

**Identifying improvement areas within a chemical
packaging facility via selected iTLS
methodologies**

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ABSTRACT

Continuous improvement is required, in order for a company to compete in the global market. Finding a balance between the organisations level of quality and throughput whilst ensuring cost-effectiveness, is a challenge.

Three of the most influential methodologies associated with continuous improvement are, Theory of Constraint, Lean and Six Sigma. Each of these methodologies have been proven and have been adopted in many competitive international companies. This mini-dissertation sets out to make use of selected tools and techniques from all three of these methodologies at a selected packaging plant. The objective of the study was to identify if the facility had any inefficiencies as a result of throughput issues, waste and quality problems.

The research began with a thorough literature study on the three methodologies and then used the combined methodology known as iTLS. iTLS is one of the new generation of continuous improvement models and rationally combines the three most influential continuous improvement philosophies, their techniques and tools. It harmonises, integrates and synchronises the three methods in a synergic mixture that produces substantially improved financial results. Due to the limited amount of research found on this methodology the study set out to determine if iTLS could provide a solution for the selected packaging facility if any constraints, wastage and process variation was identified.

A longitudinal study was performed, based on secondary data collected from six different sources. Selected tools and techniques from the three methodologies were applied in the three areas of focus, namely: throughput, waste and quality. The results showed that the facility's single most limiting factor was the large amount of waste generated. This prevented the organisation from achieving higher production yields.

A value analysis was done, which indicated that the company was only putting a quarter of all its effort into value-adding features of the product. A sigma level calculation was done, based on the number of defects per million opportunities; this was found to be uncompetitive in a competitive market.

A conclusion regarding the findings of the research study were presented and recommendation provided for implementation by the organisation.

The research study was evaluated in terms of the primary and secondary objectives, and it was concluded that both were achieved. Recommendations for further research into the iTLS methodology were proposed.

Keywords: Theory of constraints, Lean manufacturing, Six Sigma, iTLS, Packaging facility, Wastes, Throughput, Quality.

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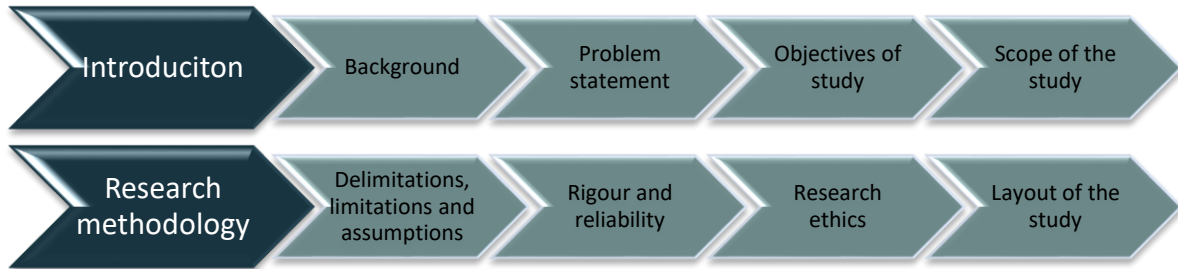
ACRONYMS

CNX	Constants, Noise and X factors.
CUSUM	Cumulative deviation / Cumulative sum
DBR	Drum-Buffer-Rope
FIBC	Flexible Industrial Bulk Containers
FY18	Financial Year 2018
IP	Intellectual Property
iTLS	Integrated Theory of Constraint, Lean and Six Sigma
JIT	Just-In-Time
Lean	Lean Manufacturing
OEE	Overall Equipment Effectiveness
QRM	Quick Response Manufacturing
RCM	Reliability Centered Maintenance
SCOM	Supply Chain Operations Management
SCM	Supply Chain Management
SOP	Standard Operating Procedure
TOC	Theory of Constraint
TPM	Total Productive Maintenance
VOC	Voice of the Customer

CHAPTER 1: NATURE AND SCOPE OF THE STUDY

Figure 1-1 provides an outline of Chapter 1 and how it has been laid out.

Figure 1-1 Chapter 1 layout

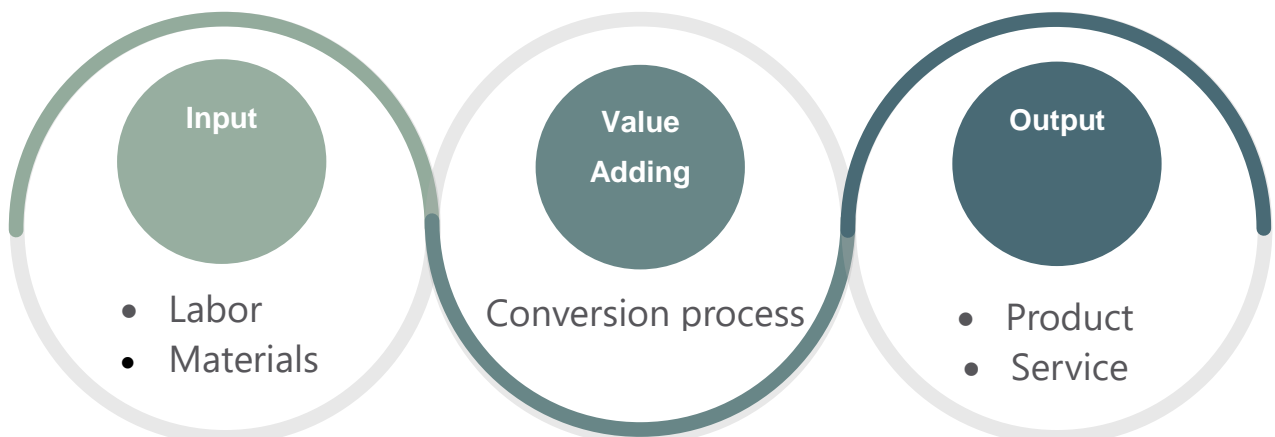


Source: Author (van Wyk, 2018)

1.1 Introduction

An operations management system aims to convert input, for example materials and labour, into an output that is of greater value, such as services and products (Figure 1-2), to ultimately match demand with supply (Christopher, 2016:85). Managing resources in order to produce products and services effectively, as measured by the ‘cost versus time versus quality triangle’, is the objective of operations management globally (Ivanov *et al.*, 2017:101). According to Ivanov *et al.* (2017:101), planning activities is the traditional way of thinking about the conversion process. However, in practice, the feedback established between planned and real processes in the control function becomes more important as operations managers tend to spend most of their time dealing with uncertainties and risks (Gong, 2015:31; Ivanov *et al.*, 2017:101).

Figure 1-2 The manufacturing conversion process



Source: Adopted from (Kalpakjian *et al.*, 2014)

The past 60 years has seen a transformation from a producer's market to a customer's market. During the 1960's, the mass production period saw an increase in marketing to an unfamiliar target market and the market being filled with products of a similar nature (Hill, 2017:56). This era, known as the economies of scale era, started to evidence the effects of quality problems. Total Quality Management (TQM) was then pursued in the 1970's (as a result); this, in turn caused an increase in individualisation of consumer requirements in the 1980's (Tan, 2018:6). This period saw the rise of the economy of the client, when great effort was being put into inventory management and reducing the production cycle. A trend called the speed-effect came into existence in the 1980's, when reacting to changes in the market became even more important (Wilmots *et al.*, 2016:24-25). As a result, external links to suppliers and internal processes were simultaneously adjusted to the roots and concepts of the Lean and Just-in-time (JIT) theories.

From the 1990's onward, globalisation and developments in IT trends saw companies concentrating on outsourcing, innovation, collaboration and core competencies (Gunasekaran *et al.*, 2015:155). The paradigm that is Supply Chain Management (SCM) was established in 1990's and has been used as the basis for developments in Supply Chain Operations Management (SCOM) of the 21st century. During the period 2010-2015, trends such as flexibility, risk management, intelligent information, smart manufacturing, leanness and agility have been shaped / developed in both research and practice within operations management (Ivanov *et al.*, 2017:113).

Manufacturing has emerged as more of a service movement and on top of that, environmental safety and energy costs force companies to re-evaluate their current and future operations management strategies (Gunasekaran *et al.*, 2015:155). According to operations management principles, the only feasible way to increase profits in an organisation is by reducing the costs of production. Increasing sales by marketing or reducing finance costs not only seem near impossible, but may not yield the same improvement in contribution to profit (Heizer & Render, 2014:51). Operational management activities add value in the form of goods and services that solve customer problems, which is the very essence of any organisation.

