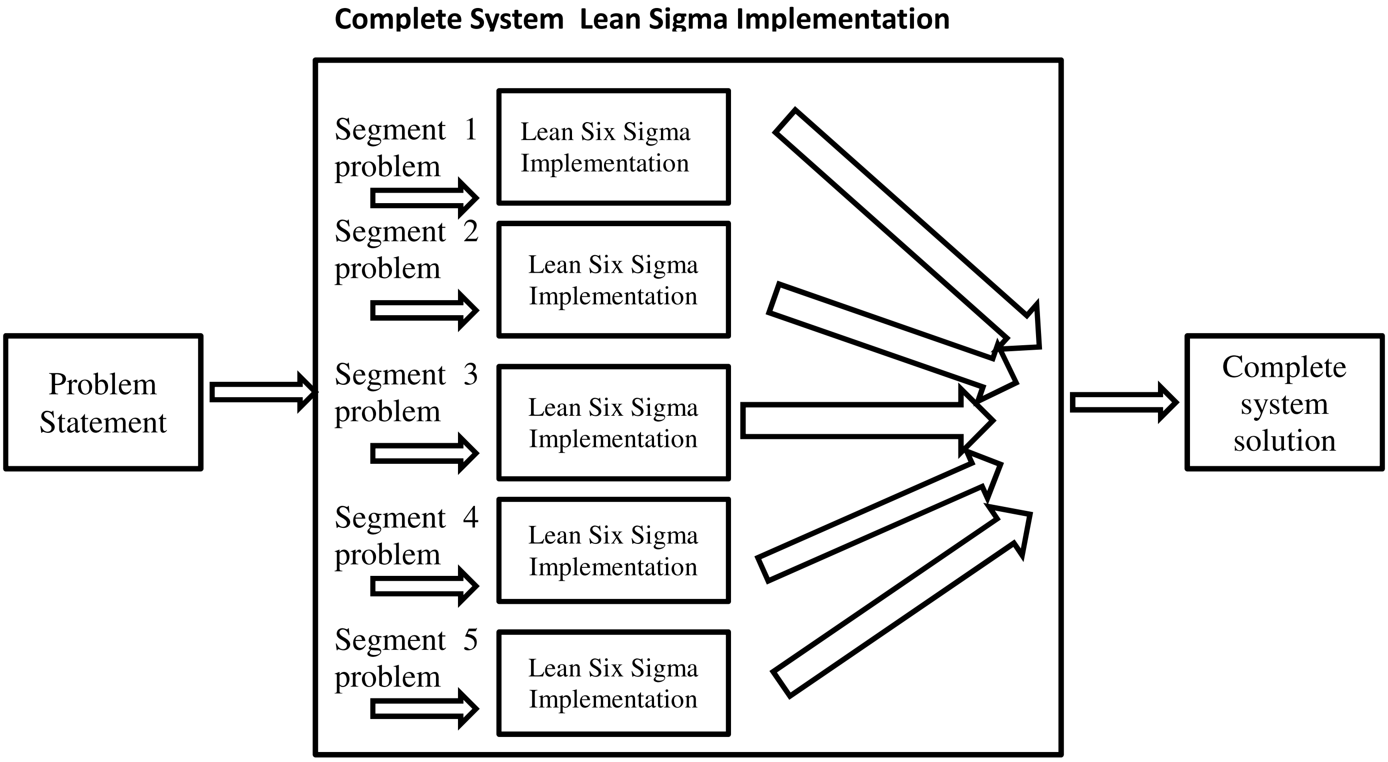


Figure 21: Conceptual visualisation of methodology (created by author)

The problem-solving framework was based on the reviewed literature (see Section 2.7.1) and included:

1. a process flow to map the process and highlight potential wastes;
2. DMAIC methodology to address each waste identified;
3. DMAIC to highlight which Lean tools were best suited for the application;
4. implementation and the process re-mapped to establish if the improvement was successful.

Once the improvement methodology had been implemented the four current state parameters –profitability, waste percentage, material variance and the waste management system– were measured and recorded again to establish if the improvement was successful.

3.5. Validity and Reliability

Validity, according to Bryman [136] is concerned with the integrity of the conclusions reached from a piece of research and relates to the question of whether a measure or measurement instrument is measuring what it is intended to measure. [136] Reliability is the ability of measuring instruments to produce consistent results and findings when a study is repeated under the same conditions. [116] Validity and reliability are essential elements to ensure the accuracy and credibility of the research, and that the data obtained is a true reflection of what is being measured and investigated. [137]

3.5.1. Validity

Validity can be further split into two subsections, namely internal validity and external validity. Within internal validity, there are a further three distinctions which are discussed.

Internal validity

Internal validity is concerned with ensuring whether a conclusion that holds a causal relationship between two or more variables is consistent. [136] Internal validity therefore assists researchers in arriving at the correct conclusions based on the research questions asked. In this research, the internal validity of the study ensured that questions on the questionnaire and structured interviews were clear and understandable as they were linked to the participants' daily functions. It is assumed that all participants answered the questions honestly as the purpose of the questions was clearly explained in the consent forms (See Appendix A). The correct conclusions could then be drawn and high construct validity could be maintained. Construct validity, along with content validity and criterion-related validity, are further tests performed by researchers to ensure that the questions are valid for their intended purpose. [138] The three tests are explained in the subsequent sections.

Construct validity is how well the results of the measuring instrument fit the theories around which the tests are designed. [139] According to Yin [116], construct validity should identify the correct operational measures for the concept that is being studied. Construct validity can be verified through a proper evaluation of the measuring instrument compared to the theory (triangulation of multiple data sources) of the subject content. [116] Triangulation is the use of multiple sources of information to address the same subject. [116]

Content validity is the extent to which the measuring instrument adequately covers the investigative questions guiding the research. [139] The content validity is perceived as good if the instrument contains a representative sample of the population of the subject matter of interest. The literature review can assist in this verification. [139] For this research, the literature review was used to guide the formation of the questionnaire and interviews.

Criterion-related validity is the ability of a measuring instrument to estimate the existence or predict the outcome of a current condition. [140] An example would be when a researcher investigates whether a new research tool relates to previous measures in a similar investigation. The criterion-related validity can be established by testing the measure to differentiate between individual factors that are known to be different. [140]

External validity

External validity is about questioning to what extent a result of a study can be generalised beyond the specific research context. [136]

To ensure validity as described above, this research used triangulation and unbiased interview and questionnaire questions. Additionally, it referenced and linked multiple sources of data to the measured, collected and analysed data.

3.5.2. Reliability

The purpose of reliability is to investigate the accuracy and precision of the measurement procedure and minimise the room for errors and bias in the study. [116] In other words, the reliability of data refers to the accurate reproducibility of data over a period of time. It considers if the same methods would produce similar outcomes under the same conditions. [141] Reliability was also achieved using triangulation as recommended by Bjorklund and Paulsson. [50]

The research protocol in Section 3.4 provided a guide to ensure that a structure was followed so as to increase reliability through repeatability. [134] Initial interviews and questionnaires followed a structured protocol to ensure reliability. The research was greatly dependent on the measured data. The data was measured on scales, linear distance instruments and/or angular velocity instruments. The scales and instruments were calibrated and will be re-calibrated bi-annually.

4. CHAPTER 4

CURRENT STATE DATA ANALYSIS

In this section the case company's operational practises are introduced. Section 4.1 details the company process and the latter sections discuss the current state conditions. The current state conditions provide a baseline against which KPI's can be measured to judge the success of this research. The current state conditions also provide the opportunity to: gauge employees' (direct and indirect labour) knowledge on the tools which will be used during the investigation and implementation, gauge employees' attitude towards waste and waste management in the company, reveal how much information is available from the company's database and prevent duplication of processes

The objectives of the current state analysis are to:

- introduce the current operating procedures of the company;
- establish the subset to be analysed;
- determine the current profitability of the company based on the subset;
- establish what information on waste is available and the state of waste management;
- determine the current process variance of the subset and validate its reliability;
- gauge how informed the company's employees are about Lean Six Sigma and waste management;
- establish key performance indicators to measure the success of the project.

4.1. Company Process

The case company produces flexible packaging servicing the food and pharmaceuticals industries. The company has two gravure machines, two flexo machines, four laminators and nine slitters that operate 24 hours a day, five days a week with a 3 x 8 shift system (3 shifts a day of 8 hours each). The company uses an ERP system, from which all the information is extracted and to which it is captured. The whole production system in the company still uses paper documents to communicate production runs, issue material, load orders, capture variances, and to capture and distribute finished goods. All paper information sheets are captured into the ERP software programme between 24 hours and a couple of days after the event. Basic Excel spread sheets are used by the planner to plan production for the week. The planner then distributes this plan to all departments via email once it is fixed for the week. Figure 22 describes the production process at the case company.

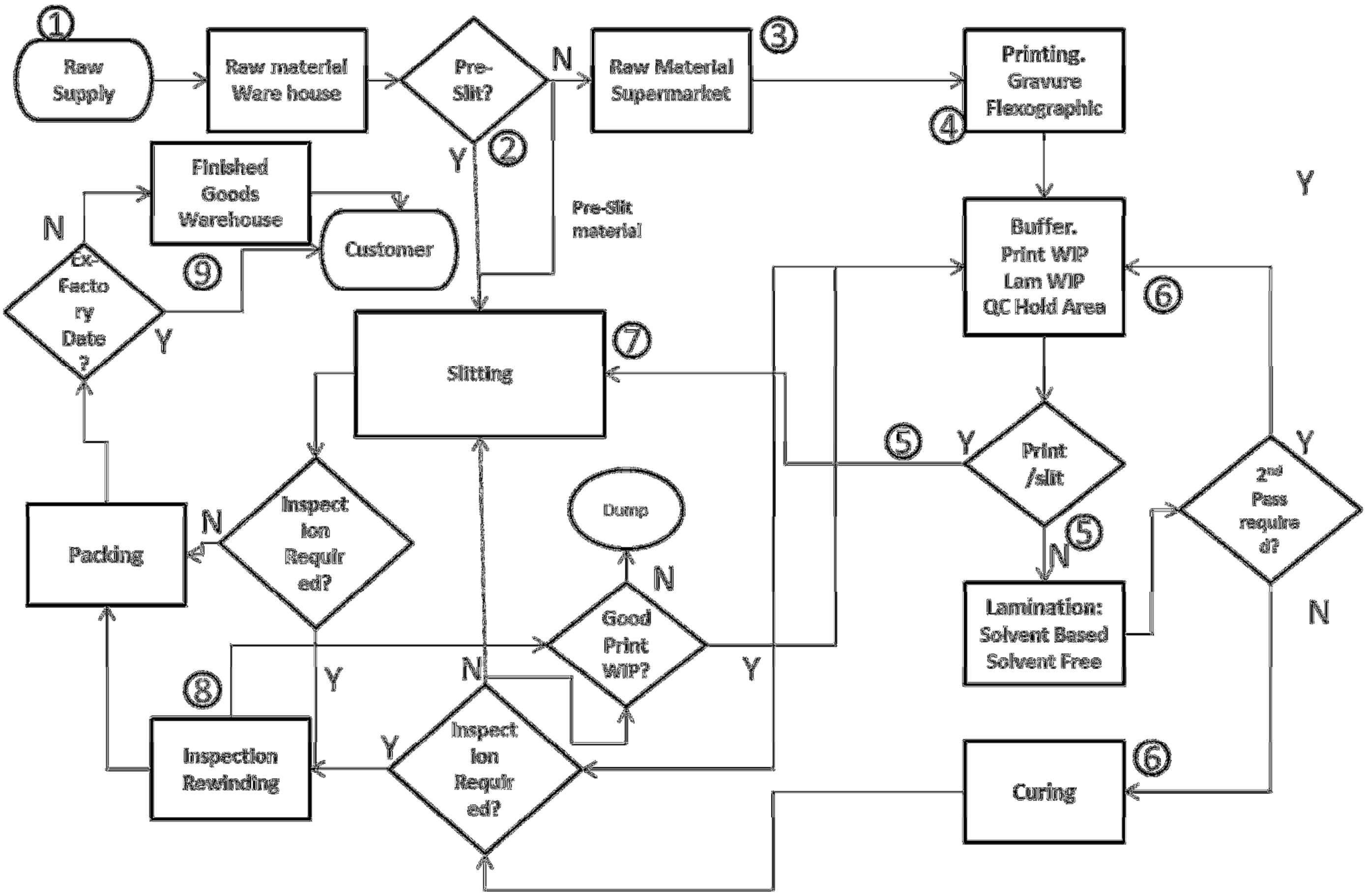


Figure 22: Case company production process (created by author)

The case company process is described such that a basis for analysis is established. This description is intended to aid understanding when the method (Section 5) is presented.

1. The production process begins with the supply of raw material substrate (paper, PET, foil, PP) to the warehouse. The warehouse then issues this material for printing and lamination to the production floor using the production plan as a guide.
2. In cases where incorrect material widths are present, the material is taken to be pre-slit before being issued. Incorrect widths result when a customer's design width plus 20mm does not fit the standard widths of substrate purchased. In these cases, material must be pre-silt to within these tolerances. [9] Pre-slitting is the process where material is processed through a slitter to remove trim to obtain the required width before it can be used in the required process.
3. The material sits in a supermarket waiting utilisation. A supermarket is a small holding area between two processes where different raw material substrates are stored whilst awaiting delivery to the required machine based on orders and utilisation rates.

A pull system is effectively created and the operator's job is to replenish the supermarket. [142]

4. The material is assigned to a job via a purchase order (PO) number. Jobs are tracked through the system using this identification number. The material is then printed using the required method and put into a buffer containing work in progress (WIP).
5. From the buffer it is either sent directly to slitting (this is called a print-slit job) or waits be laminated using the appropriate method. Jobs are run at this stage using a pull system based on material availability and then the ex-factory date. The ex-factory date is defined as the date the customer's complete order must be dispatched from the production hall or the warehouse to the customer. [7]
6. Material is then put back into the buffer if a second or third lamination pass is required or put into curing racks to cure until it is ready to slit. WIP is pulled by the different slitters based on ex-factory dates.
7. Once the material is slit it is packaged to customer specifications.
8. After the lamination process or slitting, material that has failed the internal quality inspections or is suspected of not being to customer specification is sent to inspection rewinding before going to the next process. Inspection rewinding is a process where material is rewound slowly to spot and remove the suspected defects.
9. The finished goods are either dispatched directly to the customer or sent to the finished goods warehouse waiting their call-off date. The material is transferred between departments with a series of paperwork, one floating file containing all the job information (works order) and sheets of paper stuck to the most outside layer of a roll of either the raw material or WIP.

4.2. Population and Subset

The population and subset are chosen as described in Section 3.4.1. The subset contains all the jobs that were studied and analysed through the research. Customer identification and individual job identity is kept anonymous to be in line with the ethics clearance obtained. Table 16 shows the final of the jobs which studied. The full derivation of the list can be found in Appendix E.

Table 16: List of customers and job for analysis [7]

Customer	Job to be analysed	Job construction / Substrate	Recyclable? (Y/N)	Sales Value
1	A	Foil/poly/paper	N	R 3 676 045
	B	Foil/poly/paper	N	R 3 385 247
	C	Foil/poly/paper	N	R 1 536 999
	D	Foil/poly/paper	N	R 1 396 869
2	E	Metalized PET/poly	N	R 5 787 632
	F	Metalized PET/poly	N	R 4 203 508
	G	PVC PET/poly	N	R 1 247 320
	H	Metalized PET/poly	N	R 1 237 612
5	I	BOPP/metalized BOPP	Y	R 2 575 711
	J	BOPP/metalized BOPP	Y	R 2 502 628
	K	BOPP/metalized BOPP	Y	R 834 675
	L	BOPP/metalized BOPP	Y	R 699 600
6	M	BOPP/metalized BOPP	Y	R 4 073 428
	N	Paper	Y	R 2 927 625
	O	Printed PET/BOPP	N	R 1 351 065
	P	Printed PET/BOPP	N	R 1 228 149
9	Q	Printed PET/poly	N	R 1 553 939
	R	Printed PET/poly	N	R 1 435 376
	S	Printed PET/poly	N	R 445 985
	T	Printed Pet/Surlyn	N	R 319 628
10	U	Paper/poly/foil/clear poly	N	R 2 802 191
	V	Paper/poly/foil/clear poly	N	R 1 882 209
	W	Paper/poly/foil/clear poly	N	R 372 678
	X	Paper/poly/foil/clear poly	N	R 329 902

4.3. Current State of Profitability

The jobs identified have their current state profit margins computed. The full computation can be found in Appendix F. Table 17 provides a list of initial state profitability.

Table 17: Current state of profitability [135]

Customer	Job to be analysed	Initial state profit margin	Customer	Job to be analysed	Initial state profit margin
1	A	14%	6	M	-13%
	B	-18%		N	22%
	C	-49%		O	-27%
	D	-17%		P	0%
2	E	38%	9	Q	-8%
	F	20%		R	-18%
	G	-0.8%		S	3%
	H	-38%		T	-7%
5	I	2%	10	U	-16%
	J	0.3%		V	-32%
	K	29%		W	-26%
	L	26%		X	-42%

From Table 17 it can be concluded that:

- 60% of the subset has a negative profit margin;
- 80% of the subset has a profit margin below the company standard for contribution of 15%; [7]
- the average profit margin is -7%

4.4. Current State of Waste Management

The current state of waste management is required as a benchmark before investigation. Figure 23 details waste management at the case company pre-investigation. The figure details the flow of material and information relating to the substrate whether in its raw form or converted. The substrate is the physical material that makes up the flexible package. This could be paper, PP, foil, PET or BOPP. The whole system is modelled, due to the fact that waste created in gravure printing (the focus area) cascades to the other processes, where it is identified and removed.

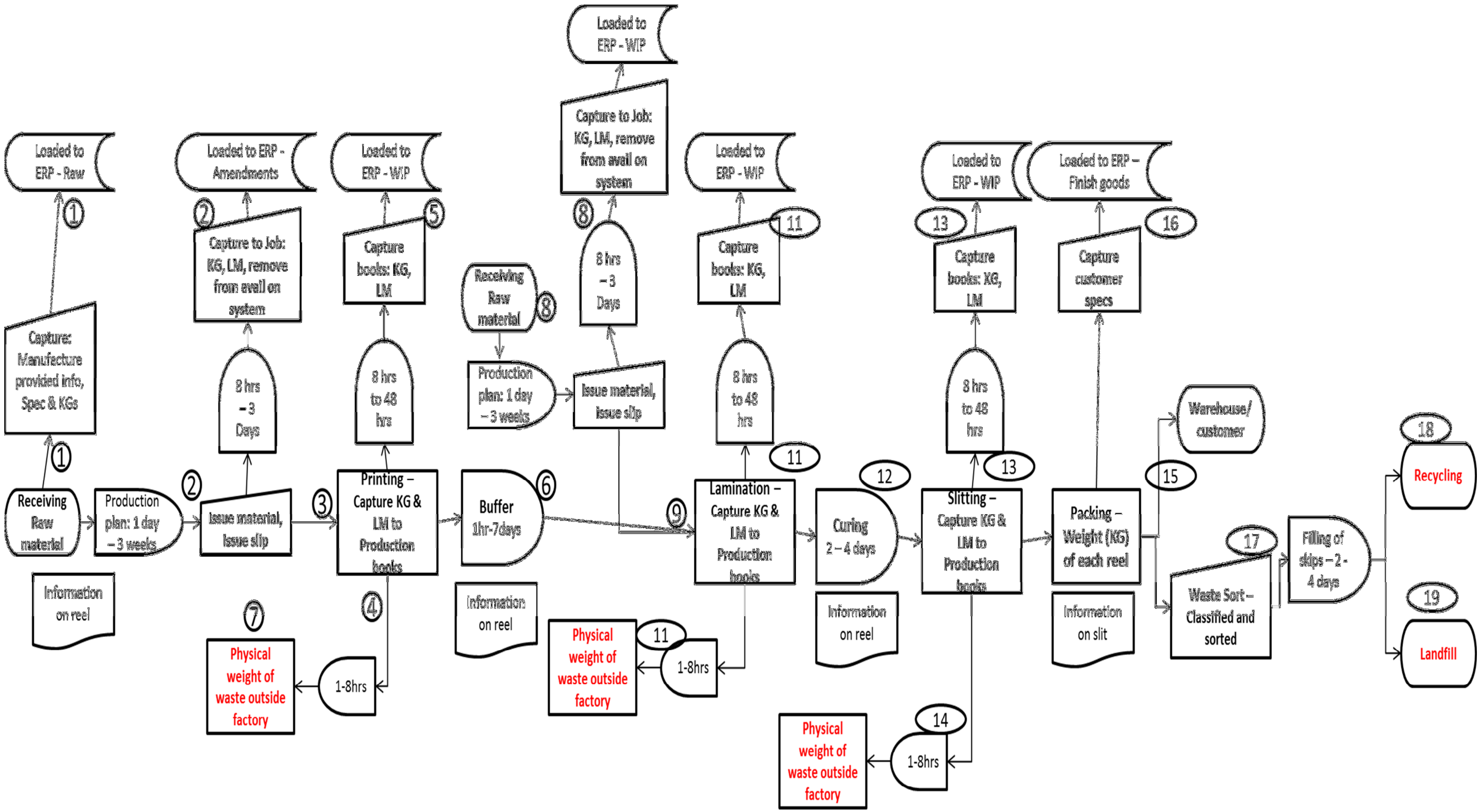


Figure 23: Waste management flowchart (created by author)

This process is the same for all printers and laminators available. The process follows a single job which goes through all the departments (for print-slit jobs, the system is the same except that there is no lamination procedure). This process is multiplied by the number of jobs scheduled per machine per day (on average 5). [135]

1. On receipt of raw material from the supplier, the supplier provided gross and net weights (kg) are captured into the ERP system. Customers order product by weight. The planner will allocate material to jobs based on availability as seen on the ERP system[2].
2. On the day the job is scheduled to run, this material is issued to production. Only then is the material removed from the system location and set as used.
3. The production order is run to the required linear metres based on the customer order.
4. The set-up waste is removed, placed in a black plastic tube and taken outside the factory (The only weighing scale available is outside the factory. This scale services the whole factory).
5. The weights are recorded in the production book. The printing and lamination machine output the linear metres (Lm) produced. Any defects spotted by the operator (with the aid of screens and an inspection system) are flagged to be removed downstream. Major defects are removed from the parent roll and the waste placed into plastic waste tubes.
6. The weight of the remaining printed products is estimated based on the ink pick up[1]. These weights are entered into the production book. The WIP is placed in a buffer zone waiting for lamination.
7. At the end of the shift, all waste that was removed is taken to the waste area to be weighed, and the information is inserted into the production book.
8. Raw material is issued in a similar manner to printing and follows the same procedure on the ERP system.
9. Jobs are pulled into the lamination process.
10. Lamination set-up waste and all the printing waste is removed during this process and put into a black plastic tube. At the end of the shift these are taken to the weigh station outside the factory.

---

[2] All Calculations can be found in Appendix D

11. Laminated product weight is estimated and put into the production book.
12. The finished product is put on curing racks to cure before slitting.
13. At slitting, any residual printing waste and lamination waste is classified by process and is removed from the final product.
14. The slitting waste (trim) is collected in collection pits, transferred to black plastic tubes and taken to the weigh station outside the factory when the pits are full.
15. Each individual slit roll is weighed, packed to customer specifications and dispatched in pallets.
16. It is only at this point that the ERP system is updated to show that the WIP has been converted into finished product.
17. The final waste from all machines is sorted into the different waste types based on the type of material i.e. Biaxially Oriented Polypropylene (BOPP), paper etc. All recyclable waste is collected into 1m x 1m bags.
18. These are put into a skip and sold to recyclers.
19. Non-recyclable waste is dumped straight into waste skips and sent to landfill.

It is important to note that the process described in Figure 23 is repeated for every job scheduled in a day. Jobs scheduled per machine per day (on average 5) results in an average of 40 repetitions of Figure 23 per day. The current systems raised concerns and lead to the problem statement given in Section 1.2. Section 4.5 provides the conditions which existed in order to reach the problem statement.

4.5. Current State System Indicators

System variances exist where the output does not equal the input or where the expected outcomes are not met. The system variances at the inception of the investigation are given in this section. This data was obtained from company documents and discussions with the quality manager, the cost accountant and the operations manager. The system variances will also be the conditions compared against at the conclusion of the investigation.

4.5.1. Material Variance

Material variance is when the material budgeted for the production process plus waste is exceeded. The calculation for material budgeting is given in Appendix D. The material variances lead to financial losses as illustrated in Figure 24. The values do not directly correlate with the profit margin percentages as job substrates have differing financial values and overused raw material is sometimes converted into sellable product that the customer accepts.

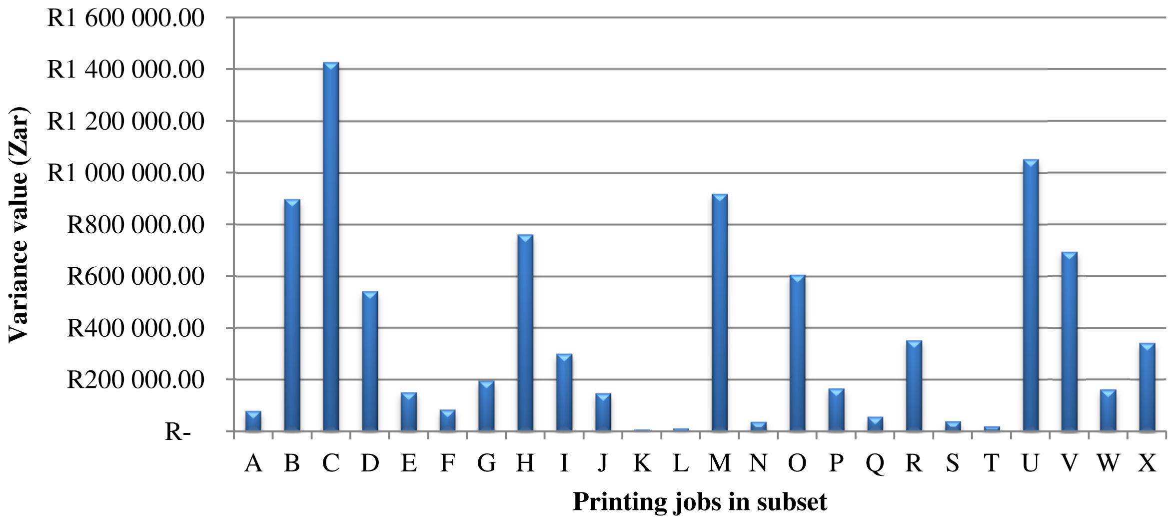


Figure 24: Raw material variances [7]

The percentage variance is computed such that analysis of jobs of similar substrate constructions can occur. Figure 25 shows the percentage material variance.

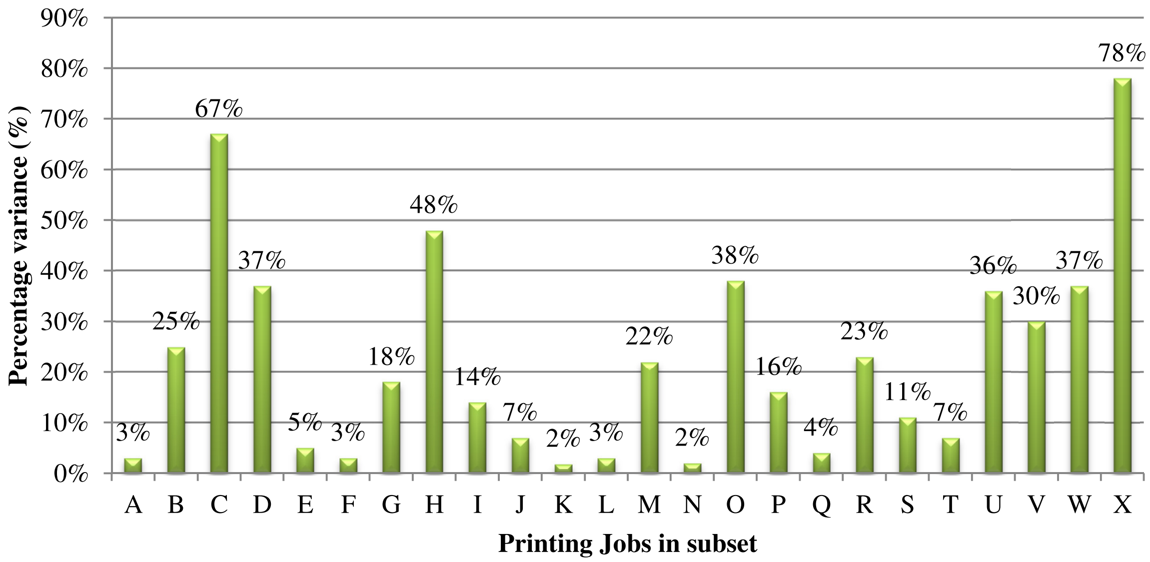


Figure 25: Raw material variance percentage [135]

4.5.2. Waste deployment

Figure 26a represents the waste percentage as understood by the case company at the initial conditions for the specified jobs. All waste was recorded in waste books. Each machine was allocated a book but in reality books were shared. As a result there is no accurate correlation between physical waste, the system captured waste, the waste book and the accounting waste. Accounting waste is a financial figure which looks at the money spent on purchasing specific raw material and how much of that issued raw material is converted into finished goods. If the material is not physically returned and receipted into stores, it is assumed that the balance is waste. The only genuinely accurate information came from the weights as material was loaded for disposal or recycling in the skips. This data correlated with the accounting waste figure. This became the standard for reporting. Figure 26b shows the waste deployment currently understood for the subset. The details known for the subset remain true for the population.

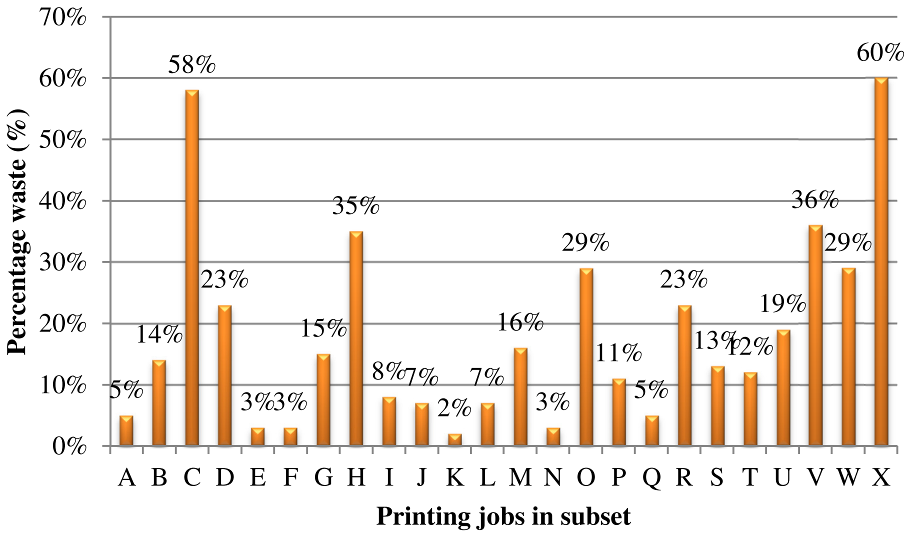


Figure 26 a

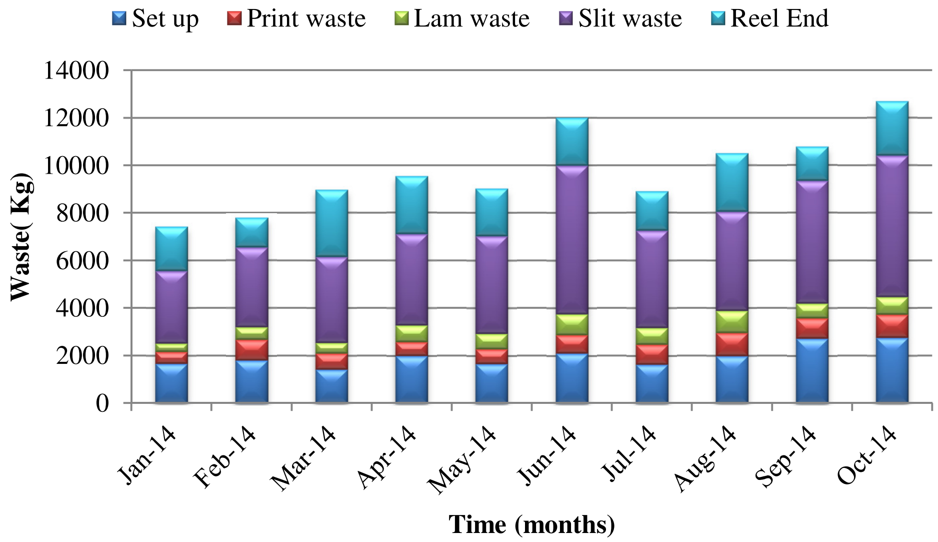


Figure 26 b

Figure 26: (a) Total waste % per job initial stage (b) Waste deployment at initial stage [7]

4.5.3. Accuracy

Accuracy is expected to be as close to 100% as possible. Figure 27, displays the accuracy of the reported data at current state. The reference point taken as true is the financial data. The money spent on raw product and the return received for finished goods is absolute. These financial figures can be linked back to physical weights as the unit price of the raw material is known. The degree of accuracy is a ratio between the financial figures and the physically recorded figures. The variations experienced in the accuracy link back to the identified problems in the problem statement. (See Section 1.2)

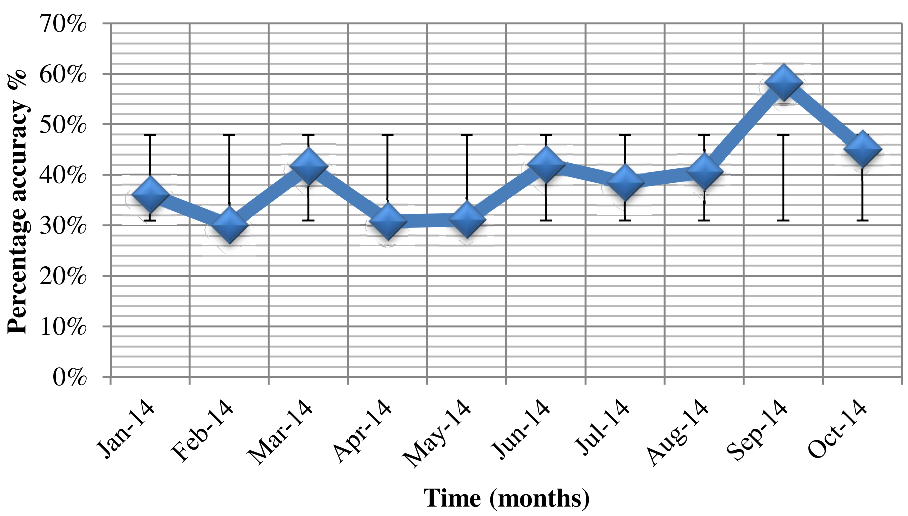


Figure 27: Degree of accuracy. [7]

4.6. Questionnaire and Interview Results

A questionnaire (see Appendix C) was then given to the employees identified in the study group. (See Section 3.1) The objectives of the questionnaire were to gauge how informed the company's employees are about waste management, the tools to be used in the research and the profitability of the company. Eight questionnaires were handed out to members of the study group. The participants were listed in Table 12 in Chapter 3. Some of the results from the questionnaire are tabulated in Table 18.

Table 18: Positive responses from questionnaire

Questions from questionnaire	Result
People who knew the what the term waste meant	100%
People who described "waste" as more than just defective product	13%
People who understood waste results in a loss of profit	100%
People who understood profitability a sustained ability to make a profit	38%
People who knew the monthly production stats, average waste and cost of waste	13%
People who believed there was waste management in the company	50%
People who knew application of Lean Six Sigma	38%

The initial state readings are the values obtained from the company records with respect to areas in question. Figure 28a shows the opinions of the people surveyed when asked, on average how much waste they thought the company produced. Figure 28b shows the opinions of the people surveyed when asked for a financial figure for the waste produced.

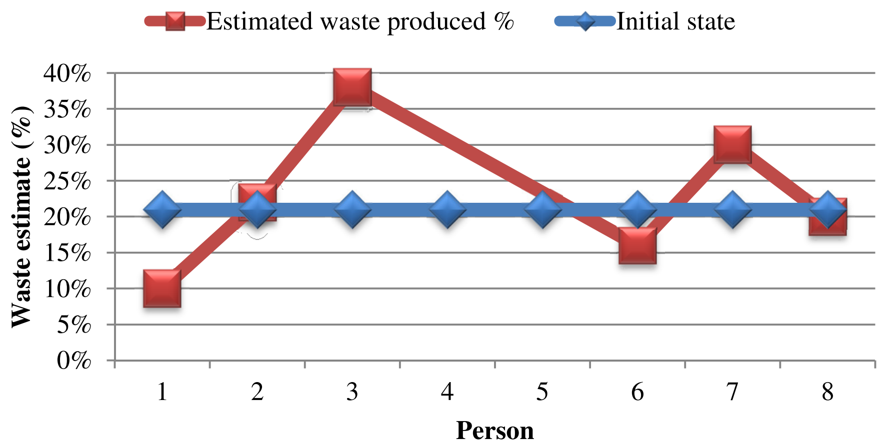


Figure 28 a

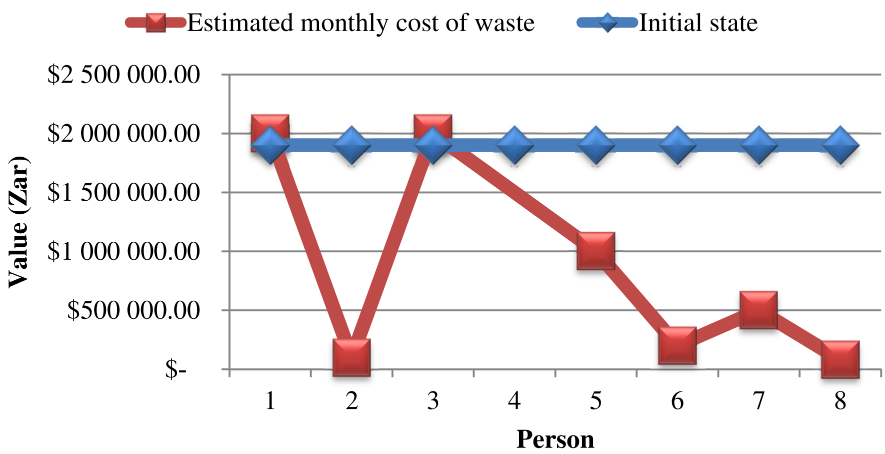


Figure 28 b

Figure 28: (a) Estimated waste produced from questionnaire (b) Estimated monthly cost of waste [7]

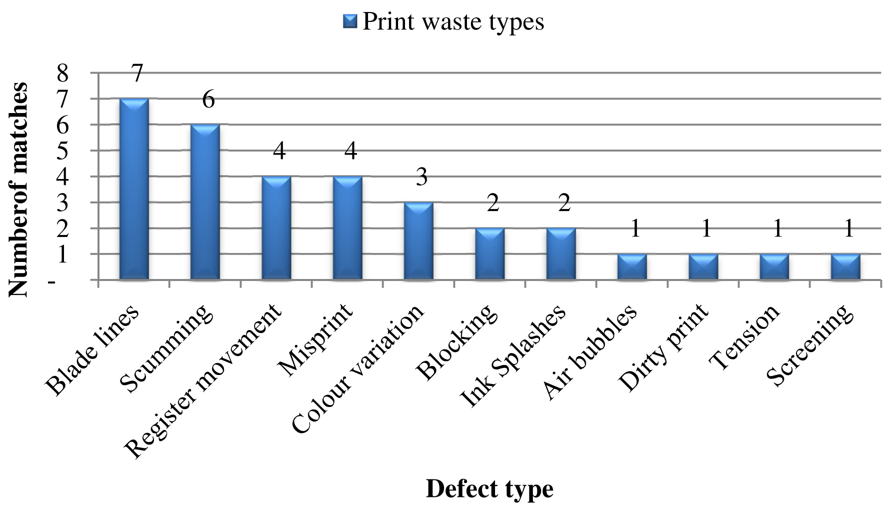


Figure 29: Print waste types occurrence graph [7]

All the respondents believed that printing was the biggest waste contributor. When asked "What top five defects caused the high waste in printing?" their responses are shown in Figure 29. Figure 29 shows the number of occurrences that a particular defect was listed in the top five.