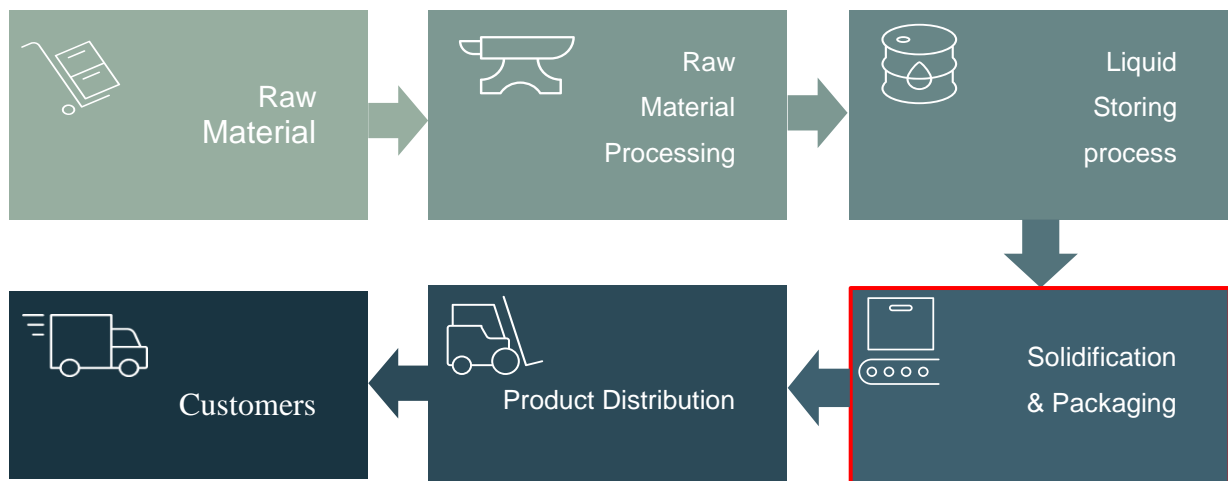
According to ReVelle (2016:66), who is supported by Pacheco *et al.* (2015:172), the current leading methodologies in operations improvement include: Lean Manufacturing (also referred to simply as Lean), Theory of Constraints, Quick Response Manufacturing (QRM), Six Sigma (also written as 6σ), Total Productive Maintenance (TPM) and Reliability Centered Maintenance (RCM). Combining three of these methodologies (TOC, Lean Manufacturing and Six Sigma) creates a system that contains the best aspects of each methodology (Pirasteh, 2010; Sproull, 2009a; Varshapetian & Semenova, 2015:16). Pirasteh (2010:26) describes this as an integrated and systematic approach for continuous improvement. Integrated Theory of Constraint, Lean and

Six Sigma (iTLS) was selected for this study, since it has the specific tools required to address a variety of situations.

1.2 Background

The selected packaging facility used for this study is one of a handful providing a distinctive chemical product globally. For this reason, the company name has been kept confidential, along with product names, process technologies and particular process information protected by the organisation's intellectual property (IP). The system that was investigated is the packaging facility that forms part of the solidification and packaging plant - see Figure 1-3.

Figure 1-3 Block flow diagram of packaging production facility

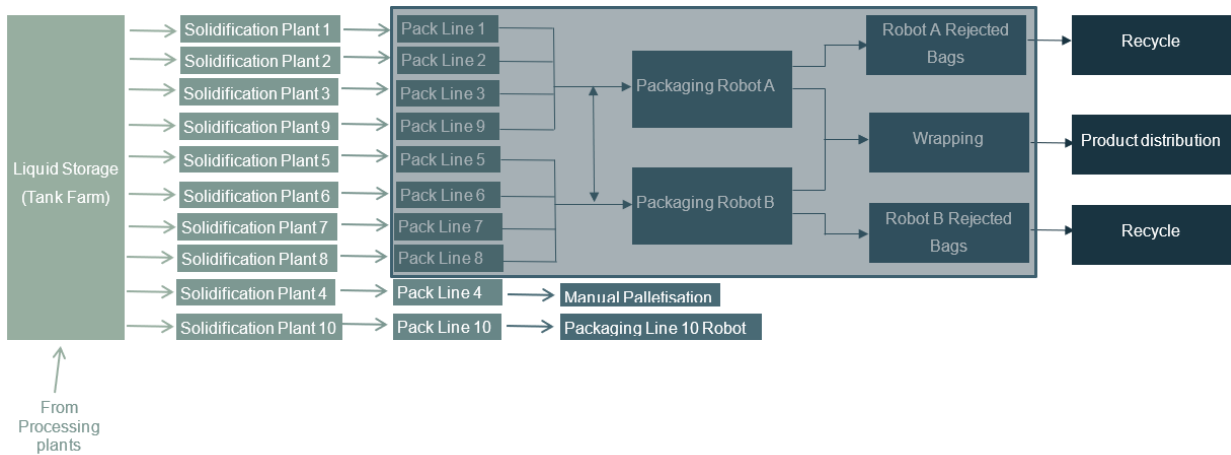


Source: Adapted from company internal information (2018)

The solidification and packaging plant is divided into 4 sections (Figure 1-4) namely:

- Tank Farm
- Solidification
- Packaging
- Storage or recycling

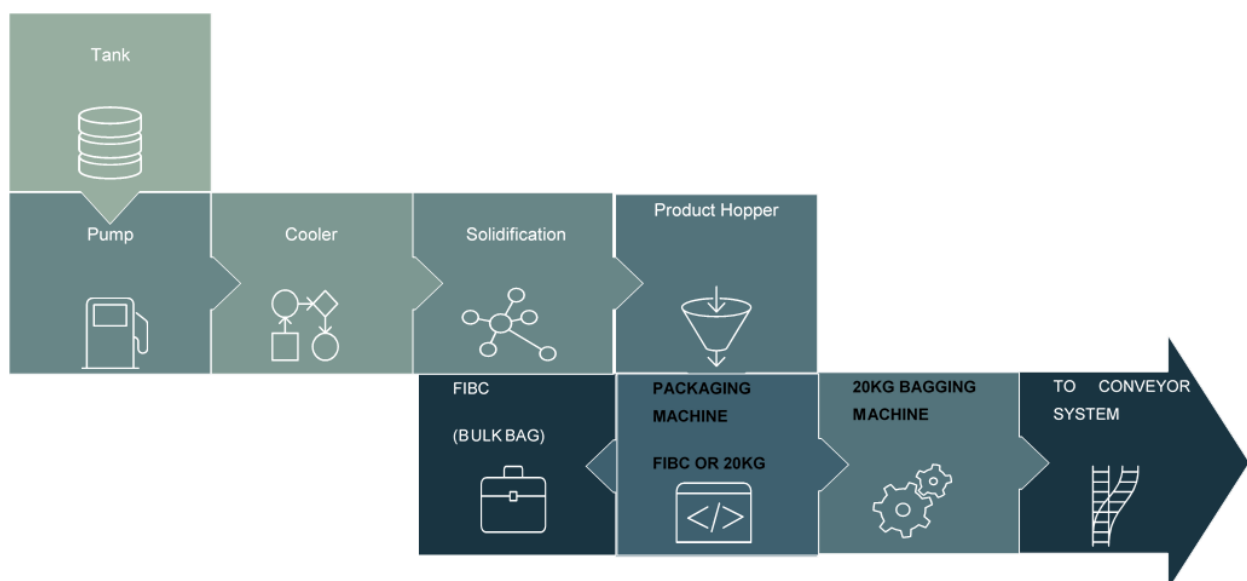
Figure 1-4 Block diagram of the solidification and packaging plant



Source: Adapted from company internal information (2018)

Process description of the solidification and packaging plant is presented in the paragraphs that follow. Figure 1-4 indicates a high-level view of the solidification and packaging system while Figure 1-5 demonstrates a simplified and typical process flow of each solidification process and the bagging systems. Feedstock is received at the tank farm in liquid form and stored at temperatures such that it does not solidify. There are 10 solidification processes in total that solidify different types of chemicals into different types of forms (each plant solidifies product into a certain form).

Figure 1-5 Process flow diagram of a typical solidification process

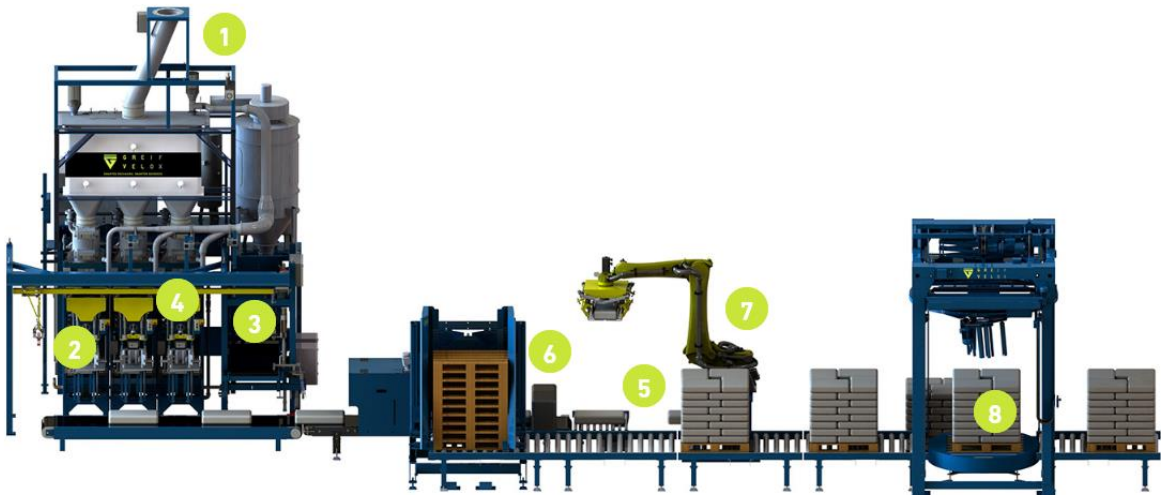


Source: Adapted from company internal information (2018)

Typically, liquid is pumped through a filter, in order to remove impurities, and then through a cooler, before it is fed into the solidification unit. At each solidification unit, the product undergoes a phase change (transition from liquid to solid) and it is then cooled down further below congealing point (sub-cooled). This product is then transferred from the solidification units to an intermediate storage hopper, before its packaged. There is an option to package product into either 20 kg bags or 500 kg Flexible Industrial Bulk Containers (FIBC).