The questionnaire also resulted in concerning outcomes (See Appendix C), these are tabulated in Table 19.

Table 19: Negative outcomes of questionnaire

Outcomes from Questionnaire	**Result**
People who considered waste as only the unsellable physical material	88%
People who took ownership of how the waste produced directly affected their income	38%
People who defined waste management correctly	0%
People who believe it is the external contractor's responsibility to manage waste	75%
People who did not know their own waste contribution values as well as the company's	88%
People believed the company was making money; this belief was solely based on the effort put into everyday job completions and the quantity of WIP	50%
People who did not know Lean Six Sigma	63%
People who answered the question regarding potential solutions to the problem with, adding more people as a solution. This suggestion would result in introducing a further inspection stage to the production process	100%
People who did not answer half the section on waste management. The same people who did not answer this section, all answered with different people or departments when asked "Who is responsible for waste?" They took no ownership of waste creation and the cost associated with it. When queried about who should pay for the waste produced, they believed that the company should foot the bill. Interestingly when asked "What would change if you paid for the waste you produced?" their responses were that if they were held personally responsible they would leave the company.	38%

The results of the questionnaire gave a broad overview of what was known or perceived about waste and the state of waste management at the company. From the concerning outcomes of the questionnaire, it was clear there was a lack of information provided to those directly responsible for production. Furthermore, the tools to be used were not understood. It is also evident that some training on business processes and Lean Six Sigma would be required, if successful implementation was to be achieved. The training also had to address the belief that using additional processes will solve a problem. Ownership of processes and accountability had to be developed. Although the use of a questionnaire did not follow the DMAIC process at this stage, it provided some helpful information required to solve the problem, as well as to use and implement the proposed tools and methodologies. Some of the results from this questionnaire will be referred to in the remainder of this report. The full table of responses can be found in Appendix C.

Interviews with Management

General interviews (see Appendix C) were carried out with the managers listed in Table 12 in Chapter 3. These interviews highlighted the opinions of management as to what the currently experienced problems were. The major recurring opinions expressed are shared below.

- The machines conditions were poor.
- People lacking the skill to effectively troubleshoot problems, so they used more material to rectify problems.
- The materials area was not clean, leading to ink and adhesive build-up, which caused quality problems.
- Information about waste was not given and if given, it came too late to rectify the problems.
- There was a lack of upper management support and money, yet results were expected; all indicated they would be willing to offer management support from their levels.
- 20% of the managers were informed about the waste status of their areas, as well the profitability of their operation.
- 20% of the managers had knowledge of Six Sigma when queried about it.
- 100% of the managers agreed that waste is their responsibility when asked, “Who is responsible for waste?”
- 60% of the managers had “clean-up area” as an answer to “Name two changes you would make to reduce waste in your area”

  The managers expressed that they felt a realistic waste reduction was in the range of 5 – 10%.

The outcomes of these opinions were combined and discussed with the group of managers in a feedback session. The feedback session resulted in a realisation that a formal waste management system is required. It seems that the managers were just as uninformed about their processes, the waste management and profitability as the operators. The following section summarises the current state as a result of the data analysed from the questionnaire and interviews.

4.7. Current State Summary

This section aims to provide an overview of the problem experienced by the case company. The company has run into financial difficulties with this current system. Left unaddressed, this could further result in job losses to cover costs.

Problem Summary

The current state problem summary, as a result of the data analysis and the interviews interpretation, is as follows.

- Information is captured on the ERP by data capturers within a minimum of eight hours to a maximum of three weeks after the event has taken place i.e. production information, material issues and waste information.
- There is no way of knowing WIP holding on the system. A physical count is required which is done once a month.
- Important information on waste and profitability is not known by the process owners.
- There is no control over or management of waste during the process. The majority of waste is weighed and captured at the end of the shift at one weigh point outside the factory. This becomes a bottleneck in the process.
- Job specific waste is only known or reported a minimum of 24 hours after the job has been packaged and dispatched to the customer. This figure is a financial waste figure and has no correlation with physical waste.
- The questionnaire and interviews indicate the employees have a poor understanding of Lean Six Sigma and waste management.
- 75% of people believe that waste is somebody else's responsibility, and this viewpoint could cause problems during the implementation phase. The employees will need to be actively engaged to change this mind-set.

  That 38% people would rather leave the company than take responsibility for their waste is alarming. These people's attitude could negatively affect progress when addressing the company culture. If their waste figures are exposed to all, there could be potential for sabotage.
- Material variances show a loss of an average of R380 000 per month.
- The average profit margin is -7%.
- Material variance is on average +22%.

- The ERP and manual entry documents are only 40% accurate on average when compared to financial figures.
- Waste is 18% on average.
- There is no effective waste management system in place.

KPI's

The following KPI's were established to be in line with the acronym S.M.A.R.T. (specific, measureable, achievable, relevant, time bound). The project team decided the operational KPI's (accuracy, waste and material variance) based on the process requirements. Upper management set the financial KPI to be in line with the business expectations from the research. The implementation KPI was decided collectively between the process leaders and upper management and given a finite time. The KPI's will be reviewed again during the final state analysis:

- Accuracy = 99%;
- Waste percentage to decrease 5% on average;
- Material variance to decrease to a mean of +10%;
- Average profit margin = +15%;
- Implement a sustainable waste management protocol within 10 months. The implementation is considered complete when the last SOP is officially signed off.

5. CHAPTER 5

IMPLEMENTATION DATA ANALYSIS AND RESULTS

This chapter contains a breakdown of how the problem statement and how the resulting current state problems were addressed. The chapter is structured such that the complete DMAIC project implementation (as described in Section 2.7.1 and in Section 3.4) is completed followed by a discussion for each section. Each of the sections build to answering the critical research question, which asks: "To what extent does the implementation of a solid waste management protocol in an FPC improve profitability?"

The implementation process is visually represented by Figure 30. The implementation began with all the problems that were identified in the current state analysis (Chapter 4). The roles required to execute the project were identified. Then the roles were filled with the people who executed the required tasks for each role. The problem was outlined, and the project was set up providing timelines and identifying the invested stakeholders. A management justification was then completed such that the appropriate financial requirements were approved. From the define phase, the boundaries, performance measures and targets were set. The problem was then simplified into smaller segments, and in each of the segments, the DMAIC methodology was used to solve the problem. A discussion emanates from each segment. The complete system was then redefined once the smaller segments were solved. The DMAIC methodology was used again and was followed by a discussion. The complete implementation began with many problems and these were funnelled– using the methods discussed in the subsequent sections– down to a singular solution hence the shape of the visual representation in .

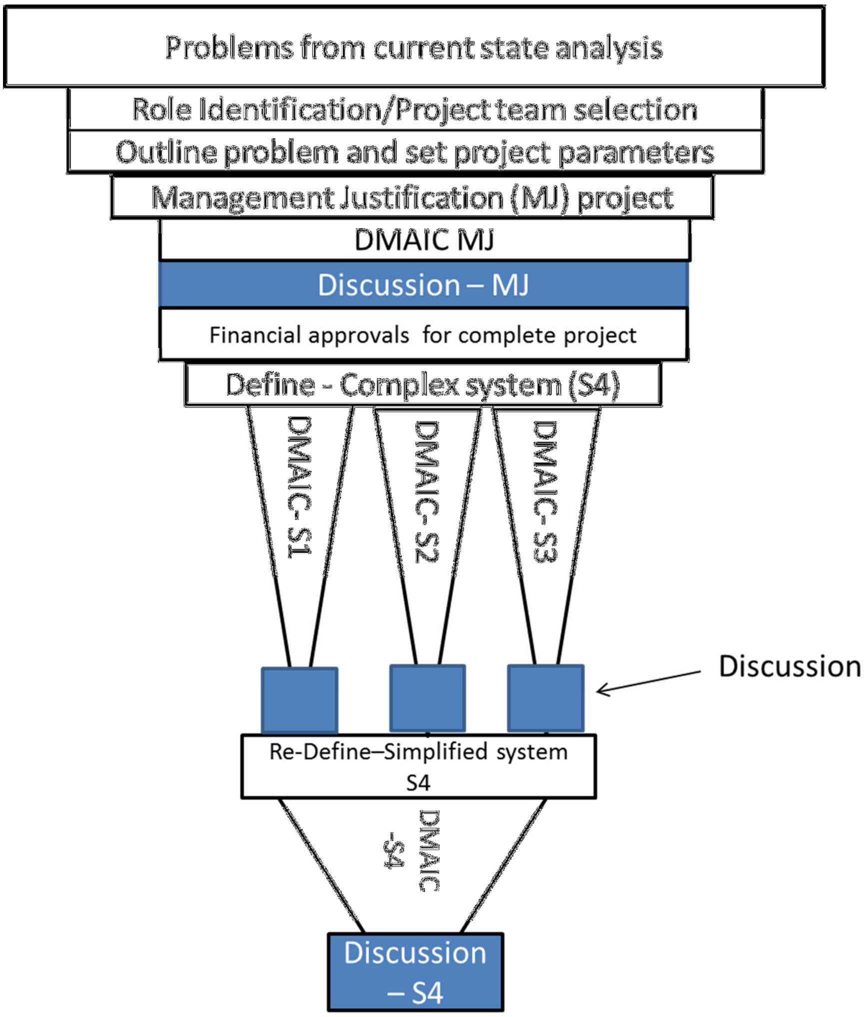


Figure 30: Implementation visual representation (created by author)

5.1. Implementation Outline

During the define phase of a project, the problem statement is confirmed, the project team is set-up (See Section 5.1.1), which leads to the project set-up, timelines and schedules (See Section 5.1.2), the problem solving approach is clearly identified, (See Section 5.1.3) the goals and targets are set out (See Section 5.1.4) for and the Lean Six Sigma initiatives are set. [82]

5.1.1. Project team

The roles required in the project are crucial as they have sub teams that they manage to obtain deliverables. There is significant cross-functional execution of deliverables so the roles identified form the core team that will see the project through to the end. [143]

The core roles identified were as follows.

- Project leader – The co-ordinator of the whole project from inception to execution. The project leader is responsible for the effective operation of the project. [143] The group industrial engineer was chosen.
- Data master – The person who will be in charge of obtaining data and communications. A vital link between the operation and the project team. The group industrial engineer performed this function.
- Process specialists – A specialist in each of the production processes affected is required to provide sound information and guidance through the duration of the project. The print, conversion and quality managers were used as the process specialists
- Project engineer – The person who will analyse the numbers and is able to provide and/or facilitate the brainstorming activities. It is preferred that this person is an engineer with Lean Six Sigma knowledge. The group industrial engineer performed this function.
- Operator representation – This must be a person who works directly with the affected processes. As an operator, this role provides first-hand experience in the affected process. Three operators from printing (one per shift) were chosen to fulfil this function.
- Top management – This is a high ranking management member. It can be either the operations manager or financial manager (FM). If available, the general manager should be involved. This is to provide the required authority when changes are required. They also highlight the importance of the project to the other role players. The operations manager was chosen to have active involvement. The general manager (GM), FM and CFO were observers who had periodic participation.
- Trainer – This is the person that will be responsible for documenting and training others in the SOP’s once obtained. They also gather and distribute minutes of all project meetings. The company technical trainer and the group industrial engineer performed this function

The roles identified are generic roles, which can be adapted to any project. They were chosen based on the core requirements of a successful project. [143] Due to the lack of resources, some roles have the same individual fulfilling them. These roles were still executed as defined.

5.1.2. Project set-up

Once the project team had been decided, a project meeting was held where, amongst other things, the project timelines were also determined (See Figure 70 in Appendix G). The project timelines provided defined boundaries within which the tasks were to be executed, to achieve the performance measures. A SIPOC diagram was developed (See Figure 31) to determine the people who had a vested interest (the stakeholders) in the process outcomes.

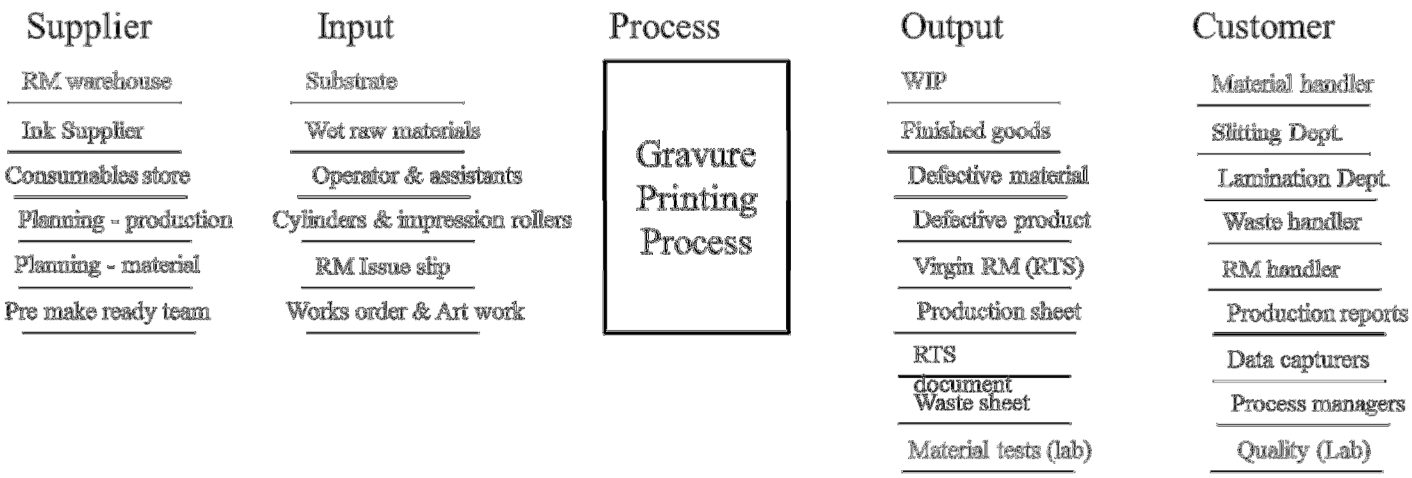


Figure 31: SIPOC diagram (created by author)

5.1.3. The problem-solving approach

The complete process as described by Figure 22 in Chapter 4 was considered. The entire project was broken down into segments as described by the high-level process map in Figure 32. Each segment represents an opportunity:

- Segment 1 is the raw material control
- Segment 2 is the process control of the substrate
- Segment 3 is the management of the waste component of the substrate during processing.
- Segment 4 is the total system considering Segment 1 as input, Segment 2 as the process and Segment 3 and finished goods as the output. The complete system includes the disposal of the waste.

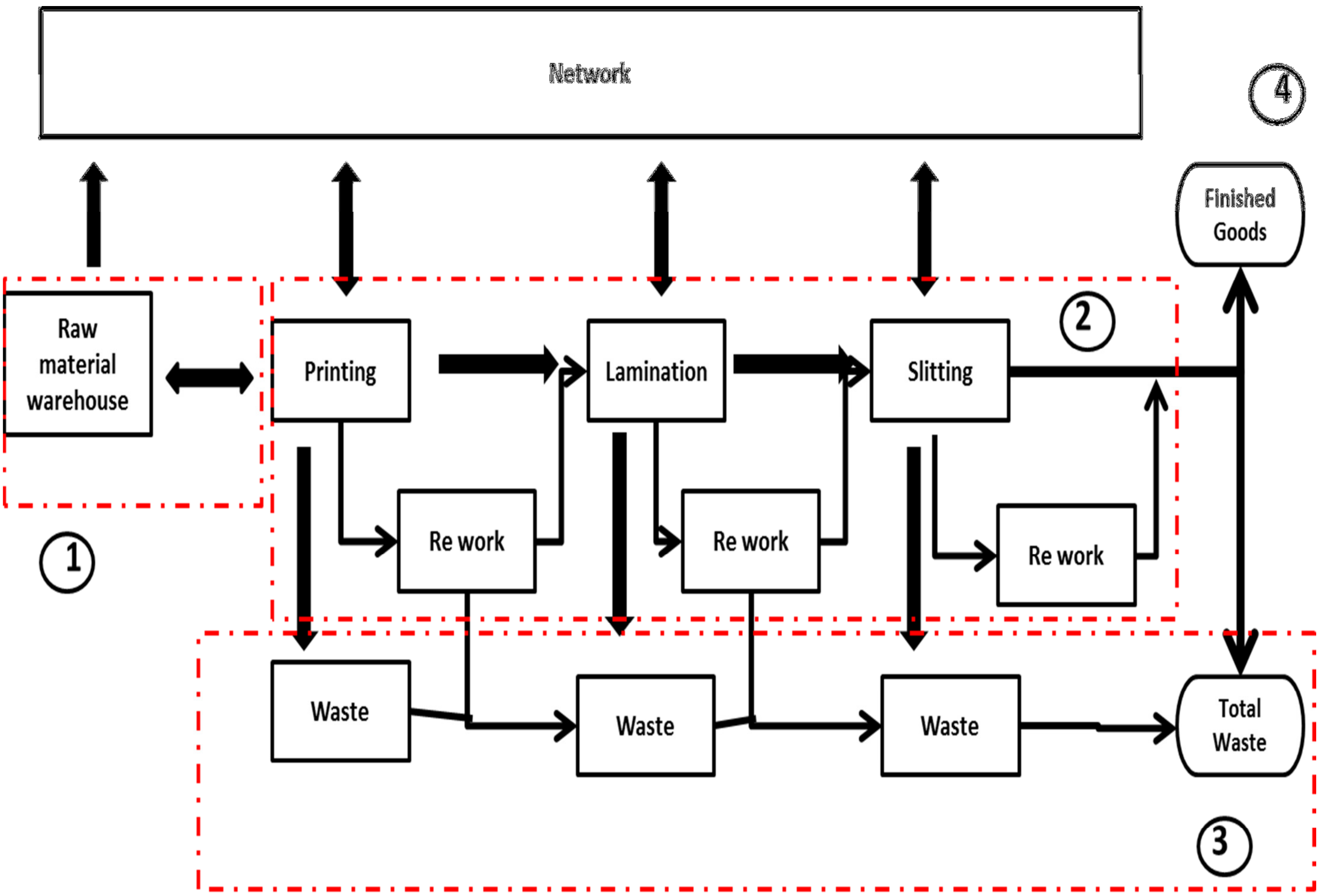


Figure 32: High-level process map (created by author)

These smaller projects (segments) contributed to the drive towards achieving the most desirable state of waste management, the reduction of waste.

Preceding Segment 1 is a management justification, a small project that focused on low hanging fruit within the same focus area. The project was done to achieve the following.

1. Display the effectiveness of the Lean Six Sigma tool.
2. Show financial savings that can be realised immediately.
3. Cement upper management support for the investigation.
4. Instil a positive attitude to the project team and belief of success.

5.1.4. Goals and targets

Performance measures were determined by the project team. These are standard measures, were used to determine the success of the project. These are critical to the Lean Six Sigma project analysis. The performance measures were identified as follows.

Accuracy of information

This target is set to ensure the accuracy of information. For accurate information, the following outcome must be met, input must equal output. This target is applicable for the primary metric as well as for the financial metric. The accuracy of information in the ERP versus manual entry (physical stock) versus the financial stock value must be 99%.

Waste deployment identification

Another target is to achieve true waste deployment. The waste deployment must be 100% accurate. For this condition to be satisfied, the data must be able to explain the source of the waste by process, machine and defect type.

Profit margin

The profit margin should be 15% and above, following the period of analysis.

Material variance

The material variance should be 10% or less.

The percentage of waste produced

The final target based on the performance measures is a reduction in the overall waste percentage to 13%.

From the initial states and the limitations set from the project scope, further targets were identified which were not performance measures. A target of a 2% reduction in production related defects was set. The initial states waste management map, Figure 23, showed that waiting for material was a major problem in the production process. As 50% of the printing machines were considered, a 50% reduction in waiting for material was set as the target.

Each segment developed its own performance measures and targets. The targets provided the project scope with defined outcomes. The targets allowed for numerical values to be given to the performance measures. These physical values determined the complete project as well as each segment's success measure.

Senior management involvement

The project team– as well as the project brief that was developed– was given full support from upper management following the management justification. To ensure successful operation, a culture of awareness, understanding, accountability and improvement needed to be instilled in the operators. From the questionnaire, it was evident that this was lacking. With the help of upper management, an awareness programme in the form of posters, discussion topics during shift meetings and employee-based improvement through suggestion boxes was developed. These suggestions were further reviewed by upper management and reported back to employees weekly by upper management to show that all suggestions, big or small, were considered and were of equal importance. This active involvement was crucial during the investigation.

5.2. Management Justification (pre-Segment 1)

The purpose of the management justification project was to obtain management support and financial approval to complete the research. The objective was to prove the effectiveness of Lean Six Sigma as a continuous improvement methodology and to display an immediate quantifiable financial saving. Management support is vital for the successful implementation of a continuous improvement methodology such as Lean Six Sigma. [111] The project had the same structure as proposed for the research.

5.2.1. Define – Management justification

The problem identified for this project was that virgin solvent used in the printing process far exceeded the cost standards. Virgin solvent is an expensive wet raw material input into the process. The area of focus was the gravure printing machines. The scope covered both machines as they shared a solvent line outlet. The performance measure was a reduction in the solvent usage determined using litres (l) as a unit of measure. The target was a 30% reduction in solvent usage in two months.

5.2.2. Current State Solvent Usage

Virgin solvent is stored in bulk underground tanks and is dispensed at the machines when required. The solvent is dispensed through a tap. Solvent is used for the production process as well as for cleaning. The total solvent usage figure combines both cleaning and process usage. The usage of solvent is dependent on the material coverage. Therefore, all figures were normalised to a common base, the current state average. For additional information, refer to Table 20.

Table 20: Current state of solvent usage [135]

Current State	Coverage 000's (m^2)	Solvent usage (l)	Standard (l)	Percentag e	Normalised	Value
November	9 050	211 167	120 666	175%	144%	R 463 210
December	5 800	174 000	77 333	225%	288%	R 381 060
Ave.	7 425	192 583	99 000	200%	200%	R 844 270

Measure – Management justificationIn order to measure, the project team decided to install flammable liquids flow at the tapping point of the solvent line. [144] The specification was determined by the project engineer and submitted to the contracts supervisor to complete the installation. The quantity of solvent used for the process and for cleaning was now distinguishable and measurable. (See Table 21)

Table 21: Measure of solvent usage [135]

	Solvent usage				
Week	Cleaning (l)	Process (1)	Standard	Deviation from standard	Cleaning percentage
1	7 464	12 036	11 800	2%	38%
2	2 600	16 900	16 250	4%	13%
3	1 387	18 112	17 250	5%	7%
4	1 692	17 808	16 800	6%	9%
5	16 862	22 032	20 400	7%	43%
6	11 609	27 285	25 500	7%	30%
7	4 559	34 335	32 700	5%	12%
8	2 564	36 330	34 600	5%	7%

5.2.3. Analyse – Management justification

The measurement instruments allowed for the ability to distinguish between process usage and cleaning. This distinction was not possible previously. Therefore all of the solvent that was used was charged to jobs. This lack of proportioning was the reason why the problem statement assumed that there was an overuse of solvent within the process. It is clear from the data presented in that the biggest source of virgin solvent waste comes from cleaning. The process solvent usage had an average deviation of 5% from the standard. This was not ideal, but following the Pareto principle that states focus should be on the vital few versus the trivial many since a large portion of the results are caused by a small number of causes, [70] further analysis was not required. Weeks three, four and eight experienced an abnormally low use of virgin solvent for cleaning when compared to the other weeks. These reductions corresponded to when the machines had long running jobs (24 hours or longer). The frequency of cleaning is reduced with long runs. Long runs are not always possible due to the high mix of customer designs. An Ishikawa diagram was completed for the excessive use of virgin solvent for cleaning. (See Figure 33)

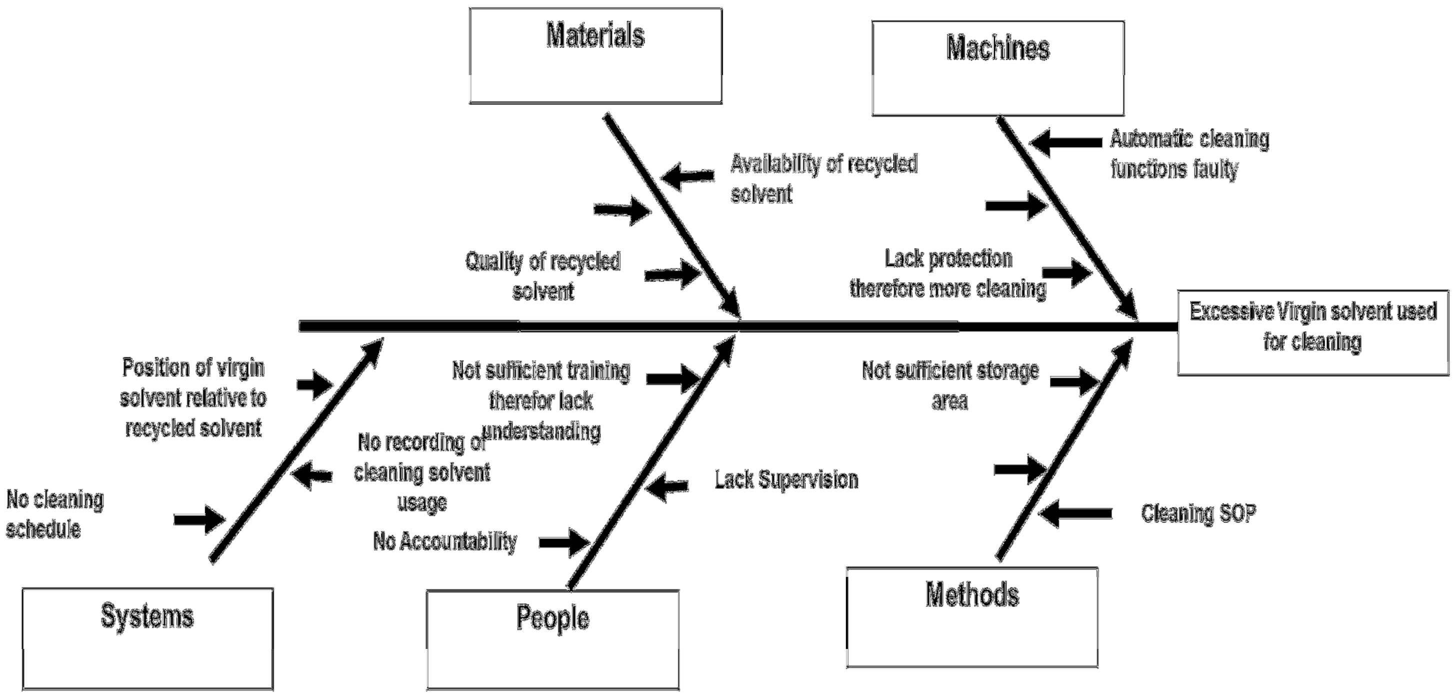


Figure 33: Ishikawa of excessive solvent use (created by author)

5.2.4. Improve – Management Justification

Based on one of the system causes identified, access to the recycled solvent was difficult. Recycled solvent again appears as a material cause due to its quality and availability when used for cleaning. The supplier of the recycled solvent was changed to one that had better technology thus providing cleaner recycled solvent. The quality of the product was addressed. Bulk storage tanks for recycled solvent (2x1000l) were installed outside the factory (to address the space constraint) and piped in to the point of use. Accessibility, space constraints, safety and availability were addressed. The dispensing points for recycled solvent were unmetered to encourage its "free" use. The virgin solvent taps were fitted with lockable dispensing heads. The ability to issue solvent per job was gained. Cleaning schedules with set procedures were introduced to limit over or under cleaning. All the people-related causes were addressed by these actions. Since solvent usage is dependent on the atmospheric conditions, it was vital that current state and final state analysis was conducted within the same season. Similar atmospheric conditions can be assumed over the analysis period. After implementation of the improvements, the final state was given.

<u>Final State Solvent Usage</u>

Table 22: Final state solvent usage (created by author)

Final State	Coverage 000's (m^2)	Solvent usage (l)	Standard (l)	Percentage Used	Normalised usage	Value
January	4 680	78 000	62 400	125%	198%	R 170 820
February	8 486	155 577	113 146	138%	120%	R 340 712
Ave.	6 583	116 788	87 773	131%	159%	R 511 532

Table 22 provides the final state solvent usage. The percentage used provides the actual usage ratio for the month based on the coverage of all the jobs run. The normalised usage value provides a base for comparison (the current state was taken as the base) such that differing coverage quantities that affect the quantity of solvent used were nullified.

5.2.5. Control – Management justification

A lack of procedures and understanding were highlighted as possible causes for overuse of virgin solvent. The implementation of cleaning schedules, updated SOP's and employee training provided the control required to eliminate the use of virgin solvent for incorrect purposes. Quarterly calibration of the flow meters and maintenance was included as part of the planned maintenance. The frequency was increased due to the corrosive nature of the solvent.

5.2.6. Discussion – Management justification

The problem of overuse of solvent was thought to stem from overuse in the process. The use of the Lean Six Sigma methodology revealed otherwise. The power in the methodology became evident as opinion was replaced by fact. The target of a 30% reduction in solvent usage was met and surpassed. An average of 41% reduction in the two months was achieved based on a normalised base. Financially, a saving of over R300 000 over two months was realised with an overall investment of R60 000. Annualised, a potential saving of over R1.5million could be realised.

The objective was to prove the effectiveness of Lean Six Sigma as a continuous improvement methodology and to display an immediate quantifiable financial saving. This objective was achieved and the purpose fulfilled as management confirmed their support as well as the required finances for the rest of the research. With management approvals and finances agreed, the four segments could now be addressed.

The Four, Segment Projects

The Define phase divided the problem into four segments. In each of the segments, opportunities were identified. Y = F(x) was satisfied in each segment. The DMAIC methodology was then applied to each segment.

5.3. Segment 1 – Raw Material Control

5.3.1. Define – Raw material control problem

From the initial conditions– refer to Figure 23 in Section 4.4– it was established that a there was a lack of control around the raw materials and their movements. As this is the birthplace of waste, it requires utmost control to ensure that only precisely enough substrate is available to produce the required finished goods. This limits potential waste creation and reduces material variance and overproduction (Muda). The following additional problems were identified after the project team clearly defined the problem.

- High values of stock were written off as missing and/or damaged.
- There was no procedure or successful system in place for location.
- The packing configuration was cramped, and some material could be forgotten or lost and ended up as aged stock or stock that was written off as its credentials were unknown.
- All material credentials input to the system were from manufacturers' labels. No checks and balances were performed at the birth of waste. Defective product could, therefore, unknowingly be used in the production process.

The raw material control scope was considered from the time material was received from the warehouse, until it was issued to production and any returns. The timeframe between these events range from one hour to 24 hours; this is dictated by production requirements and performance. The flowchart shows the actual operation around the raw materials (See Figure 34), not including any ERP system changes. This flowchart was repeated for the number of jobs scheduled daily as stipulated by the production plan. The red boxes in the flowchart (See Figure 34) show delays incurred whilst looking for material and space. The lack of order made it easy to lose stock. Therefore, input material did not equal output material. When defective material was discovered, further delays were experienced at the production end. In both cases, the result was production waiting for material. Waiting for material became the performance measure. The target set by the project team was to reduce waiting for material by 80% within six months. Measurements are required to understand and mitigate the delays and fulfil the performance measure.

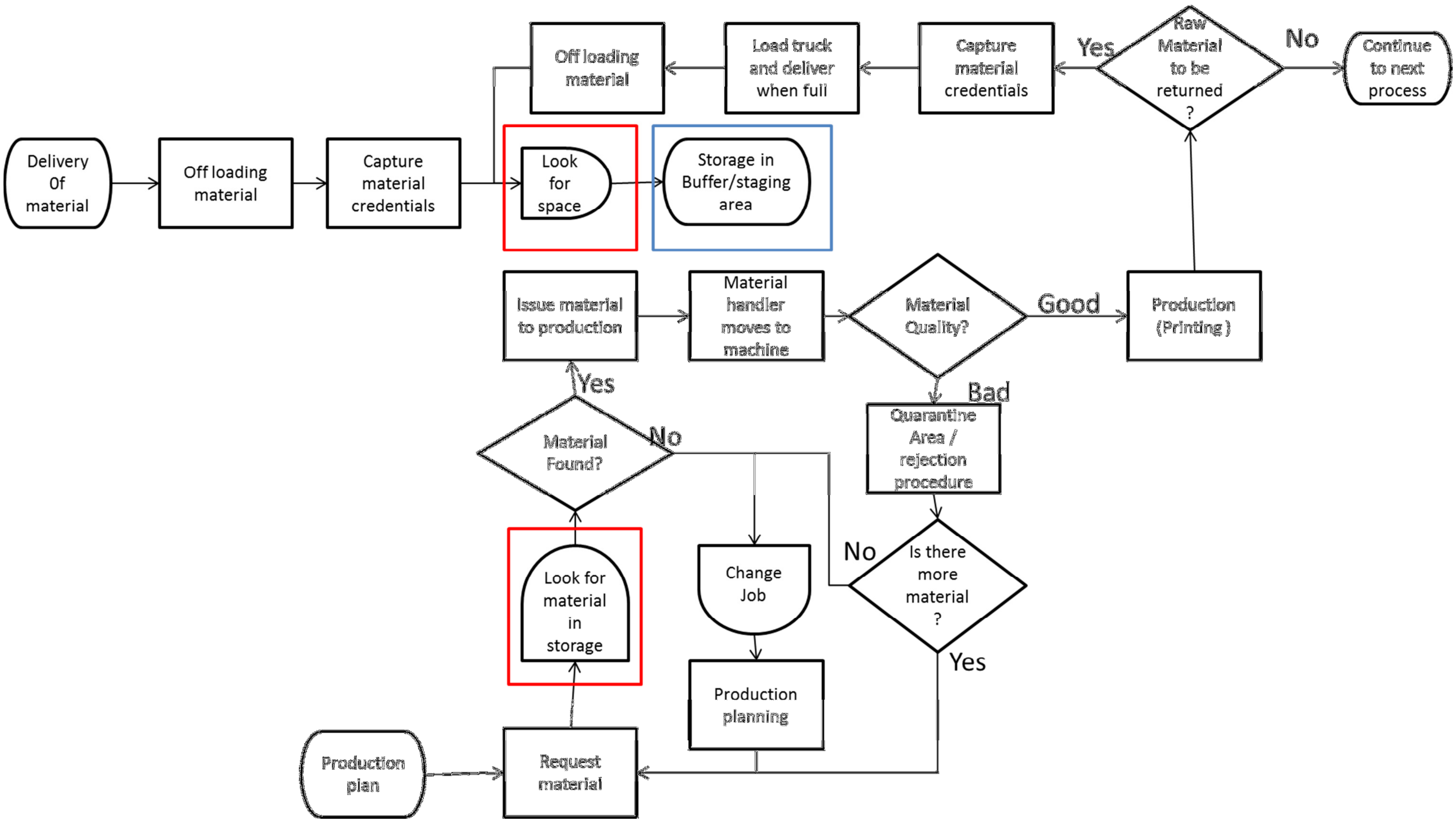


Figure 34: Raw material control process map (created by author)

5.3.2. Measure – Raw material control

The operations at the buffer/staging area are indicated with blue boxes (See Figure 34) and are controlled by a single data capturer and a material handler. Delays – the red boxes in – were experienced, which had an impact on the operations through waiting for material time downtimes recorded in the production sheets. [7] A time and motion study was required to establish the root cause of these delays and eliminate them. Video footage as well as physical measurement using a stopwatch were used to obtain the time elapsed between functions.

The following measurements were taken.

- The time taken to locate material was defined as the time from when a request was given to the material handler to the time when the first reel of correct material was found and physically lifted with the reach truck.
- The total time taken was defined as the total time needed to execute the complete operation, from receiving the request to delivering the last required reel.

Data collected can be reviewed in Table 42 in Appendix G. The average time spent to deliver a complete order was 26.75 minutes, and the average time spent locating material was 13.9 minutes.

The impact of any material delay was that the machine was kept waiting. Waiting for raw material time was recorded from the production sheets identified using the downtime code "waiting for raw material". This information was also obtained from the ERP system. Waiting for material was defined as cases when the operator was due to run the machine but could not solely due to having to wait for material. Figure 35 shows the monthly trend of machines waiting for raw material from July 2014 until June 2015.

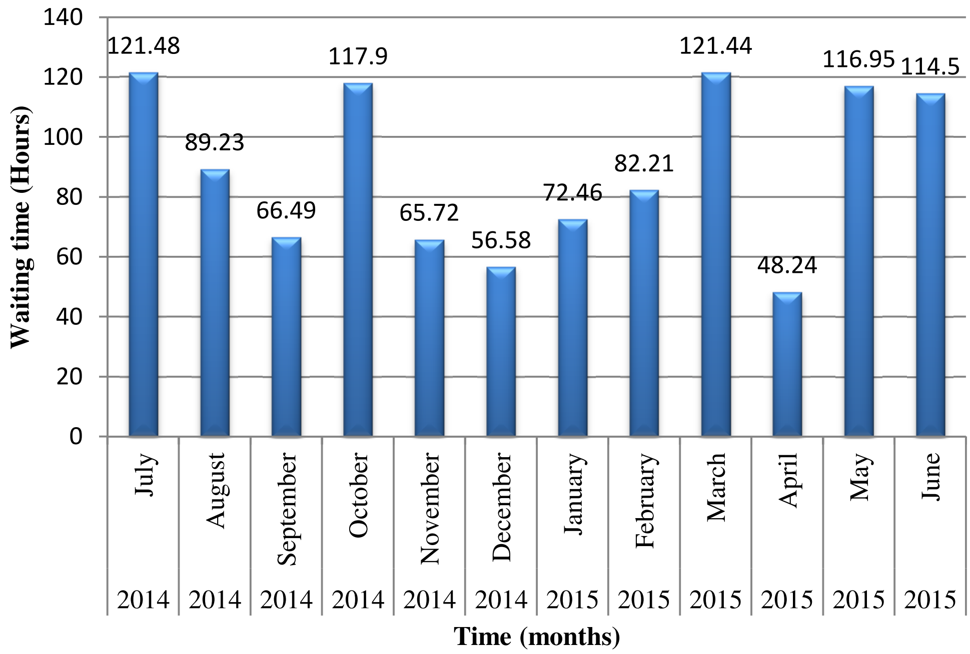


Figure 35: Waiting for raw material trend [135]

Only six months were examined before the analysis phase commenced. Since this information is readily available, a better trend could be obtained. The average waiting time was 89 hours per month.

5.3.3. Analyse – Raw material control

The time taken to locate material provides the lead times for production planning. There were common procedures required with both operations. If the common procedures were taken as constant, the biggest source of variability for completing the task was looking for the material and making space. This variability hindered the ability to accurately plan action points (the times at which material was requested for the next job) during production runs. This resulted in the machines waiting for material. The project team decided to brainstorm the root causes of waiting for material (See Figure 36).

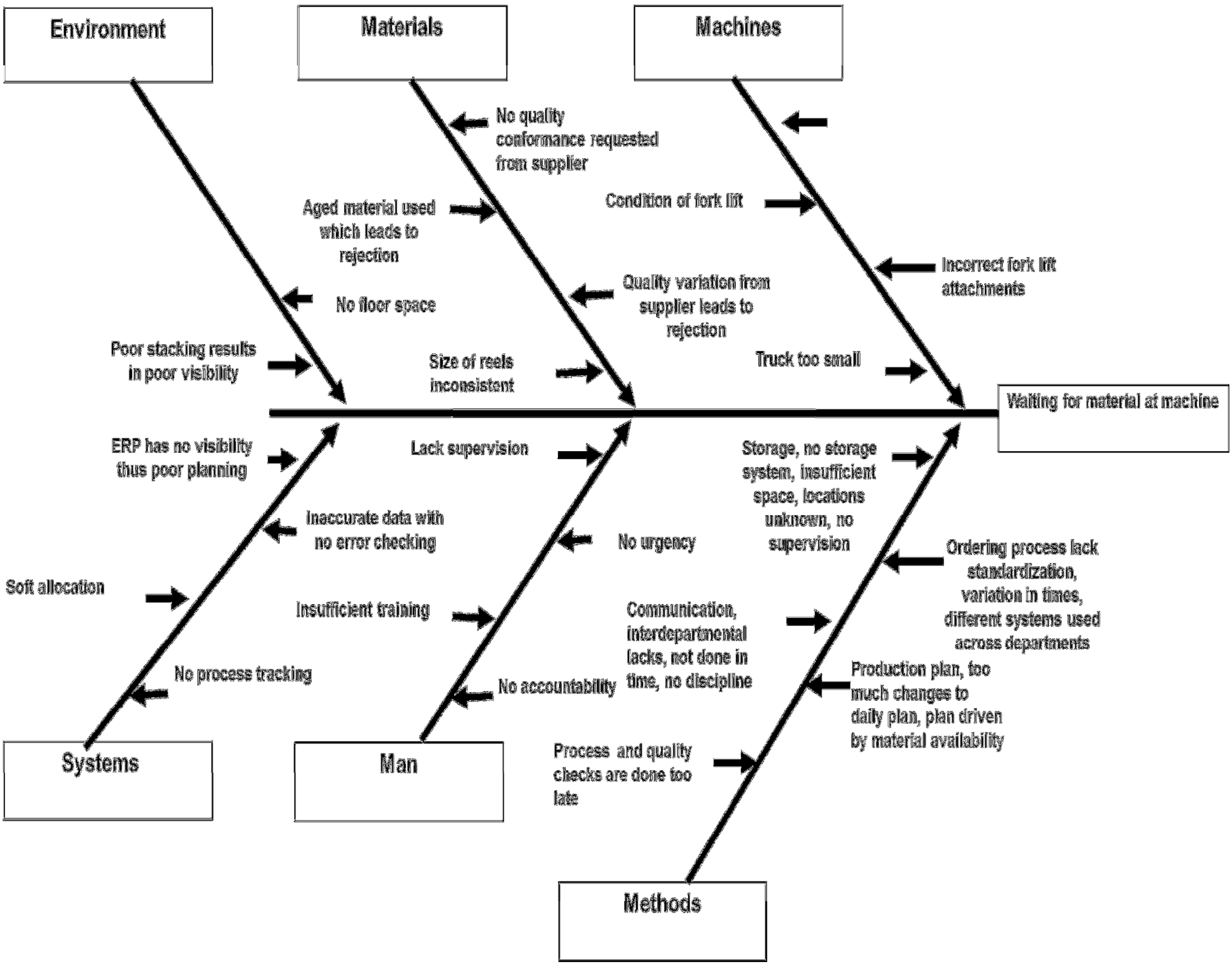


Figure 36: Ishikawa diagram for waiting for material (created by author)

5.3.4. Improve – Raw material control

The team then brainstormed possible solutions based on the causes identified in the Ishikawa diagram under, “man”, “environment”, “method” and “system”. These were targeted as their solutions would: solve the majority of the other root causes, mitigate the variability in the process and at same time provided a means to satisfy the equation where input must equal output.

Man: The current supervisor exhibited a lack of ability, control and systems thinking. It was agreed that a better raw materials supervisor was required to address the man cause. The supervisor was changed and the new supervisor added to the project team. The new supervisor was tasked to aid in the implementation of the ideas.

Environment: The environmental contribution cause was addressed through a 5S exercise. The exercise cleared the staging area of unidentifiable and unusable stock. A proper racking system was installed to achieve better inventory management and increase the storage capacity of the staging area. This process was done over three months to reduce the financial burden.

System: Resolving the system causes was limited due to financial constraints but an entry level location tagging and barcode system was purchased. The new system has functionality that makes it possible to categorise and locate all raw materials. It allowed for the physical locations of material to be fed back into the ERP such that the material picking list included the physical location. Material could then be scanned in and out of a location resulting in 100% traceability of all material. The system automatically allocated a first-expired-first-out (FEFO) system when materials were being picked for jobs, thus reducing the amount of aged material. A system to request material was also implemented such that the lead time for delivery of material was always satisfied.

Method: The method causes were addressed through implementing a change in the procedure to deal with rejects and returns. The procedure required moving the quality checks to before the material had been issued to production. Quality checks were conducted on arriving material. The material handling equipment was also upgraded to suit the application. This was achieved at no additional cost to the company, as a service level agreement with an external supplier included providing machinery that was “fit for purpose”.

Following the implementation of the changes, data was recollected. The data collected is shown in Table 43 in Appendix G. The time taken to look for material showed a decrease in the average initial time from 13.9 minutes to 1 minute. Additionally, the number of reels required in an order was retrieved consistently. On average, the time to locate material decreased by 92.8% for the observed period.

A combination of the two procedural changes– firstly, to inspect material before acceptance into production and secondly, to have material stored in a known location– resulted in minimising the delay caused from changing jobs and waiting for material. A new buffer location for return to stores (RTS) material was created. RTS material was issued directly back to the raw material warehouse and the location was scanned to this newly created buffer area. The material is then immediately available for allocation to other jobs. If the production plan for that week did not require any of the material in the buffer area only then was it removed from the staging area.

Figure 37 shows the change in the process flow diagram. These changes are highlighted with red blocks and include:

- the inclusion of quality checks when the material is delivered to the staging area;
- the inclusion of a quality checks before the material was issued to production;
- a removal of the delays which were for looking for material, finding or making space and changing the job;
- a returns policy that allows for proactive planning as returns material are immediately available.

The new control procedure contributed to the reduction in the time spent waiting for material. All the queries and checks are done within the lead time window. Waiting for material average reduced to 48 hours during the observed period.

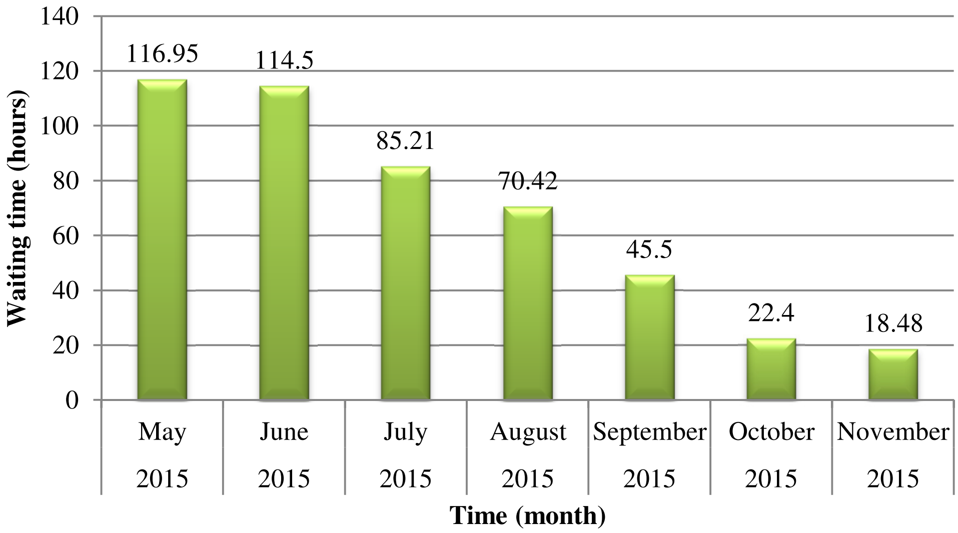
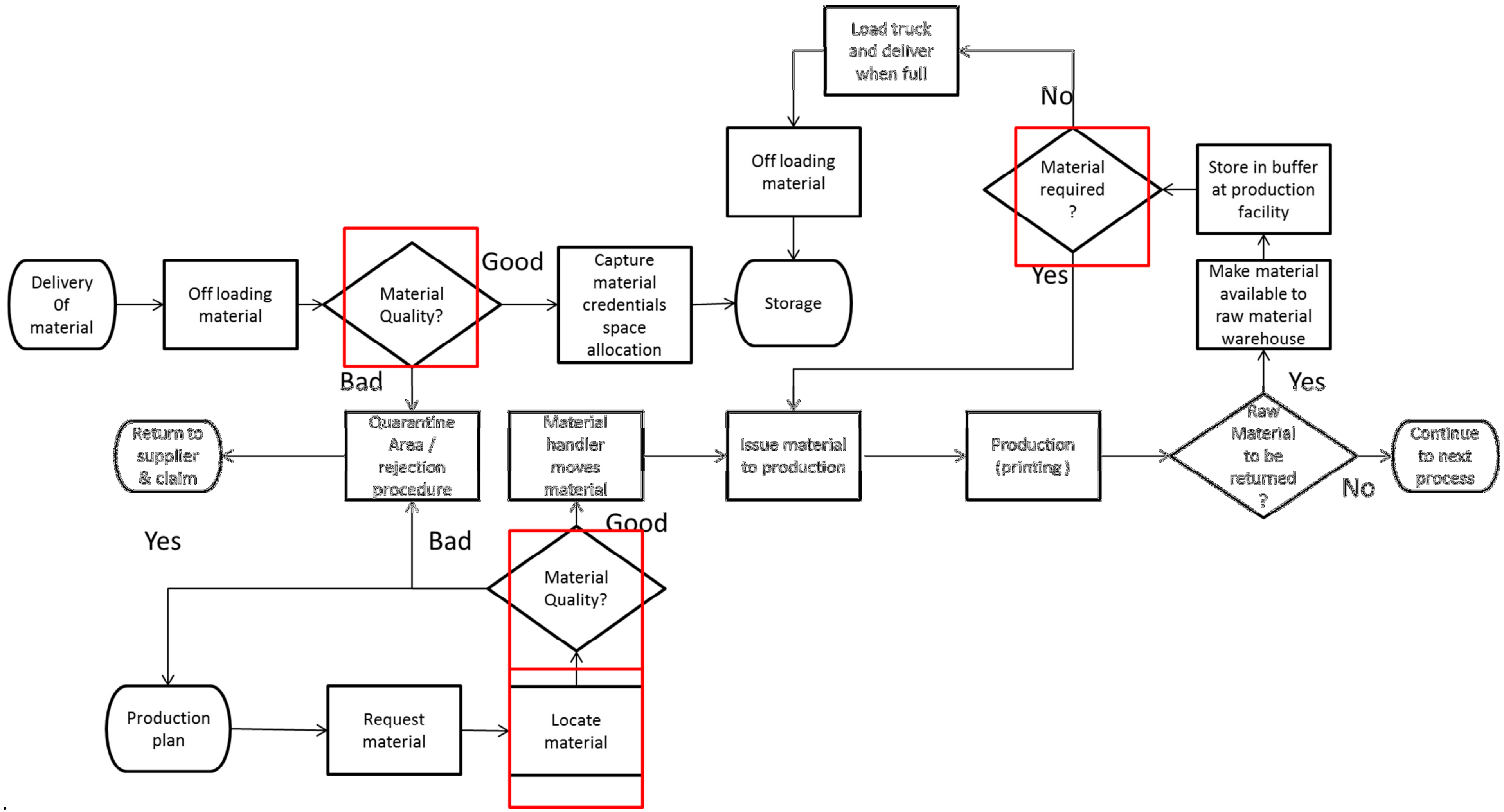


Figure 37: Waiting for material trend after system changes [145]



.

Figure 38: Raw material control process flow after improvements (created by author)

5.3.5. Control – Raw material control

The process flow was amended to suit the operational conditions. The raw material supervisor was vital in driving the behavioural change needed for sustainable implementation. The corrective actions require a system in place to sustain them. A set of SOP's was developed for the operation of the scanning location system. The current system SOP's were amended to suit the new procedural changes. Part of the SOP included grouping material using a three-level break down; material type, material properties and material width.

Every job has a works order. This is the document that contains all the information pertaining to the job. In the works order, a status control card was added, and this card was given to any raw material supplier (substrate, ink, varnish, release lacquer or cold seal). The card was filled in by the operator at the start of a job. A sample of a status control card is shown in Table 44 in Appendix G. It ensured that all materials required to execute the next job on the plan would be ready on time, thus eliminating any waiting. This was accomplished by providing each handler with the time that they should start preparation for the next job on a specific machine. Cumulative production downtime longer than 1.5 hours resulted in an amendment of the status card. Improvements in the time taken to finish the job, resulting from the increased efficiency, had a two-hour buffer due to the changeover period for the next job. If the jobs exceeded this two-hour mark, which was highly unlikely, then the job standard speed needed to be changed on the works order to prevent a reoccurrence.

5.3.6. Discussion – Raw material control

Raw material control has dual benefits. On the one hand, the benefits of production efficiency are gained and on the other, the foundation of waste management is built. Raw material control prevents defective material from entering the production environment therefore reducing the ability to create waste and Muda. The investment in an automated location system and the application of 5S to the staging area lead to notable changes in procedures such as:

- location of raw material became quicker and easier;
- elimination of the requirement to make space or clear other raw material to access the required job material;
- decreased handling of material thus reducing the risk of damage.

With 5S, a racking system was included. The time spent looking for material in the staging area decreased by 92.8%. Safety in the area increased as dangerous stacking was eliminated. The amount of material damaged through poor handling and bad stacking practises reduced from an average of 13 incidents to 2 during the analysis period. All this material previously represented wasted opportunity, which decreased the profitability of production. The racks and the addition of new light fixtures also increased the safety of the operators. Based on the root cause analysis in Figure 36 in Section 5.3.4 and data recorded in Table 42 in Appendix G bad stacking practices were highlighted as a safety risk as well as a cause of waiting for material. Two financially quantifiable figures emerged as a result of the changes to the staging area.

1. The time spent looking for material. The time spent waiting for material decreased from an average of 89 hours to an average of 48 hours for the period observed. At 46% reduction, this fell well short of the target. The higher average was due to teething issues during the implementation of the system and the length of the analysis period. Waiting for material increases the cost of production and is an indication of poor material management systems. The reduction in this downtime resulted in more production availability (opportunity). The downward trend of Figure 38, suggests that the employees became better at operating the system. This was confirmed by the fact that the final two months that were measured had an average of 20.4 hours waiting for material down time, a 77% improvement from the initial state. The target was still not met, but it is expected that process standardisation and a longer analysis period will achieve a consistent result that exceeds the target.
2. The amount of defective material reaching the production stage. The amount of defective material reaching the production stage decreased based on the fact that raw material rejections from supplier increased 3.4% over the analysis period. [135] Because material was inspected upon arrival, quality rejects were identified early and a credit note requested from suppliers. The material therefore does not incur any storage cost. More importantly, the material is not scheduled for production and then rejected at the machine resulting in lost production time and creation of waste.

Unquantifiable savings were also realised through raw material control. These were observed when material was rejected before it ever got onto the production floor. Such savings resulted from the fact that the material potentially could have followed the complete production process and accumulated value only to get dumped at the end. Previously, the oldest substrate based on first-in-first-out (FIFO) was allocated to a job. As this was a manual task, sometimes this rule was not followed and the best fit substrate based on the weight requirements was allocated.

The date the material is received into the staging area is used as the start date for ageing the material. The FIFO system also assumes that all material delivered from the manufacturer is from the same batch and thus ages similarly. These two conditions can result in quality variances and the production of product that will be rejected by the customer. The first-expired-first-out (FEFO) system uses the date of manufacturing and the batch number to group similar material thus ageing them at the same rate. It is therefore possible that a shipment of material arriving to the staging area last can be utilised first. The FEFO system achieves the most desirable state of waste management in that the waste is reduced by reducing the likelihood of aged material going through the production process.

Controlling raw material will positively affect the upstream process because the input to the system is stable.

5.4. Segment 2 - Process Control

The following segment looks at how value is added to the substrate. This is where the most waste is created as established in Section 4.5. The opportunity exists to achieve the most desirable outcome of the waste management hierarchy, which is reduction of waste at the source.

5.4.1. Define – Process Control Problem

The initial conditions state (See Section 4.5 Figure 26b) that there are five variants of waste defined as; set-up, reel end, print, lamination and slit waste. The waste of interest was print waste. Cumulatively, the print waste figure was recorded, but not verified. The composition of the unverified print waste figure was unknown. The inability to identify the source of the waste resulted in ineffective waste combating strategies. The result was a continued loss of profit, as material was wasted with no factually accurate root cause. Reworking (over processing) was introduced to try and salvage good material.

The team was tasked to address the high waste figures being obtained. The performance measures were identified as waste deployment and the accuracy of information. The target was to understand the waste deployment of all processes and ensure 99% accurate information. By understanding the waste deployment, waste reduction initiatives were to be implemented to achieve a waste reduction.

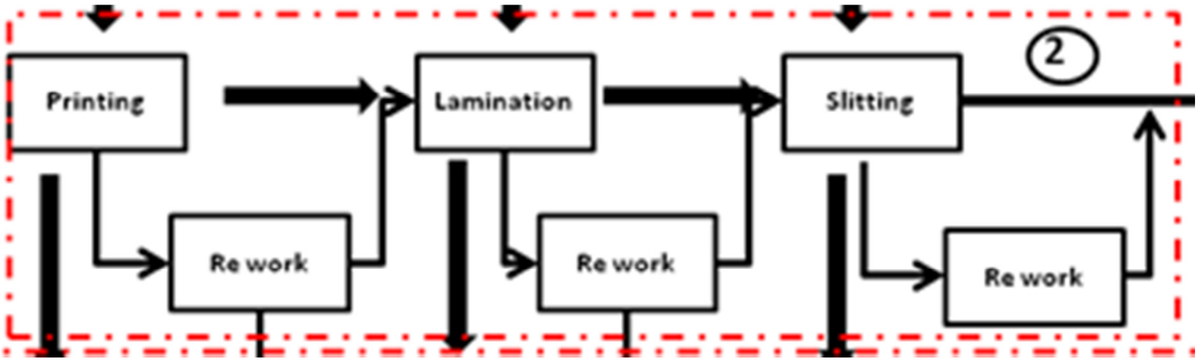


Figure 39: Segment from contain high level process flow (created by author)

Figure 39 is a high-level process map of the process that will be considered. The reason the complete system is of interest is because print waste can be, and is, removed at all the downstream processes.

A known weight of raw material is input into the printing process. During the printing process set-up, waste is removed and dumped into a bin. When the job is ready to run, camera systems display the print for the operator to check and detect where defects occur for the operator to flag. A flag is a coloured tab stuck to the substrate at the edge for visible identification. Only major defects are removed during printing. The decision to rework is made by the quality controller (QC) if a reel is suspected to have major defects that were missed by flagging or if the defects extend further than expected making it economically unviable to move the reel as is to the next process.

At lamination, reels are run to the flag. Then the print waste cut out and the web is re-joined and flagged at the joints. The amount of stop/starts and the efficiency of the lamination process is directly proportional to the number of flags received from printing. Again, decisions to rework come from the QC if reels have a large amount of suspected lamination or missed printing defects. Sometimes is it more economical to laminate with the print defect.

The slitting process machines are run at high speed so minimal inspection of the web for print and lamination defects is possible. The operators stop the machines at the flags to remove lamination joins and once again when the customer required slit specifications are met. These times are also used to visually inspect the reel. Slit product is sent to be reworked if the reels do not meet customer specifications or a defect is identified post slitting. All slit reels from that batch will then need to be reworked. The rework station consists of two machines that can rework one jumbo reel or slit reel at a time. Slit reel pallets vary in size from four to 36 units.

All material from the complete process requiring rework goes to these rework stations. A measure to understand the quantity and type of waste produced and the effects of the rework station is required. A target of a 50% reduction in reworking was set by the project team. The project team believed this figure was achievable and in line with the financial target for profitability (See Section 4.7) set by upper management. Measurement was done for the printing process based on the initial conditions stated in Section 4.5.2.

5.4.2. Measure – Process control

Overall quantities of waste by process were recorded, but unverified. Measurement of waste by machine was required to verify the recorded figures. The data was manually measured at the end of each shift, for a duration of three months before being analysed. Figure 40 shows waste measurement overall, and then split by process. Figure 41 shows the measurement of waste by machine. M1 and M2 are gravure machines, that are mirror images of each other, and M3 and M4 are flexo machines.

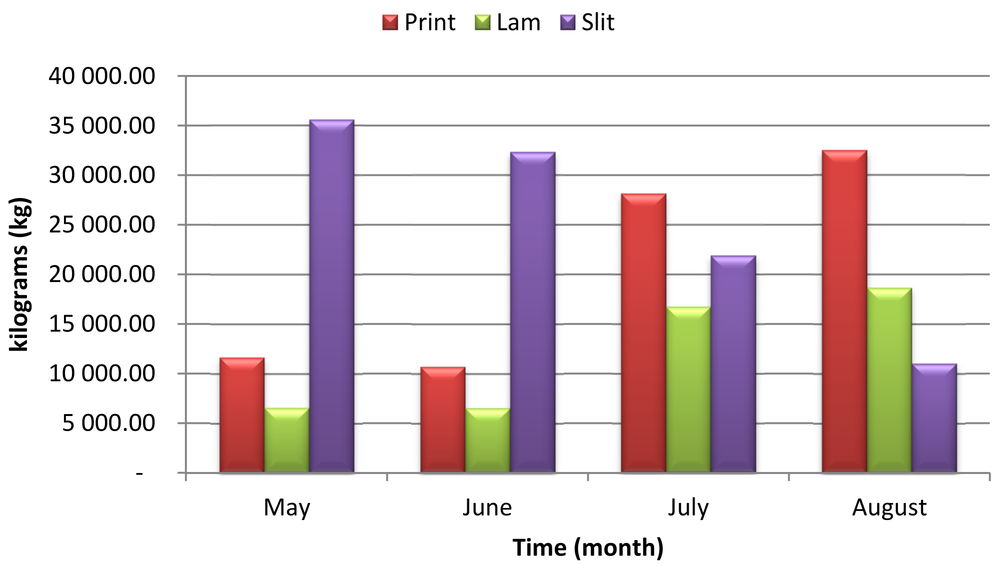


Figure 40: Waste per process of total factory [135]

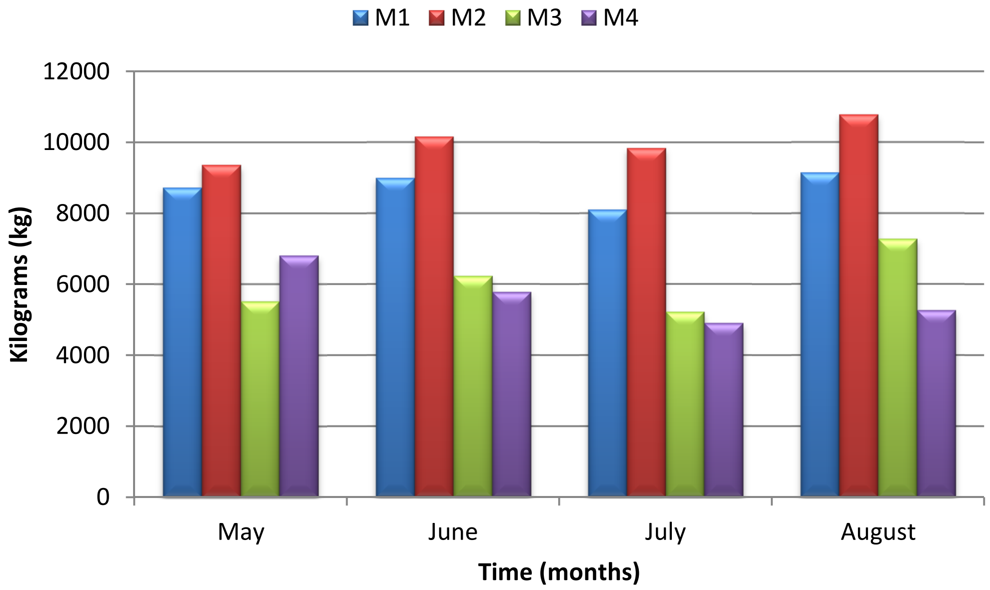


Figure 41: Waste measurement by machine [135]

All defects are flagged, and these provided an idea of the deployment of waste. Based on the contributions of waste from printing, a measure of the quantity of flags (See Figure 42) was carried out for the gravure machine, M2, as it was the biggest contributor. A Pareto of the flags is shown in Figure 43. The Pareto identified the critical reasons provided for defects produced on machine M2. A focus point was gained for analysis.

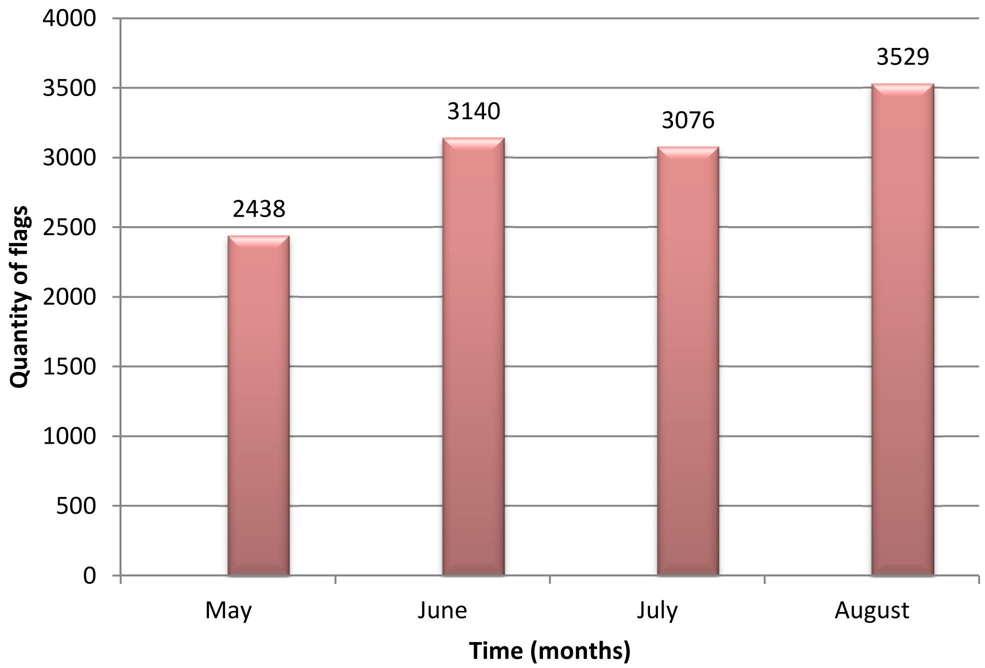


Figure 42: Flag analysis of M2 [135]

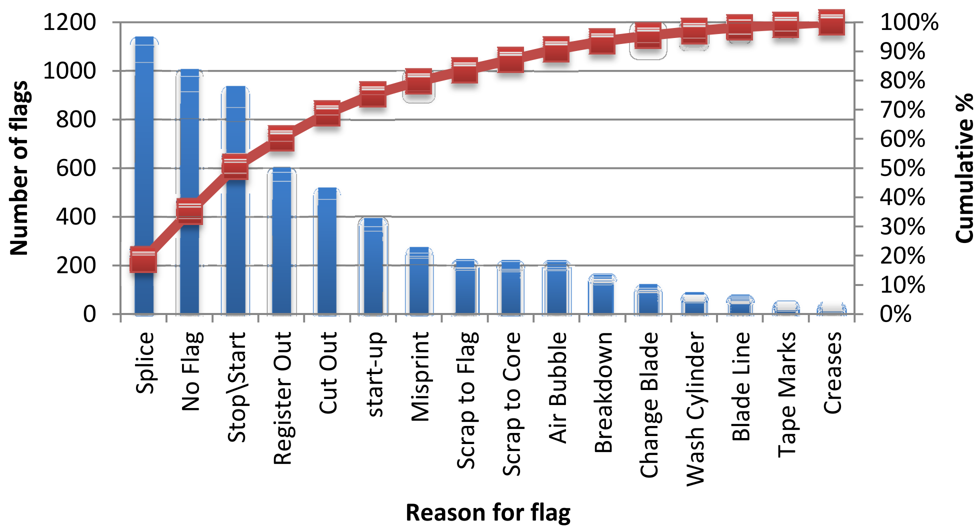


Figure 43: Pareto of flag reasons [135]

The quantity of rework was very high, and could often be seen piling up before the rework station. Measurements were taken to understand the quantity of rework processed by the case company, and an assessment of the reasons why jobs were sent for rework was carried out. The quantity of material reworked was measured and shown in Figure 44. An average of 4.5% of all output is reworked.

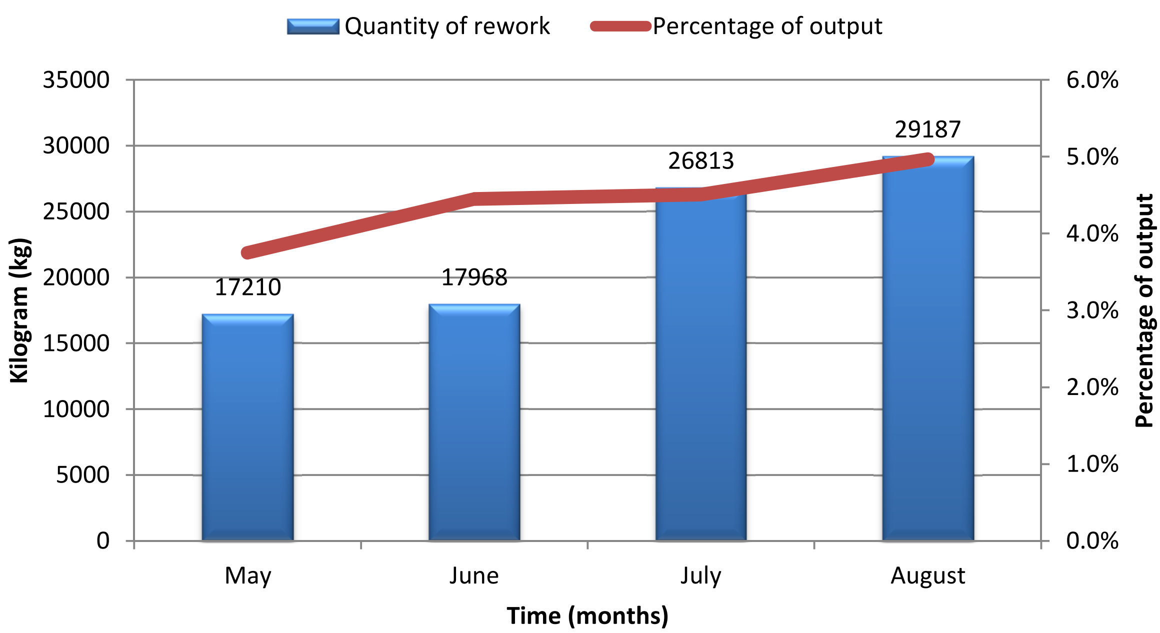


Figure 44: Quantity of reworked material and quantity as a percentage of output [135]

A table of the data collected is shown in Table 45 in Appendix G. The outcomes from the table showing the defect type or reasons why material was reworked are shown in Figure 45.

The Pareto identifies profile and inspection as the key defect occurrences at the rework station. For analysis ink splash was also considered, as it was a quick win.

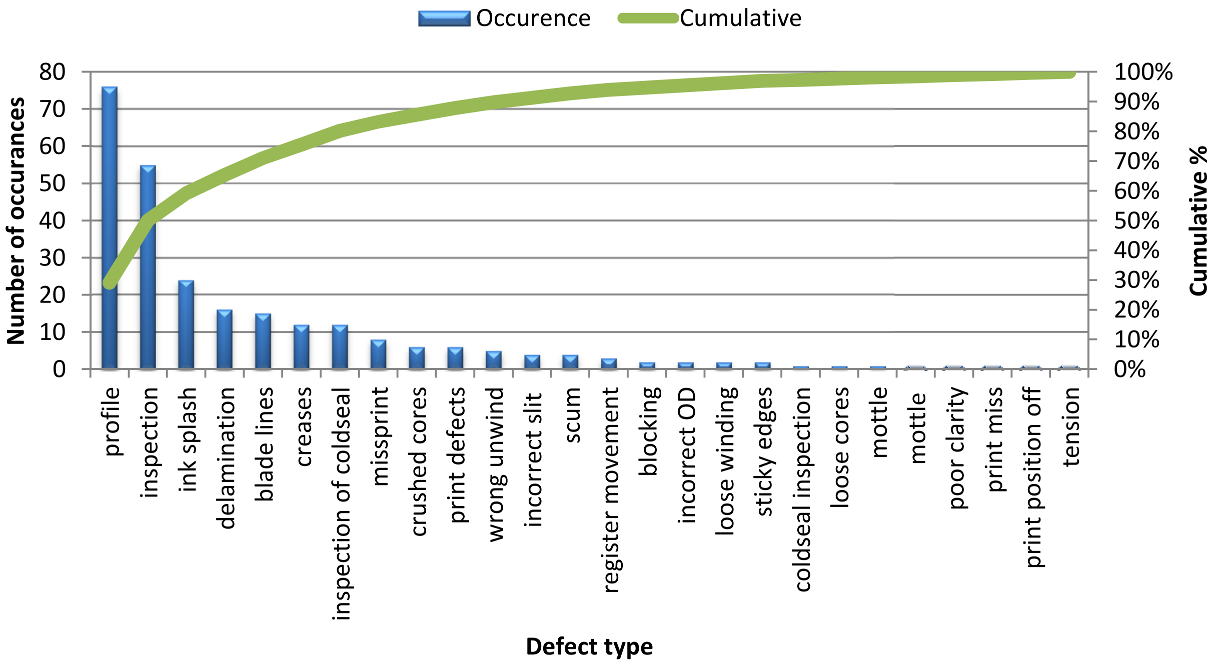


Figure 45: Pareto of defects causing rework [145]

5.4.3. Analyse – Process control

The flag analysis did not provide any usable information in terms of understanding the defects off the machine. Because the operators inputted the reasons for the flag, there seemed to be an element of dishonesty. The top reasons provided for flagging were splice, no flag, and stop/start.

- Splice is where two reels are joined together. The quality manager believes that this is not possible as the most splice flags a WIP reel will have is three. "Splice flags are not common in WIP." [9]
- No flag is where no description is provided for the flag.
- Stop/Start is when the operator stopped the machine for some reason –the reason the operator stopped is the information required– and started again.

For this reason, more focus was given to the rework analysis as the reasons provided for the defects were from independent employees and provided more direction. The data revealed that the rework procedure was a bottleneck. In Lean manufacturing, over processing is one of the eight wastes. [3] Optimising the procedure around this bottleneck would not solve the root cause of the problem. Elimination of the process completely was the desired outcome. In order to achieve this, the project team analysed why WIP requires reworking.

According to the measurement, the top reason for sending work to be reworked was suspected print defects. (See Table 45 in Appendix G). Applying the 80/20 principle to the Pareto Chart (See Figure 45), the project team did a FMEA. The defects analysed were profile, inspection and ink splashes. (See Table 46 found in Appendix G)

5.4.4. Improve – Process control

Measurement revealed that the majority of defects came from gravure machine M2. Upon further inspection, the camera system installed was found to be below standard and different to that of gravure machine M1. It had lower sensitivity and resolution. Thus, some defects were never flagged. The original equipment manufacturer (OEM) was contacted, and a trade-in deal at a fraction of the cost of a new system was negotiated. The capital expenditure budget (Capex) was approved, and the system was installed.

The new system was a 100% inspection system. The master template approved by the customer is loaded as the reference sample into the system. The production job is checked against this. The system does not eliminate defects, but it allows the operator to identify previously missed defects and to classify them correctly for further analysis.

Along with the new system, further analysis revealed modifications on the machines that resulted in deviations from the OEM specifications. These deviations were the causes of some of the failure modes. A process of restoring machines to basic conditions began. Actions items were prioritised using a perspective-modelling matrix. (See Table 47 in Appendix G) Each action item was measured and scored against the driving objectives (total being 100%), which were cost, added value, required machine time, availability of parts, criticalness to quality ratings, and whether the work could be done in-house or would need to be outsourced. A summary of the actions and their execution prioritisation is provided (See Table 23). The rank provided the order in which the contracts supervisor in the project team executed the actions.

Table 23: Summary of perspective modelling matrix (created by author)

Action	Prioritization (%)	Rank
Ventilation of machine	80	1
Calibration	79	2
Deep cleaning	76	3
Water treatment	71	4
Inspection system	70	5
Modification of chucks and bearing	68	6
Dryer hoods service	65	7
Standardisation of machine trolley	63	8
Chill rollers	60	9
Alignment	50	10
Spare parts	43	11

The defects caused by ink splashes were a problem that was not addressed by the mentioned improvements. It was found that some passes did not have any splash guards installed. Ink splashes were addressed via cleaning the machine and replacing all splash guards. The pneumatic pumps were erratically returning too much ink to the ink trough and at a high velocity. This also created ink splashes that exceeded the area covered by the splash guards. The air pressures of the pneumatic pumps were given physical upper and lower limits that the operators could not exceed. Should a pump need to be operated outside these bounds, the pump was removed from the machine and replaced with a spare while the defective pump was serviced.