The focus of the study is on only eight of these solidification process units, as can be seen in Figure 1-4. This excludes the tank farm, distribution and different solidification processes. It includes the bagging station, conveyor, robot and wrapping system, as indicated in the shaded section in Figure 1-4. The packaging system and layout is summarised in the process flow diagram in Figure 1-5.

Figure 1-6 Example of the packaging line process

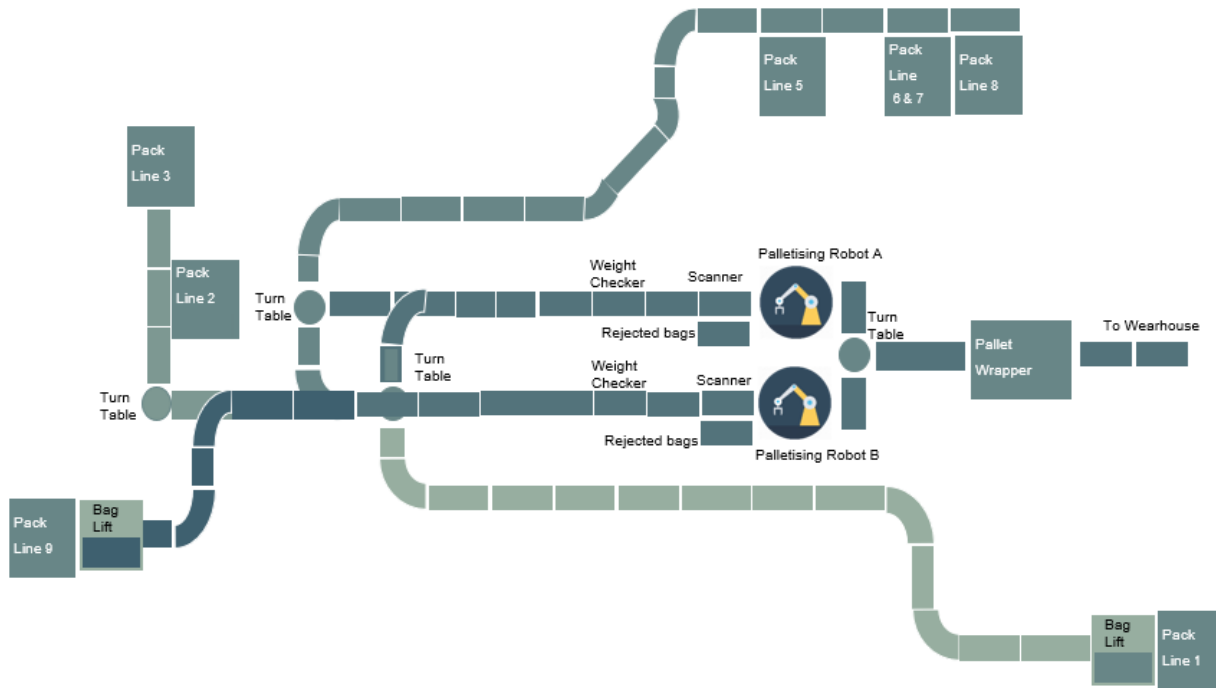


Source: Greif-Verlox (2018)

The sequence at the packaging system, as shown in Figure 1-6, is as follows:

- 1) From the intermediate hopper, the product is gravity-fed into a bagging station (also referred to as a packaging line or pack line).
- 2) At the printer section:
 - a. An empty small bag is fed into a label printer.
 - b. A label printer prints a bar code and timestamp on a label and then attached the label onto the empty bag.
 - c. The bag is transferred to the bagging spout.
- 3) At the bagging station:
 - a. Product is fed by gravity from the intermediate storage hopper into a bagging hopper.
 - b. Product is the fluidised in the bagging hopper.
 - c. The spout that is in the mouth of an empty bag is opened and then product flows through this spout and into the bag.
 - d. The bag weight is constantly checked (by the machine) and filling stops once the weight is to specifications.
- 4) When filling is completed, the bag is moved away from the spout and then ultrasonically sealed.
- 5) After the bag is sealed the bagging machine waits for the conveyor belt that is directly below it to be free and then drops the bag onto the belt. The conveyor system transfers all 20kg bags from the bagging stations to the different palletising robots passing various lifts, inclines, turn tables, scales and scanners on it way.
- 6) Each bag's weight and label are checked right before it is packed on the pallet by the robot. In the event of a defect, e.g. under-weight or it cannot read the label, the robot will reject the bag on a separate rejection shoot. The software of the process logs the reason for the rejection.
- 7) If the product passes the final check-weight and scan test, it is packed on one of four pallets, according to the order. Each robot can palletise four pallets at any instant.
- 8) The full pallet is then transferred to a shrink wrapper that wraps the pallet with an elastic plastic sheet to protect the pallet from weather conditions.

Figure 1-7 Process layout of the conveyor packaging system



Source: Adapted from company internal information (2018)

The process layout in Figure 1-7 shows that the system has two palletising robots, and each robot can palletise product from a maximum of four bagging stations at a time hence only eight bagging stations are served by this system. The system was designed so that bags from any of the eight bagging stations could be sent to any of the two palletising robots for balancing of loads between the two robots. Each packaging line is designed to also fill a FIBC (Jumbo bag) weighing 500kg. This type of packaging is not popular compared to the palletised 20kg bags, since handling the bags at the customer's facilities can only be done using a forklift.

The FIBC bags are filled by placing the bag on a frame that is fed from the pack line hopper by means of a spout (Figure 1-8). The packaging machine continuously measures the weight of the FIBC and automatically stop filling once it reaches the set value. FIBC bags is used as a back-up to divert product from the small bagging machine in the event of a breakdown. This is because the solidification process will shut down if the product hopper reaches the full level. The solidification process requires some time and resources to start up, which always results in a large amount of scrap and other financial losses; therefore, the company would rather fill the FIBC bags, without an order for this.

Figure 1-8 Example of Flexible Industrial Bulk Containers (FIBC) bag and a pallet of 20kg bags



Source: LC-Packaging (2018)

The company's quality assurance check is done on each pallet leaving the conveyer system to ensure that the product meets the customers' requirements and that it comply to the internal standards. All pallets and bags rejected by the robots will be taken to a melt pot, where each bag will be cut open and the product will be re-melted. The re-melted product will be transferred back to the feeding plant to be processed again.

1.3 Problem statement

In today's world of global markets and stiff competition in every product along with increasing consumer demand, it becomes imperative for companies to explore ways to improve their productivity in terms of maintaining safety, using sustainable packaging materials, implementing flexible and standardized technology, and adopting proven continuous improvement principles (Rosenfeld, 2017). While continuous improvement can range from simple changes in the day-to-day workings of the company to major shifts in focus and procedures across a global structure, in all cases, it is required to implement the right instruments to achieve success and to sustain it (Cummings & Worley, 2014).

At a basic level, continuous improvement is about improving organizational performance. This seems obvious. But many companies lack a formal process for improvement and as a result, their ongoing goals for corporate betterment will not likely succeed (Boer *et al.*, 2017). The selected packaging facility does not make use of any continuous improvement process such as TOC, Lean Manufacturing or Six Sigma methodologies. The packaging facility is complex with a variety of manufacturing processes, it has multiple linked activities that could possibly create constraints or waste in the system. Any waste, equipment breakdown, bottle neck or quality fluctuation could have a dramatic result on the profit margin of the organisation. The organisation could improve business performance by selling more product, or by reducing the amount of resources, or by rather investing in a continuous improvement methodology. This study investigated operations improvement methodologies.

1.4 Objectives of the study

The desired outcomes of this research process can be defined by one primary and two secondary research objectives:

1.4.1 Primary objective

The primary objective of this study was to identify inefficiencies related to waste, throughput and quality in the selected facility, by utilising selected tools and techniques of TOC, Lean and Six Sigma.