To understand the waste deployment, waste must be classified by process, by machine and by defect type. Standard defect type categories were established based on the information gathered about the type of defects in reworking (See Figure 45) and information provided by the quality manger on defects that were not re-workable, but had a record of occurrence in the company records. [9] These were also used as the reasons for flags so they could be identified in the next process. The flags were given colours specific to the process where the waste was created for easier identification.

The downstream process mainly served to remove the waste from an upstream process. A cross-functional training programme in defect identification and troubleshooting was also implemented alongside the procedural change. This was done to aid the accuracy of waste recording. Table 24 shows the waste defect reason given for deployment per process. These reasons became the only reasons available for operators to input as part of the flagging system as well as the rework description. The table and the training provided eliminated the guesswork and unreliable data that was previous obtained (See Figure 42 in Section 5.4.3).

Table 24 constitutes a critical component in understanding waste creation, as waste is now understood by machine, process and defect type. The basis for all future analysis required to execute continuous improvement projects and the operational KPI for waste deployment are fulfilled with Table 24.

Table 24: Waste deployment table (created by author)

Waste deployment reasons						
Print defect reasons		**Lam defect reasons**	**Slit waste reasons**	**Raw material**	**Supply Chain**	**All purpose**
-Air bubble -Bar code fail -Blade lines -Blocking -Cold seal blocking -Cold seal out of register -Colour variation -Creases -Cylinder wash -Dirty print -Filling in	-Ink splashes -Miss print -No cold seal -Pin holing -Pitch variation -Reel end -Register movement -Rejected material -Scuff marks -Scum -Sticky material -Weak cold seal	-Adhesive miss -Blade lines -Cold seal blocking -Cold seal out of register -Creases -Delamination -No cold seal -Scum -Weak cold seal -Cuts in material -Mottle	-Trim -Reel end -Incorrect - slit position	-Hyster damage -Slack edge -Transport crushed core -Transport damaged reel -Raw material not sealing -Creases -Loose winding -De-lamination from supplier -Foil wash -Film breaking	-Damage in transit	-Cores -General -25l metal drum -Wooden boards -Metal -Scrap pallets

The target of implementing a working waste deployment solution was achieved during the period of analysis; however, SOP's were not completed in the same period. The improvements began to show a reduction in the amount of material requiring rework after printing. The amount of rework from printing decreased 53% at the end of the evaluation period. Figure 46 provides the average baseline calculated before the improvement and the monthly figures recorded after the improvement.

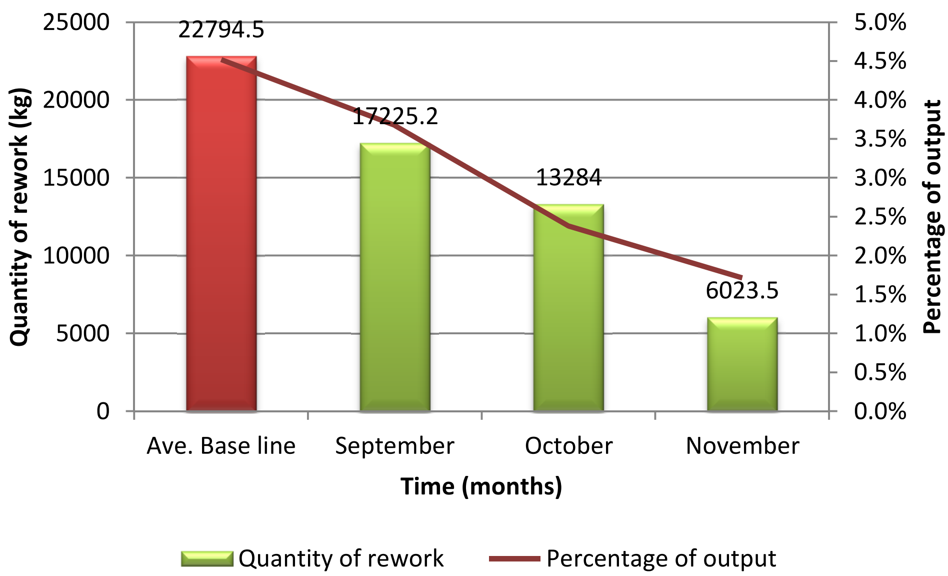


Figure 46: Quantity of rework following improvements [135]

With the correct waste deployment, the waste from printing increased initially, which confirmed the suspicion that there was an incorrect allocation. The printing waste then displayed a decreasing trend (See Figure 47). The split of waste by machine (See Figure 48) showed on average a 27% decrease in waste production by the analysed machine (M2) during the analysis period.

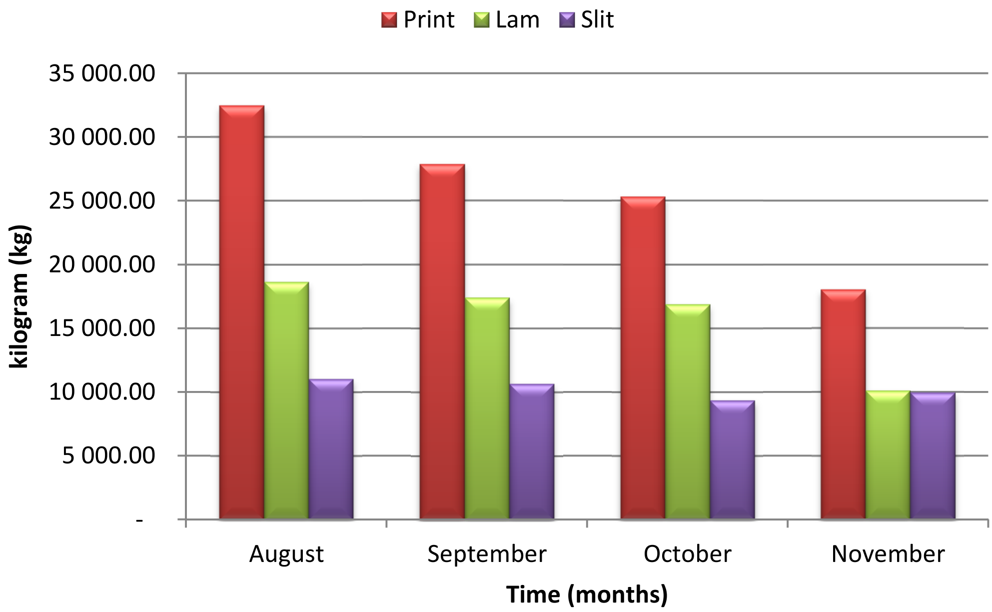


Figure 47: Waste by process after analysis post improvements [135]

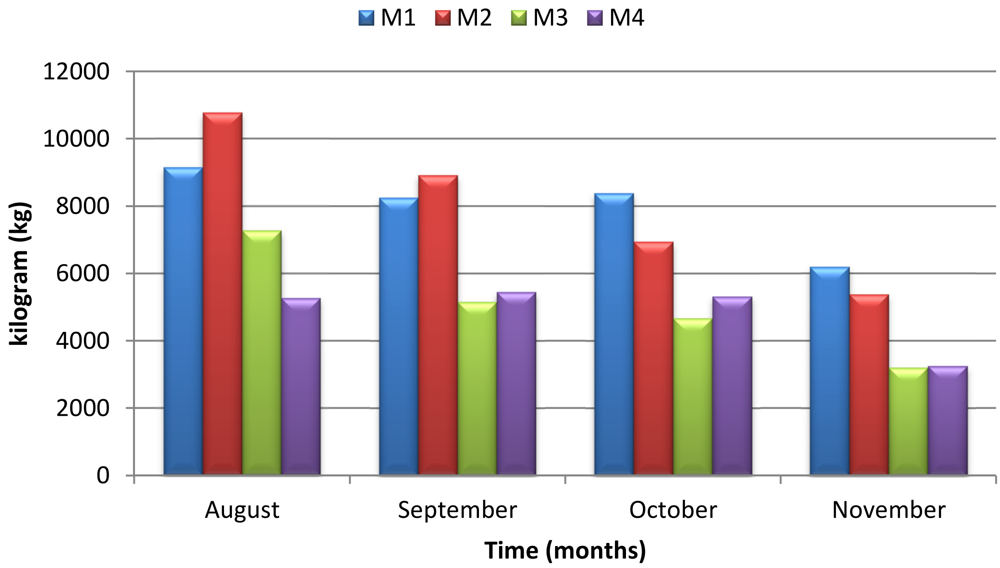


Figure 48: Waste by machine, post improvements [135]

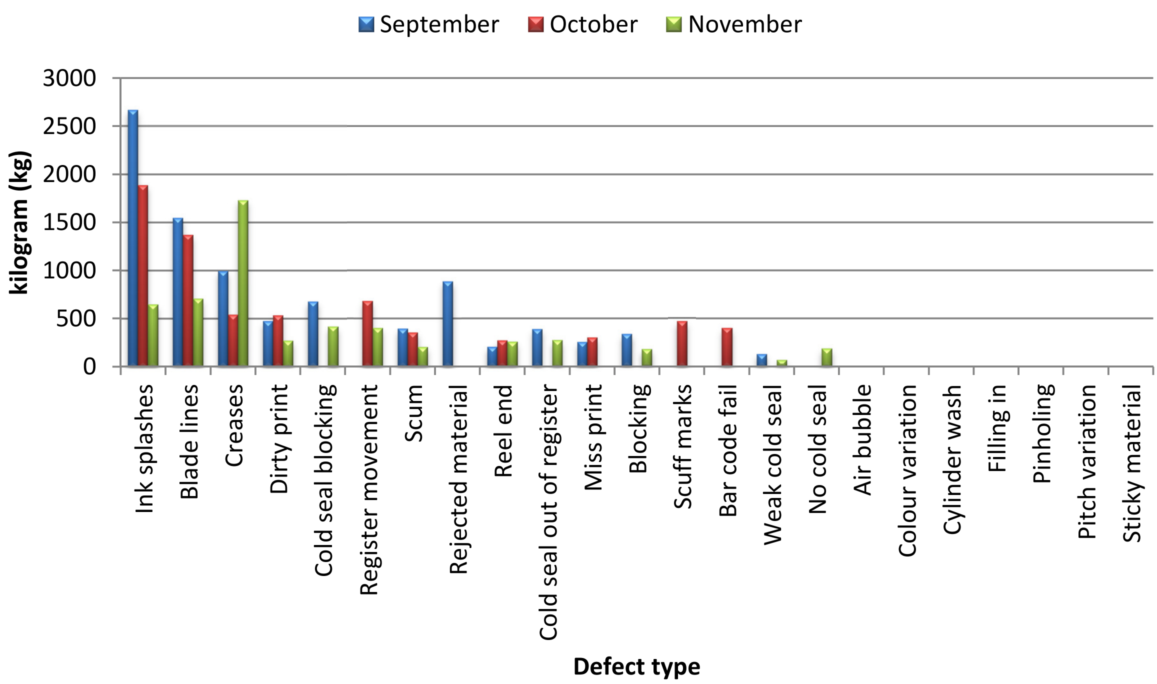


Figure 49: Waste deployment over the improvement period [135]

The contribution of waste per process weight and the deployment of waste per defect weight (See Figure 49) at the end of the evaluation period had a 1% variation. Input versus output had an accuracy of 99%, which the company found acceptable.

5.4.5. Control – Process control

The improvement that was implemented for restoring machines to basic conditions requires an active preventative maintenance programme to ensure that the machines are kept good as new and increase availability. [146] A training programme for the 100% inspection system was implemented with the intent to retrain operators biannually. SOP's were redrafted to include the process changes in recording waste, as well as the new flagging system. Shift handover documentation was more accurately checked, and operators were disciplined when instructions were not followed and deemed to be gross negligence. The shift handover book proved to be very important, as each operator could communicate the life of the doctor blades such that blade lines were avoided and unnecessary changes did not occur.

5.4.6. Discussion – Process control

An analysis of the origins of the flags established the foundation of a third level of waste deployment, the defect level. The defect level provided a more direct explanation as to where the source of waste creation was. Information on defects from the measured data and from the process specialist achieved the deployment classification. The solution (See Table 24 in Section5.5.4) theoretically is expected to be sustainable, but requires constant checking for reliability. Considering the process operators previously were negligent in the classification of defects with the flags there was a real risk that the same could be repeated with the waste deployment. While this cannot be guaranteed, the differences as described below were in place to mitigate this risk.

- The waste was classified by the next process downstream process and only supervisors were allowed to verify the defect.
- Documentation that was stuck on the reel pertaining to defects was eliminated and replaced with a single waste book. This reduced the risk of information being lost and replaced with guesses.
- Employees were involved in the formulation of the solution, therefore process ownership was observed.

The waste deployment process could be improved by reducing the number of defect options available. Large lists could be tedious and lead to repetitive classification based on the first options presented. This again could lead to skewed results and incorrect focus points. The list could be reduced by not considering each and every possible classification of defects but instead, focusing on the top five major defects. The waste deployment document would need to be a live document and, through continuous improvement exercises, be modified by the operators.

Machines were returned to the OEM specification. Over time, as machines were repaired, financial pressures had force the maintenance team to use out-of-specification replacement parts or take parts from a working model to repair component failure. A 53% reduction in the rework was realised for printing and a 27% reduction in overall waste percentage was observed by the machine M2 (See Figure 48). These changes, along with the implemented solution, represent a long-term solution with immediate effects. The solution will continue to be effective for as long as maintenance is carried out to OEM specifications.

The solution can be improved upon through the inclusion of human skill level as a solution. The cause was solely addressed from the machine perspective, including training from the OEM on the correct use of equipment should be considered. The solution could therefore include having the correct tools for the job as well as having operators who know how to use those tools correctly. The impact on process control is not easily quantified but there is 47% of opportunity left in the reduction of rework and 73% in the reduction of overall waste in M2, that could be addressed.

5.5. Segment 3 - Substrate Management

By ensuring that all information was up to date and accurate, the next step was to consider the primary substrate management more closely. The current state (See Figure 23 in Section 4.4) showed substrate production information was, in some cases, days behind the process and did not allow for effective management of the substrate. The following section covers how the substrate was managed within the production process.

5.5.1. Define – Substrate Management Problem

The substrate makes up 93% of the finished product as shown in Figure 2 in Section 1.2. This also means the substrate is a very important asset financially. The company financial records from the ERP showed that on average R1.9 million was lost per month due to material variances. [7] The current state revealed that the printing process was responsible for 45% of that figure (See Figure 24 in Section 4.5). The high-level process map (Figure 50) describes how the substrate weight is monitored throughout the whole production process. The complete process needs to be considered when dealing with the substrate, as no process can stand in isolation. The upstream processes are dependent on the downstream processes.

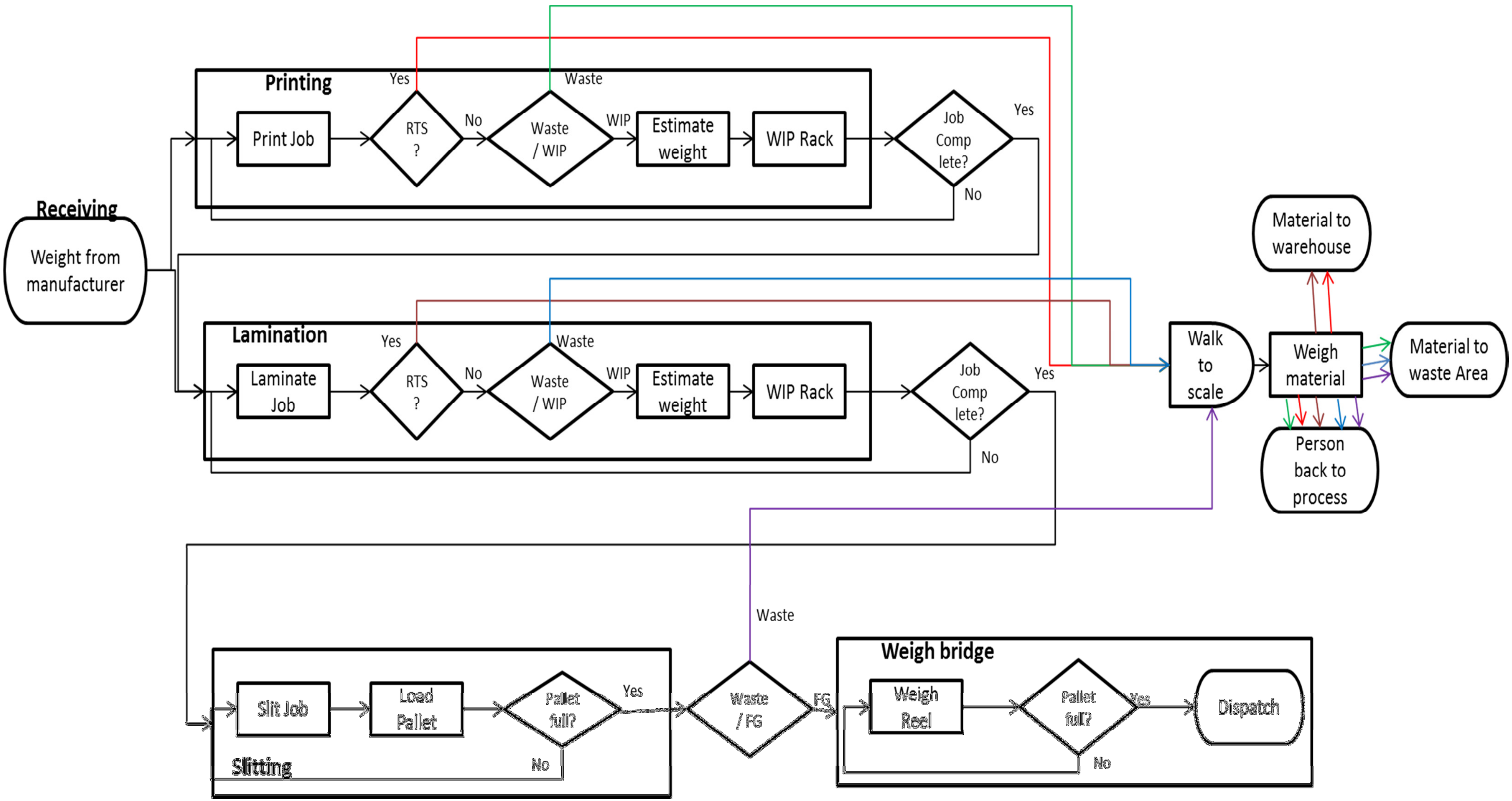


Figure 50: Process flow of substrate management (created by author)

On arrival, the substrate net weight is given by the manufactures' details. The substrate is issued to production jobs to be utilised and the remainder is returned to stores. This net weight is used as the starting weight (W_{in0}). The substrate is processed, and two weight streams are created: good product (W_{gp1}) and waste (W_{x1}). W_{gp1} becomes input weight for the next process (lamination). Lamination raw substrate utilised minus that returned will be (W_{in1}). It too will produce good product (W_{gp2}) and waste (W_{x2}). If a second substrate is required, W_{gp2} becomes the input weight into the process and the raw second pass substrate becomes W_{in2}. This process will produce W_{gp3} and W_{x3}. This pattern continues until the final product is weighed after slitting.

All W_{gp} values are estimated using a formula found in Appendix D and all W_x values are physically weighed on a scale located outside the factory.

Equation 2 describes this process in the form of a mathematical formula for n processes.

$$W_{in0} + \sum_{k=1}^{n} W_{ink} = W_{gp(k+1)} + \sum_{k=0}^{n} W_{x(k+1)} \quad (2)$$

The formula will be defined as the conservation of substrate. Derived from the principles of the conservation of mass, [147] this closed-loop system must remain true to understand where material variances exist. The recorded data must show the conservation of substrate to be true or the case company will record high financial losses through material variances. The target was to ensure that Equation 2 is 100% true for all jobs.

5.5.2. Measure – Substrate management

All weights were measured in kg using a flat-top above ground scale. 20 complete jobs were picked at random to see if they satisfy the conservation of substrate. Table 25 is a segment of the results obtained. The complete table can be found in Appendix G, Table 40.

Table 25: Conservation of substrate measurement segment (created by author)

Conservation of Substrate					
	$W_{\_in0}$	W_{gp}	W_x	Variation	Conservation
1	4 280	3 150	565	13%	No
2	640	450	185	1%	Yes
3	3 840	2 750	320	20%	No
4	890	630	120	16%	No
5	3 385	3 005	300	2%	Yes
6	1 600	1 520	85	0%	Yes
7	6 810	5 800	150	13%	No
8	440	300	100	9%	No
9	2 010	1 780	90	7%	No
10	1 110	800	162	13%	No

Figure 50 in Section 5.5.1 shows a Muda of motion (visualised by the coloured lines) and a likely bottleneck at the weighing material process, as there are 20 machines sharing one scale at a decentralised measuring point. The time taken to weigh substrate and return to the workstation was measured for four conditions. 10 readings for each condition were obtained.

The conditions for measurement were as follows:

1. The middle of the shift for a machine close to the weigh point
2. The middle of the shift for the furthest machine from the weigh point
3. End of the shift for a machine close to the weigh point
4. End of the shift for the furthest machine from the weigh point

Close to the weigh point was taken as within a 10m radius from the weigh point. The furthest machine was approximately 130m away based on the walking path to the weigh point. Table 26 summarises the average times obtained from the measurements.

Table 26: Average times to measure weight for the four conditions (created by author)

Time measurement	Ave time (mm:ss)
Middle Shift close machine	00:46
Middle shift far machine	03:59
End shift close machine	04:15
End shift far machine	10:26

The time readings that were obtained showed large variations when repeating the same actions at different time points in the day. It must be noted that the measurement procedure was repeated for each job completion during the shift, and at the end of every shift. The furthest machine in a normal working week therefore lost 2.6 hours of production time.

5.5.3. Analyse – Substrate management

Based on the measured data (See Table 40 in Appendix G,), the conversion of substrate formula only held true for 25% of the reviewed jobs. 75% of jobs did not satisfy the conservation of substrate and had an average variation of 9%. This was a very large figure since the unaccounted-for material could not be traced on the system. This figure directly translates into a loss in profitability. All virgin substrate issued to a job over and above the compensated waste that is not returned or converted into good product results in a loss in profitability for that particular job.

The project team met and brainstormed on possible causes of why the conservation of substrate was not true for the reviewed jobs. These causes were tabled and ranked against each other in isolation using a technique called numerical evaluation (See Table 41 in Appendix G)

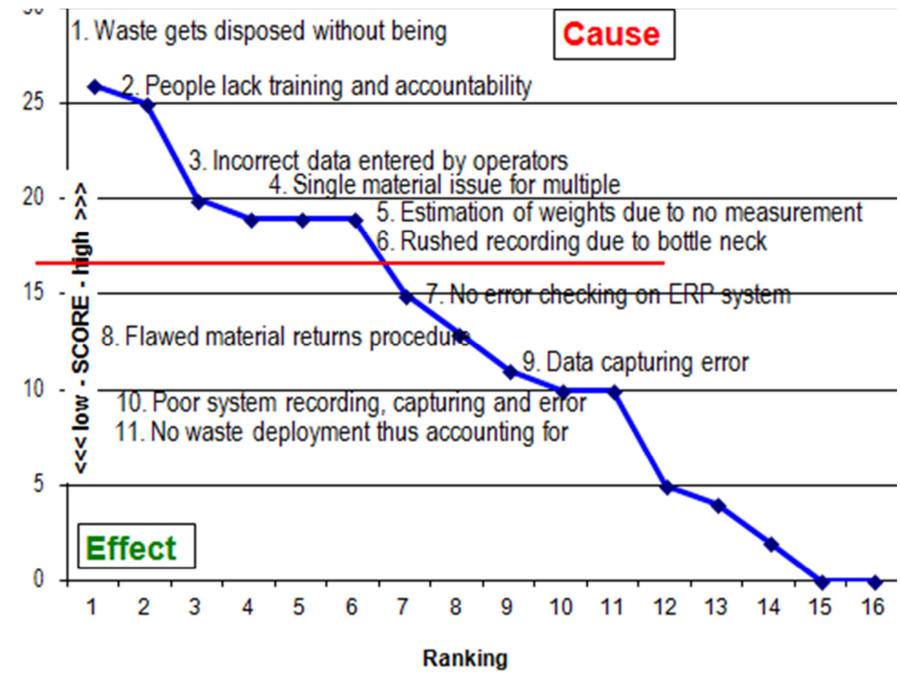


Figure 51: Cause and effect graph for numerical evaluation (created by author)

Figure 51 is a graphical representation of the numerical evaluation. Cause numbers one to six were addressed. The numerical evaluation suggests eliminating all causes above a 15 score as these are the most critical and would address most of the causes below.

The results of showed a significant difference between the times taken to weigh substrate during the middle of the shift and at the end of the shift. A Cause and Effect diagram was used to obtain the causes of this variability (See Figure 52).

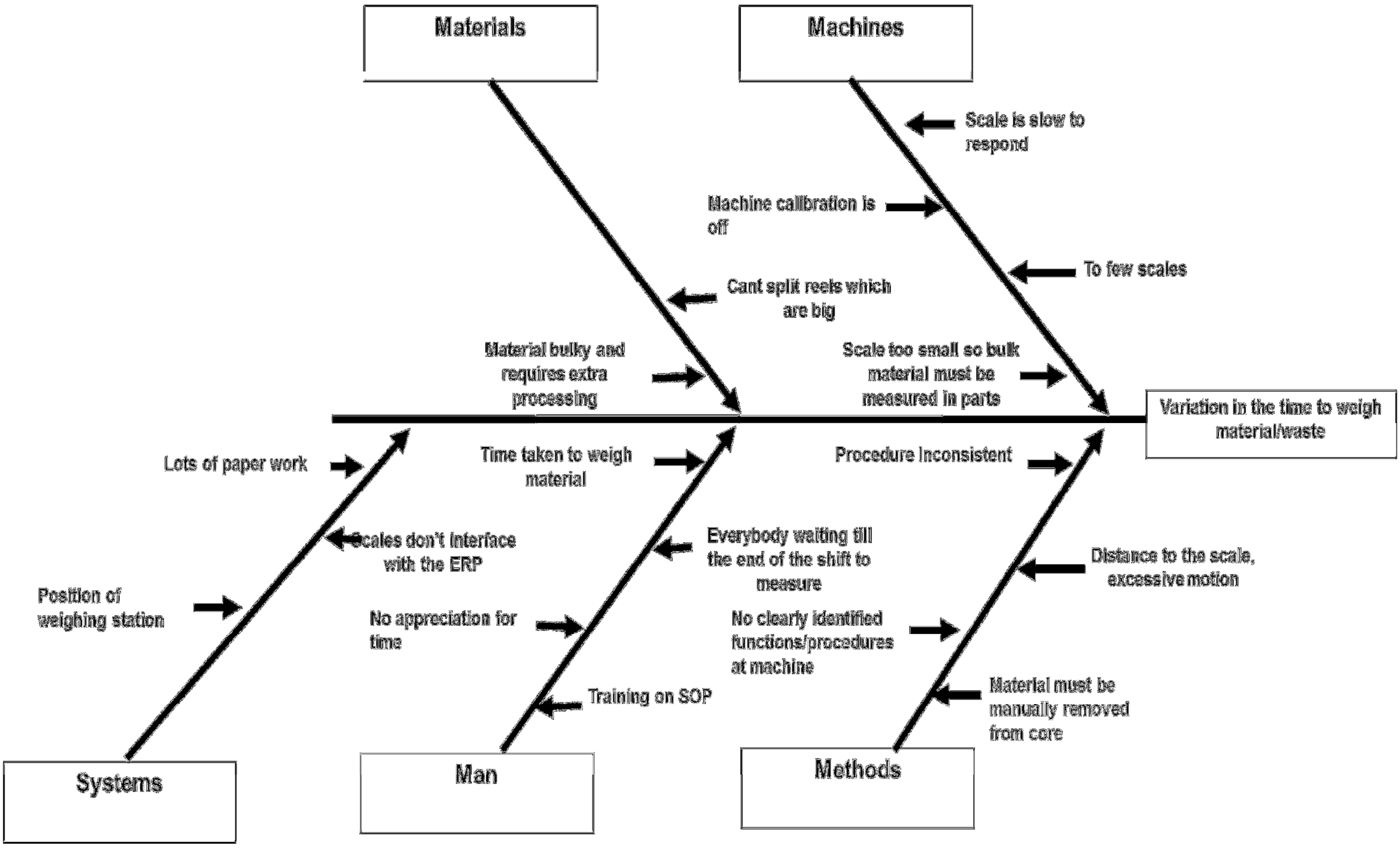


Figure 52: Ishikawa diagram for measurement variation (created by author)

5.5.4. Improve – Substrate management

The identified issues were addressed by introducing additional weighing. Five additional scales were purchased and strategically positioned in the factory. The scales included logic that linked data directly to the ERP, thus removing probability of human errors. Causes 1, 3, 4, 5 and 6 from and from Table 41 in Appendix G, as well as the time waste of motion, the bottleneck and the time to weigh waste, all benefited from this improvement.

The scales allowed for substrate to be accurately quantified at the source, performed error checking on jobs to adhere to the conservation of substrate and simplified the waste recording procedure. The causes of the Ishikawa, (See Figure 52) were further eliminated as described below:

Method

The implementation of the scale system also addressed the variation in measurement time as described in the Ishikawa. Additional scales eliminated the long walk from the machine to the single point of measurement. Reduction of this Muda created more time for production. The time allocated to the job was therefore reduced, increasing the profitability of that job.

Man and Material

The storage and transportation of waste within the factory was observed to add to the time spent measuring waste. Previously black plastic tubes were used to store the waste and these were dragged through the factory to the weigh point. With the changes implemented, waste carts were designed to store and transport waste. Introducing the waste carts removes the requirement of using black plastic tubes which reduced the quantity of waste sent to landfill. The waste carts had pigeon holes with different labels to store waste. This segregation allowed for the waste to be split by defect at the source of creation, for waste deployment analysis (See Section 5.3.4).

System

Previously, 20 machines, the quality assurance department, two inspection/doctoring stations, the waste disposal contractor and raw material handling department all shared one scale (roughly 26 operations per shift sharing one scale). The implemented solution created a dedicated scale for waste disposal and resulted in roughly five operations per scale. After the changes were implemented, the average time to record information changed as shown in Table 27.

Table 27: Average time to measure weight after changes (created by author)

Time measurement	Ave time (mm:ss) Before	Ave time (mm:ss) After	% change
Middle shift, close machine	00:46	00:40	13%
Middle shift, far machine	03:59	00:51	73%
End shift, close machine	04:15	01:15	71%
End shift, far machine	10:26	01:26	86%

A check on the conservation of substrate was performed. 20 jobs were again chosen at random to verify their alignment to the formula. No jobs were found to have a variance above 2%. The process flow changed as shown in Figure 53. Notable changes in the process map include the number of weigh stations and the delays associated with weighing of material. The number of scales per specific area is determined by the requirements to weigh/measure reels. Although the reduction in the delays is not visually represented, summarises this reduction.

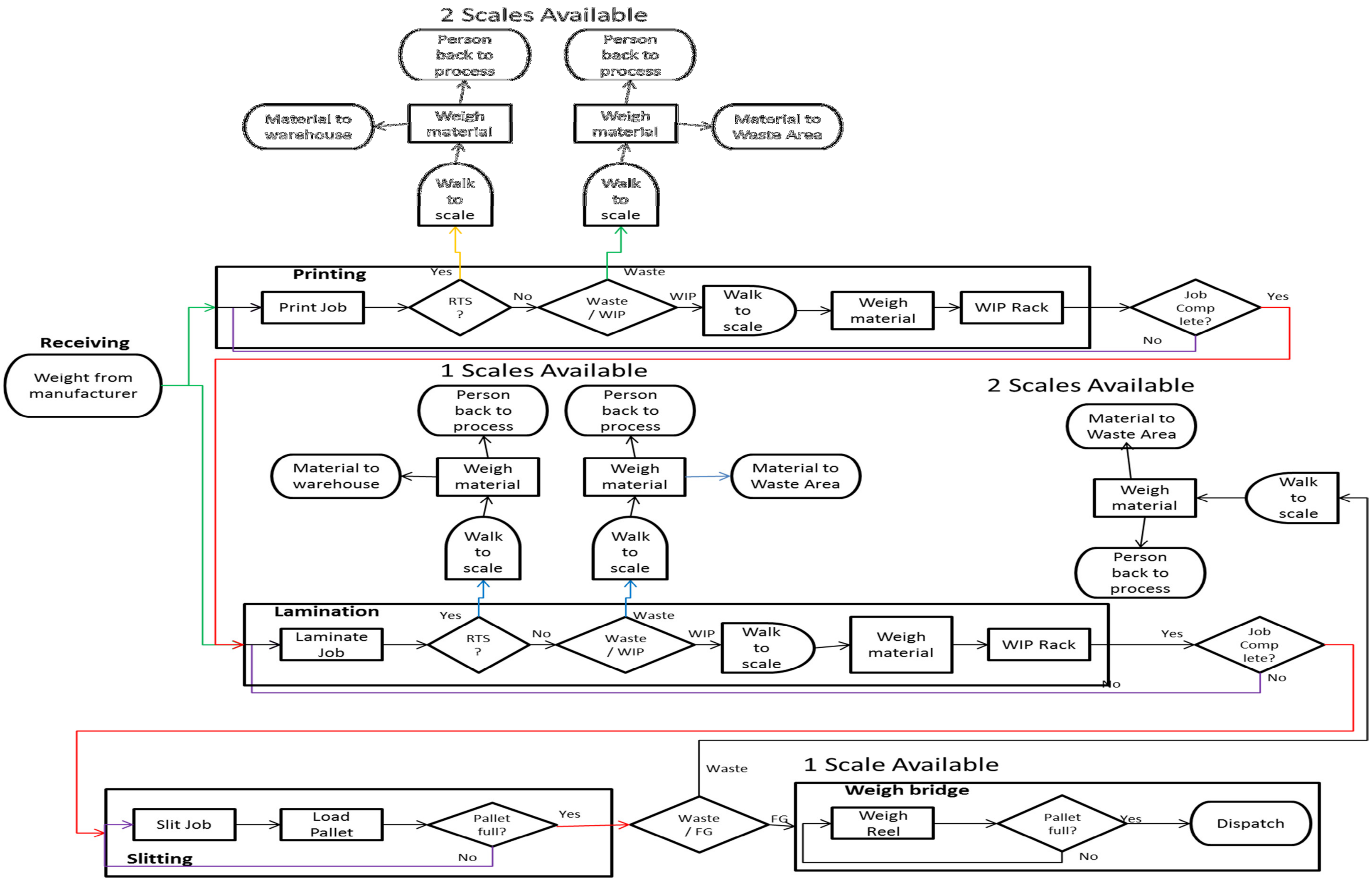


Figure 53: High level process map of improved substrate management (created by author)

5.5.5. Control – Substrate management

The system implemented cost R380 000. This equated to less than a quarter of the material variance value recorded per month (See Section 4.5.1.) All SOP's were changed to include weighing of all material into and out of any process. An error-checking interface was also added to the ERP because of the scale interface system.

Implementing these changes required, operator training. Root cause two from Figure 51, stating that 'people lack training and accountability' was addressed through this training programme.

Cascaded learning was used to roll out the training. As such, the supervisors and a single operator from each machine were trained to use the system by the manufacturers of the scale add-on. They became the master users. The master users in turn each taught one further operator to have the same level of proficiency. The process repeated for the next operator, and the master user continued by teaching a further operator. Effectively, two trainers were then obtained. By maintaining all trained employees as trainers, the number of trainers grew exponentially. The operators were now accountable for their waste figures immediately during their shift. This was achieved through regular performance checks (through short interval control) from their superiors. These changes allowed employees to take ownership of their contribution to waste.

5.5.6. Discussion – Substrate management

The substrate is the biggest contributor to the product provided by the FPC. Discrepancies in the conservation of substrate cost the company money. In the case of waste management, when the conservation of substrate does not hold true, it removes the ability to successfully perform root cause analysis for the waste produced. Thus, the opportunity is lost to reduce waste at the source of creation. It must be noted that the conservation of substrate only confirms that all material has been accounted for. It will not stop the mismanagement of raw material. Hence, it must be coupled with obtaining raw material control. The conservation of substrate can also be implemented using the linear metre as the unit of measure. For this solution to be implemented, rotary encoders are required on each machine's unwind and rewind. Linear metres in must equal linear metres out. Therefore, any difference in these values must represent material that has been cut out and thus equals the linear metres of waste.

Substrate management helped the company understand the source of financial loss. It has also exposed substrate mismanagement. Previously when substrate allocations were exceeded, the offences went unnoticed until the job had gone through all the processes. This overuse and over allocation added to the volume of waste produced and/or discarded. It also reduced the job profitability. The conservation of substrate provided the company with the information required to report on waste percentage. The waste percentage (See Equation 3) reported daily using previous methods was for WIP/incomplete jobs.

$$waste\% = \sum_1^n x_n / \sum_1^n Y_n + x_n \times 100 \qquad (3)$$

- Where: x_n is the waste captured for the days production
- y_n are all the finished jobs (good product) for that day transferred into finished goods.

Jobs are run over days, weeks or months before the finished product is completely recorded into the system and dispatched. This system of recording is only accurate if all the jobs produced in the week or month are the same jobs that are converted into finished goods. As such there was a disconnect between the waste figure and the finished goods produced. To correct this, the case company converted its reporting of waste to a job-by-job, basis and only jobs closed/completed in the same month were considered in monthly reporting. The conservation of substrate principle is used for substrate in this report. But in reality, it should have considered all the input raw materials. Waste management cannot be achieved without the conservation of substrate.

5.6. Segment 4 - Whole System

The complete process was broken down systematically into segments for ease of problem solving. Segment 1-3 covered the inputs to the process and the operation within the processes until completion. The purpose of looking at the whole system was to ensure the flow of waste was managed from the beginning to the end without the production complexities. Accurate knowledge of these operational zones resulted in the accurate measurement and analysis of the waste to be disposed and continuous improvement.

5.6.1. Define – Whole System Problem

The whole system considered the input of the substrate, the process– which was considered as one even though it consists of many parts– and output of finished goods or waste. The process focus area defined in the scope was gravure printing, but the analysis shown here also includes lamination and slitting. The reason processes outside the scope were included, was because print waste can be removed at lamination and at slitting. The data, the analysis and the solutions obtained remain true for printing in isolation. Implementation of the solutions, on the other hand, would not be possible in isolation, as all the processes would be affected. A high-level process flow is given by Figure 54.

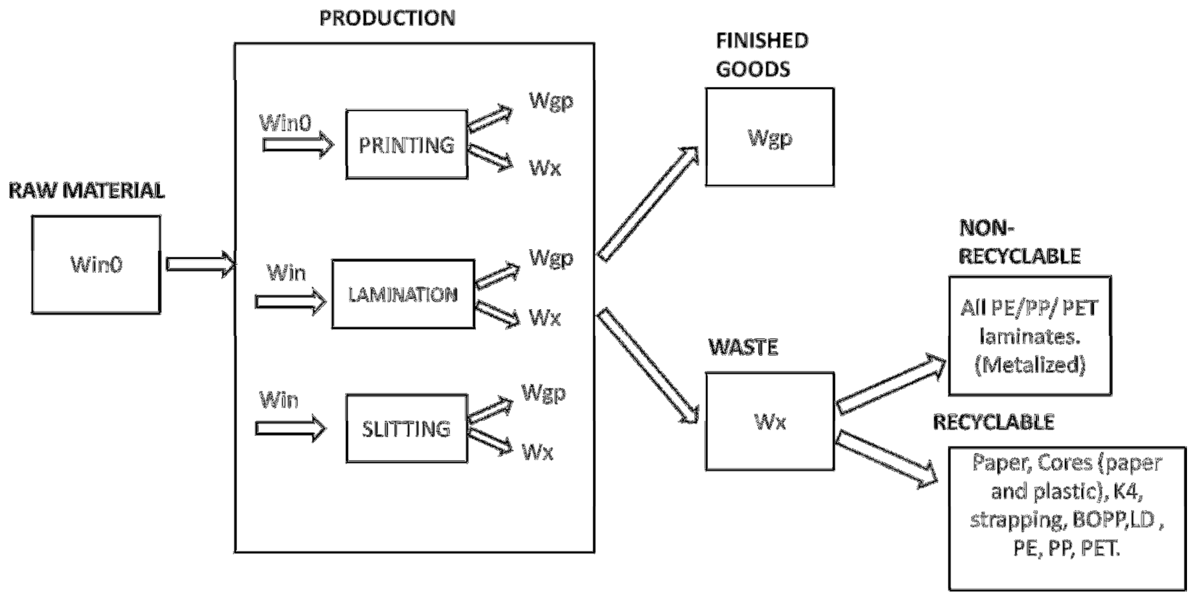


Figure 54: Complete system process flow chart (created by author)

Material was input into a process (production), and had some value added operation performed to it. The output was good product and waste. This waste was then further classified as recyclable and non-recyclable.

The area of interest was the virgin raw material input to production that ends up as waste. The performance measure is then quantity of virgin raw material used. The target set is to achieve 5% or less deviation from standard of virgin RM used. Waste management included but is not limited to the collection, treatment, transportation, prevention, monitoring and disposal of waste. [5] The secondary performance measure is the management of waste once it was created. These two parameters are measured.

5.6.2. Measure – Whole System

Raw material bought for the intention to convert into sellable product, but does not achieve this purpose was a huge loss in profit for the company. The circumstances which resulted in this outcome being realised were:

1. Virgin material over utilised during set-up: A measure of monthly deviation from the standard set-up material expected to be consumed is shown in Table 28.

Table 28: Over utilisation of set-up material [135]

Month	Used RM	Set-up Waste	Estimate RM	Estimate Set-up	Deviation
May-15	525 409	26 270	426 972	21 349	19%
Jun-15	489 658	24 483	375 682	18 784	23%
Jul-15	571 587	28 579	553 139	27 657	3%
Aug-15	604 030	30 202	546 582	27 329	10%

2. Raw material with variation in quality after the production process had begun: A measure of the raw material rejected during the production process is given by a. An opportunity to reduce this waste was identified. The reasons behind this material rejection are given by the Pareto in b.

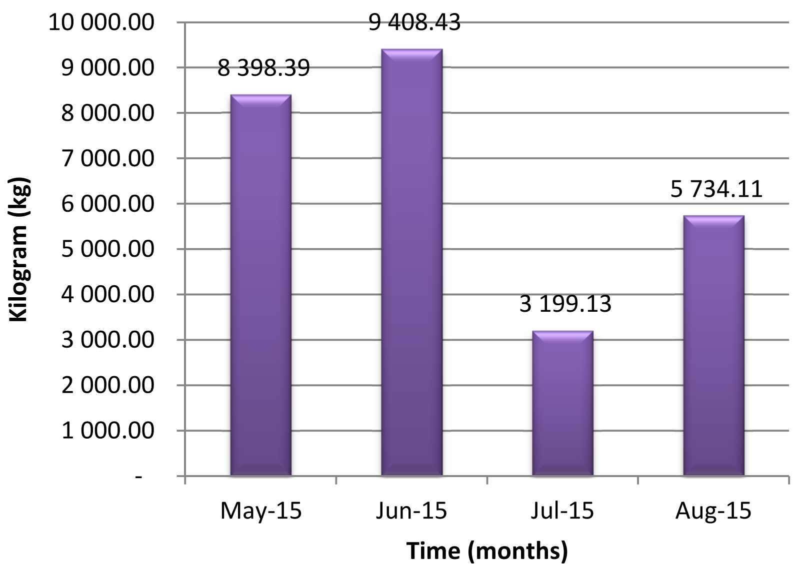


Figure 55 (a)

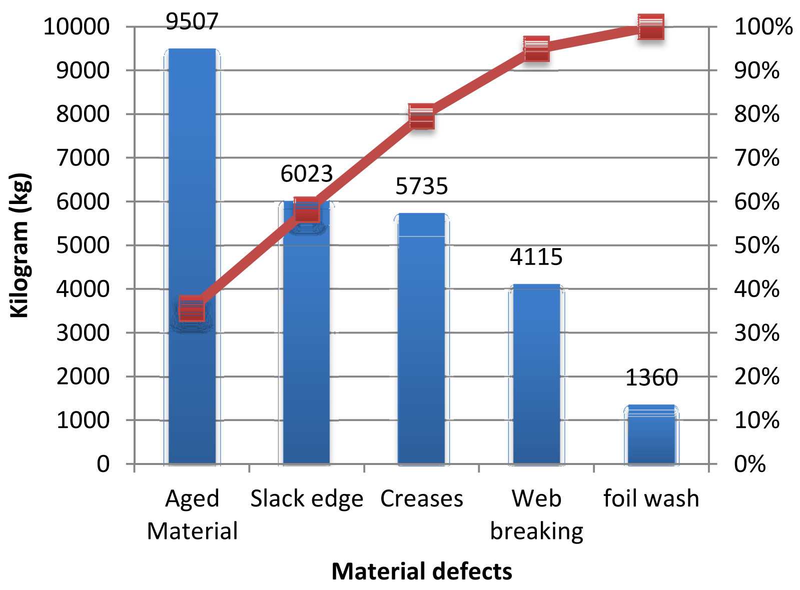


Figure 55 (b)

Figure 55: (a) Quantity of rejected material (b) Pareto of reasons for material rejection [135]

Opportunities existed to reuse and recycle more substrate. In order to identify these opportunities, the quantities recyclable and non-recyclable (sent to landfill) waste were measured. These results are shown in a. b represents the monetary value associated with these opportunities.

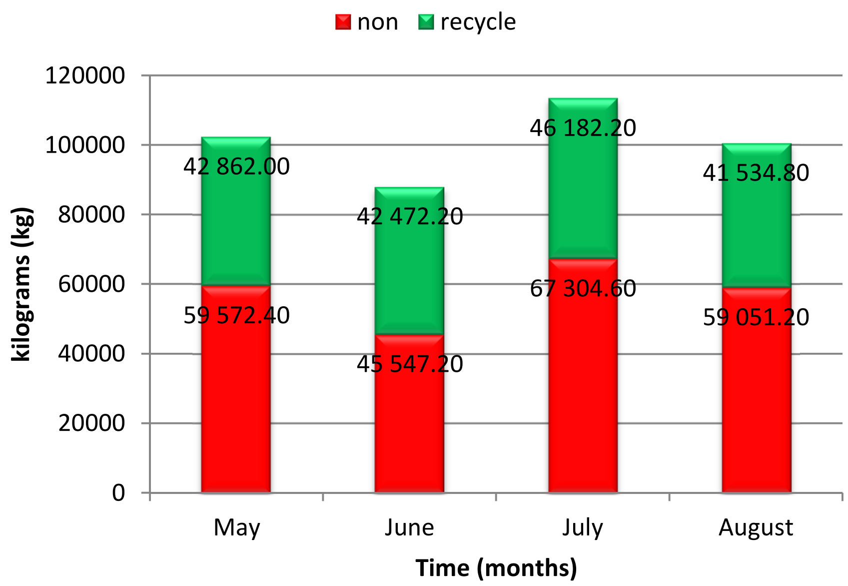


Figure 56 (a)

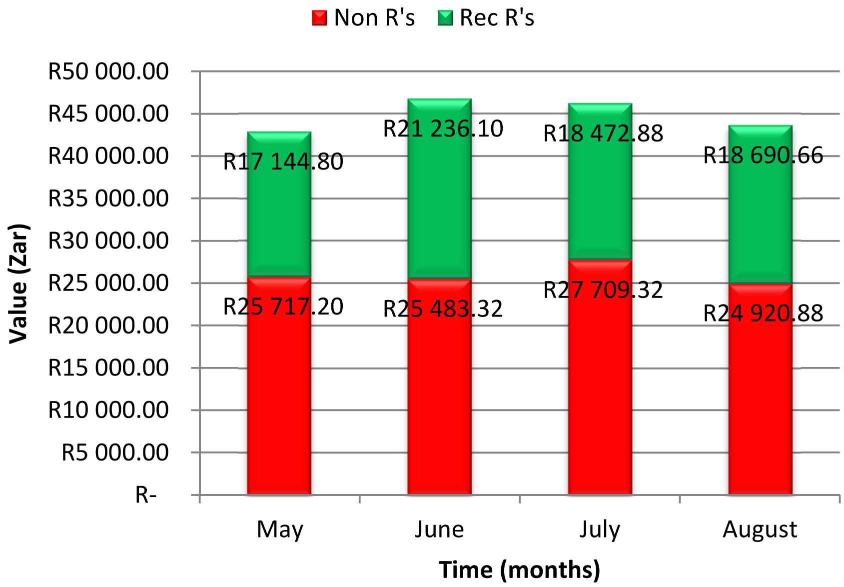


Figure 56 (b)

Figure 56: (a) Quantity of waste and (b) Rand value of dumping vs. Recycling [135]

The composition of the different waste streams aided in identifying opportunities. If the waste source was known, mitigating steps were taken. Figure 57 shows the composition of waste over the measurement period for recyclable (a) and non-recyclable (b) waste.

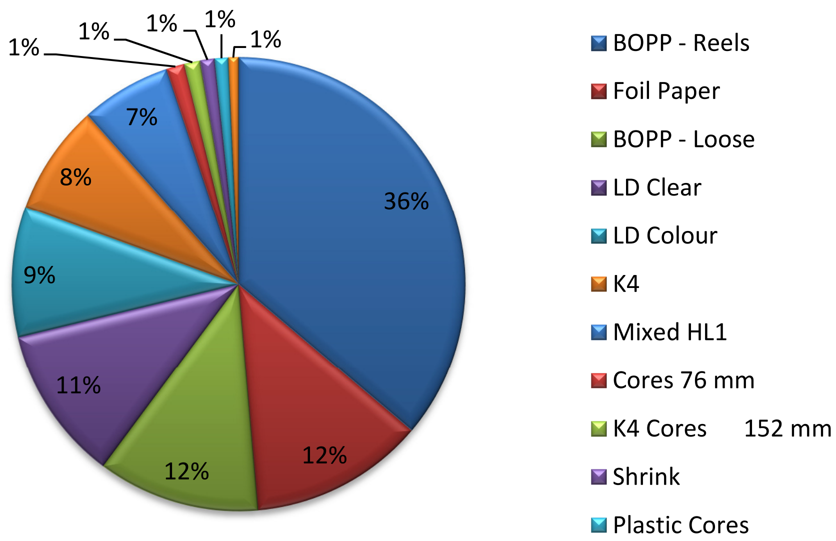


Figure 57 (a)

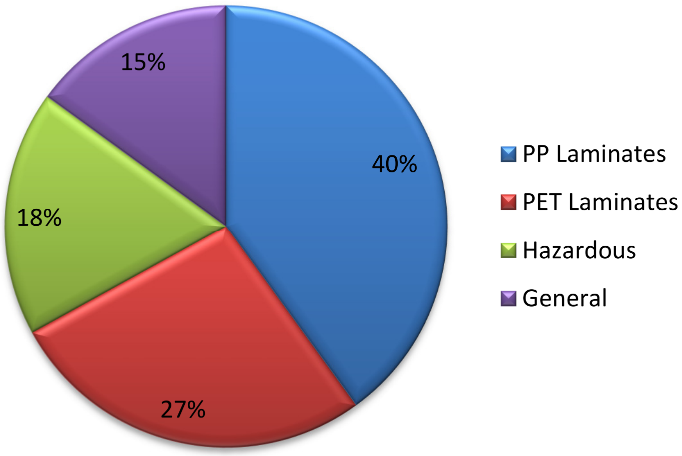


Figure 57 (b)

Figure 57: (a) composition of recyclable waste (b) composition of landfill waste [135]

Waste was removed off site using trucks loaded with eight ton skips. Two were dedicated to recyclable waste and two were used for landfill waste. Given the quantities of waste measured, the number of waste collections was measured with the intention to reduce it. Reducing waste pick-ups would result in a saving for dumping, a reduction in transportation and a reduction in the carbon footprint to be in line with good waste management practises. Figure 58presents the number of waste collections per month.

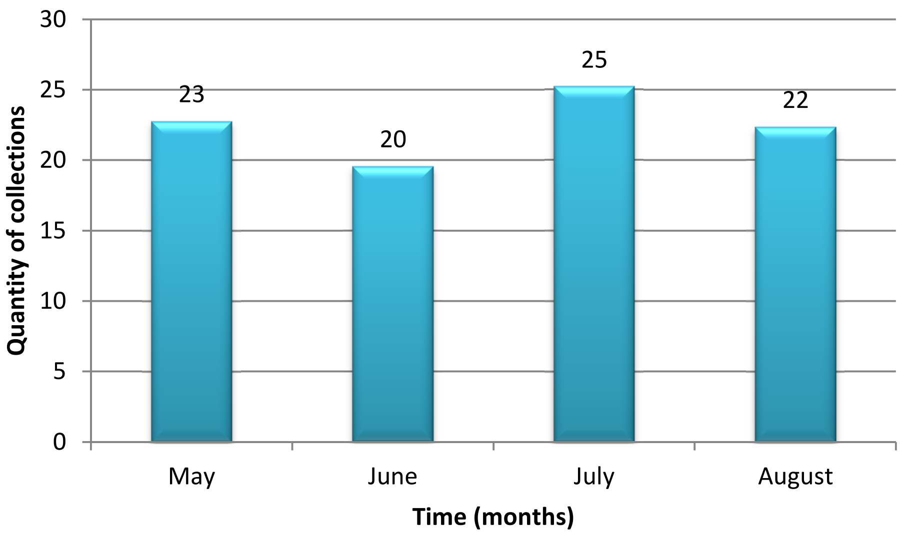


Figure 58: Number of skip pick ups [135]

5.6.3. Analyse - Whole system

Virgin raw material was overused by 15% on average in the set-up of the machine. This deviation from the estimated usage standard costs the company an average of R250 000 per month. Possible causes of the overuse were investigated by the project team. Table 29 presents the outcome from a brainstorming exercise with the project team.

Table 29: Potential causes of virgin material over use [135]

Potential causes of virgin material overuse								
No.	**Cause**	**Effect on substrate**	**Accuracy to cause**	**Degree of influence on waste**	**Ease to address**	**Cost**	**%**	**Rank**
1	Over issue of material	7	8	7	10	10	84%	1
2	Colour matching skills	4	10	6	4	2	52%	6
3	Quality of Ink	5	7	10	2	4	56%	5
4	Too many mechanical issues at set-up	5	6	4	3	1	38%	7
5	Material disposed instead of returned	8	8	9	9	8	84%	1
6	Poor recording	7	8	9	7	9	80%	3
7	Set-up procedure variations	7	10	5	6	8	72%	4

Figure 57b shows a Pareto of the reasons the raw material was rejected during production runs. The use of aged material was determined to be the largest contributor and was investigated further to determine the root causes (See Figure 59).

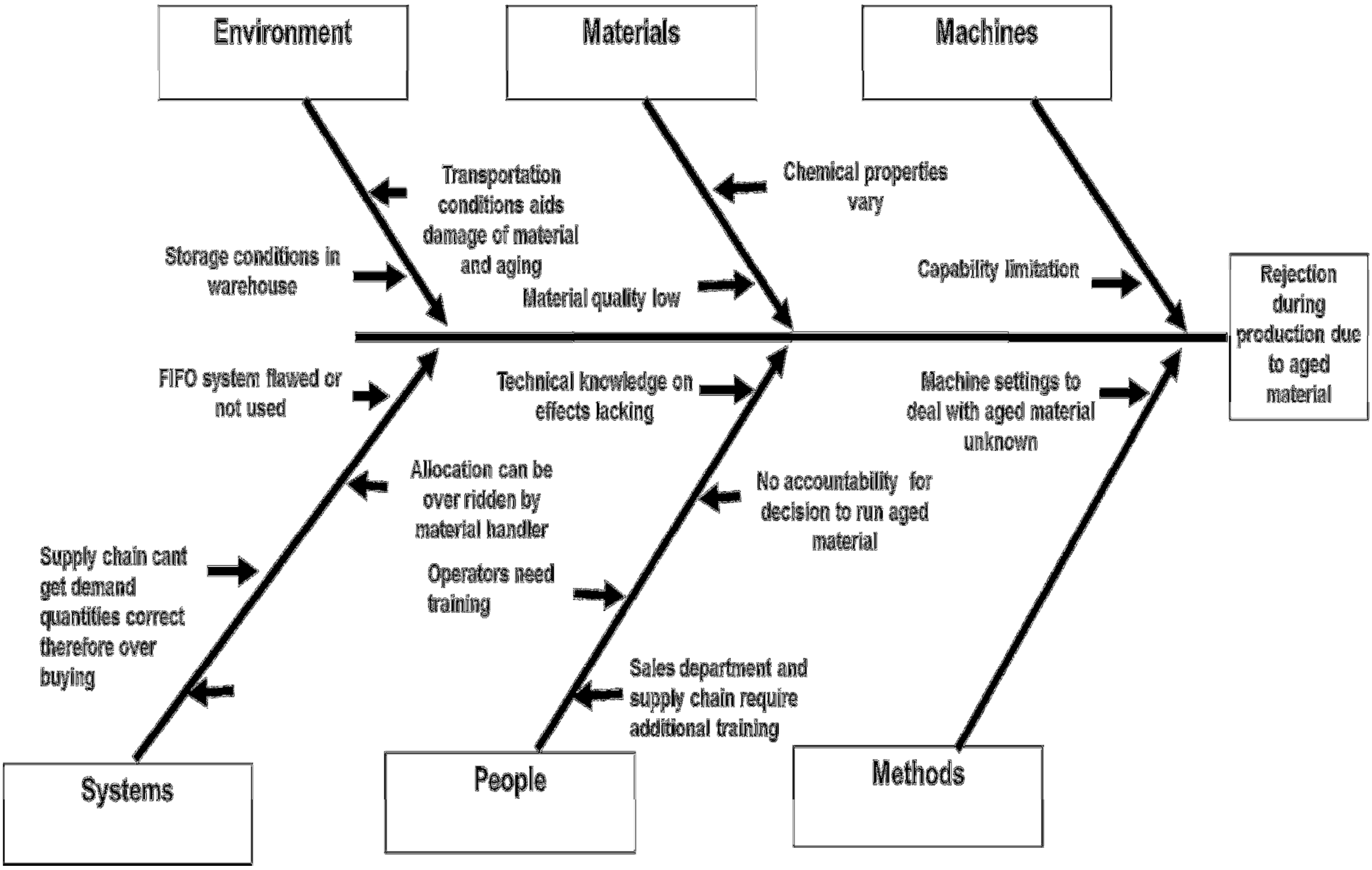


Figure 59: Ishikawa diagram of use of aged material (created by author)

The values for non-recyclable waste were much higher than recyclable waste (See Figure 56). The desirable outcome was the diversion of waste from landfill. The case company would have needed 13 collections to dispose of the 101 Tons of waste with the waste bins full (8 Tons per skip) per month. However, the company averaged 22 collections per month. Optimisation of the number of collections presented an opportunity to reduce the disposal charges and the carbon footprint while better managing the waste. Figure 60 explores the causes of why the company had more disposals than required.

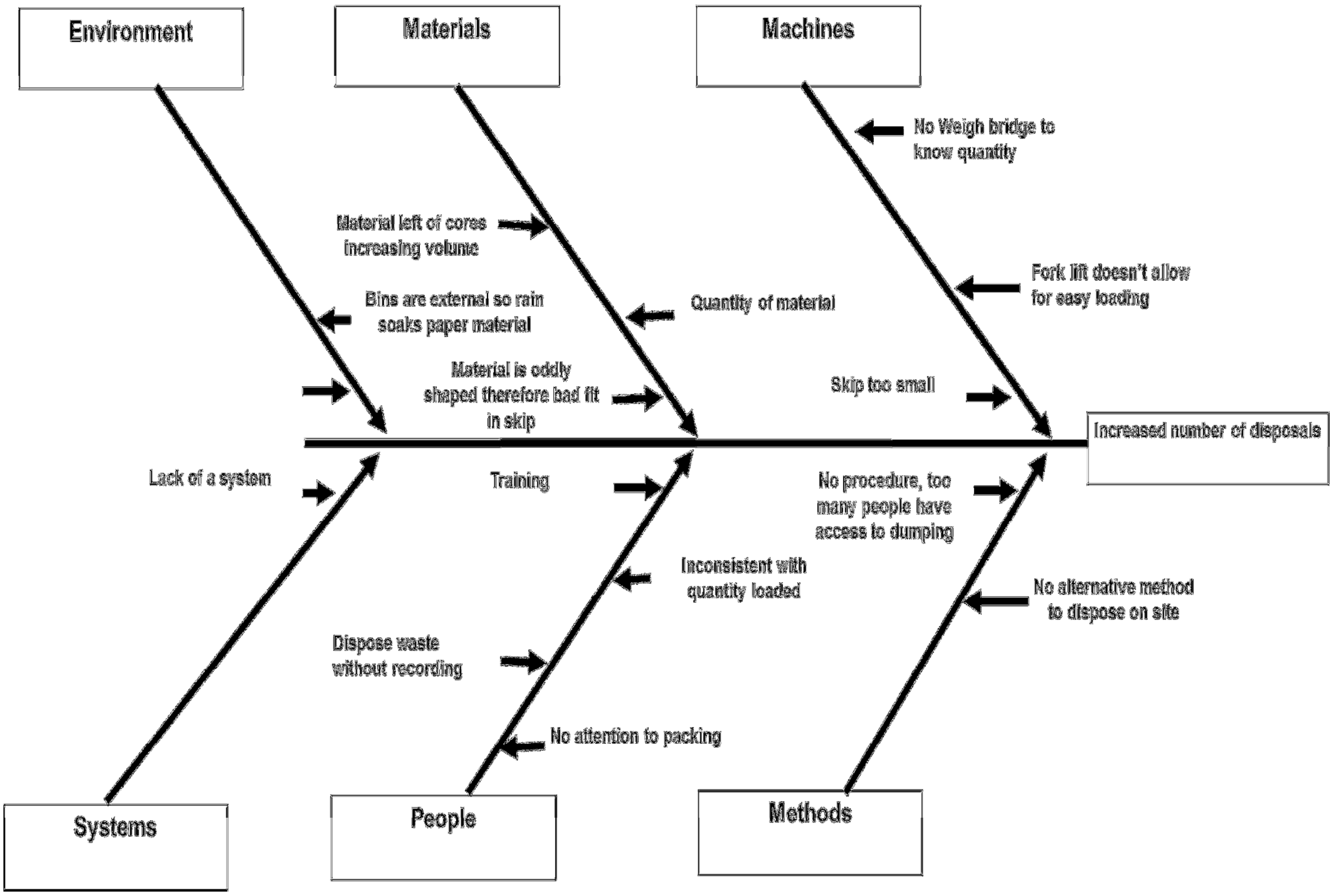


Figure 60: Ishikawa diagram of number of disposals (created by author)

5.6.4. Improve whole system

The top causes for virgin RM waste were, over issue of virgin material, material being disposed instead of being returned and poor material recording. These have been addressed in Segment 1 – Raw Material Control (Section 5.3.4), Segment 2 – Process Control (Section 5.4.4) and Segment 3 – Substrate Management (Section 5.5.4). These solutions were successfully implemented. An opportunity to reuse or recycle virgin material was discovered from the solutions implemented. On average, 28 Tons of set-up waste material was used and added to the total waste figure. This waste was either disposed into a landfill or recycled. The set-up material was reused to reduce this average figure. The virgin material used to set-up can be rewound and stored in areas close to the machine which allowed for reuse. Table 30 shows the set-up waste after the implementation of reusing set-up waste. A standard deviation of 10.6% was achieved, which was an improvement from 15% previously.

Table 30: Set-up waste deviation after savings implementation [135]

Month	Used RM	Set-up Waste	Estimate RM	Estimate Set-up	Deviation
May-15	525 409	26 270	426 972	21 349	19%
Jun-15	489 658	24 483	375 682	18 784	23%
Jul-15	571 587	28 579	553 139	27 657	3%
Aug-15	604 030	30 202	546 582	27 329	10%
Sep-15	579 212	26 065	436 193	21 810	16%
Oct-15	601 820	27 684	518 729	25 936	6%
Nov-15	441 627	18 107	326 843	16 342	10%

The waste created during the production run was mainly caused by the use of aged material. Segment 1 – Raw Material Control(Section 5.3) addressed the presence of aged material for production purposes through financial write off i.e. accepting the financial loss and removing the raw material from the system, such that it could not be utilised for production. Where applicable, this aged material was used for set-up such that good virgin material was conserved for sellable product. Aged material was further addressed through the implementation of FEFO and quality checks on raw materials before the production process. FEFO ensured that the batch of material expiring first was utilised as opposed to the material that was entered in the system first. Having different suppliers of material (international and local) made it a regular occurrence that expiry and ageing via capture date did not correlate.

Figure 61 shows the Pareto of the reasons material was rejected during a production run in the improve phase. The initial conditions have been improved, and opportunity now exists to eliminate or reduce creases.

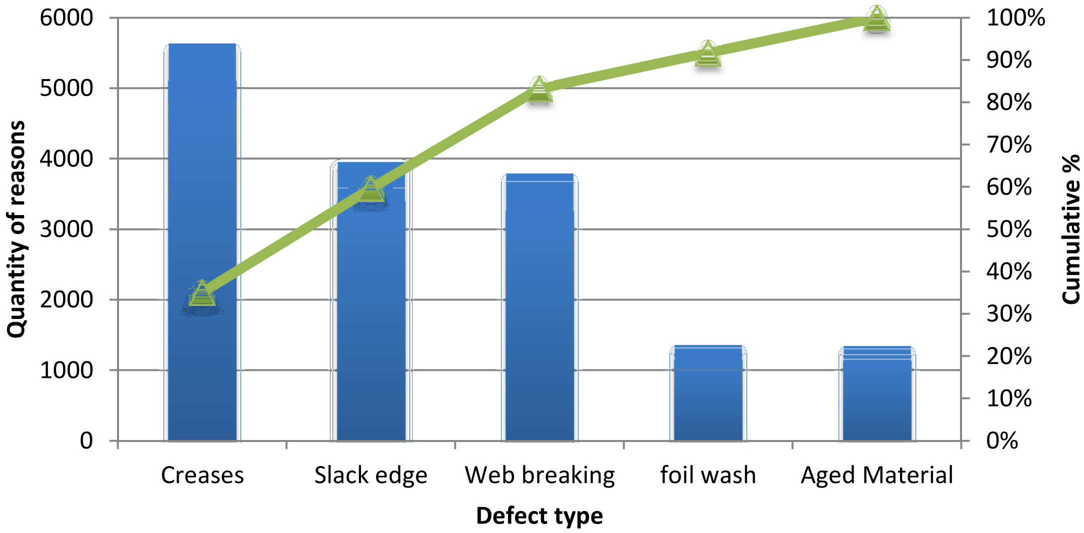


Figure 61: Pareto of reasons for material rejection during runs [135]

Mitigating actions for excessive waste were implemented but due to the nature of the operation, some waste was still inevitable. Financial recovery was realised through waste disposal optimisation. The addition of a reel-end stripper and shredder-baler process before disposal achieved the following results and addressed the “material” and “system” causes in the Ishikawa diagram (See Figure 60):

1. Compacted all the waste, therefore achieving more waste in the disposal/recycling skips.
2. Reduced the number of skip collections, thus reducing the carbon footprint.
3. Reduced the disposal costs.
4. Increased the value of recyclable waste.
5. Allowed cores to be reused, instead of being disposed with the reel end. This action saved in both the weight of waste disposed and the cost of purchasing new cores.

Table 31 shows the financial gains experienced due to the reel end stripper, shredder-baler process.

Table 31: Changes experienced due to reel end stripper, shredder baler process [135]

	Before	After
Average number of collections	22	14
Average disposal cost	R 26 000	R 21 000
Average recycling value	R 18 000	R 24 000

The baler packed bales that are 250-300kg. In comparison to the previous method, four 1m x 1m bags compressed to make one bale. It was necessary to include a different sorting method, as bales of like material were not built up fast enough. The decision was made to sacrifice some of the recyclable value and mix smaller material types in a bale. The resulting bale would need secondary processing at the recycler, reducing its financial value, but the process of making the bales and removing waste off site was more efficient. For the main recyclable waste streams, such as BOPP, a self-compacting skip was requested, as the volumes justified this purchase by the waste management company.

5.6.5. Control - Whole system

The value of virgin material was previously overlooked by the operators. Due to the lack of control, more was always made available to execute a job. A system of bright luminous stickers was introduced to show the origins or the destination of raw material. All raw materials could then be tracked, and were only authorised to be moved if they contained the relevant sticker (Refer to Figure 71 in Appendix G).

ERP system constraints, gaining raw material control and the introduction of set-up material have increased awareness of the abuse of virgin raw material. Awareness signage and posters were added around the material loading area querying the presence of set-up material and encouraging operators to use set-up material first. All operators and ink technicians were put through refresher courses on the first principles of colour matching and the set-up procedure. These courses were the same as what an apprentice would need to pass to become an operator or ink technician. Successful completion of these courses meant the operator was sufficiently equipped to colour match using less set-up material. The customer colour standard was achieved faster and, therefore, sellable product was produced sooner, which increased profit.

Waste disposal procedures were amended to cater for a build-up of enough waste to shred and bale. Waste operators were trained in the use of the reel end stripper, the shredder and the baler. As these machines were high safety risk machines, re-training was scheduled biannually. The amendment of the SOP's also included a new designated lockable waste area servicing all the waste disposal requirements of the factory. No waste was disposed without being correctly processed with this new configuration, which ensured accuracy of information.

5.6.6. Discussion – Whole System

For the system to balance, the input minus the output must equal waste. Virgin raw material being issued incorrectly, unknowingly disposed of or over used was an avoidable increase to the waste figure. The changes to the SOP and raw material control reduced the average deviation from the estimated standard over the implementation period from 15% to 10.6%. This was a welcome saving on virgin material but the target was not met. Part of the reason was the difficulty of implementation and adherence to SPC in the colour matching procedure. The atmospheric conditions are not controlled in the factory therefore blends are made to specifically match the conditions on the day. Opportunity still exists to further explore the economic viability of climate control in the factory. A second reason for failure to reach the target was that the reuse of set-up material was only partially successful. The initiative became difficult to enforce rendering it practically ineffective. Where set-up material was used, the company gained profit from the value of the virgin material not used for setting up. The difficulties experienced in implementing the use of set-up material were that:

- Not all set-up waste was compatible to run with the jobs on the production plan
- There was a lack of availability of the correct quantity or width of set-up waste which frustrated the operators. It was easier for them to use virgin raw material to set up than to look for set-up material.
- A big stockpile of set-up material ended up building up next to the machines and affecting 5S initiatives implemented during the same time.

In total, the ability to reuse the material was highly dependent on the set-up waste being present in the correct type, width and quantity.

Aged material was the top cause of in-process rejections. The results of these stoppages were more than just the waste of substrate, they decreased the profitability of a job. The waste of other raw materials (ink, adhesives etc.), machine and labour time and delays to customer deliveries also occurred. After the FEFO system was implemented, the overall quantity of material rejected during runs was reduced by 62.5%. The solution implemented was a corrective action which addressed the large volumes of inventory and the over use of raw material which would lead to increased demands and the requirement for a buffer to counter the overuse. High inventory hides other causes such as, skills shortage, supplier deliveries, poor scheduling and rejects to name a few. [67] A root cause of the high inventory yet to be addressed which would provide a sustainable solution would be to look at the customer forecasts. Material is purchased based on the forecasts. A study on forecast accuracy, factors leading to changes and trend analysis over periods and seasons with consumer economic conditions as they greatly influence spending in the confectionary industry is required.

The shredder-baler does not reduce the quantity of waste produced, it simply manages the waste better and provides more efficient disposal methods. Financial benefits of R11 000 monthly (See Table 31) were realised due to the shredder-baler process. The solution provided better management of waste but diversion from landfill should be the ultimate goal. Energy from waste possibilities should be considered and further explored.

Transferring waste from non-recyclable to recyclable replaces the disposal cost with financial gain. In order to do this, customer products will have to be redesigned. Redesign of packaging is difficult for the case company as it does not have a research and development (R&D) division. Customer specifications are matched with the material they request since the product they will contain has specific requirements. There are many variables that need to be considered when redesigning packaging including:

- the contents of the flexible packaging;
- the oxygen permeability (barrier properties) required;
- the climate where the product will be stored;
- the material properties;
- the intended shelf life of the product. [9]

Transferring more waste to recycling will not result in a reduction of waste produced but presents an opportunity for the reuse thereof. The most common non-recyclable wastes produced are metalised laminates. These materials are usually recyclable in their individual capacities but due to different chemical properties once laminated they become non-recyclable. No commercially viable solutions were found to deal with these substrates. In Japan, Toppan developed the first environmentally friendly laminated packaging made from recycled PET film. [148] The limiting factor is access to enough PET bottles to recycle to produce this material in sufficient quantity. [148] For the case company, access to a constant supply of the recycled material to suit demand, the cost of this material and the cost associated with returning the material to Japan for recycling are all limiting factors. Until solutions for recycling non recyclables become commercially available, metalised laminates will be sent to landfill or incinerated.

5.6.7. Summary

The define phase of the project (Section 5.1), resulted in smaller projects that aided in the drive towards achieving the most desirable state of waste management, which is the reduction or prevention of waste creation. Emphasis was placed on obtaining accurate information from the raw material to disposal of waste. Performance measures and targets were set for each investigation. These performance measures and targets were assessed at the end of each investigation to gauge its success. In some cases, these targets were met, while other initiatives fell short. Observing how the initial state parameters changed allowed for the analysis of the effects of the various solutions that were implemented.

6. CHAPTER 6

FINAL STATE DATA ANALYSIS

The final state data was taken at the end of November 2015. The objectives of this analysis were to:

- Provide measurable data to compare to the initial states;
- Check the validity of the implemented solutions;
- Measure the success or failure of the investigation against the KPI's
- Review the profitability of the subset following the changes

6.1. Final State Profitability

The final state profit margins are computed following the improvements. (See Table 32) A four month period following the implementation of the improvements is used to compute the figures. In some cases, implementation of solutions included processes outside of printing and jobs that are part of the population but not in the subset. However, the benefits were shared. Success experienced by jobs outside the subset, though very beneficial to the company, do not form part of the final discussion.

Table 32: Final state profitability [135]

Customer	Job to be analysed	Initial state profit margin	Final state profit margin	% Change	Customer	Job to be analysed	Initial state profit margin	Final state profit margin	% Change
1	A	14%	27%	13%	6	M	-13%	18%	31%
	B	-18%	19%	33%		N	22%	25%	3%
	C	-49%	25%	74%		O	-27%	-14%	13%
	D	-17%	29%	46%		P	0%	-11%	-11%
2	E	38%	36%	-2%	9	Q	-8%	24%	32%
	F	20%	34%	14%		R	-18%	26%	45%
	G	-0.8%	-0.5%	0.3%		S	3%	28%	25%
	H	-38%	12%	50%		T	-7%	6%	13%
5	I	2%	17%	15%	10	U	-16%	-11%	5%
	J	0.3%	16%	15%		V	-32%	-30%	2%
	K	29%	29%	0.2%		W	-26%	-29%	-3%
	L	26%	23%	-3%		X	-42%	-38%	4%

From Table 32 it can be concluded that:

- 29% of the subset has a negative profit margin, this is an improvement from 60% in the initial state;

- 37.5% of the subset has a profit margin below the company standard profit margin contribution of 15%; [7] this is an improvement from 80% in the initial state.
- The overall percentage change on average was a 17% improvement in profitability

6.2. Final State Waste Management

The whole system of waste management has been remodelled as changes made in the focus area ripple through all the other processes and, as such, isolation would incorrectly represent the waste management efforts of the case company. Figure 62 is a process flowchart representing the final state waste management. For the waste management flowchart before the implementation of the initiatives discussed in Chapter 5, see Figure 23.

Table 33 tabulates the changes to the flowchart as well as the waste management procedures that are contained within some of the processes blocks. The areas affected by the changes are visualised by red outlines in Figure 62.

Table 33: Process flow for waste management improvements (created by author)

	Change	Initial state	Final state
1	Capture true net weight of raw material	Did not exist	Implemented
2	Capturing of issued material delay	8 hrs - 3 days	1 - 2 hrs
3	Printing production capture Lamination production capture Slitting production capture	8 - 48 hrs	1 - 2 hrs
4	Waste capturing and recording (time to process)	1 - 8 hrs	0.5 hrs
5	Time to filling skips	2-4 days	5-8 days
6	Weigh station	1 scale	6 scales
7	Waste system capture	Manual, waste book	Electronic input direct into system
8	Transportation and storage at source	Black plastic bag	Waste trolley
9	Sorting /Classification	Secondary	At source
10	Storage once discarded	1x1m bulk bag	250-300kg bale

The changes to process flow of the waste management protocol, impacted through each segment of the developed solution. Table 34 looks at a summary of the costs involved in the protocol changes, as well as their effective impact on profitability. The impact on profitability considers how the savings realised from the waste protocol change the profitability of a single job with no other external influence besides the improvement. The impact on profitability was defined by the author as, the expected percentage increase to profit based on an action taken. The savings per job in the subset was calculated and this value was then applied to the average number of jobs per annum, to achieve the annualised saving. Refer to Appendix D for a more complete breakdown of the calculations.