1.4.2 Secondary objectives

The secondary objectives were:

- To apply TOC, Lean and Six Sigma evaluation techniques to a selected packaging facility
- To verify if the existing performance measuring tools used are accurate.
- To provide the facility with a recommended iTLS methodology implementation plan.

The objectives indicated above aided in answering the primary research question:

Can the iTLS continuous improvement methodology provide a solution to the problems of constraint, wastage and process variation at a selected packaging facility?

1.5 Scope of the study

The study focused on the operations improvement methodologies known as TOC, Lean and Six Sigma. The emphasis was on a South African chemical packaging facility to evaluate the synergy of the methodologies and to determine if inefficiencies can be identified.

1.6 Research methodology

A systematic research approach is used to study the solution to the research problem. The research methodology consists of two sections, namely: a literature review and an empirical study.

1.6.1 Literature review

The literature review examined the key concepts related to the research and provide understanding and insight to iTLS and operational efficiency. Previous research in the field of study will be critically evaluated with arguments. Different relevant sources were consulted as part of this review, including academic journals, books, articles, reports and previous studies on the selected methodologies. Each methodology provides a background, key definitions, respective tools, techniques and philosophies that apply to the research objective of the study. Theory of Constraint, Lean and Six Sigma are dealt with separately, and then in combination, as the iTLS theory. The study concludes with an evaluation of operational efficiency and its measuring tools. The literature review focuses on the areas listed below:

- Introduction to the methodology of: TOC, Lean Manufacturing, Six Sigma and iTLS
- Methodology of TOC, Lean, Six Sigma and iTLS
- Focusing steps of TOC, Lean, Six Sigma and iTLS
- Theory of the methodologies linked to study
- iTLS methodology versus single methodologies
- A case study of TOC, Lean, Six Sigma and iTLS
- Defining operational efficiency
- Measuring tools used to determine operational efficiency
- Shortcomings of the measuring tools

1.6.2 Empirical study

The empirical study was carried out using relevant information gained from the literature review, as well as relevant available production data, so as to establish the modes of measurement and to conduct an investigation on the findings.

The organisation does not want to reveal any production figures to the public or their competitors. This may complicate the depth of detail to which the production data will be discussed. An approval letter has already been obtained from the Vice President for this study, but it stipulates that the department names not be disclosed. The actual units of analysis (tonnage reports) were easily available from the different departments via the intranet and only those not uploaded to the intranet, such as the logbooks, had to be collected for the research study.

1.7 Delimitations, limitations and assumptions

Delimitations are conscious inclusions and exclusions that are made in order to develop boundaries within the research scope and study plan and which involve things like variables of interest, and the amount of data and type of data to be collected. Assumptions are the beliefs that the principles upon which the study is based, are true and factual. These assumptions include transparency, accuracy and distribution of data and more, which are discussed below (Rubin & Babbie, 2016:5).

1.7.1 Delimitations

- There are bound to be multiple problems in a chemical plant, however, the problem that was identified occurs in the packaging facility, and it was selected due to an observation made by the researcher. The packaging facility had difficulty keeping up with the supply from the feeding plant, thus, causing delays, wastage, product inaccuracies, packaging faults and cost over-runs that are due to plant downtime.
- The methodology framework chosen to exploit the problems is known as iTLS. The packaging plant inspired the study, because of the inefficiencies in the production process, which could benefit enormously from the implementation of a continuous improvement methodology like iTLS.
- Quantitative research methods were used to provide reliable projectable results, in order to limit variables, waste and quality issues under controlled conditions, which can be directly aligned with iTLS methodology (Robson & McCartan, 2016:78).
- A multi-level longitudinal analysis was conducted, rather than cross-sectional analysis, since three performance indicators had to be analysed in this study, in order to address the

research question and the longitudinal analysis was to be done based on the amount of data repeated over two fiscal years. Two fiscal years is believed to give enough reporting data to visualise patterns in idle times and problems as this study is limited in both time and resource availability.

- The unit of analysis comprises five internal company reports: Actual Daily Production Report; Overall Equipment Effectiveness Report; QAQC Rejection Logbook and Customer Complaints Report. These are used as secondary data due to its reliability and consistency.
- Two units of analysis were excluded: firstly, the SAP system was deliberately excluded, due to the enormous amount of information it provides. This could make data analysis much more challenging and labour intensive, since sampling is done per second. Secondly, formal questionnaires (surveys) sent to all 64 production staff members, as this too would add an immense amount of data to the vast amount of data already captured.
- The views and opinions of employees have been excluded, as qualitative data is subject to subjectivity. It is difficult to determine the point of data saturation with qualitative research, as a substantial number of interviews must be done, in the hope of reaching a point at which the same result is realised. Another reason why qualitative interviews were excluded from this study is the publication of private and confidential information and the legal limitations thereof. Voluntary participation and the lack thereof (due to anonymity concerns) can affect the number of participants, which could also affect the point of data saturation.
- No financial data is published in this study, due to legal constraints, as well as restrictions specified by the organisation with regard to publishing price-sensitive information that could be of interest to competitors.

1.7.2 Limitations

- There are statistical model restraints due to the IP governing the product grades and forms. This meant that all data that references products, has been converted and expressed per packaging line.
- IP limitations: the company name and name of the specific plants may not be published.
- A limitation exists in the accuracy of the data collected by the Overall Equipment Effectiveness Report, as it reflects hourly intervals, which can be problematic, as there are idle times that are caused by inspections, routine maintenance and breakdowns. No pallets are packaged during this time. This results in inaccurate per hour packaging quantities in the data model.
- A data model limitation exists when clients do not report all quality issues, which limit the number of quality complaints registered.

1.7.3 Assumptions

- The assumption is that iTLS methodology can help to identify all areas requiring improvement in the operational process.
- The assumption is made that the internal reports scrutinised will balance out the requirements for the iTLS framework that is needed and accurately identify shortfalls.
- Another assumption made relates to the statistical model of the internal data collected, i.e. that no economic, social or environmental trends affected the overall production and packaging machinery or plant operators during the two fiscal years from which the data was pulled.

1.8 Rigour & reliability

When sound research design is met with proper research data, the answers should lead to comprehensive conclusions and new knowledge that is reliable and transparent (Mårtensson *et al.*, 2015:39). What is the best way of assessing the adequacy and credibility of reporting detail when using the secondary data of the facility, especially in this case, where there are no external auditors? The answer lies in utilising the core attributes and common standards related to quality (accuracy, neutrality, applicability and consistency), to assess the appraisal criteria, according to Claydon (2015). Table 1-3 lists the standards against which quality / rigour were measured for this study.

Table 1-3: Standards by which quality and rigour are measured

STANDARD	QUANTITATIVE INTERNAL DATA
Veracity / Accuracy	Internal Validity – The internal data collected by the Overall Equipment Effectiveness Report reflects actual tonnage available, performance and quality. The report reflects 24-hour intervals, and this can be problematic, as there are idle times when no pallets are packaged; this is caused by inspections, routine maintenance and breakdowns. This results in inaccurate per hour packaging quantities in the data model. Not all quality issues are reported by customers. However, other production data are gathered and analysed, which should result in the gaps being filled.

Neutrality	Objectivity – This study is mainly quantitative, as data and numbers cannot lie, nor can there be inherent bias. The field of study (operational management) and the field of work of the researcher (maintenance manager) has some common points; however, remaining distant from the nature of the study should prove to be manageable. The independent reality that exists due to factual data, denounces any retrospective views of findings.
Applicability	Generalisability – Considering the data as reliable reproduced measurements, in set time increments and under specific conditions that are used throughout, not only the packaging plant, but the whole site – thus accomplishing applicability and generalisability throughout.
Consistency	Reliability – The degree to which the instrument - in this case, the OEE - measures the tonnage manufactured, availability and quality over time always remains consistent. The measurements are repeated every hour, 24/7, 365 days a year on the same substances in the same environment. This gives the scientific data collected a sound and accurate benchmark.

Source: Adapted from Claydon (2015)

1.9 Research ethics

According to Bryman and Bell (2015), ethical considerations are an important element in a research study. The research study needs to comply with certain standards to encourage the aims of the research, which are: imparting authentic knowledge, actuality and prevention of error. Research ethics protects the welfare of research participants and covers areas of scientific misconduct and plagiarism (Eriksson & Kovalainen, 2015).

1.9.1 Ethical considerations

In order to comply with the requirements set out in the North-West University ethical guidelines for research, the following requirements were adhered to:

- A Letter of Consent was obtained from the selected organisation to undertake the research.
- Permission was obtained from the selected organisation to allow the organisational data to be used in the study.
- All sources used in this study were acknowledged and referenced as per the North-West University referencing guide.

- The study was not funded by the organisation and the research will not be compromised by any source of funding.
- The research study has received ethics clearance from the Ethics in Commerce Research Committee (ECRM) of the university.