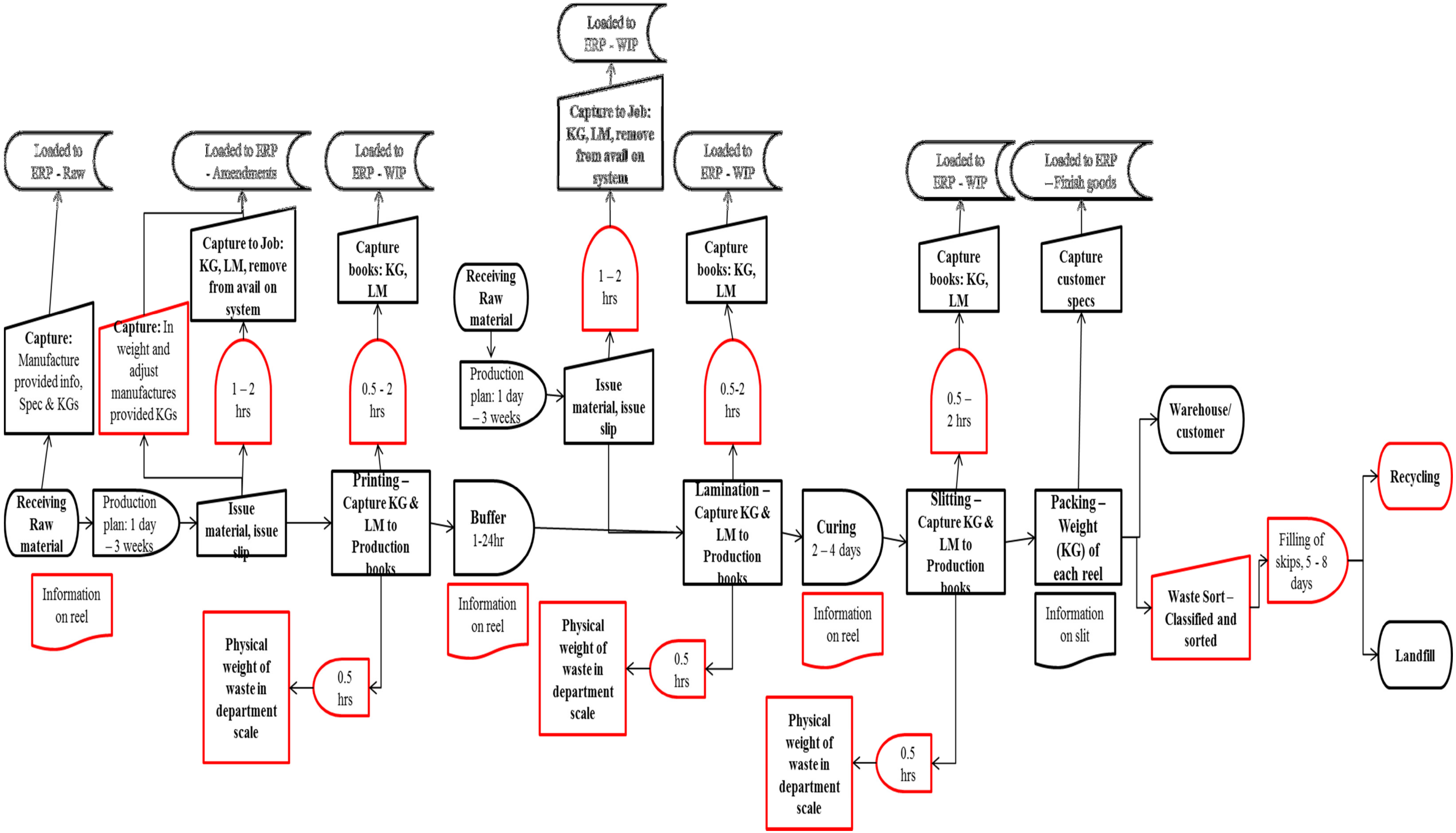


Figure 62 : Process flow of waste management , final state (created by author)

Table 34: Summary of waste management protocol changes (created by author)

Item	Improvement	Waste Hierarchy area [waste management]	Action (section where addressed)	Total cost of implementation	Saving annualised (overall)	Impact on profitability (per job basis)
1	Capture true net weight of raw material	Cleaner production [prevention and monitoring]	Section 5.3 - Raw material control	R 325 450	R 187 200	0.03%
2	Issue material Capture	Cleaner production and recycling [prevention and monitoring]			R 1 698 720	8%
3	Printing production capture	Cleaner production [Collection, prevention, monitoring]	Section 5.4 - Process control	R 180 000	R 385 680	1%
	Lamination production capture					
	Slitting production capture					
4	Rework reduction	Cleaner production and recycling [prevention and monitoring]		R 2 645 600	R 8 299 800	35%
5	Waste reduction	Cleaner production [prevention and monitoring]		R 1 007 800	R 7 697 760	36%
6	Material variance	Cleaner production [prevention and monitoring]		R 0	R 2 280 000	10%
7	Conservation of substrate	N/A [monitoring]	Section 5.5 - Substrate management	R 380 000	R 692 640	3%
8	Waste capturing and recording	Cleaner production and recycling [Collection, monitoring, transportation]	Section 5.5 - Substrate management, Section 5.3 Process control	R 0	R 424 500	2%
9	Efficient waste skip management	Recycle, treatment & disposal [treatment, transportation, disposal]	Section 5.6 - Whole system	R 542 000	R 394 500	1%

The most desirable state of waste management is to reduce the waste produced and then to recycle as much of the remaining waste as possible. The investigation has achieved both those outcomes. Since the waste management changes affected the complete system, the complete system waste figures are represented in to observe the overall effect of the changes. The quantity of waste produced was reduced from an average of 134 tons to 90 tons in the investigation period. (Refer to Section 4.5.2 Waste deployment) The quantity of recyclable versus non-recyclable is greatly dependant on the product mix produced. The final state had an increase in recyclable waste from 38.5 tons to 39.6 tons. The final state also resulted in an average of 46% (41 tons) diversion from landfill.

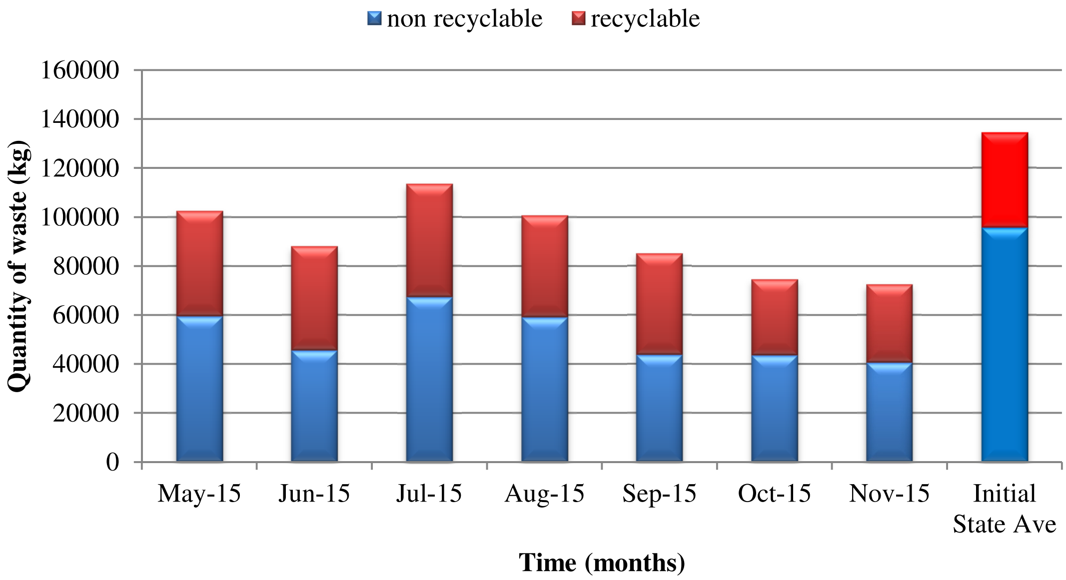
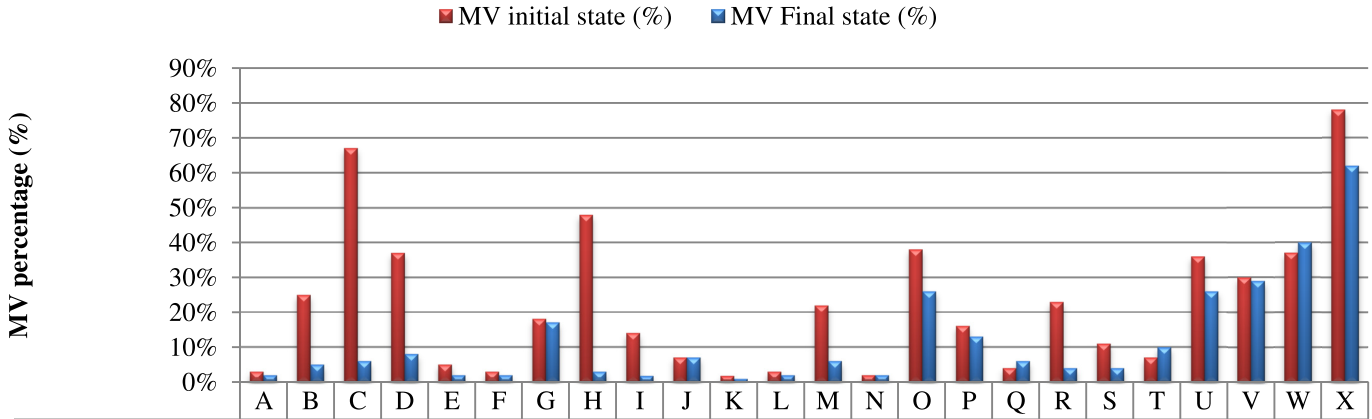


Figure 63: Total waste composition [135]

6.3. Final State System Indicators

6.3.1. Final State Material Variances

The material variances experienced in the final state are presented in Figure 64. The average material variance of the subset is 11.87%, a decrease from 21.5% obtained in the current state (refer to Section 4.5.1 Material Variance)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
MV initial state (%)	3%	25%	67%	37%	5%	3%	18%	48%	14%	7%	2%	3%	22%	2%	38%	16%	4%	23%	11%	7%	36%	30%	37%	78%
MV Final state (%)	2%	5%	6%	8%	2%	2%	17%	3%	2%	7%	1%	2%	6%	2%	26%	13%	6%	4%	4%	10%	26%	29%	40%	62%

Printing jobs in subset

Figure 64: Final state material variances [135]

6.3.2. Final State Waste Deployment

The waste deployment achieved is graphically represented in Figure 65. A target was set to achieve 100% waste deployment. To achieve 100% waste deployment, the following conditions had to be met:

1. Accurately report waste by process.
2. Accurately report waste by machine.
3. Accurately report waste by defect.
4. Have an accurate reconciliation of defect weights to machine waste.

All four conditions were met with 100% accuracy (refer to Figure 48, Figure 49 Section 5.4.4). A fourth level of waste deployment, which is used by process owners, is the personal level. This level allows the process owner to performance manage their employees and provide suitable corrective measures to address recurring defects from an individual.

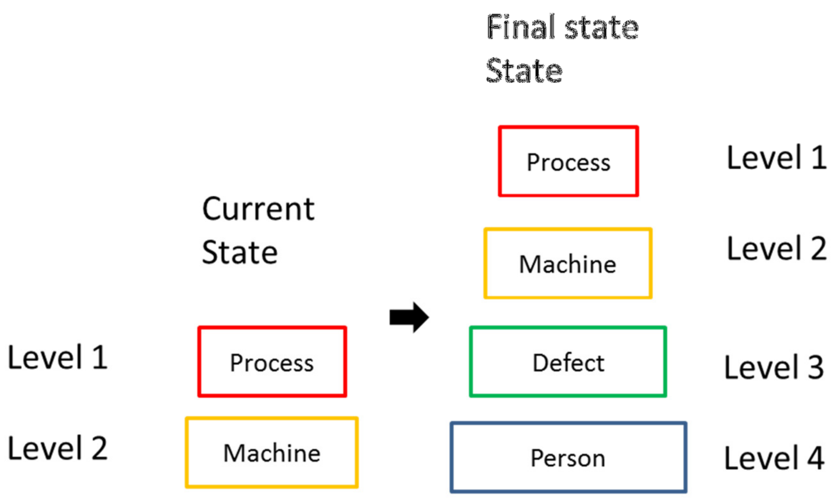


Figure 65: Waste deployment levels (created by author)

The waste captured on the ERP correlates with the accuracy of the physical information recorded. Figure shows printing waste increased and slitting was drastically reduced. From the investigation and since the correct deployment was achieved, it can be concluded that the previous information was misleading. Slit waste was at 77% and print waste at 14%. (See Figure 26 in Section 4.5.2) If this were taken at face value, the area of concern would have been the slitting operation. However, the incorrect recording of waste gave a false conclusion as some of the recorded waste from slitting actually originated from the print and lamination processes. Correcting the waste recording naturally increases the percentage of waste that originates from printing processes. The final state apportionment of recorded waste on the ERP is print 51%, lamination 34% and slitting 15%. This ratio is approximately equal to and consistent with the company's standard costing model (refer Appendix D). One can conclude that the information is accurate at a departmental level.

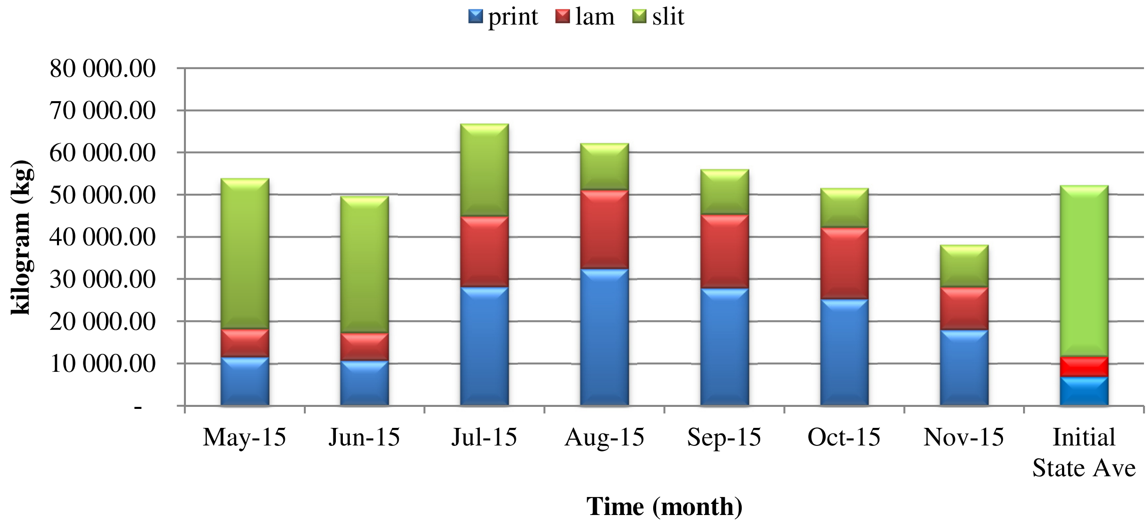
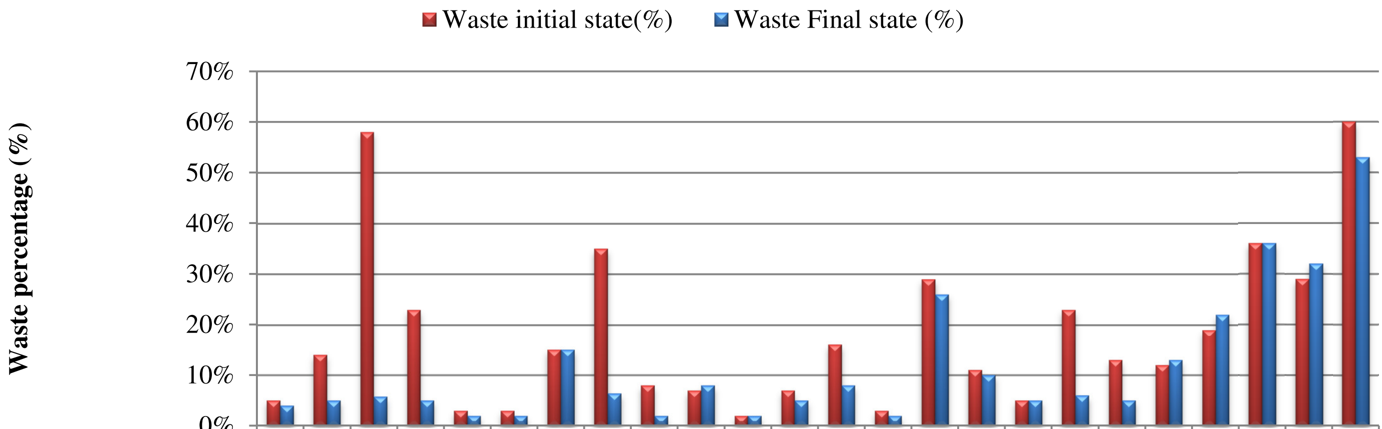


Figure 66: Waste captured on the ERP [135]

The final state waste of the subset following the improvements is provided in Figure 67. The average waste of the subset is 11.68% a decrease from 18% in the current conditions (Section 4.5.2)



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Waste initial state(%)	5%	14%	58%	23%	3%	3%	15%	35%	8%	7%	2%	7%	16%	3%	29%	11%	5%	23%	13%	12%	19%	36%	29%	60%
Waste Final state (%)	4%	5%	6%	5%	2%	2%	15%	6%	2%	8%	2%	5%	8%	2%	26%	10%	5%	6%	5%	13%	22%	36%	32%	53%

Printing jobs in subset

Figure 67: Final state waste per job [135]

6.3.3. Final State Accuracy

Based on the financial data, issues with the accuracy of the production information were suspected at the initial stages. Upon comparison of the ERP system information and physical checks, it was found that the accuracy was 40% (See Figure 27 in Section 4.5.3). The investigation intended to achieve an accuracy of 95%. The outcome is shown in Figure 68.

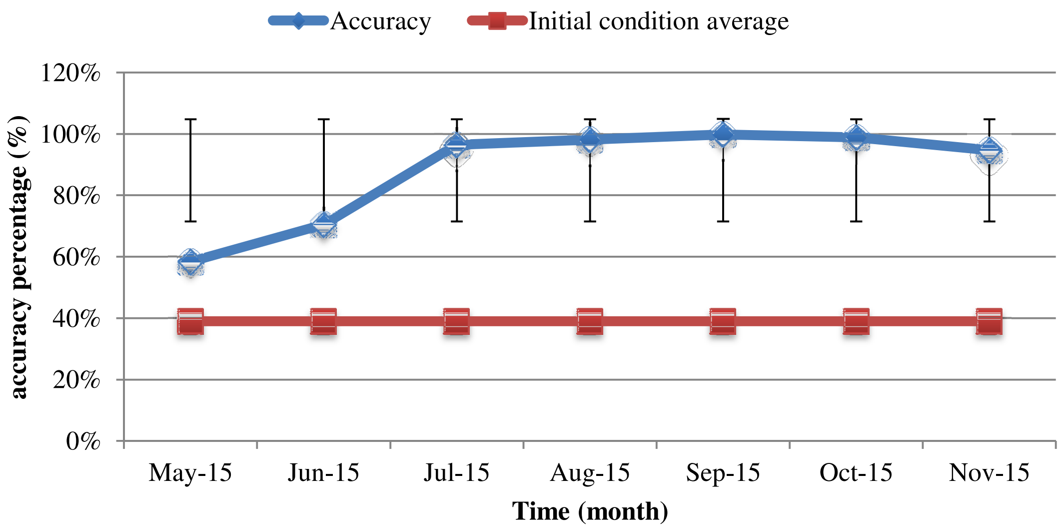


Figure 68: Accuracy of information [135]

A standard deviation of 31% in the final state is achieved, compared to 18% in the initial state. This is because during the period of transition, the accuracy percentage value increased by 30% in three months. The initial mean describes a better picture, rising from 40% to 88% in the period observed. Over the last four months of analysis, however, this value is 98% and has a standard deviation of 2%. The reason the last four months are a better measure is because the earlier months were when procedural and behavioural changes were being implemented. The poor results are merely the residual results of teething issues experienced in the early stages. The same condition applies for all the results presented. One can conclude that the analysed and reported data is accurate and symbolises the physical situation at the case company.

6.4. Final State Implementation Summary

Table 35 presents a brief summary of the performance measures given for the investigation.

Table 35: Summary of performance measures (created by author)

Performance measure/Target	Target	End of analysis	Status	Last 4 months	Status	Section to reference
Degree of accuracy	99%	88%	Unsuccessful	98%	Unsuccessful but acceptable	5.4
Conservation of substrate	100%	100%	Successful	100%	Successful	5.5
Rework	50% reduction	53%	Successful	53%	Successful	5.4
Virgin RM usage	5% deviation	14%	Unsuccessful	10.6	Unsuccessful	5.6
Waste deployment	100%	100%	Successful	100%	Successful	5.4
Waiting for material reduction	80% reduction	50%	Unsuccessful	78%	Unsuccessful but acceptable	5.3

The investigation overall was a success. Table 35 reiterates the results from Chapter 5. These were discussed individually in the referenced sections. The culminations of these results are the KPI's.

6.5. Key Performance Indicators

The KPI's set at the beginning of the analysis are reviewed. (See Table36)

Table 36: KPI summary (created by author)

KPI	Target	Achieved	Notes
Accuracy	99%	98%	Acceptable
Average profit margin	15%	10.90%	Not met
Waste percentage	Decrease 5% on average	Decrease 6.32% on average	Achieved
Material variance	Mean of +10%	Mean of +10.2%	Achieved
Implementing a sustainable waste management protocol	<10 months	11 months	Not met

The subsequent chapter interprets and comments on the final state results. The KPI's are reviewed to gauge the success of the waste management protocol. The research is critiqued based on the problem statement and objectives to determine if the critical review question was sufficiently answered.

7. CHAPTER 7

DISCUSSION

The purpose of this research was to investigate how waste management affected profitability through the implementation of an effective waste management protocol. Lean Six Sigma was the methodology used to achieve waste management. This discussion will review all the research objectives, explain the significance of the results obtained in relation to the KPIs and determine to what degree the critical review question has been answered.

The starting point is accuracy; a KPI that was achieved. The current state revealed that the financial figures, the manual figures entered in the ERP and the physical stocks did not match, even though they are different forms of the same information. The accuracy of information is fundamental to the methodology employed to achieve waste management. The information needs to be reliable for the analysis to be valid. For information to be accurate, the providers of the information need to be provided with knowledge and actively engaged throughout the process. The information analysed is only as good as the information provided. The initial conditions indicated that the information the company measured its performance by, and used for analysis and waste management planning, was only 40% accurate when actual measurements were compared to the stock financial figures. This caused problems such as:

- incorrect material quantity allocation: This problem had a knock-on effect, as incorrect quantity allocation led to incorrect planning and resulted in incorrect material quantity demands. The lack of stock accuracy resulted in employees being busy, but not productive.
- Incorrect costing and after-job cost: The information fed into the system was used to price jobs for customers and to conduct checks on profitability. The inaccuracy of information removes the ability to gauge where profits and losses were made. The ability to make the wrong strategic decisions existed. This was evident by the value of money lost on material variance. Operationally physical stocks do not match with the ERP system, which in turn did not match the accounting financial values.
- Incorrect waste deployment: Incorrect waste deployments due to the inaccuracy of information led to the incorrect derivation of the root cause of waste. The wrong information was being analysed. Statistically, no accurate conclusions could be drawn from the information available on the system – hence, no focus was available. If there was any focus, it was in the wrong area. A key factor in developing a waste

management system is to understand how much waste is being created, from where this waste originates and what the reasons for the waste creation are. This information then allows the waste to be managed by addressing the underlying causes to achieve the desired outcome of the waste hierarchy.

The accuracy of the information is vital in an FPC, as there is potential for high gains and very high losses. The company data indicated slitting as the area that contributed the most waste – yet the reworking operations revealed mainly printing defects. A test case identified three sources of data considered accurate via opinion or fact: the questionnaire, the financial data and the standard costing model. These all suggested printing should be the main source of waste. The disjoint from the company-captured information and reality is the reason, when investigated, that only 40% accuracy was found. The cause could be linked to the human intervention in capturing data. The operators who provide the information, recorded information incorrectly for reasons which could be:

- a force of habit;
- a lack of knowledge because information was not fed back to them about the importance of the information they record;
- a lack of education, or intentional sabotage where the incorrect readings are recorded, such that overtime is required;
- an unintentional sabotage, where employees protect themselves from an employer who might have a history of harsh discipline;
- due to employees feeling that providing incorrect favourable information provides job security.

It does bring to question how much management involved the employees in everyday operations. Without the investigation or any form of intervention, these conditions would persist. Achieving 98% accuracy provided the ability to analyse the correct information to achieve raw material control, waste deployment, substrate control, more reliable after-job costing and accurate computation of profitability. The remaining 2% of inaccurate data can be attributed to teething issues during the transitional phase or human error.

The KPI for accuracy was achieved. Achieving this KPI means all data collected on the company ERP was a true and accurate reflection of the actual state of the company. It was therefore certain that the data collected, the analysis done and the conclusions reached were from correct data. The impact of incorrect data is misdirection in the analysis phase.

Achieving accurate information also addressed the company culture. Employees are the custodians of company data. Employees no longer felt the need to falsify information, due to a change in management style that encouraged employee engagement. The old methodology of punishment for mistakes was replaced with improvement after mistakes. The value of this change was only realised because of accurate information. This metric was vital to the completion of the research. In order to continue a profitable operation and to have waste management under statistical control, information must be accurate, reliable and available in a timely manner.

When gauging how successful the investigation was, it is important to understand the benefits gained from the improvement actions that were taken. Some of the actions did not directly address the problem, but were discovered because of the problem. Their inclusion influenced the outcomes of performance measures by which the success of the implementation is measured and the KPIs by which the success of the investigation was gauged.

The first objective was to determine the magnitude of loss or gain in profitability due to the current state waste management. The current state waste management protocol was determined by mapping the whole process, considering how waste was measured, transported, transformed and what processes are in place which promote reduction of waste. (See Figure 23 in Section 4.4) The process flow chart revealed Muda in waste management and a lack of value-adding processes that reduce waste. The Muda that were revealed included excessive movement, over processing and excessive waiting. This information highlighted the opportunities available to make changes in the process. An understanding of the critical inputs to be operated on or transformed was gained. These operations were performed to achieve the desired state of waste management.

The current state was also required to provide a baseline in terms of profitability. The baseline only considered the population subset chosen through stratified sampling. A wide spread of jobs with the biggest value-gain potential, based on sales, were considered. At the current state stage, the accuracy and reliability of data was unknown. Therefore, the safest metric to use was the sales value, as this was absolute. Opportunity was lost to analyse low sales value jobs, which potentially could have higher profit margins when compared to those with higher sales value. The current state showed a loss in profitability, with the average profit margin being -7%. Jobs, on average, cost the company 7% over and above the selling price. At this point, however, there was no direct correlation between the profitability measured and the current state of waste management. It is also likely that the profitability was affected or influenced by incorrect pricing, over processing or extended machine time. What could be concluded was that the current state waste management was poor and lacks effectiveness. Similarly, the magnitude of profitability with the current state waste management was a loss of 7%.

The second objective was to implement specific solid waste management protocols. The waste management protocol specifically targeted solid waste through the collection, treatment, transportation, prevention, monitoring and disposal of waste. However, the protocol exposed weaknesses in the process flow that applied to solid waste management, as well as addressing issues directly related to profitability. The solid waste management protocol was implemented through the following segments:

- Segment 1: this segment addressed the input to the process: i.e. how the substrate was managed and optimised at the birth of potential waste.
- Segment 2: this segment addressed the value-adding process of printing. This segment ensured that the operation of transforming the substrate was completed with predictable quality output, therefore defects were reduced.
- Segment 3: this segment ensured that the substrate within the process (converted or raw) was accounted for along the complete value stream. What was allocated to be used within a process needed to remain balanced with the output from the process.
- Segment 4: this segment considers the flow of the process (with respect to solid waste management) simplified by the implementation of segments 1-3. The transportation, storage and processing of solid waste was addressed.

The implementation success of the protocol was determined by the KPIs. Each segment provided different information, which helped the company achieve the waste management hierarchy and influence the outcomes of the KPIs. The objective of the raw material control was to achieve a minimisation or reduction of waste. Raw material control optimised the substrate before it was input to the process. This optimisation resulted in less available substrate that could potentially create waste, therefore it reduced the amount of waste that could be created. The implementation resulted in 3.4% reduction in virgin raw material usage on average. The target was not met, but the outcome supports the statements about waste minimisation at the source, made in the 1975 framework directive about the waste management hierarchy. [30] The unsuccessful outcome highlighted the fact that virgin raw material usage was influenced by more than just input optimisation. Potentially, the same outcome could be reached under the conditions described below.

- Different operators ran the same job. Purely on skill level, an operator could use less material to produce the exact same job.
- Different atmospheric conditions – as the factory is in a non-controlled environment, it is a real possibility that conditions differed between the initial test case and the final analysis.
- Unforeseen circumstances – such as damage to cylinder in the initial case, resulting in the job being removed while waiting for the new cylinder. When the new cylinder arrived, the job was returned to print with the same production number – thus compounding the set-up waste: i.e. increasing the initial virgin RM used. If the analysed job had not gone through this process, a reduction in virgin RM may have been achieved.
- Use of different machines, as they have different technologies for defect prevention. This could create difference between jobs.

From the alternative explanations, the same result could be achieved on an individual job-by-job basis. The analysis, however, considered over 20 varying jobs that supported the initial explanation in all cases, apart from one type of substrate construction. . Further investigation is required into why the one substrate did not show any improvement. Further research could be conducted to eliminate the alternative explanations and, in isolation, correlate raw material control with virgin raw material usage.

The objective of process control is to prevent waste within the process. Prevention of waste is the highest and most desired state of the waste management hierarchy. [30] Process control requires an understanding of how the raw materials are converted within the printing process. To gain the required understanding, the process itself needs to be fully understood. The investigator needs to know: where the waste creation areas are, what waste is being produced, how the waste is being produced, and how much waste is being produced. Once this understanding is gained, the necessary tool or tools must be used to identify opportunities to prevent waste.

The tools that were used are from the Lean Six Sigma methodology. These include process mapping, VOC, Pareto, DMAIC, FMEA and standardisation. The waste percentage decreased an average of 6.32%, which surpassed the KPI of 5%. The chosen KPI followed the S.M.A.R.T. principle and, most importantly, was achievable. George (2002) mentions that companies fail when they expect the Lean Six Sigma methodology to achieve dramatic changes and they see little improvement. [60] In comparison, the printing department in a paper mill achieved a 0.78% reduction in solid waste from the implementation of Lean Six Sigma. [82] This outcome was deemed successful, as benefits in OEE were also realised. It is important that the KPI was in line with the business strategy of the company.

Furthermore, the GM of the company was completely supportive through the implementation process. The outcome achieved supports the statement made by George that, "Lean Six Sigma effort will succeed or fail based on the engagement and buy-in of the CEO and executives with P&L (Profit and Loss statement) responsibility". [60] There was a concern about the choice of implementing Lean Six Sigma methodology due to the education level of the employees. This result not only demonstrates the success of the implementation of Lean Six Sigma, but it also proves the effectiveness of the training programme implemented to change the company culture. According to the literature, waste management efforts had failed in Polokwane municipality, and one of the reasons cited was poor education (academic and/or on waste management). [82]

Process control and raw material control together produce results that affect the material variance. Material variance is defined as a deviation from the standard costing model for material and is expressed as a percentage. The KPI for material variance was to reduce the mean variance from 22% to 10%. The mean material variance was reduced to 10.2%, which constitutes a 54% improvement. Process control and raw material control were performed, firstly to optimise the input material and secondly to ensure defects were prevented. Input material optimisation reduced the material available to print by providing the best combination of items using weight and batch expiry as conditions. Material within specification was still provided, but optimisation reduced over issuing.

Defect prevention converts the maximum amount of material into sellable printed product. The improvements shown do not correlate with the waste figure, since the point of reference for material variance is a theoretical standard, and waste is what is actually produced. It is possible to show no material variance, yet show waste produced. The outcome would be a short order that gets put back to production under a different order. It is for this reason that the waste figure and material variance figures have alternative explanations. Short orders, in the production system, register as an independent job, with standards for waste and material allocation etc. There is no correlation with the initial order that initially created waste, and now requires completely new machine time and material, creating a material variance.

This material variance goes unrecorded and cascades to production planning, since the material used was originally not assigned for the short make. Further research is required in this area, as there will be questions about the system and considerations of Lean manufacturing principles. Alternatively, such reductions can be experienced from changes in the raw substrate used. If the original specification was obtained from the company's preferred material supplier, it is likely that changes in their formulation due to their cost-saving initiatives or their processes consistently being out of specification (either higher or lower bound) could go unnoticed. The result could have a positive effect on the print quality achieved. The printing process being dynamic, this could result in the case company adapting to the "new" material without any knowledge. If the supplier reverts back to the original specification, it could then have a negative effect on the material variance, while the case company re-adapts to the "old" material. Although these alternatives are possible, it is highly unlikely that they could happen solely to the subset, or cause a 54% improvement in such a short space of time.

Substrate management and considerations of a simplified system tie the whole waste management protocol together. Substrate management ensures that all substrate can be accounted for when it is entered into the system. This is a failsafe management system that introduced the concept of conservation of substrate, not an unfamiliar concept in the sciences. In lay terms, if 250m of substrate that weighs 10kg goes into the process, 250m and 10kg of substrate must come out the process. The output is split between good and defective product. In the investigation it was found that the information recorded by the operators did not adhere to this concept. Further investigation revealed that operators were recording information incorrectly, because they feared the outcomes of poor performance and the consequences of creating waste.

One could argue that this problem was caused by management themselves, due to: the style of management used, biased enforcement of the rules, the relationship developed with the employees, not providing the correct tools, and a lack of understanding of the skill strengths or the skill limitations of the operators. On the other hand, it could also be argued that the operators' actions were doing a disservice to the company, and that their actions were dishonest; or that the operators were forced into behaving in this manner due to the situation they were put in. The root cause of this situation could be unique to the case company, or experienced by a lot more companies in different industries – it could be region, race or gender specific. Additionally, it requires further research before definitive conclusions can be reached. In terms of the case company, based on the information available, attempts were made to remove uncertainties.

The conservation of substrate is a system that makes it very difficult to falsify data, and it is clearly identifiable if attempts are made to do so. The process control segment ensured that all the correct tools were provided or updated to the OEM specifications. The employees were engaged through; Lean Six Sigma workshops, regular feedback sessions and their involvement in the project team. When people know they are being monitored, their behaviour changes; it is for this reason that completely different jobs from the subset were used to validate the conservation of substrate. The efforts resulted in 100% of the jobs following the conservation of substrate, whereas previously only 25% held true. It can be concluded that when employees are actively engaged by management, management tasks are executed accurately with employees taking ownership.

Considerations of the whole system cover the final requirements of the implementation of the waste management protocol. Once the waste has been created, how is it collected, transported, and disposed? The main functions of these waste management actions are to consider the environmental effects of these actions, and to recover as much money as possible from the waste that has been created already. The environmental effects go beyond the scope of the research, but the recovery of lost profit has been covered. The recyclable gains achieved do not mean that more material has been diverted from landfill to recycling. They merely reflect that the on-site processing of waste has increased the value of the recyclable waste. The inclusion of the correct sorting, classification and transportation process at the source yielded a 30% growth in the value of recyclable waste and reduced transportation costs by 20%. The disposal costs are negligible when considering the cost of production. However, they do affect the overall profitability of the company, as outlined in objective three, where the impact of the protocol was evaluated with respect to profitability.

Before evaluating the impact of the waste management protocol on profitability, alternatives that could influence profitability need to be considered. The initial conditions revealed 40% accuracy of the financial information relative to the actual system-recorded information. The initial conditions were developed under these conditions. The financial numbers were used as a baseline, and as a result, all financial numbers aligned from the beginning to the end of the investigation. The accuracy became a focal point to ensure that the information recorded on the production floor matched the financial figures. There was a lot of emphasis on the accuracy of information early on in the investigation. Incorrect figures became less likely to skew the evaluation, because an accuracy of 98% of system versus physical stock was achieved.

Possible alternatives exist, where system figures were used to benchmark. From the research, it was discovered that these figures were misreported to look better. Therefore, the results discussed have higher margins than recorded, since the initial conditions were worse than the recorded figures. For uniform analysis, the recorded figures were taken as true, and it must be emphasised that the financial figures will not be affected by this anomaly. There potentially could have been cost-cutting exercises external to the investigation that reduced the cost of sales. These could include the reason below.

- Air freighting material versus sea freighting – for the subset analysed, this was not likely, as the stratification started with the top 10 customers based on sales. These customers had high volume demand. And as most material was imported with a three-month lead time, stock was always kept on hand to fulfil the demand. If these customers exceeded their forecasted demand, airfreight commonly would have been used to satisfy such urgencies. However, due to the vast price difference, it would have been avoided at all costs.
- Reducing the labour rate or the size of the work force: this would not be possible in the short space of time, due to labour laws in South Africa. There are also minimum requirements to operate printing presses safely which must be adhered to.
- Substitution of substrate or sourcing substrate from an alternate supplier at a lower cost – for substrates to have been substituted, customers would have needed to be informed, and tests would have needed to be performed to prove the functionality and to ensure the quality of the contents. Substitutes take up to six months for approval. [20] The probability that the FPC produced quality finished goods with raw material of

lesser value over the analysis period is highly unlikely. Material has a three-month lead time. Therefore, the case company purchases ahead. The four-month analysis period covered seasonally high grossing months, during which customers increased stocks and production to provide for the forecasted increase in consumer spending over the last two months of the year.

Considering that the selling price remained constant, there are no other singular actions that could have resulted in positive profitability shifts of between 15% and 50% in some cases. Table 32 showed this relationship but also displayed some unfavourable results. Jobs O, P, U, V, W and X showed a substantial loss in the profit margin. The suspected reasons behind why these jobs did not respond positively to the waste management protocol were that:

- different operators ran the jobs under differing conditions;
- the costing standards and thus the selling prices were incorrect;
- the jobs O and P, and U, V, W and X were the same construction respectively. These constructions were potentially the wrong constructions for the application, resulting in high waste. Alternatively, the operators might have struggled to trouble shoot errors with these specific constructions.

The jobs' profitability outcomes present an opportunity for a further Lean Six Sigma intervention to understand the root cause of the negative profit margin. However, this would be outside the scope of the investigation and not in line with the objectives. It can be concluded that the resulting profitability indicators were a result of the actions laid out in the waste management protocol. The waste management protocols were tabulated in Table 34 in Section 6.2, and their impact on profitability also evaluated. The subsequent paragraphs discuss items as listed in Table 34, from the action with the least impact on profitability to the action with the most.