1.10 Layout of the study

Chapter 1: Nature and scope of study

This chapter of the research study sets the context and background. It introduces the reader to the topic, what the problems are and the reason for the research. The problem statement is formulated and the research goals, research method, and limitations are stated.

Chapter 2: Literature study

In this chapter a theoretical framework of iTLS is broken down into its three different methodologies, namely:

- TOC
- Lean
- Six Sigma

To conclude, the final section combines the abovementioned methodologies known as iTLS. Research that had already been done on the study topic was reviewed and compared.

Chapter 3: Research design

In this chapter, the following matters are discussed: research design used in the study; the measuring instruments that were used to gather data; the data analysis techniques used.

Chapter 4: Results and findings

The measuring tools results of the empirical study were analysed to establish a conceptual background for the proposed theoretical framework. Data was arranged in tables and figures in such a way that specific groups of data correspond.

Chapter 5: Conclusion and recommendations

Founded on the results of the empirical study, this chapter provides the conclusions and recommendations. The conclusions and recommendations are motivated by the facts obtained from the data analysis.

CHAPTER 2: LITERATURE REVIEW

Figure 2-1 provides an outline of Chapter 2 and how it has been laid out.

Figure 2-1 Chapter layout



Source: Author (van Wyk, 2018)

2.1 Introduction

In today's global competitive environment, manufacturers are struggling to squeeze out 5 – 7% operating cost saving (Deming, 2018:44). The reality is staggering. If an organisation is not continually elevating performance, it is in danger of closing its doors (Ismail, 2014:229). The drive for continuous improvement requires research, statistics and proof before implementing any methodology in any organisation (Bryman, 2016:75). Three improvement methodologies have been described in seminal books and have had a ground-breaking effect on output, especially in manufacturing:

- TOC is described in "The Goal" by Eliyahu Goldratt (1984).
- Lean production was first described by John Krafcik in a 1988 article, "Triumph of the Lean Production System", which was based on the Toyota Production System by Taiichi Ohno (developed between 1948 to 1975 and published in the 1981 article, "The machine that changed the world" by James P. Womack, Daniel Jones, and Daniel Roos).
- Six Sigma, as developed by Bill Smith for Motorola in 1980 and described in "The Six Sigma way" (by Peter S. Pande, Robert P. Neuman and Roland Cavanagh (2000)).

These publications are all listed by Time Magazine as part of the top 25 most influential business management books (Sproull, 2009a:40). The acronym iTLS is a distinctive integration of three methodologies: TOC, Lean and Six Sigma. This management system focuses on identifying core improvement areas on continuous opportunities in order to quantify prospective benefits, establish priorities and implement the solutions identified (Pirasteh, 2010; Sproull, 2009a).

The selected packaging facility inspired the study, due to the inefficiencies in the production process, which could be significantly improved by implementing a continuous improvement methodology like TOC, Lean Manufacturing and Six Sigma or an integrated iTLS methodology. However, since there are so many improvement methodologies that appear to suggest conflicting

strategies, an in-depth literature review had to be done, in order to determine the correct fit for the organisation under study. In the first chapter, the study was outlined and the objectives that were set for the study specified. In order to ensure a good understanding of the iTLS methodology, Chapter 2 starts with a brief introduction of the three methodologies, and then provides a review of the goals and process steps of each of the individual initiatives. It then concludes with the iTLS theory, which integrates the theories. Details are provided of its tools and techniques, which align with the study objectives and, finally, a case study is used to demonstrate the benefits of implementing these continuous improvement methodologies. The chapter ends with a conclusion on the literature review findings.

2.2 Theory of Constraints

2.2.1 Introduction

Developed by the late Dr Eliyahu M. Goldratt, TOC postulates the overall goal of every business is “to make (Dinis-Carvalho *et al.*) money” (Goldratt & Cox, 2016:11). When Dr Goldratt was asked (in an interview) to define TOC in one sentence, he replied: “I can do it in one word: focus”. Theory of constraint focuses on improvement where it would have the most impact on profit (Goldratt & Cox, 2016:24-25). More than 20 years after Eliyahu Goldratt first presented the TOC, in his book “The Goal”, the pressure to increase profit in the manufacturing industry has increased significantly, especially as a result of globalisation. (Clegg *et al.*, 2015:33) state that organisations are continually trying to find the best philosophy, in order to gain a competitive advantage; however, they should instead be focusing on understanding their own structure in terms of process flows.

2.2.2 TOC Methodology

TOC is a methodology that identifies the most significant limiting factor that restricts accomplishing certain goals, in order to then systematically improve that constraint until it is no longer the cause of a bottleneck. A system is a collection of co-dependent links that form a chain, the constraint is the weak link (Goldratt & Cox, 2016:5).

According to Woeppel (2016:48-51) and Goldratt and Cox (2016:21), a constraint can be defined as anything that restricts a system from achieving a higher performance rate in comparison to its goal. Constraints can be either internal or external. External constraints are outside the organisation’s control, for example a decrease in market demand. Internal constraints fall within the organisation’s area of control and can be categorised into three types (Goldratt & Cox, 2016:20-21):

- People: skills shortages, training, behaviour issues and mind-set.
- Equipment: output constraints due to sub-optimal operation of equipment.
- Policy: company written or unwritten policies that hinder production.

A system is a collection of parts or processes that work together to achieve a common goal (Webster new world college dictionary, 2014). Any system, no matter how well it performs, always has at least one constraint (West, 2016:66). As there can only be one single constraint that is considered the weakest link in the system, the other weaknesses remain non-constraints until they surface as the weakest link in the system (Goldratt & Cox, 2016:60-61). In the book, The Goal, (Goldratt & Cox, 2016:30-33) indicate that the TOC presents three measures in terms of which the impact of decision is easier to predict, i.e.:

- Throughput – profit made through earnings of sales
- Inventory – money invested in material intended to sell
- Operating expenses – all money spend to change inventory into throughput

Net profit = throughput – operating cost

Return on investment = (throughput – operating expenses) / inventory

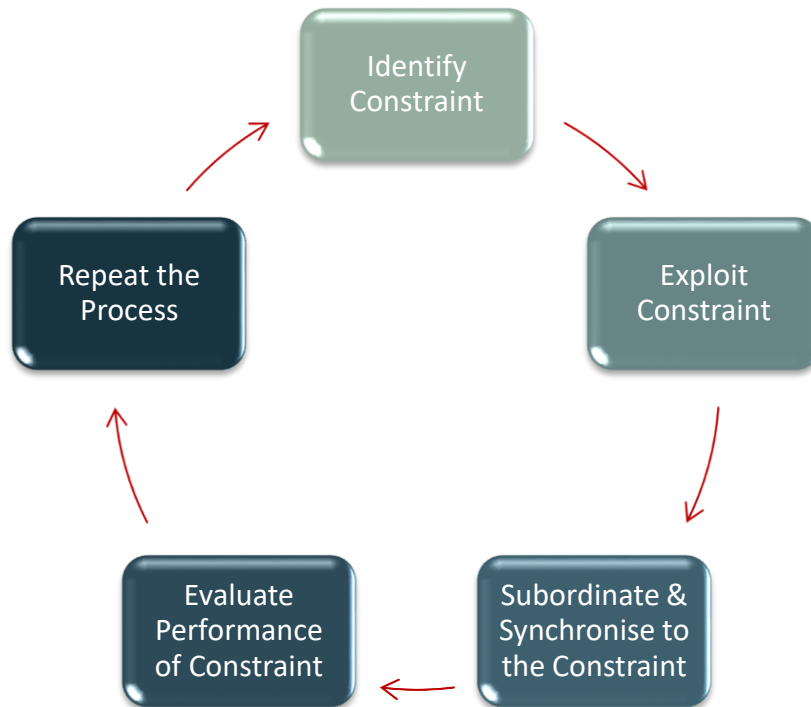
Thus, ideally, throughput needs to increase, while inventory and operating expenses need to decrease.

2.2.3 Five Focusing steps of TOC

The performance of any system is limited by the rate of throughput at the constraint: therefore identifying the systems constraint as the weakest link of the chain is the first step of on-going improvement process. Goldratt and Cox (2016:90-112) suggest that TOC approaches improvement scientifically by using the five improvement steps as tools:

- Identify the system constraint: the single part of the process that limits the rate at which the goal is achieved.
- Decide how to exploit the system constraint: make improvements to the throughput of the constraint using existing resources.
- Subordinate everything else to the above decisions: review all other activities in the process to ensure that they are aligned with and truly support the needs of the constraint.
- Elevate the system constraint: if it still exists, consider what further action can be taken to eliminate it from being the constraint.
- Repeat the process: this is a continuous improvement cycle and once a constraint is resolved the next constraint should immediately be addressed.

Figure 2-2 Theory of Constraints cycle of improvement



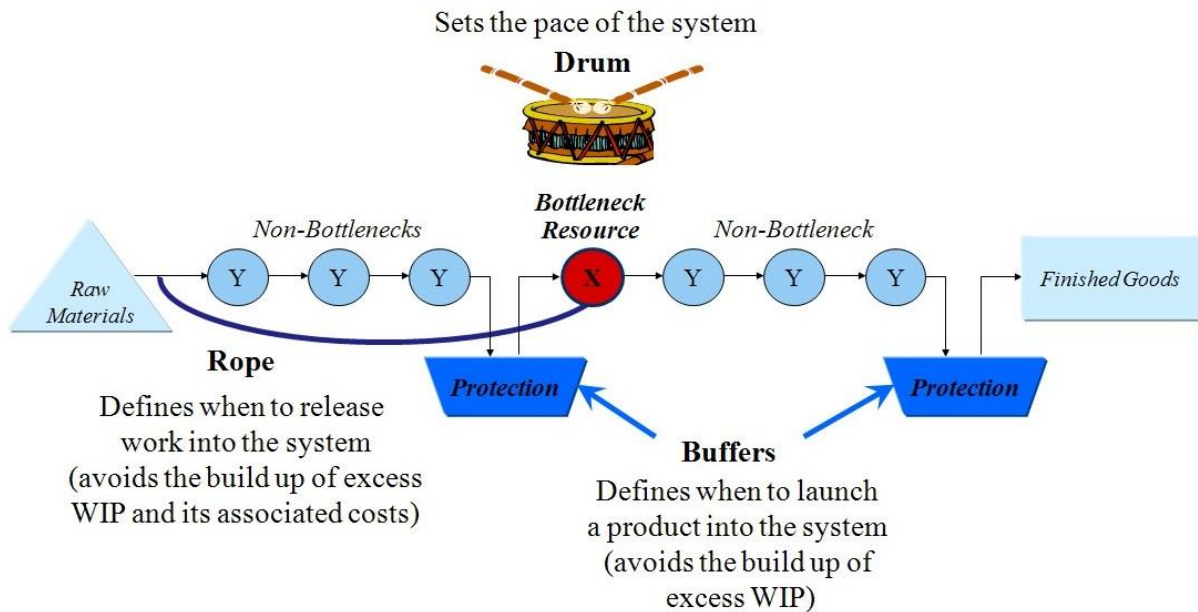
Source: Adapted from the ultimate improvement cycle by Sproull (2012).

2.2.4 TOC tools and techniques

2.2.4.1 Drum-Buffer-Rope

Goldratt & Cox (2016:212) define synchronised manufacturing as any systematic way used in an attempt to move material through the various resources of the plant in concert with the demand. Goldratt & Cox (2016:212) developed a system of synchronising a manufacturing plant, called the Drum-Buffer-Rope (DBR) approach. The approach is based on the assumption that every plant has a bottleneck or constrained. Since the constraint is the weakest link in the system, it should dictate the pace of the proceedings (Goldratt & Cox, 2016:241-245).

Figure 2-3 The Drum-Buffer-Rope illustration



Source: L'Agiliste (2018)

The DBR system functions as follows:

- The bottleneck or constraint resource should dictate the schedule based on market demand and its own potential. It is the drumbeat to which the other resources march.
- The schedule for future operations should be designed accordingly. In other words, downstream operations should be forward-scheduled-based as the output of the constraint.
- The schedule for preceding operations should support the time buffer and thus be derived backward in time from the bottleneck. Thus, “a rope” tied from the bottleneck to the first operation should regulate the tempo of the first operation; therefore, the first operation is referred to as the gating operation.
- In order to protect the bottleneck from disturbances that might occur at the preceding operations, a time buffer is created ahead of the bottleneck resource. Any unforeseen disruption can be overcome within the time buffer, and therefore it will not affect the throughput of the plant.

The most appealing characteristics of this methodology are it inherently prioritises improvement activities; the highest priority item is always the current constraint. It also provides a focused methodology for creating rapid improvement. This process has the ability to continuously improve any organisation, Bryman (2016:75) stated that there will always be at least one constraint that limits the company from advancing.

2.3 Lean

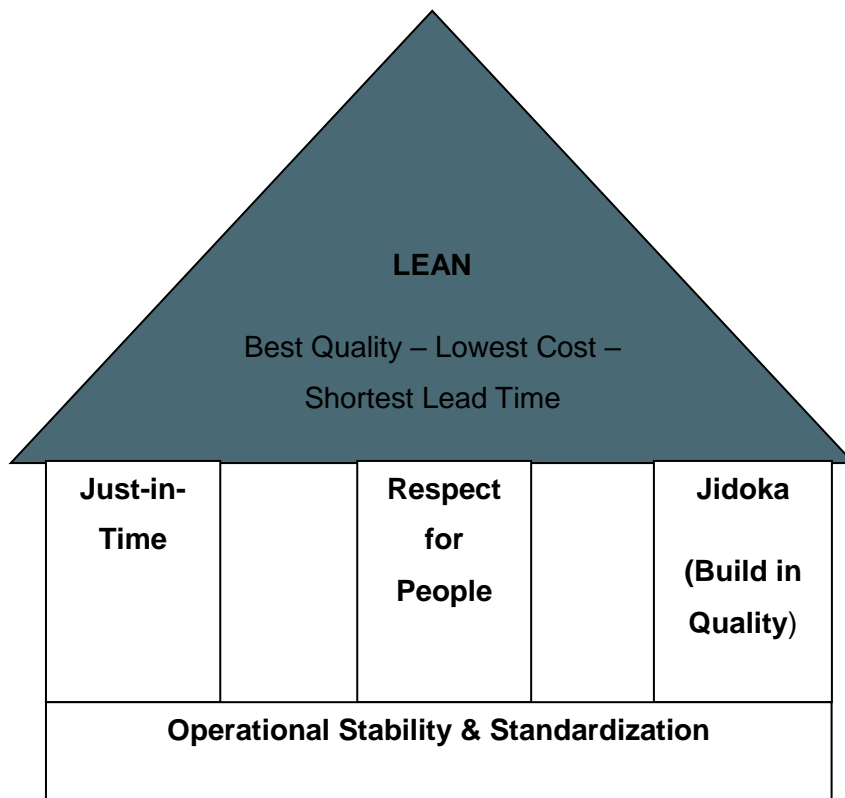
2.3.1 Introduction

Lean Manufacturing is attributed to the Toyota Motor Company that developed the Toyota Production System (TPS), which is commonly recognised as the basis of Lean (Kochan *et al.*, 2018:106). Even though it was developed in the 1950s, development and improvement to the system was carried out throughout the decades, until 1988, when TPS was strategically introduced. Subsequently an economic crisis resulted in a severe shortage of material, financial and human resources. This highly efficient and productive system resulted in Toyota's sustained success and prosperity (Zokaei *et al.*, 2017:61). The term Lean was made popular with the publication of two books, namely: *The Machine That Changed the World* by Womack *et al.* (1990) and *Lean Thinking*, by Womack and Jones (1997).

2.3.2 Methodology

The definition of Lean is: "A systematic approach to identify and eliminating waste through continuous improvement and flowing the product at the pull of the customer in pursuit of perfection" (Jones & Womack, 2016:166). Lean is a manufacturing system that emphasises the need to reduce waste by focusing on the concept of specified customer value (Cabrita *et al.*, 2016:23-33). It measures touch-time of the product – the number of times the product comes into contact with the worker or the machinery. Waste can be defined as anything not required producing the product or service ((Fletcher, 2018:66). Jones and Womack (2016) define value as, "a capability provided to the customer at the right time, at an appropriate price, and as defined in each case by the customer". Through Lean, manufacturing can be achieved using less human effort in the factory, less space, less financial resources and less material to produce the same product. In order to achieve Lean, a number of tools and practices have been developed by (Bicheno & Holweg, 2000:5-6). This is graphically represented in the "House of Lean" in Figure 2-4.

Figure 2-4 House of Lean



Source: Compiled from Chapman (2005)

The House of Lean provides a useful tool and a logical sequence to follow for implementation (Pepper & Spedding, 2010). The foundation of the house needs to be set, before the house can be built. The foundation embodies firstly, people and purpose and secondly, stability and standardisation of operations. Under people and purpose; a strong leadership, engaged employees, mutual trust and clearly defined goals are required. Lean tools used for this include Kaizen, a strategy where employees work proactively to achieve regular, incremental improvements (Singh & Singh, 2015).

Stability and standardisation ensure that the work is done the correct way, every time. This is imperative, since it is impossible to sustain improvements without stable processes (Hernandez, 2017). The Lean tool that can help with stabilisation comes in the form of control charts that help people to understand processes, where they fail, and how to improve them (Mann, 2014). The 5S system can help improve standardisation, as it is a powerful systematic method to reduce waste using five steps: Sort (eliminate that which is not needed); Set in Order (organize remaining items); Shine (clean and inspect work area); Standardise (write standards for the above); Sustain (regularly apply the standards) (Locher, 2016).