In item nine, a shredder, a baler and waste cages were introduced to the waste management process flow. Savings were realised due to reduced transport costs, an increase in the recyclable value of waste material, and the ability to destroy sensitive material instead of storing it for a minimum of one year before disposal. Item nine achieved a 1.89% impact on profitability. The item was expected to be the lowest impact, as it addressed waste from the lower tiers of the waste management hierarchy. More value could be gained through the use of self-compacting skips. Self-compacting skips would reduce the capital investment by 70%, but they are not expected to influence the magnitude of the savings realised. Due to the fact that the goal for waste is to prevent/minimise waste, this solution would have short-lived success. Initially the impact on profitability would surpass 1.89% because of financial recovery, but over time, the most desired state of waste management would be achieved and the impact on profitability would decline, resulting in an unsustainable solution.

Items seven and eight (see Table 34) complement each other. Item seven provides a monitoring tool that acts as a set of checks and balances, while item eight ensures these checks and balances are reliably available on the system in a timely manner. A waste measurement system using scales and timely recording was introduced. Some capital investment was required for the measurement system. The actions achieved savings due to: conformance to the conservation of substrate, labour and machine time saved by removing the bottleneck at the measurement points, and savings experienced due to incorrect or missing data. The impact on profitability was 5.35%. This outcome highlights the importance of an accurate measurement system. The implemented solution satisfied the requirement of the company; however, a better system could be employed. Integrating a barcode and location scanning system to the scale interface would allow for full traceability throughout the whole process and greater savings in labour. An additional investment of R500 000 would be required for the implementation of the improved system. In the long term, this improved system would be more sustainable and cost efficient. The improved system could have an impact of 14.13% on profitability, due to the fact the improved system addresses items 1, 2, 3 and 8.

Item one (see Table 34) considered working with the true weight of raw material. The test case yielded some variation in the supplier weights stipulated on the label versus the actual weights. The saving experienced were due to the sheer volume of raw material processed at the case company, which totalled over 7500 tons in 2015. However, the impact on profitability was only 0.03%. The actions are not sustainable and result in a Muda of over-processing. The measurement and verification process which is in place to inspect every reel should be removed and replaced with batch verification. Each batch delivered from the supplier would have one reel physically measured against the reel label. Only a variance outside a 5% tolerance will be returned to the supplier. Quality control would be ensured without impacting the profitability of a job by including unnecessary checks.

Item two (see Table 34) was an extension of item one. The Muda of waiting was eliminated through 5S and "live" capture of material specifications when issued to a job. The 5S intervention reduced the time spent looking for and waiting for material. This intervention achieved an 8.14% improvement on profitability. Savings were realised through labour and machine rate hours saved. The live capture achieved an increase in stock accuracy, and therefore reduced incorrect demand. The overall stock levels were reduced, which addressed a Muda of inventory.

The overall solution could be improved through the implementation of a paperless real-time system integrated to the bar code and scale system. Although this solution may be expensive upfront due to the costs of importing the system and the technological upgrades that would be required, the increase in efficiency and opportunity cost achieved justifies the investment. An additional investment of €100 000 (±R1.4 million) would result in R2.3 million annualised saving, with an impact of 10.68% on profitability.

Items three to six target process control. With process control, the capturing of information was again brought as close to live as possible (item 3), machines were restored to basic conditions, waste deployment was implemented to understand the root causes of waste, and SPC was used to ensure consistent quality output. These actions achieved a reduction in:

- Muda of over processing through rework (item 4);
- Muda of defects through the reduction of waste (item 5); and
- Material variance (item 6).

The processes implemented offer long-term solutions that promote the concept of getting production right the first time. The most desired state of waste management (prevention and monitoring) was achieved through the implemented actions, and also resulted in the greatest impact on profitability. More specifically, reduction of rework had an impact of 35% on profitability and realised the largest annualised saving.

The rework procedure is tedious, time consuming and removes potential value added procedures. Moreover, this process cannot be charged to the customer. For this reason, it is costly to operate; however, the process is a high value gain process, since material that would have been discarded can be salvaged and reworked into sellable product. The rework procedure avoids a complete remake of the product, which would in fact result in a highly negative profit margin.

Waste is non-recoverable product. The actions of the investigation resulted in the reduction of waste and had a profitability impact of 36.87%. This result magnifies the requirement to produce right the first time. While addressing items 4 and 5, rework and the reduction in defects, the reduction in material variance was achieved. No direct investment can be made for this KPI (as shown in column 5 of Table 34) without addressing the production of waste. The successful implementation of the reduction of waste determines the success of material variance. The impact on profitability was 10.92%.

In Section 5.5, it was theorised that the non-conformance to the conservation of substrate was one of the biggest risks to company profitability, due to the fact that the product was 93% substrate. The evaluation of the data disagreed with this hypothesis. In fact, if the Pareto principle is followed, it would not even be considered for evaluation.

To achieve a better, more sustainable solution for waste and rework reduction, investing in increasing the skill level of the operator should be considered. This action will naturally result in decreased waste, and addresses the eighth Muda: underutilised talent or skill. [3] This option does, however, take longer – but the results are more permanent. It is easier and less costly for a skilful operator to produce good quality product by navigating and troubleshooting imperfect machines and systems, than it is for an unskilled operator, even with the best tools and systems. These two options are not mutually exclusive, and should be addressed simultaneously. The gravure printing process, being high-speed and continuous, requires sharp troubleshooting skills to minimise waste. The minimisation of waste has been shown to have the highest impact on profitability when compared to other waste management initiatives.

8. CHAPTER 8

CONCLUSION AND RECOMMENDATIONS

The case company was producing, on average, 500 tonnes of finished product monthly, but was still registering a negative gross profit margin. Trialled and failed solutions cascaded into further profit-draining problems such as:

- increased raw material usage;
- increased labour costs;
- increased customer rejections (waste) and returns (potentially recoverable waste);
- long lead times (inefficient production);
- inconsistent quality.

The aim of the research was to investigate if the implementation of a solid waste management protocol could influence the profitability of a flexible packaging company and to what extent. The research conducted focused on the gravure printing process, as it was identified as the biggest opportunity for profit recovery. The scope encompassed from the delivery of raw material to the gravure printing process until the waste was sorted for disposal within the company premise. Waste management involves all the actions required to manage waste from creation to disposal – including, but not limited to, the collection, treatment, transportation, prevention, monitoring and disposal of waste. [5] The ultimate goal of the research was to sustainably realise profit for the case company using an academic methodology.

The scientific method was used to conduct the research because it was in line with the research aims, and it provided the ability to construct an accurate representation of the world that is reliable, consistent and non-arbitrary. [115] The scientific method was applied through the utilisation of the Lean Six Sigma methodology, DMAIC. The problem solution was broken down into four segments, each containing a micro problem that addressed the macro problem. The segment problems are presented, and the final findings are discussed thereafter.

Raw material control: A disorganised raw material store containing aged and suspected defective material resulted in material delays at the production process and the production of defective material.

Process control: Defective product was continuously created, which resulted in an added rework process to salvage material. The rework process reduced the full loss of the defect created. There was no clear identification and classification of the defects created and, thus, poor RCA.

Substrate control: Substrate quantities were only known on issue, and could only be reconciled again, once the information was captured at the end of the job. The capture times varied from 8 hours to 3 days. Material was not easily accounted for, resulting in losses through the system with no easily identifiable point of origin.

Whole system control: The usage of virgin raw material was unmonitored and unregulated. Losses were experienced from the excessive use. Excessive material use was a cover-up for the problems, which were addressed in the process control segment. The waste already created was not optimally managed, resulting in lower-than-expected recoveries.

The implemented solutions identified, analysed and challenged the existence of different types of wastes, based on operational requirements and financial impact. The key findings from the solutions were as follows.

- An 8% impact on profitability was computed through gaining raw material control. Waste was eliminated before it had the potential to be created. A 78% reduction in waiting for material down time was realised. This outcome was expected based on the literature. [54], [61] The literature confirms that the implementation of 5S results in a reduction in Muda of time and motion, variation in operation, the ability to optimise other processes and an increase in productivity. [54], [61]
- An 83% impact on profitability was computed through gaining process control. Process control addressed classification of waste, such that the appropriate actions were taken to prevent waste from being created within the process. A 53% reduction in rework material was experienced, and the accuracy of information increased to 98%. Within the printing process, the overall waste decreased by 6.32%. The magnitude of the findings exceeded the targets set, and the theory supported the outcomes achieved. In the food manufacturing industry, the correct classification of defects and SPC was used for consistent quality. A 0.3% reduction in the defect was experienced, as well as a 70% reduction in rework caused by the defect. [99]
- A 5% impact on profitability was computed through substrate management. Substrate management introduced the concept of the conservation of substrate. The conservation of substrate ensured that the same quantity of raw material input into the process

equalled the sum of output and the waste produced. The focus was on the process of measurement and the accuracy obtained. Early detection of non-conformance resulted, and 100% adherence to the conservation of substrate within a 2% tolerance, was also achieved. When it came to the process, the worst-case scenario achieved an 83% saving in process time.

- A 4% impact on profitability was computed through gaining control of the whole system with respect to waste management. The solution focused on ensuring that the required amount of raw material at the correct quality went into the process and that the output waste was managed properly thereafter. A 4.4% reduction in the raw material variation was achieved. A recovery of R11 000 per month was realised through the implementation of waste management activities, which considered transportation, storage and recycling of waste. The solid waste management framework from the literature – to collect the waste, transport the waste using the appropriate mode, sort the waste (through third parties), recycle that which is recyclable and dispose the rest to landfill – was followed, and it produced similar results. [48], [49], [50]

To what extent does the implementation of a solid waste management protocol in a FPC improve profitability? The successful implementation of a waste management protocol using Lean Six Sigma methodology improved job profitability, on average, by 17% over 11 months. The number of jobs with a profit margin above 15% increased by 80% over the same period. As a result, more jobs were making a profit in the FPC. Further profitability opportunities can be realised as a result of the implementation of a solid waste management protocol. These include a high customer satisfaction index and meeting OTIF requirements. These opportunities do not have a direct financial gains value associated with them, but if neglected, they will decrease profitability.

The literature reviewed has extensively addressed management of already created waste and the environmental aspects of disposal, which covers the complete definition of waste management. However, the literature does not describe what the outcomes would be of implementing such a program in a FPC in South Africa. Much of the literature focuses on municipal entities, construction and the health care sector. Additionally, there is limited information regarding the application of these methodologies in African manufacturing companies. There is also a gap in the literature, where the waste management protocol was used purely with the intention of financial gain, as opposed to where financial gain was the result of the implementation of the protocol. Therefore, this research sought to fill these gaps in the literature by conducting research within an African FPC with the view of financial gain.

In many ways, the findings supported previous research in which Lean Six Sigma tools were used and the waste management framework followed (described in the section above). However, in some regards, the outcomes achieved during this research did not align with what would be expected based on the literature – for example, regarding the reuse of waste material and the dependence on human intervention for accurate information. These unexpected outcomes could be due to inherent differences between the examples cited in the literature and the case company, such as:

- the education level of the employees;
- the ability to use technology;
- the maturity of the industry within South Africa;
- the financial constraints of the company.

It is also possible that the expected results were not achieved due the limitations of the study. Only considering the substrate for analysis limited the overall ability to expand on possible waste creation zones. The waste management of a singular process – though providing the biggest return – becomes insufficient if the downstream processes are not under the same control. The profitability – ability to make profit – is high, but the actual realised profit of the complete product could be low as a result.

The findings can be generally accepted and applied through any flexible packaging manufacturer. The differing factors will be the cost of implementation and the financial gains realised. The impact on profitability percentage is expected to remain true. This research study successfully demonstrates that profitability can be improved by 17% in a FPC in South Africa. However, this research is limited to a single case company. In the context of this success, the research principles outlined by this project should be applied more broadly in a multi-site case study, to see if these results are reproducible more broadly within the field. A consideration to include the complete process (lamination and slitting) and supply chain (the logistics and wet raw materials) will provide a holistic view of the flexible packaging manufacturing process.

Using Lean Six Sigma methodology proved successful, but without a comparative study, it cannot be concluded that this methodology will provide the best results under similar constraints. Further investigation into waste management using a different tool, which can then be compared to the effectiveness of the current methodology to obtain best practice, is required. Additionally, this methodology could be generalised and applied to other industries within South Africa. Such studies are important, because they could not only improve the profitability of specific companies, but reduce the environmental impact of solid waste from packaging, strengthen the recycling and manufacturing sectors of the South African economy, create employment across different skill levels and make such companies more internationally competitive – thus boosting South Africa's viability as an international player in secondary and tertiary economic sectors as well.

The research and development of materials and advancements in the technological sector greatly influence the creation and processing of waste. It is the author's wish that the financial rewards received could fund research and development, encourage social and environmental awareness of waste management, allow waste management policies to be adopted into African countries faster, and encourage continuous improvement within manufacturing companies and their employee's personal lives.

Overall, the major conclusion of this research is that waste management shares a symbiotic relationship with profitability. This research successfully demonstrates that increased profitability can be achieved through the implementation of a waste management protocol using Lean Six Sigma Methodology.

References

[1] Erin J Wolford. (2015, February) Positive Business Growth for Flexible Packaging Industry. [Online]. https://iceusaexpo.wordpress.com/2015/02/03/positive-business-and-growth-projected-for-the-flexible-packaging-industry/

[2] Smithers Group. (2013, December) Briefing: The Shift from rigid to flexible packaging. [Online]. http://www.smitherspira.com/news/2013/december/the-shift-from-rigid-to-flexible-packaging

[3] Debashis Sarkar. (2009, June) 8 wastes of lean manufacturing in a service context. [Online]. http://www.processexcellencenetwork.com/lean-six-sigma-business-transformation/columns/8-wastes-of-lean-manufacturing-in-a-services-conte/

[4] James P. Womack, Daniel Roos, and Daniel T. Jones, *The Machine that Changed the World*. New york: Harper Perennial, 1990.

[5] United Nations Statistics Division. (1997) Environmantal glossary: Waste management. [Online]. http://unstats.un.org/unsd/environmentgl/gesform.asp?getitem=1182

[6] Daniel Hoorweg and Laura Thomas, "What a Waste: Solid Waste Management in Asia," *Urban developement sector unit East Asia and Pacific*, no. 1, p. 5, 1999.

[7] Case Company, ERP Records, 2014.

[8] BRC Trading. BRC Global Standards. [Online]. http://www.brcglobalstandards.com/

[9] Anuka Bajoo Brown, Quality Manager, April 30, 2015.

[10] J Harrington, *Business Improvement: The Breakthrough Strategy for Total Quality, Productivity and Competitiveness*. New York: McGraw Hill, 1991.

[11] Business case studies LLP. Operations Theory - Production processes. [Online]. http://businesscasestudies.co.uk/business-theory/operations/production-process.html#axzz4CysJOU3d

[12] Visionary IB Education - (VIBE). IB Business and Management: 5.1 Production Methods.

[Online]. http://www.ibbusinessandmanagement.com/51-production-methods.html

[13] Smriti Chand. Types of production: with it's charateristics and limitations. [Online]. http://www.yourarticlelibrary.com/project-management/types-of-production-with-its-characteristics-and-limitations/26120/

[14] Tom Ronaldo, "Rigid vs. Flexible Packaging: Which has the Edge in being Green?," Illinois, 2010.

[15] Paula Hook and Joe E. Heimlich, *A History of Packaging*. Columbus: Ohio State university.

[16] BMSI Packaging. (2008) Packaging History and the role of BMSI. [Online]. http://www.bmsipackaging.com/packaging-history-and-the-role-of-bmsi.xhtml

[17] Erin Hoppe, "Flexible Packaging Innovations and Developments," Wisconsin, 2009.

[18] Barry A Morris, *The Science and Technology of Flexible Packaging*, Edward Payne, Ed. Oxford, United Kingdom: Elsevier, 2016.

[19] Uflex Ltd. (2015, October) Uflex Corporate Profile. [Online]. http://www.slideshare.net/Uflexltd/uflex-corporate-profile

[20] Anuka Bajoo Brown, Quality Mananger, April 30, 2015.

[21] David J. Bentley Jr. (2005, December) About Cold seal adhesives. [Online]. http://pffc-online.com/ar/4038-cold-seal-adhesives-0106

[22] (PNEAC), Printers National Envirionmental Assistance Center. Gravure Printing. [Online]. http://www.pneac.org/printprocesses/gravure/

[23] Iggesund Holmen group. Gravure printing. [Online]. http://www.iggesund.com/Iggesund/IAM/RM/Gravure-printing/

[24] David Homer, "Definition of Profit or Loss," in *Accounting for Non-accountants: A Manual for Managers and Students: 7th Ed.* London: Kogan Page Limited, 2008, p. 30.

[25] SM Trivedi. (2010) Profitability Analysis. [Online].

http://shodhganga.inflibnet.ac.in/bitstream/10603/705/16/17_chapter8.pdf

[26] David Homer, "Accounting Standards," in *Accounting for Non-accountants: A manual for managers and students: 10th Ed.* London: Kogan Page Limited, 2015, pp. 319-321.

[27] Investopedia. Operating Expense. [Online]. http://www.investopedia.com/terms/o/operating_expense.asp?ad=dirN&qo=investopediaSiteSearch&qsrc=0&o=40186

[28] C J Watts, *The Cost of Production*. Muskegon, Michigan: The Shaw-Walker company, 1902.

[29] Bob McCally, *Demonstrated Labour Efficiency: An Effective Labour Cost Control and Analytical Tool.*: AACE International transactions, pp. 12-16.

[30] Official Journal of European Communities, "Council directive 75/442/EEC on waste," ammended by Council directive 91/156/EEC, 15 July 1975.

[31] S.H.H Oelofse and L Godfrey, "Defining Waste in South Africa: Moving Beyond the Age of 'Waste'," *South African Journal of Science*, vol. 104, no. 7-8, Sep/Aug 2008.

[32] Act 14 of 1987 Environmental Public Act. (2002) Singapore Ministry of Environment. [Online]. http://statutes.agc.gov.sg

[33] Martin Medina. (2002, 10 November) Globalization, Development and Municipal Solid Waste Management in Third World Cities. [Online]. http://www.gdnet.org/pdf/2002AwardsMedalsWinners/OutstandingResearchDvelopment/martin_medina_martinez_paper.pdf

[34] Interwaste. Intergrated Waste Management. [Online]. http://www.interwaste.co.za/management.html

[35] Oxford Dictionaires. British and World English: Technique. [Online]. http://www.oxforddictionaries.com/definition/english/technique

[36] European Environment Agency (EEA), "Diverting Waste from Landfill. Effectiveness of Waste Management Policies in the European Union," Copenhagen, Denmark, EEA Report No 7, 2009.

[37] Amar Nath, "Profitiability and Sustainability from Waste Management Practices in Hotels and it's Impact on the Environment," Jaypee Business School, Noida, India, Thesis 2014.

[38] F.R. McDougal, "Life Cycle Inventory Tools: Development of Sustainable Solid Waste Management Systems," *Corporate Environmental Strategy*, vol. 8, no. 2, pp. 142-147, 2001.

[39] Upendra M. Pradhan, "Sustainable Solid Waste Management in a Mountain Ecosystem: Darjeeling, west Bengal, India," University of Manitoba, Manitoba, Masters Thesis 2008.

[40] P Bishop, *Pollution Prevention: fundementals and practise*.: McGraw-Hill Inc, 2000. [Online]. https://engineering.dartmouth.edu/~d30345d/courses/engs171/LCA.pdf

[41] European Environment Agency, "Life Cycle Assesment, a Guide to Approaches, Experiences and Information sources," *Environmental Issues*, no. 6, August 1997.

[42] Society of Environmental Toxicology and Chemistry (SETAC), "A Technical Framework for Life Cycle Asssessment," Washington D.C., 1991.

[43] Lauri Koskela, "Re-engineering, Concurrent Engineering, Lean Production"What is the ideal antidote for the construction industry ailments? or what is the right question," VVT building Technology, Espoo, Finland, Paper 1997.

[44] Galway Education Centre. (2016, 16 October) Scribd. [Online]. https://www.scribd.com/presentation/60658413/Concurrent-Engineering

[45] Prudence Hlamarisa Maluleke, "A Review of Solid Waste Management Practices in Polokwane City," 2014.

[46] Yetunde O Agbesola, "Sustainability of Municipal Solid Waste Management in Nigeria: A Case Study of Lagos," Lagos, 2013.

[47] Rohit Bhagwat, "Site Waste Management Practices in Construction Industry in the United Kingdom," Manchester, 2008.

[48] P Agamuthu. (2013) Waste management & research. [Online]. http://0-wmr.sagepub.com.innopac.wits.ac.za/

[49] Ramokate Tuduetso, "Knowledge and Practices of Doctors and Nurses about Management of Healthcare Waste at Johannesburg Hospital in the Gauteng Province, South Africa," Gauteng, 2008.

[50] Jens Arleroth and Henrik Kristensson, "Waste in Lean Construction," Sweden, 2011.

[51] William A. Levinson, "Variation Reduction: Single Unit Processing," in *Beyond the Theory of Constaints: How to eliminate variation & maximise capacity*. Florida: CRC Press, 2007, pp. 83-86.

[52] Celep Oguz, Yong-Woo Kim, John Hutchison, and Seungheon Han, "Implementing Lean Six Sigma: A Case Study in Concrete Panel Production," in *20th Annual Conference of the international group for lean construction*, San Diego, 2012.

[53] Herb Lichtenberg. Applying Lean Principals in Proces Industries. [Online]. http://www.reliableplant.com/Read/13156/lean-principles-process-industries

[54] Jeffrey K Liker, *The Toyota Way*. New York: Tata McGraw-Hill, 2004.

[55] P Vidyut Chandra, Nitesh Reddy Nalla, and Nikhil Polineni, "Establishing Lean Management in Manufacturing Organizations as a Systems Approach for Effective Implementation and Results," *International Journal of Engineeering Science and Innovative Technology (IJESIT)*, vol. II, no. 6, pp. 519-525, 2013.

[56] A Raghmath and DR Jayathirtha, "Lean and Six Sigma Approach for Manufacturing SME's," Bangalore,.

[57] Maciej Pienkowski, "Waste Measurement Techniques for Lean Companies," *International Journal of Lean Thinking*, vol. V, no. 1, pp. 2-6, December 2014.

[58] P Hines, M Holwe, and N Rich, "Leaning to Evolve - A Review of Contemporary Lean thinking," *International Journal of Operations & Production Management*, vol. 10, no. 24, pp. 994 - 1011, 2004.

[59] James P. Womack and Daniel T. Jones, *Lean Thinking*. London: Simon & Schuster, 2003.

[60] Micheal L. George, *Lean Six Sigma: Combining Six Sigma Quality and Lean Speed*. New

York: McGraw-Hill, 2002.

[61] Micheal L. George, David Rowlands, Mark Price, and John Maxey, *The Lean Six Sigma Pocket Toolbook*. New York: McGraw-Hill, 2005.

[62] Shigeo Shingo, *Zero Quality Control: Source Inspection and the Poka-Yoke System*. Portland, Oregon: Productivity Press, 1986.

[63] Nikkan Kogyo Shimbun, *Poka Yoke: Improving Quality by Preventing defects*. Portland, Oregon: Productivity Press, 1988, p. 282.

[64] Martin C. Hinckley, *Make No Mistake! An Outcome-based Approach to Mistake-proofing*. Porland Oregan: Productivity Press, 2001.

[65] p Maarberg Buss, *A Framework for Lean Implementation: Lessons from Grundfos Manufacturing*. Hungary: Aalborg University, 2011, p. 125.

[66] Y. Monden, *Toyota Production System- An Integrated Approach to Just-in-Time. 3rd ed.* Norcross Georgia: Engineering and Management Press, 1998.

[67] J. Bicheno and M. Holweg, *The Lean Toolbox: The Essential Guide to Lean Transformation. 4th ed.* Buckingham: PICSIE Books, 2009.

[68] Syque. Further Kanban. [Online]. http://www.syque.com/quality_tools/tools/Tools61.htm

[69] T Ahrens, "Lean Production: Successful Implementation of Organisational Change in Operations Instead of Short Term Cost Reduction Efforts," 2006.

[70] Heidi Wiesenfelder. (2013, February) The Pareto Principle. [Online]. http://www.brighthubpm.com/six-sigma/36907-the-pareto-principle-and-its-application-in-six-sigma/

[71] MoreSteam. Pareto Chart (manufacturing example). [Online]. https://www.moresteam.com/toolbox/pareto-chart-manufacturing.cfm

[72] The Blog from a Lean thinker. Shigeo Shingo: Brainstorming. [Online]. https://pablo-cebrian.com/tools-strategy/brainstorming-by-shigeo-shingo/

[73] Randal Wilson and Arthur V. Hill, *The Operations Management Complete Toolbox Collection*. New Jersey: Financial Times Press (FT press), 2013.

[74] Nick Rich, Nicola Bateman, and Ann Esain Lynn, *Lean Evolution: Lessons from the Workplace*. Cambridge: Cambridge Unviversity Press, 2006.

[75] Carl S. Carlson, "Effective FMEAs: Achieving Safe, Reliable and Economical Products and Processes using Failure Mode and Effects Analysis," John Wiley & Sons, 2012.

[76] J Kilpatrick, "Lean Principles," Utah, 2003.

[77] Felix Damrath, "Increasing Competitiveness of Service Companies Developing Conceptual Models for Implementing Lean Management in Service Companies," 2012.

[78] Amber N Dudley, "The Application of Lean Principles in a High Mix Low Volume Environment," Massachusetts, 2005.

[79] Alaa Aljunaidi and Ankrah Samuel, "The Application of Lean Principles in Fast Moving Consumer Goods (FMCG) Industry," *Journal of Operations and Supply Chain Management*, vol. 7, no. 2, pp. 01-25, December 2014.

[80] H Chen, R.R. Lindeke, and A Wyrick, "Lean Automated Manufacturing: Avoiding the Pitfalls to Embrace the Opportunities.," *Assembly Automation*, vol. 30, no. 2, pp. 117-123, 2010.

[81] T Devane, *Integrating Lean Six Sigma and High-Performance Organiszations: Leading the Change Towards Dramatic, Rapid and Sustainable Improvement*, 1st ed. San Francisco, United States of America: Pfeiffer, 2004.

[82] Rami ALHadeethi, Suleiman Obeidat Nabeel Mandahawi, "An Application of Customised Lean Six Sigma to Enhance Productivity in a Paper Mill Company," Jordan,.

[83] Ulrich Kohler and Frauke Kreuter, *Data Analysis using Stata*. College Station, Texas: Stata Press, 2005.

[84] G Watson, *Design for Six Sigma*. Salem: GOAL/QPC, 2005, p. 396.

[85] Mike J. Harry and Richard Schroeder, "Six Sigma: The Break Through Management Strategy Revolutionizing the World's Top Corporations," United States, 2000.

[86] W Hopp and M Spearman, *Factory Physics 3rd Edition*. Illinois: Waveland Press Inc., 2008.

[87] C. K. Shing, S Nadarajan, and S Chandren, "Scraps Management with Lean Six Sigma," *Supply Chain Management*, vol. III, no. 3, Septemebr 2014.

[88] G Watson, *Six Sigma for Business Leaders. First Edition*. Salem: GOAL/QPC, 2004.

[89] Mikel J. Harry, Prem S. Mann, Ofelia C. De Hodgins, Richard L. Hulbert, and Christopher J. Lacke, *Practitioners Guide to Statistics ad Lean Six Sigma for Process Improvement*. New Jersey: Wiley, 2010.

[90] Rama Shankar, *Process Improvement using Six Sigmas*. Milwaukee: Quality Press, 1956.

[91] Ron Basu, *Implementing Quality*. Cornwall: Thomson, 2004.

[92] T. M. Kublak and D.W Benbow, *The Certified Six Sigma Black Belt Handbook, 2nd Edition*. Milwaukee, Wisconsin: ASQ Quality Press, 2008.

[93] Fred Soleimannejed, *6Sigma Basic Steps & Implementation*.: AuthorHouse, 2004.

[94] C Hagemeyer and J.K. Gershenson, "Classification and Application of Problem Solving Quality Tools," *The TQM Magazine*, vol. 18, no. 5, pp. 455-483, 2005.

[95] Bjorn Andersen, *Root Cause Analysis, Simplified Tools and Techniques*. Milwaukee: ASQ, Quality Press, 2006.

[96] Robert V Krejcie and Daryle W Morgan, "Determining Sample Size for Research activities," *Educational and Psychological*, no. 30, pp. 607-610, 1970.

[97] Wenchang Vincent Chen, "Multivariate Statistical Process Control," Neatherlands, 2015.

[98] WA Shewhart, *Economic Control of Quality of Manufactured Product*. New York: Van Nostrand Company, 1931.

[99] Hsiang-Chin Hung and Sung Ming-Hsien, "Applying Six Sigma to Manufacturing Processes

in the Food Industry to Reduce Quality Cost," *Scientific Research and Essays*, vol. XI, no. 3, pp. 580-597, February 2011.

[100] Min Zhang, "Using Six Sigma to Achieve Sustainable Manufacturing - A Case Study in Aviation Company," Concordia University, Montreal, Masters Thesis 2014.

[101] Gustav Nyren, "A Six Sigma Project at Ericsson Netwrok Technology," Lulea University of Technology, Lulea, MSc Thesis ISSN 1402-1617, 2007.

[102] ZAEIRIOU ZAPARTA, "Implementation of the Six Sigma Methodology in the Maintenance Process of Crown Hellas Can," ΕΛΛΗΝΙΚΗ ΔΗΜΟΚΡΑΤΙΑ, Greece, MSc Thesis 2012.

[103] M.P.J Pepper and T.A Spedding, "The Evolution of Lean Six Sigma," *International Journal pf Quality & Reliability Management*, vol. 27, no. 2, pp. 138 - 155, 2010.

[104] G Mika, "Six Sigma isn't lean," *Manufacturing Engineering*, vol. 137, no. 1, 2006.

[105] Forrest W. Breyfogle III, James M. Cupello, and Meadows Becki, *Managing Six Sigma: A Practical Guide to Understanding, Assessing, and Implementing the Strategy that Yields Bottom-Line Success*. New york: John Wiley & Sons Inc., 2001.

[106] Malcom T. Upton and Charles Cox, "Lean Six Sigma: A Fusion of Pan-Pacific Process Improvement," in *Pan-Pacific Conference XXI*, Anchorage, AK, 2004.

[107] Philip Stephen, "Application of DMAIC to Integrate Lean Manufacturing and Six Sigma," Blacksburg, 2004.

[108] Rita Bruecknerand Kenneth Siehr, "Use of Lean Six Sigma Methodology to Reduce Defects in a High Volume Unit of use Dispensing in a mail order pharmacy system," United states of America,.

[109] Siddhartan Ramamoorthy, "Lean Six Sigma Application in Aircraft Assembly," Masters Dissertation 2007.

[110] Sergio De Gracia, "The Implementation of Lean Six Sigma Methodology in the Wine Sector: Analysis of a Wine Bottling Line in Trentino," Barcelona, 2013/14.

[111] Jeffrey L. Liker and Thomas Y. Choi, *Becoming Lean: Inside Stories of U.S. Manufacturers: The Success and Failures of Implementing Countinuous Improvement Programs: Cases of Seven Automotive Parts Suppliers*. Portland, United States of America: Productivity Press, 1998.

[112] L. Eskildson, "Improving the Odds of TQM Success," *Quality Progress*, vol. 27, no. 4, pp. 61-63, 1994.

[113] U Hellsten and B Klefsjo, "TQM as a Management System Consisting of Values, Techniques and Tools," *TQM Magazine*, vol. 12, no. 4, pp. 238-244, 2000.

[114] Awasare anant Dattaray and M. V. Kavdade, "A Review of Assembly Line Changes for Lean Manufacturing," *ISOR Journal of Mechanical and Civil Engineering*, vol. Second international Conference on emerging trends in engineering, pp. 1-5.

[115] E. B Wilson, *An Introduction to Scientific Research*. New Yorks, United States of America: McGraw-Hill, 1952.

[116] Robert K. Yin, *Case Study Research Design and Methods, 4th Edition*. California: Sage Publications inc., 2009.

[117] McGraw-Hill Ryerson Limited. (2001) Chapter 2: Psychology Scientific Methods. [Online]. http://www.mcgrawhill.ca/college/santrock/graphics/santrock1pcs_student/slideshow/sld02.pdf

[118] Lisa M Given and S.K., "Convenience Sample. ," in *The Sage Encyclopedia of Qualitative Research Methods*. Thousand Oaks, California: Sage, 2008.

[119] PennState Eberly College of Science. (2016) Lesson 3.5 Simple Random Sampling and Other Sampling Methods. [Online]. https://onlinecourses.science.psu.edu/stat100/node/18

[120] Department of Health and Human Service, "Data Collection Methods for Program Evaluation: Focus group," *Evaluation briefs*, no. 13, pp. 1-2, July 2008.

[121] The Open University. 6 Methods of data collection and analysis. [Online]. www.open.edu/openlearnworks/mod/resource/view.php?id=52658

[122] S Ackroyd and J.A. Hughes, *Data Collection in Context*. New York, United States of America: Longman, 1981.

[123] John Milne. (1999, March) Evaluations Cookbook. [Online]. http://www.icbl.hw.ac.uk/ltdi/cookbook/info_questionnaires/

[124] Erica McAteer. (1999, March) Interviews. [Online]. http://www.icbl.hw.ac.uk/ltdi/cookbook/interviews/index.html#endhead

[125] University of Surrey. Ethics and Data Protection. [Online]. http://libweb.surrey.ac.uk/library/skills/Introduction%20to%20Research%20and%20Managing%20Information%20Leicester/page_63.htm

[126] Clover Scales, Low Profile Platforms, Specifications data sheet.

[127] Runrite Electronics Brand. Zenith Instruments. [Online]. http://www.zi.co.za/wp-content/uploads/2013/06/100mm-display.pdf

[128] Microsoft. Microsoft Office Home. [Online]. https://www.office.com/

[129] Siemens, "Simatic ET200SP," Siemens AG, Digital Factory, Nürnberg, Data Sheet 2015.

[130] Siemens Industry Inc. (2015) Siemens Answrs with Advanced Variable Frequency. [Online]. https://mall.industry.siemens.com/mall/en/us/Catalog/Products/10007361?tree=CatalogTree

[131] Bobst. (2006) Rotomec 4003 - Gravure Printing Press. [Online]. http://www.bobst.com/usen/products/rotogravure-printing/gravure-presses/overview/machine/rotomec-4003/#.WEvWTrJ97IU

[132] Siemens AG. (2015) Technical Defenitions. [Online]. https://mall.industry.siemens.com/mall/en/central/Catalog/Products/10036418

[133] Amy Blackstone. (2006) Principles of sociological inquiry: Qualitative and Quantitative methods, v. 1.0. [Online]. http://catalog.flatworldknowledge.com/bookhub/reader/3585?e=blackstone_1.0-ch02_s03

[134] Robert K. Yin, "The Case Study Protocol," in *Case Study Research: Design and Methods,*

Fourth edition. California: Sage Inc, 2009, pp. 79-82.

[135] Case company, Observations, Recordings, Documents, Interpretations and System data, 2015.

[136] A. Bryman, *Social Research Methods*. Gosport, Hampshire: Oxford University Press, 2004.

[137] Andrew P Johnson, "Methods of Analyzing Data," in *A Short Guide to Action Research*.: Pearson, 2002, pp. 71-82.

[138] D.R. Cooper and P.S. Schindler, *Business Research Methods*, 9th ed. New York, United States of America: McGraw-Hill, 2006.

[139] M. Saunders, P. Lewis, and A. Thornhill, *Research Methods for Business Students*, 5th ed. United Kinddom: FT/Prentice Hall, 2009.

[140] U Sekaran, *Research Methods for Business*, 4th ed. New York, Unted States of America: John Wiley and Sons, 2006.

[141] The Writing Studio. Issues of reliability and validity. [Online]. http://writing.colostate.edu/guides/page.cfm?pageid=1317&guideid=61

[142] Matt Wrye. (2010, October) Super Market pull system. [Online]. https://beyondlean.wordpress.com/2011/10/10/supermarket-pull-system/

[143] Boston College. Strategic project teams set up tool. [Online]. https://www.bc.edu/content/dam/files/offices/vpsa/pdf/StratProjTeam-compos.pdf

[144] PIUSI. (2016, December) K24, Fluid Handling Innovation. [Online]. http://www.piusi.com/products/flow-meters/k24

[145] Case company records, Report/ERP/Accounting system, 2015.

[146] E.T. Newbrough, *Effective Maintenance Management*. New York, United States of America: McGraw-Hill, 1967.

[147] Keneth A Kroos and Merle C Potter, *Thermodynamics for Engineers*, SI edition ed.

Stamford, United States of America: Cengage learning, Feb 2014.

[148] Kyoei Industry Co. Ltd., "A Mechanically Recycled PET Packaging Material for a Recycling-orientated Society," *Toppan CSR Report*, p. 9, 2013.

Appendix A – Ethics

Ethics clearance details

A copy of the ethics application made by the author, the criteria for the application and necessary approval can be obtained from:

Names: Dr Bruno Emwanu

Email: Bruno.Emwanu@wits.ac.za

Ref: MIAEC 049/15, Quote this reference to receive the correct documentation corresponding to this research report.

Example participant information sheet

Date 07/04/2014

Dear Manager,

Participation in Research on waste management in the company

I am a part-time MSc student in the School of Mechanical, Industrial and Aeronautical Engineering at the University of the Witwatersrand, under the supervision of Ms Bernadette Sunjka. My MSc title is: *The development of a waste management system for a flexible packaging company.* The research is to complete my MSc (Eng) 50/50.

My belief is that waste is eating away at the profitability of most production orders. I would specifically like to investigate the current waste status and develop a tool one can use in the management of waste going forward. Successful management of waste could lead to financial benefits. This study will let me establish any relationship between waste management and profitability.

I would like to formally invite you to participate in this study. As a manager in a well-established flexible packaging company in South Africa, your knowledge and experience would contribute significantly.

The study will be conducted between June 2015 and November 2015. Involvement in the study would entail a questionnaire, two (2) or three (3) face-to-face one(1) to two(2) hour long interviews with you, at your convenience. During these interviews I would like to understand how your company operates, map your processes, understand more about the waste produced in the daily operations of your business, the causes of this waste and the impact to the business to your understanding. The interviews would be conducted at your company on the factory floor.

Participation in the study is voluntary, and you may withdraw at any time. Anonymity (regarding company name and any owner/manager/employee names) and confidentiality of information provided will be assured and respected.

The results of the study will form part of my MSc dissertation report, and may also be reported in academic papers and at conferences. A summary of the results of the research will be made available to you on request.

Please contact me if you have any questions regarding the research and participation in the study. A copy of my findings can be made available to you upon request.

I look forward to hearing from you.

Yours faithfully

……………………………………

Zakhele Myeza – MSc Student

Tel: 0826838545 Email: zakmyeza@yahoo.com

Supervisor: Tel: +2711 717 7367 Email: bernadette.sunjka@wits.ac.za

Example letter of agreement to participate in study

Letter of Consent

I, ____, agree to participate in the MSc research entitled "The development of a waste management system for a flexible packaging company" to be undertaken by Zakhele Myeza under the supervision of Ms Bernadette Sunjka, and certify that I have received a copy of this letter of consent.

I acknowledge that the research has been explained to me and I understand what it entails, as follows:

1. I agree to allow access to my company and manufacturing facilities for the purpose of this research.
2. There will be two interviews, which are expected to take no more than 1 hour each.
3. The interviews will be transcribed for analysis by the researcher.
4. The interviews will be based on the waste produced in the company, by my operation and will critically examine operations directly linked to me.
5. The processes of my company will be mapped.
6. I will provide you with access to private company information for the purpose of the research
7. I have the right to withdraw my assistance from this project at any time without penalty, even after signing the letter of consent.
8. I have the right to refuse to answer one or more of the questions without penalty and may continue to be a part of the study.
9. I may request a report summary, which will come as a result of this study.
10. I am entirely free to discuss issues and will not be in any way coerced into providing information that is confidential or of a sensitive nature.
11. Pseudonyms will be used to conceal my identity, and that of my company, my employees, my suppliers and my customers. The information disclosed in the interviews will be confidential.
12. All transcripts will be kept securely stored during the research and after the research has been completed.
13. This project was approved by the Faculty of Engineering and the Built Environment of the University of the Witwatersrand and the School of Mechanical, Industrial and Aeronautical Research Ethics Committee (non-medical) of the University.
14. If I have any questions or concerns about my rights or treatment as a participant, I may contact the Chair of the School of Mechanical, Industrial and Aeronautical Research Ethics Committee (non-medical) at +27 11 717 1157 or by email Mary.Scholes@wits.ac.za

Signed:

____

Date:

____

Questions concerning the study can be directed to:

Zakhele Myeza – MSc student

Tel: 0826838545 and Email: zakmyeza@yahoo.com Or

Supervisor: Tel: +2711 717 7367 Email: bernadette.sunjka@wits.ac.za

Appendix B – Production Sheet

The below is an example of a production sheet used to record job information.

Printing Production Sheet					Ref No.	XXXX
PC No: ____________________		Machine: ____________			Date: ____/_____/20______	
				1	2	3	4	5
Time on other machines: ____ - ____		Time: ____ - ____	Shift	6-2	2-10	10-6	6am-6pm	6pm-6am

			Time clocking Record for Shift				
Operator			on	off	Run	Code	Description
Assistant 1:							
Assistant 2:							
Customer							
Design							
Order Quantity		Kg					
Meters Req		L/M					
Material Desc.							
Material Supplier							
Material Width							
Raw Material Allocation							
Raw material issued							
Total Used							
R.T.S							
Rejected			Sub Total				Total ____ Hrs

Ex Label	Production				
Lot num	**Roll N#**	**Meters**	**InWeight**	**Out Weight**	**Meters**
Totals					

Waste	
Set up Material	
Reel end	
Production waste	
Damaged material	
Set up Material	
Total	

Waste Ref No.

Printed: __________ l/m ________ Kg Supervisor: ______________

Balance: ________ l/m ________ Kg Name: ______________

Figure 69: Example of printing production sheet

Appendix C – Sample of Questionnaire

Waste management Questionnaire and Answers

This questionnaire is to assist with the fulfilment of a master's degree in industrial engineering. A study is being conducted which seeks to obtain the relationship between waste management and profitability in the company. The Purpose of the questionnaire is to gather as much information as possible from you with respects to waste management and profitability in the company currently. Please complete these with your own thoughts, there are no incorrect answers

1. Are you directly involved in manufacturing?

   ____

2. How are you involved in manufacturing?

   ____

   ____

   ______

3. Do you know what waste is (Yes/No)?

   ____

   3.1. Briefly describe your understanding of waste?

   ____

   ____

   ____

   ____

4. Does waste affect the company (Yes/No)?

   ____

   4.1. If yes, how does waste affect the company?

   ____

   ____

   ____

   ____

   ____

5. Who is responsible for waste? ____

5.1. Why?

____

____

____

____

6. Does waste affect you (Yes/No)? ____

   6.1. If yes, How does waste affect you?

____

____

____

____

____

____

7. Who must pay for waste? ____
8. On average, how much sellable product does the company produce (tons)?

____

____

9. On average, how much waste does the company produce (tons)?

____

____

10. Do you know what profitability is (Yes/No):

____

   10.1. If yes briefly describe profitability:

____

____

____

____

11. Does the company make money (Yes/No)?____

   11.1. Please provide reason for your answer above:_______________________________

____

____

____

____

12. Do you know how much the company's waste costs monthly (Yes/No)?

____

12.1. If So, How much? ____

12.2. If not, can you estimate a figure?

____

13. Do you think waste is a problem (Yes/No)?

____

The Next couple of questions are specifically for the gravure printing process.

14. Are you involved in the printing process (Yes/No)? __________________________

15. Can you classify the types of waste produced in printing process (Yes/No)?

____

15.1. If so, can you list five(5)?

____

____

____

____

____

____

16. Does printing waste affect any other process (Yes/No)?

____

16.1. Why do you believe that?

____

____

____

____

17. On average, how much waste does gravure printing produce?

____

18. What happens to the printing waste after a job is complete?

____

____

____

____

19. Looking at defects, do you know what defects are (Yes/No)?

____

19.1. If yes, what are defects?

____
____
____
____
____

20. What are the most common types of defects in the gravure printing process?

____
____
____
____

21. What are the top 5 defects produced in the gravure printing process, list in order from biggest to smallest?

1.____
2.____
3.____
4.____5
.____
_____

22. Do you know the average quantity (tons/kg) monthly of these top 5 defects listed (Yes/No)?______

22.1. List and state quantities:

1.____
2.____
3.____
4.____
5.____
______

23. Do you know defects affect you (Yes/No)? ______________________

23.1. Please further explain How?

____

____

____

____

____

____

24. If you are directly involved in printing, do you know how much your waste contribution is (Yes/No)? ____

    24.1. If yes, do you know the rand value?

    ____

25. Can your waste be stopped or reduced (Yes/No)?

    ____

    25.1. If so, How, list 3 possible solutions:

    ____

    ____

    ____

    ____

    ____

    ____

    ____

    ____

    ____

    ____

    25.2. What would you need to stop/reduce your waste?_

    ____

    ____

    ____

    ____

26. If you knew more about waste would it help (Yes/No)?

    ____

    26.1. Provide reason for your answer,

    ____

    ____

____

27. What would change if you paid for the waste you produced?

____

28. What do you understand by the term waste management?

____

29. Do you believe there is waste management in the company (yes/no)?

____

30. Would waste management help reduce waste (Yes/No)?

____

30.1. How?

____

31. Have your heard of Lean Six Sigma (Yes/No)

31.1. If yes, can you describe what you know:____________________________________

____

31.2. Are you willing to learn more about Lean Six Sigma (yes\no)?________________

Thank you for your participation.

Summary of results from questionnaire

Question number	**Question summary**	**Respondent 1**	**Respondent 2**	**Respondent 3**	**Respondent 4**	**Respondent 5**	**Respondent 6**	**Respondent 7**	**Respondent 8**
1	Manufacturing involvement	Yes	Yes	Yes	Yes	Yes	No	No	No
2	Manufacturing classification	Printer	Printer	Printer	QA	QA	Conv man	Print man	Quality man
3	Waste knowledge	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.1	Description	defective product	defective product	defective product	defective product	defective product	defective product	defective product	anything that costs us money
4	waste affect company	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.1	Description	loss in money	loss in money	loss in money	loss in money/customer complaints	loss in profits	loss in profits	loss in money delay orders	loss in money/customer satisfaction/waste in time
5	Waste responsibility	external company/lab	external company/lab	external company/lab	operators	external company	external company	external company/lab	everybody

5.1	Why	paid to do it	paid to do it	they clear out	produce the product	paid to do it	manage waste	contractors	everyone contributes
6	Waste affect personal	No	Yes	No	No	No	No	yes	yes
6.1	Description		reduced money avail for increase					no bonus	ability to do job/salary
7	Who pays for waste	company	company	company	company	company	producer of waste	company	department responsible
8	Production quantity		700				480	520	500
9	Waste quantity	10%	22%	38%			16%	30%	20%
10	Profitability knowledge	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10.1	Description	how much money you make	how much money you make	how much money you make	how much money you make	how much money you make	ability to make money	being within spec to make money	costing correct to make money
11	company profitability view	Yes	Yes	Yes	No	No	No	Yes	No
11.1	Description	we always working		lots of WIP on the floor			don’t cost properly and we waste	we waste it	money lost in waste and customer returns

12	Cost of company waste								
12.1	Figure(R) if yes	1900000	100000	1900000		100000	200000	500000	80000
12.2	Estimate if no								
13	Problem waste	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
14	Printing involvement	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
15	Waste classification	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
15.1	List	bladeline/scumming/reg movement/colour variation	bladeline/scumming/reg movement/colour variation	blade lines/reg movement/misprint/colour variation	blade lines/ink splashes/reg movement/miss print/scumming	blade lines/scumming	misprint/colour variation/air bubbles/tension/scumming	blocking/ink dirty print/reg movement/scumming/blade lines	blade lines/scumming/screening/blocking/ink splash
16	Printing effect	Yes	Yes	No	Yes	Yes	No	Yes	Yes
16.1	Why	flags slow down process	make them produce more scrap	each process can run on its own	process run slow		people must work with what they get	dependant on it	dependant on it
17	Printing waste production	don’t know	don’t know	don’t know	20T	50T	Don't know	58T	60T
18	Waste process	throw it away	Give to external		throw it away	external company	throw it away	Given to external	throw it way

			contractor					company	
19	Defects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
19.1	What's Defects	mistake	product not properly produced	mistake from customer spec	deviation from customer spec	deviation from customer spec	deviation from customer spec	deviation from customer spec	deviation from customer spec
20	Types of defects	wrong design/colour not correct	colour/print/design	blade lines/colour/ wrong design	blade lines/barcode error/colour variation	blade lines/scumming/wrong design	old design/blade lines/barcode	blades lines/old design	ink blocking/blade lines/incorrect design
21	Top 5 defects	Ink splash/blade lines/register/ scumming	Ink splash/blade lines/register/ scumming	Blade lines/ink splash/scumming/colour	blade lines/colour/scumming/register	register/blade lines/colour/scumming	bladelines/scumming/register/ink splash/colour	bladelines/scumming/register/ink splash/colour	bladelines/scumming/register/ink splash/colour
22	Quantity of Top 5	No	No	No	No	No	No	23/18/16/10	33/24/16/10
23	Quantity gauging							Yes	Yes
24	Waste quantity contribution	No	No	No	No	No			

24.1	Rand value								
25	Reduction of waste	Yes	Yes	Yes	No	No			
25.1	List	splash guards/error checking/planning	splash guards/paying attention/clean equipment	correct tools/more focus					
25.2	How	splash guards/extra person/better error checking	more people/slash guards/new equipment	more people/splash guards/upgrade equipment					
26	Knowledge of waste	yes	yes	yes	yes	yes	yes	yes	yes
26.1	Reasons	know where problems are	know where problems are	no repeating mistakes	help fix problem area	address waste cause	identify and fix problem	better RCA	better RCA
27	Changes if waste was paid	leave company	leave company	pay more attention	ensure less waste created	leave company	ensure less waste is created	active involvement in production	pay more attention

28	Waste management knowledge	managing waste	managing waste	managing waste	having someone to control waste	managing waste	supervision of waste	making sure waste is controlled	controlling waste
29	Waste management in company	Yes	Yes	Yes	No	No	Yes	No	No
30	Use of Waste management	No	No	No	Yes	Yes	No	Yes	Yes
30.1	how				guide to reducing waste	people put more focus on waste		there is people dedicated to waste	put the right systems in place
31	Lean six sigma	No	No	No	No	Yes	Yes	No	Yes
31.1	Description					system to reduce waste	program used to save money and reduce waste		system to save money and increase quality
31.2	Willing to learn	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Management interview questions

Waste, management Questionnaire

This questionnaire is to assist with the fulfilment of a master's degree in industrial engineering. A study is being conducted which seeks to obtain the relationship between waste management and profitability in the company. The Purpose of the questionnaire is to gather as much information from a management perspective with respects to waste management and profitability in the company currently. It is also to gauge the management understanding and willingness to support initiatives. Please complete these with your own thoughts, there are no incorrect answers

1. Do you know what waste management is (Yes/No)? ______________________
   1.1. If yes, briefly expand on your understanding

   ____

   ____

   ____

2. If we consider waste as anything that does not make the company money within your process, what is your biggest waste headache? ____

   ____

   ____

3. Do you know the cause of waste in your area (Yes/No)?

   ____

   3.1. If yes, please elaborate?

   ____

   ____

   ____

   ______

From here onwards waste is physical material which is defective.

4. Do you know how much waste is produced in your area (Yes/No) and quantity?

   ____

5. Do you know how much waste is produced in the factory (Yes/No) and quantity?

   ____

6. Do you know the cost of waste produced both in your area and the factory (Yes/No)?

____

    6.1. If yes, please provide figures.

    ____

    6.2. Who is responsible for these figures?

7. What benefits do you think can be gained from reducing waste in your area? __________

____

____

____

____

    7.1. Name two changes you would make to reduce waste. _________________________

    ____

    ____

    7.2. What can the company do to help you? _____________________________________

    ____

    ____

    ____

8. Have your heard of Lean Six Sigma (Yes/No)?

____

    8.1. If yes, what is your understanding of Lean Six Sigma?

    ____

    ____

    ____

    ____

9. Would you be willing to attend a weekend workshop to learn more about Lean Six Sigma?

____

    9.1. If not why?

    ____

    ____

    ____

Lean Six Sigma is a methodology which, if implemented with management support has been proven to provide successful results in value creation. Waste management could be a value creating initiative where Lean Six Sigma can be used.

10. Would you be willing to provide management support (Yes/No)?

____

11. Realistically what decrease in waste would you expect after implementation of such an initiative?

____

____

____

12. Do you know how profitable your operation is?

____

    12.1. If yes, please quantify in terms of a % contribution. ____________________

13. Do you think there is any link between waste management and profitability (Yes/No)? _______

    13.1. Please expand on your answer above.

    ____

    ____

    ____

    ____

Summary of results

Question number	Question summary	Respondent 1	Respondent 2	Respondent 3	Respondent 4	Respondent 5
1	Waste management	Yes	Yes	Yes	Yes	Yes
1.1	Expand	Management of waste in order to control it	Supervision of waste throughout each process	Making sure waste is controlled through management	Controlling waste	Controlling waste
2	Biggest waste head ache	Changes overs taking too long	Print defects	Reworking jobs	Print defects	Print defects
3	Cause of waste	Yes	Yes	Yes	Yes	Yes
3.1	Expand	No make ready crew, training	Lack in operator skill, cleaning of equipment	Lack in operator skill, training	Lack in operator skill, cleaning of equipment	Incorrect tools, operator training
4	Waste produced in area	No	No	No	Yes, 67T/month	Yes, 15T/month
5	Waste produced in factory	Yes, 100T/month	Yes, 90T/month	Yes, 110T/month	Yes, 85T/month	Yes, 90T/month
6	Cost of waste in Area & Factory	No/Yes	No/Yes	No/Yes	No/Yes	Yes/Yes
6.1	Expand on figures	0/R1mil	0/R1.5mil	0/R1mil	0/T1.8mil	R420k/R1.4mil
6.2	Responsibility for figures	I am	I am	I am	I am	I am
7	Benefits from reducing waste	Increase productivity, better downstream	Save money in cost of production, increase output	Increased quality, increase Productivity	Increased quality, increase Productivity	Faster production, reduction in people and processes
7.1	Changes to reduce waste	Organise area better, increase resources	clean up area, provide better tools	Re-train operators, clean tools	Operator training, better structure SOP	Clean area and tools, increase resources

7.2	Company involvement	provide budget	upgrade machines	provide budget and resources and training	Provide training from OEM, increase resources	Provide training and tools
8	Lean six sigma	No	Yes	No	No	No
8.1	Expand		Methodology to improve processes and reduce waste			
9	Willingness to learn	Yes	Yes	Yes	Yes	Yes
9.1	Reason for negative response					
10	Management Support	Yes	Yes	Yes	Yes	Yes
11	Expected outcome from waste reduction	5%	10%	8%	10%	5%
12	Profitability of operation	No I can guess	No	No	Yes	No
12.1	Quantify contribution	7%			16%	
13	Link between waste man and profitability	Yes	Yes	Yes	Yes	Yes
13.1	Expand	Reduction of waste = increase yield	Jobs cost less to produce thus more profitable	Jobs cost less to produce thus more profitable	Management of waste means more focus on waste therefor better quality	Waste management means focus ion waste =reduction in production cost

Appendix D – Formula and Calculations

This Appendix contains calculations and formula used in the research.

Raw material Allocation

This example if for a print slit job which uses adhesive and cold seal. The percentages used differ from number of colours, types of adhesive used, climatic conditions which influences your drying and the drying agents used, ink supplier, width of material for job requirements, the use of material and whether there will be lamination (two pass or three pass).

Ordered quantity of finished goods: 800kg

Primary Web Material (substrate) @ 93%: 800 x 0.94 = 744kg

Waste allowance @ 15% = 752 x 1.15 = 865 kg

The rest of the raw materials (ink, adhesive, cold seal) required will make up 7% = 56kg they too will have associated waste figures

Thus required primary web = 870kg. Cost = RX/kg x 870

Raw material variance

$$material\ variance\% = {issued\ material - return\ material}/{required\ material}$$

Where:

Issued material – is the material physically give to the process

Returned material – is the material returned to the stores which can be reused

Required material – is the material which was required to fulfil the order quantity

Waste Allowance

These are the percentages which are allowable to waste substrate. They are charged to the customer and are acceptable. With the production of flexible packaging being a continuous process, this waste cannot be avoided. Any waste above the stipulated tolerances is absorbed by the company

Printing Waste: 7%

Lamination waste: 5 %

Slitting waste: 3%

Total allowable waste = 15%

Estimation of material weight

The following formula is used to estimate the material weight:

The linear metres are known, and the output obtained from the printing or lamination machines.

$$kg = Lm \times GSM \times w$$

Lm = Linear metres

GSM = gram per square metre (converted to kg/m^2)

w = width of the substrate (usually given in mm will need to be converted to metres)

The calculation breakdown of CHAPTER 7.

<u>Annualised saving calculation</u>

Required:

- The total savings for the complete subset (R) in rands
- Analysis period (A), number of months
- Total number of jobs in the subset (N)
- The average number of jobs per month (J)

$$Annualised\ saving\ (Zar) = (\frac{R}{N}/A) \times J \times 12$$

<u>Impact on profitability</u>

Information used for calculations:

- Machine rate = R3500/hour, only used where hours of machine time are saved
- Selling price per kilogram of product = R87
- Standard production per hour in kilograms = 200
- The average number of jobs per month (J)
- The total savings for the complete subset (R) in rands
- Analysis period (A), number of months
- Total number of jobs in the subset (N)

$$Impact\ (\%) = \frac{\frac{\frac{R}{N}}{A}}{480}/(200 \times 87)$$

Appendix E – Population and Subset

List of top 10 customers by sales value. Top, median and last two customers are chosen.

Table 37: Top 10 customers based on sales value [145]

Rank	Customer number	Annual Sales Value	
1	1	R 61 879 736.84	Customers chosen
2	2	R 56 418 240.83	
3	3	R 50 455 963.51	
4	4	R 34 479 994.42	
5	5	R 26 755 022.64	Customers chosen
6	6	R 25 962 878.84	
7	7	R 22 618 369.60	
8	8	R 17 176 084.50	
9	9	R 12 478 230.01	Customers chosen
10	10	R 8 538 191.77	

The top 10 customer's gravure printing jobs are then ranked into a top 10. The top two and the bottom two jobs per customer form the subset.

Table 38: First criteria qualifying customers [145]

Customer	Job to be analysed	Sales Value
1	A	R 3 676 045.77
	B	R 3 385 247.21
	C	R 1 536 999.17
	D	R 1 396 869.44
2	E	R 5 787 632.22
	F	R 4 203 508.62
	G	R 1 247 320.61
	H	R 1 237 612.81
5	I	R 2 575 711.38
	J	R 2 502 628.92
	K	R 834 675.48
	L	R 699 600.06
6	M	R 4 073 428.98
	N	R 2 927 625.68
	O	R 1 351 065.46
	P	R 1 228 149.31
9	Q	R 1 553 939.88
	R	R 1 435 376.45
	S	R 445 985.36
	T	R 319 628.73
10	U	R 2 802 191.86
	V	R 1 882 209.56
	W	R 372 678.22
	X	R 329 902.68

Appendix F – Profitability

The profitability is computed using the below formula

$$profit\ margin = {sales - cost}/{sales}$$

Wet raw materials are ink, adhesive, cold seal etc. this is simply the financial value of the quantities issued to the jobs. Labour only considers direct labour for the complete process from raw material to finished product.

Table 39: Complete subset of customers and jobs profitability [145]

Customer	Job to be analysed	Sales Value	Substrate	Wet raw materials	Labour	Overhead (admin salaries, facilities, utilities etc.)	Total cost of sales	Initial state profit margin
1	A	R 3 676 045.77	R 2 687 189.46	R 94 841.98	R 221 297.96	R 158 069.97	R 3 161 399.36	14%
	B	R 3 385 247.21	R 3 595 132.54	R 79 891.83	R 239 675.50	R 79 891.83	R 3 994 591.71	-18%
	C	R 1 536 999.17	R 2 129 819.75	R 45 802.58	R 91 605.15	R 22 901.29	R 2 290 128.76	-49%
	D	R 1 396 869.44	R 1 470 903.52	R 32 686.74	R 98 060.23	R 32 686.74	R 1 634 337.24	-17%
2	E	R 5 787 632.22	R 3 050 082.18	R 107 649.96	R 251 183.24	R 179 416.60	R 3 588 331.98	38%
	F	R 4 203 508.62	R 2 854 812.88	R 100 758.10	R 235 102.24	R 167 930.17	R 3 358 603.39	20.10%
	G	R 1 247 320.61	R 1 093 850.28	R 37 718.98	R 113 156.93	R 12 572.99	R 1 257 299.17	-0.80%
	H	R 1 237 612.81	R 1 588 352.28	R 34 158.11	R 68 316.23	R 17 079.06	R 1 707 905.68	-38%
5	I	R 2 575 711.38	R 2 145 567.58	R 75 725.91	R 176 693.80	R 126 209.86	R 2 524 197.15	2%
	J	R 2 502 628.92	R 2 120 852.88	R 74 853.63	R 174 658.47	R 124 756.05	R 2 495 121.03	0.30%
	K	R 834 675.48	R 503 726.65	R 17 778.59	R 41 483.37	R 29 630.98	R 592 619.59	29%
	L	R 699 600.06	R 435 885.82	R 15 384.21	R 35 896.48	R 25 640.34	R 512 806.84	26.70%
6	M	R 4 073 428.98	R 4 175 672.05	R 92 792.71	R 278 378.14	R 92 792.71	R 4 639 635.61	-13.90%
	N	R 2 927 625.68	R 1 936 038.86	R 68 330.78	R 159 438.49	R 113 884.64	R 2 277 692.78	22.20%
	O	R 1 351 065.46	R 1 599 512.89	R 34 398.13	R 68 796.25	R 17 199.06	R 1 719 906.33	-27.30%
	P	R 1 228 149.31	R 1 043 926.91	R 36 844.48	R 85 970.45	R 61 407.47	R 1 228 149.31	0.00%
9	Q	R 1 553 939.88	R 1 460 081.91	R 50 347.65	R 151 042.96	R 16 782.55	R 1 678 255.07	-8.00%
	R	R 1 435 376.45	R 1 533 412.66	R 34 075.84	R 102 227.51	R 34 075.84	R 1 703 791.85	-18.70%
	S	R 445 985.36	R 367 714.93	R 12 978.17	R 30 282.41	R 21 630.29	R 432 605.80	3.00%
	T	R 319 628.73	R 298 098.54	R 10 279.26	R 30 837.78	R 3 426.42	R 342 642.00	-7.20%
10	U	R 2 802 191.86	R 2 930 532.25	R 65 122.94	R 195 368.82	R 65 122.94	R 3 256 146.94	-16.20%
	V	R 1 882 209.56	R 2 310 600.46	R 49 690.33	R 99 380.66	R 24 845.17	R 2 484 516.62	-32.00%
	W	R 372 678.22	R 436 704.34	R 9 391.49	R 18 782.98	R 4 695.75	R 469 574.56	-26.00%
	X	R 329 902.68	R 437 817.15	R 9 415.42	R 18 830.84	R 4 707.71	R 470 771.12	-42.70%

Appendix G – Additional Data

The following is the complete table from Section 5.5.2

Table 40: Conservation of substrate measurement

Conservation of Substrate					
	W_in0	**Wgp**	**Wx**	**Variation**	**Conservation**
1	4 280	3 150	565	13%	No
2	640	450	185	1%	Yes
3	3 840	2 750	320	20%	No
4	890	630	120	16%	No
5	3 385	3 005	300	2%	Yes
6	1 600	1 520	85	0%	Yes
7	6 810	5 800	150	13%	No
8	440	300	100	9%	No
9	2 010	1 780	90	7%	No
10	1 110	800	162	13%	No
11	5 700	5 100	250	6%	No
12	6 350	6 160	190	0%	Yes
13	4 400	3 700	350	8%	No
14	1 050	830	110	10%	No
15	750	600	50	13%	No
16	880	700	80	11%	No
17	7 200	5 800	300	15%	No
18	580	460	110	2%	Yes
19	2 010	1 786	96	6%	No
20	1 100	800	160	13%	No

The numerical evaluation used in Chapter 5, 1

A letter is assigned to represent the best suited causes from the brainstorming activity. Thereafter the causes are ranked by the level of suitability. 1 is slightly suited, 2 moderately suited and 3 is strongly suited. Table 41 shows the numerical evaluation done to achieve the ranking.

Table 41: Numerical evaluation for possible causes

Numerical Evaluation																Possible causes	Score	Rank
A	B3	C3	A1	E2	F2	G3	H3	I3	J1	K2	L2	M3	A1	O1	A	Measurement errors scale calibration	2	14
	B	C1	B2	B2	B1	G3	H2	B2	B2	B1	B2	M1	B3	B2	B	Incorrect data entered by operators	20	3
		C	C3	E2	C3	C1	C2	C3	C1	C1	L2	C2	C3	C3	C	Waste gets disposed without being recorded	26	1
			D	D1	D1	G1	H3	D1	D2	D3	L2	D3	D3	D1	D	No error checking on ERP system	15	7
				E	E1	G1	H1	E3	J1	K2	L3	M1	E3	O3	E	Data capturing error	11	9
					F	F1	H3	F1	J1	K1	L3	M3	F1	O1	F	Recording system calculation and conversions error	5	12
						G	H2	G3	G1	G1	L1	M1	G3	G3	G	Rushed recording due to bottle neck	19	6
							H	H1	J2	H1	L2	M1	H3	O1	H	Estimation of weights due to no measurement	19	5
								I	J2	K1	L1	M1	I1	O1	I	too much paper work therefore incorrectly done	4	13
									J	K3	L2	M1	J3	O1	J	No waste deployment thus accounting for material inaccurate	10	11
										K	L3	M1	K2	K2	K	Flawed material returns procedure	13	8
											L	M1	L3	L1	L	People lack training and accountability	25	2
												M	M3	M2	M	Single material issue for multiple campaign jobs	19	4
													N	O3	N	Inconsistent material properties when compared to standard	0	15
														O	O	Poor system recording, capturing and error correction procedure	10	10

Project time line from in Chapter 5

Project Lead: Zakhele Myeza
Start Date: 01/10/2014 Wednesday

[?#?] *First Day of Week (Mon=2):* 2

WBS	Tasks	Task Lead	Start	End	Duration (Days)	% Complete	Working Days	Days Complete	Days Remaining
1	Define	ZM	10/1/14	2/25/15	148	0%	106	0	148
1.1	Project team + role identification		10/1/14	10/21/14	21	0%	15	0	21
1.2	Project setup & goals		10/22/14	10/26/14	5	0%	3	0	5
1.3	Management Justification		10/11/14	1/13/15	95	0%	67	0	95
1.3.1	Low hanging fruit		10/31/14	1/28/15	90	0%	64	0	90
1.3.2	Management presentation		1/29/15	2/11/15	14	0%	10	0	14
1.4	Financial application		2/12/15	2/25/15	14	0%	10	0	14
2	Measure	ZM	2/25/15	9/10/15	198	0%	142	0	198
2.1	Current state		2/25/15	3/17/15	21	0%	15	0	21
2.2	Segment 1		3/17/15	8/13/15	150	0%	108	0	150
2.3	Segment 2		3/24/15	8/20/15	150	0%	108	0	150
2.4	Segment 3		3/31/15	8/27/15	150	0%	108	0	150
2.5	Segment 4		4/7/15	9/3/15	150	0%	108	0	150
2.6	Segment 5		4/14/15	9/10/15	150	0%	108	0	150
3	Analyse	ZM	7/29/15	9/8/15	42	0%	30	0	42
3.1	Segment 1		7/29/15	8/11/15	14	0%	10	0	14
3.2	Segment 2		8/5/15	8/18/15	14	0%	10	0	14
3.3	Segment 3		8/12/15	8/25/15	14	0%	10	0	14
3.4	Segment 4		8/19/15	9/1/15	14	0%	10	0	14
3.5	Segment 5		8/26/15	9/8/15	14	0%	10	0	14
4	Improve	ZM	8/16/15	1/10/16	148	0%	105	0	148
4.1	Segment 1		8/16/15	12/13/15	120	0%	85	0	120
4.2	Segment 2		8/21/15	12/18/15	120	0%	86	0	120
4.3	Segment 3		8/26/15	12/23/15	120	0%	86	0	120
4.4	Segment 4		8/31/15	12/28/15	120	0%	86	0	120
4.5	Segment 5		8/31/15	12/28/15	120	0%	86	0	120
5	Control	ZM	8/16/15	1/10/16	148	0%	105	0	148
5.1	Final state		12/13/15	12/26/15	14	0%	10	0	14
5.2	SOP's		8/16/15	12/13/15	120	0%	85	0	120
5.3	Management feedback		1/6/16	1/10/16	5	0%	3	0	5

Figure 70: Project time line (created by author)

Refer to Chapter 5, 1

Table 42: Table of times taken to locate raw material [135]

Time to locate material and complete delivery				
Request Number	Number of Reels	Total Time [3]Taken (mins)	Time Taken to Locate Material (mins)	Notes
1	4	26	20	
2	8	15	3	
3	6	23	14	
4	6	20	11.5	
5	5	15	7	
6	5	15	6	
7	6	56	5	Operator went to lunch (40mins)
8	2	4	1	
9	7	80	30	Operator cleared area for space to finish delivery
10	3	13	8	
11	4	15	7	
12	7	63	45	No space, time spent moving material to obtain the desired material.
13	7	22	12	
14	5	14	7	
15	6	14	8.5	
16	10	56	38	Operator cleared area for space to finish delivery
17	5	20	16	
18	8	16	9	
19	6	25	16	
20	5	23	14	
Ave.		26.75	13.9	

[3] The times recorded are not in any production sequence and are a mix of the video footage as well as physical measurement. The time measurements are rounded down to the nearest increment of 0.5 minutes.

Refer to Chapter 5, 1

Table 43: Time taken to find material after system implementation [135]

Time to locate material				
Request Number	**Number of Reels**	**Total Time Taken (mins)**	**Time Taken to Locate Material (mins)**	**Notes**
1	3	4	1	
2	4	4.5	1	
3	7	8.5	1	
4	7	8	0.5	
5	5	5	1	
6	6	6.5	1.5	
7	6	6	1.5	
8	2	2.5	1	
9	7	8	1	
10	5	4.5	0.5	
11	6	17	0.5	Handler stopped and had a chat
12	3	5	1.5	
13	5	4.5	1	
14	8	10	1.5	
15	6	5.5	1	
16	5	5.5	1	
17	5	5	1	
18	8	10.5	1	
19	6	23	1.5	Handler went for smoke break/toilet
20	5	4.5	1	
Ave.		7.4	1	

Refer to Chapter 5, 1

Table 44 provides an example of the status control card.

Table 44: Sample next job status card (created by author)

Printing Status Control Card				
Machine			**Operator**	
Start Job			**Handler**	
End Job			**Delivery time**	
Next Job Requirements				
Item	**Time 1**	**Time 2**	**Time 3**	**Description**
Wash up				
Mounting				
Substrate				
Ink				
Varnish				
Cold Seal				
Adhesive				
Release Lacquer				

Special notes:

Refer to Chapter 5, 1

An extract from the data measured to determine the reasons behind rework. The complete results are graphically represented in the document.

Table 45: Extract from measurement of rework [135]

Re Work Measurement				
Source	**Quantity (kg)**	**Time taken (hrs)**	**Reason for rework**	**Notes**
Lamination	5 130	60	Lamination marks	
Lamination	3 696	43	Print defect suspect	
Lamination	2 652	31	Print defect suspect	
Lamination	372	4	Sticky edges	
Lamination	607	7	Sticky edges	
Printing	11 925	24	blocking	stock batch processed
Printing	7 088	83	Print defect suspect	
Lamination	7 080	73	Cold seal register	
Lamination	3 520	41	Cold seal register	
Lamination	7 214	84	Print defect suspect	
Slitting	21 816	25	Ink splash	Customer recalled stock
Printing	5 042	59	blocking	
Slitting	150	2	Profile	
Slitting	2 852	33	Profile	
Lamination	5 923	69	Print defect suspect	

Refer to Chapter 5, 1

Table 46: FMEA on defects from reworking [135]

Failure Mode	Effect of Failure	Cause of Failure
Profile	Jagged edges of reel	Slack edge on material
	Loose material in core	Inconsistent GSM
	Folded edges	Poor handling
	All material needs to be rewound	Low co-efficient of friction
		Incorrect tension settings
Inspection	Defective product sent to customer	Inspection system failure
	Decrease efficiency of subsequent processes	Dirty print
	Delay in delivery date	Miss print
	Increase production cost of customer order	Poor clarity
	Huge stock write offs	Print position off
		Too many flags
		Excessive blade lines
		Delamination
		Cold Seal register
		Print defect
Ink Splashes	Ink marks on print	Pump incorrect pressure
	Easily missed as happens very quickly and ends up visible at customer	Splashing from ink feed
	Increased waste figures as ink splashes cannot be salvaged	Missing splash guards
	Increased customer dissatisfaction as majority of rejections happen at the customer	Defective manufacturer design

Refer to Chapter 5, 1

Table 47: Perspective modelling matrix for restoring machines to OEM specifications [135]

	Criteria	Critical to quality		Value		Cost		Duration machine will be down		Availability of parts		In-house work or Outsourced			
	Weight Factor	10		8		10		5		7		4		220	100%
	Options													Total	%
		score		score		score		score		score		score			
1	**Ventilation of machine**	5	50	4	32	3	30	5	25	5	35	1	4	176	80
2	**Alignment**	4	40	3	24	2	20	2	10	2	14	1	4	112	50
3	**Inspection system**	5	50	5	40	2	20	1	5	4	28	3	12	155	70
4	**Chill rollers**	4	40	4	32	2	20	3	15	2	14	3	12	133	60
5	**Water treatment**	3	30	4	32	4	40	4	20	4	28	2	8	158	71
6	**Dryer hoods service**	5	50	5	40	3	30	1	5	2	14	1	4	143	65
7	**Calibration**	4	40	5	40	4	40	3	15	5	35	1	4	174	79
8	**Spare parts**	1	10	4	32	1	10	5	25	2	14	1	4	95	43
9	**Modification of chucks and bearing**	2	20	4	32	5	50	1	5	5	35	2	8	150	68
10	**Standardisation of trolley**	3	30	3	24	2	20	5	25	4	28	3	12	139	63
11	**Deep cleaning**	5	50	5	40	3	30	2	10	5	35	1	4	169	76

Key (rating scale): Excellent/high = 5 Bad/low = 1

Refer to Chapter 5, 1

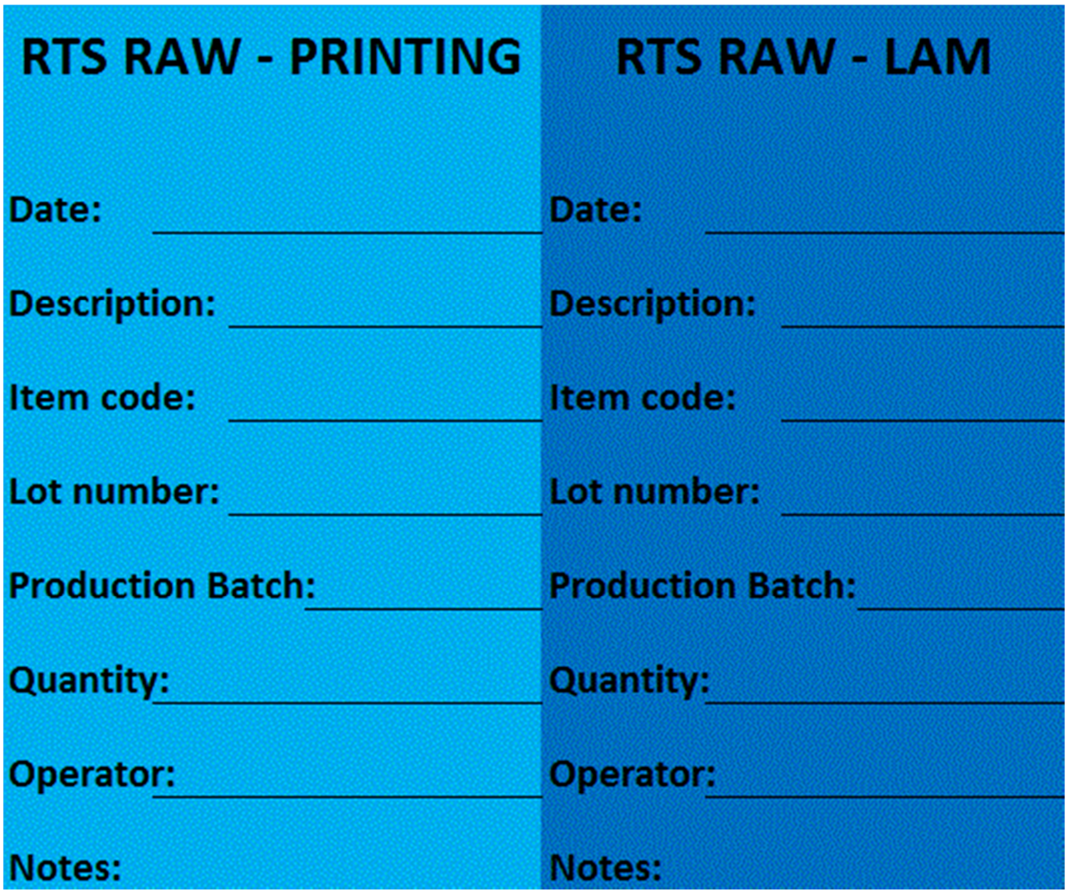


Figure 71: Example of RTS sheets (created by author)