The walls of the house represent optimised production and quality. Production optimisation is required to ensure efficient and cost-effective operations (Alsyof *et al.*, 2018). Quality optimisation safeguards to ensure expanded production is protected against bad results. The tools that are used for production optimisation include Kanban, Heijunka, JIT; those used for quality optimisation include poka-yoke, the five why's, and Jidoka (Pinto *et al.*, 2018b). Kanban eliminates waste from inventory and over-production by regulating the flow of goods, both within the factory and outside of it (suppliers and customers). The customer demand pulls products through the production manufacturing process (Shah & Patel, 2018).

Heijunka is a production scheduling tool that purposely manufactures smaller batches, instead of large batches, in order to reduce idle time (Schmidtke, 2015). Smaller batches ensure a balance of goods is produced at a constant rate, ensuring the pull of products through the system. Poka-yoke is a design error detection and prevention tool that is used to achieve zero defects (Vinod *et al.*, 2015). Defects and errors slow the manufacturing process down, resulting in waste. The five why's is a method of asking "Why" until the root cause of the problem is discovered. This ensures the problem is addressed and not contributing to problems. Jidoka (built in quality) is the practice of controlling variables within a process, ensuring the quality at the facility and not passing on poor quality. This means that work stops until the cause of the defect is identified (five why's) and eliminated (Kiran, 2016).

The centre of the house is all the people working for the organisation. Every employee is respected and is expected to perform as part of the team. Continuous improvement by training your people to identify waste and solve problems, and setting specific, measurable, attainable, relevant and time-specific (SMART) goals (Locher, 2016). The roof represents customer focus and is achieved by providing the best quality product, at a reasonable price with the shortest lead time. Each element of the house is significant, but it is even more important to realise how the elements reinforce each other (Hernandez, 2017).

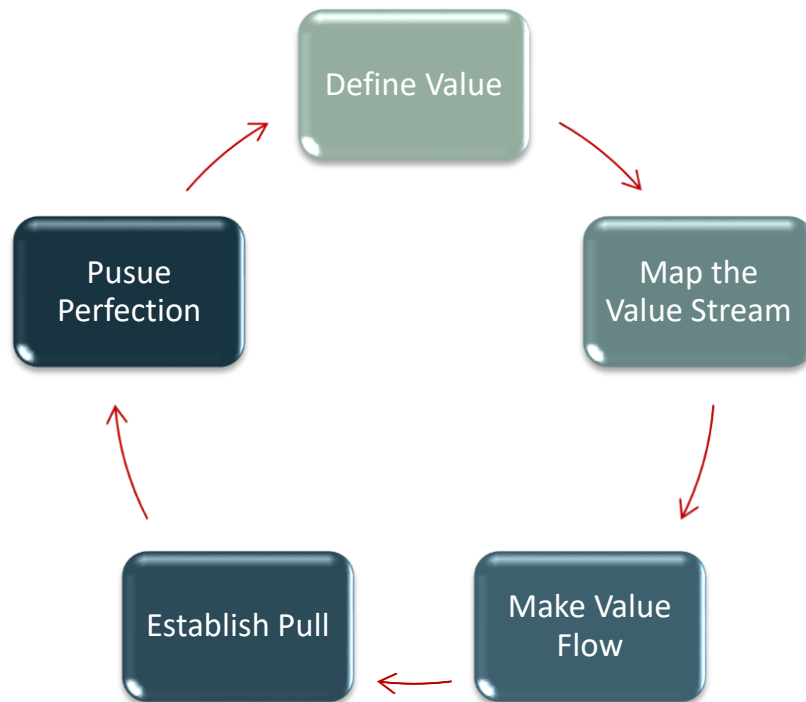
2.3.3 Five-step process

The Lean methodology has a five-step process for eliminating waste, according to Pirasteh (2010):

- Identify value creating features: Specify value from the viewpoint of the end customer.
- Map the value stream: Identify the sequence of events in the value stream for each respective product family, eliminating whenever possible those steps that do not add value.
- Make value flow: Ensure that the value-creating steps occur in a close-fitting sequence to enable the product to flow smoothly towards the customer.
- Establish pull: Let the customer pull product from the process.

- Pursue perfection: Repeat the efforts to improve flow, add value, reduce waste and satisfy customer needs.

Figure 2-5 Five step Lean improvement cycle



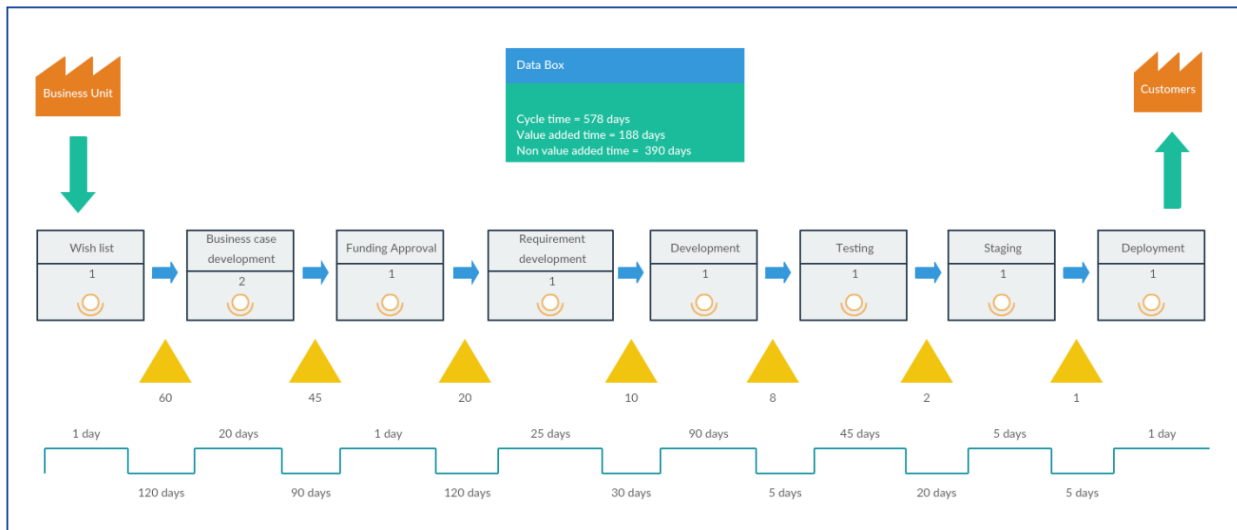
Source: Adapted from the ultimate improvement cycle by Bob Sproull (2009:5).

2.3.4 Lean tools and techniques

2.3.4.1 Value stream mapping

Value stream mapping is a method used to depict how material and information flows across and throughout the processes that occur in a company. Using this method, a one-page picture is created from the time a customer places an order until the customer received that product at their own facility. The value stream map easily identifies waste that occurs in the process, by visually indicating time and activities. Once the current state value stream mapping (CSVSM) is created, it becomes the baseline for improvement. A future state value stream map (FSVSM) is then developed, based on identified non-value adding items. An action plan is then developed to make the FSVSM the CSVSM.

Figure 2-6 Example of a value stream map



Source: Athuraliya (2018)

2.3.4.2 Kaizen

Continuous improvement is a philosophy that Demming (2018E) described as “improvement initiatives that increase successes and reduce failures”. Continuous improvement is driven by management and results in a culture change in the company. Johansson and Sundin (2014) stated that a company needs to continually develop in order to stay competitive, i.e. it needs become a learning organisation that sees standardisation and innovation as two sides of the same coin.

The lean culture of Kaizen was simplified by using the following steps:

1. Learning from one’s mistakes.
2. Determining the root cause of the problems.
3. Providing effective counter-measures.
4. Empowering people to implement those measures.
5. Having a process to transfer the new knowledge to the right people, with a view to making it part of the company’s repertoire of understanding and behaviour.

Backlund and Sundqvist (2018) states that for a company to learn means to build on the past and move forward incrementally, rather than starting over and reinventing the wheel with new personnel with each project.

Part of the Kaizen culture is the five-why analysis. This helps identify the root cause of something that went wrong. It is simply a tool that requires a person to ask why five times over, in order to dig deeper into the hidden cause of a problem.

2.3.4.3 Eight forms of waste

The co-developer of the Toyota production system stated that 95% of all costs in non-lean manufacturing environments account for non-value adding activities (Kavalić *et al.*, 2017). These non-value adding activities - also known as Muda - can be identified as the eight forms of waste (Dinis-Carvalho *et al.*, 2015). The acronym TIMWOODS is used to remember these types of wastes, as listed below:

1. Transportation
2. Inventory
3. Motion
4. Waiting
5. Over-production
6. Over-processing
7. Defects
8. Skills

1. Transportation

Transportation does not transform the product in any way that the customer is paying for (Womack & Jones, 2015). Transportation is required, but must be controlled in terms of times and distance. Every time a product is transported, it stands a chance of being damaged, lost or delayed; and from the customer's perspective, it does not add value in terms of physical transformation to produce the end product (Blijleven *et al.*, 2017). Additionally, materials and consumables used in the manufacturing process should be delivered at the point in the assembly line where they are used (Black & Kohser, 2017).

2. Inventory

According to Saraswat *et al.* (2015), inventory can be divided into three categories: raw material, work-in-progress (WIP) and finished goods. Inventory has a physical cost associated with it, such as the transportation and movement, storage, administration and keeping track, insurance and damages and losses costs (Vlachos, 2015). Excess inventory is related to over-production, and based on the research done by (Arunagiri & Gnanavelbabu, 2014), anything that is produced

beyond what is required negatively influences cash flow and wastes valuable floor space. High inventory levels hide problems that occur in the production system and which ultimately prevent them from being solved. By lowering inventory levels, problems become visible and can therefore be addressed (Drew *et al.*, 2016). Issues that are commonly found when inventory is lowered are:

- Machine capacity
- Skill shortage
- Transportation delays
- Breakdowns
- Supplier deliveries
- Defects or rejections
- Long set-up times
- Scheduling

3. Motion

Waste as result of motion is any motion a worker is doing that does not add value to the product (Weiss *et al.*, 2017). Motion studies done by Frank Gilbreth (Gilbreth & Kent, 1911) showed that by improving ergonomics and process layout, a company could increase work efficiency significantly and reduce the number of strain-induced injuries. The wasteful motion is mainly caused by (Womack & Jones, 2015):

- Poor workstation layout that results in excess walking, bending and reaching.
- Poor method design that results in transferring product or equipment parts from one hand to another.
- Poor workplace organisation.
- Large batch sizes.
- Reorientation of materials.

4. Waiting

As salaries of employees is a high cost, time spent not adding value to the product as a result of waiting is regarded as a waste (Nicholas, 2015). Waiting is not something that customers are willing to pay for, and the cost of time spent waiting will have to be paid from the company's profit margin (Womack & Jones, 2015).

Waste due to waiting is any idle time produced when two interdependent processes are not synchronised, e.g. if operators are kept waiting or simply work slowly whilst the machining cycles (Ramadan, 2016).

Waiting waste results from (Soliman, 2017):

- Long change-overs.
- Time required to perform re-work.
- Batch completion, not single piece transfer between operations.
- Poor man-to-machine coordination.
- Unreliable processes or quality.

5. Over-production

Waste as a result of over-production is regarded as the worst of the eight waste types, as it involves making a product in too great a quantity or making a product before it is actually needed, which results in excess inventory (Hartman, 2015). As with excess inventory, over-production obscures all the other problems within the process. Lean manufacturing principles require the production facility to make only what the customer wants, when they want it (Womack & Jones, 2015). This is regarded as a pulling system, which will be discussed later in section 2.3.4.2

Over-production waste is caused by (Jasti & Kodali, 2016):

- Unstable schedules.
- Working to forecasted information and not to actual demand.
- Large batch sizes.
- Unreliable processes.
- Unbalanced cells or departments.

6. Over-processing

Waste due to over-processing occurs when the facility is putting more into a product than what is valued by the customer (Soliman, 2017). Over-processing is caused by non-standardisation of best techniques or unclear specifications and quality standards (Kanafani, 2015). Examples of non-value-adding processing according to Soliman (2017) are:

- Reworking – when products are not manufactured correctly the first time.
- Out-of-tolerance product – such as products that have been produced with burrs or are oversized and need to be re-worked.
- Inspection – products should be produced with controlled processes, which limit the need for inspections.

7. Defects

This type of waste accounts for all manufactured products that deviate from what the customer requires (Soliman, 2017). The cost of defects and re-work are often compared to an iceberg, since only a small fraction of the true cost is visible above the water level. According to Womack and Jones (2015), the general rule is to multiply the cost of the defects by a factor of ten, in order to arrive at the true cost to a business. Womack (2015:127) stated that defects are caused by:

- Skills shortage.
- Operator error.
- Transportation.
- Inadequate training.
- Incapable processes.
- Excessive stock.
- Incapable suppliers.

8. Skills

Failure to make use of the creativity and skills of employees to continuously improving operations is regarded as the eighth waste (Drew *et al.*, 2016). As employees are regarded as the most valuable resource in a company, without their involvement and loyalty, the company compete less effectively (Womack & Jones, 2015). In the current globally competitive marketplace, an organisation needs all the help it can get to maintain and improve business performance (Stark, 2015). Employees need to be developed beyond their immediate job requirements, so that they can support problem solving at the heart of the process.

2.3.4.4 5S

5S is a simple Lean tool used to organise the workplace in a clean, efficient and safe manner, so as to enhance productivity and visual management, and to ensure the introduction of standardised working (Gupta & Jain, 2015). One of the most important factors of the 5S tool is that it ensure that problems are immediately obvious. The five S's stand for (Womack & Jones, 2015) (Japanese):

- Seiri - sort, clear, classify.
- Seiton - straighten, simplify, set in order, configure.
- Seiso - sweep, shine, scrub, clean and check.
- Seiketsu - standardise, stabilise, conformity.
- Shitsuke - sustain, self-discipline, custom and practice.

2.3.4.5 Just-in-time (JIT)

As the name suggests, this is a management philosophy that requires manufacturing of products to be based on what the customers wants, when they want it and in the quantities requested (Ali, 2016). Instead of having large inventory stock of what the company forecasts the customer might want, the company should only make exactly what the customer actually asks for, when the customer asks for it (Ross, 2016). This streamlines the organisation's processes, so that the focus is on only fulfilling value-adding activities that the customer is prepared to pay for.

According to Pinto *et al.* (2018a) JIT provides the following benefits:

- Reduction in the order to payment timeline
- Reduction in inventory costs
- Reduction in space required
- Reduction in handling equipment and other costs
- Lead time reductions
- Reduced planning complexity
- Improved quality
- Productivity increases
- Problems are highlighted quicker
- Employee empowerment

2.3.4.6 Overall Equipment Effectiveness (OEE)

OEE is a performance measure that reflects the health of a process (Chiarini, 2015). With the complex processes involved in manufacturing in the twenty-first century, OEE provides a metric and guideline to manage the production process (Maskell *et al.*, 2016). It is a composite measure that is calculated based on the machine's availability, performance and quality output, which is expressed as a percentage (Chiarini, 2015). OEE is key performance indicator (KPI) that provides the focus required to drive improvement. The specific process information can be used for root cause analysis (Chiarini, 2015). Developed by (Tang, 2017), the six big losses are grouped under the three main areas of availability, performance and quality.

Availability rate

This is the asset operating time as a percentage of operating time available. Lack of availability can be due to two main reasons (Tang, 2017):

- Breakdown – unplanned downtime due to equipment failure.
- Change-over – planned stoppages to change to producing a different product.

Performance rate

This measures asset performance in terms of actual output against what is expected of the machine, if the machine runs at its designed speed. According to (Tang, 2017), poor performance can be as a result of:

- Reduced speed losses – this occurs when the machine produces at a rate that is lower than what it is supposed to be.
- Losses due to minor stoppages - this is a result of small stoppages that result from process issues such as jamming.

Quality rate

This measures defective products produced from either within the process, during normal production, or during the set-up process. (Tang, 2017) identified the following quality defects contributing to quality rate:

- Set-up losses – when the setting up process result in defective products such as flushing's
- Defects – This is rejected products produced that are not within specification.

OEE calculation methods will be discussed in section 3.5

2.4 Six Sigma

2.4.1 Introduction

This process improvement methodology was introduced by two engineers working for Motorola in 1986, Mikel J. Harry and Bill Smith (Rogers, 2016). The chairman, Bob Galvin, decided that measuring defects per thousand opportunities was inadequate; instead he wanted per million opportunities measured (Gao, 2016). The popularity of Six sigma further increased when Jack Welch successfully introduced it into General Electric in 1995 (Eckes, 2002).

Six Sigma may be written as 6σ (where sigma is indicated in its true Greek form in lower case) or 6Σ (upper case). Sigma is the 18th letter of the Greek alphabet and somewhat corresponds to our letter S, sigma is generally used to represent a concept that begins with S. Σ (upper case) is mostly used to indicate a sum, whereas the σ (lower case) usually represents standard deviation in mathematics (Hirsch, 2005). Standard deviation is the distance from the mean (average) in the dataset for individual elements in a bell-shaped curve; it indicates the variance values of the

product characteristics, compared to the mean value that falls under this bell-shaped curve, which is known as the normal distribution (Devore, 2015). This acts as a tolerance index for process variability and product characteristics (Mitra, 2016). Six Sigma strives to establish a benchmark of 3.4 defects per million opportunities, which means a good quality rate of 99,99966% (Dumitrescu & Dumitrache, 2011; Filipe, 2016). However, Six Sigma is about more than just defects (Pyzdek & Keller, 2014).

2.4.2 The Methodology

This continuous performance process focusses on the end-result, which is the essence of customer satisfaction (Munro *et al.*, 2015). The means should never affect the ends. There will always be a natural variation in product characteristics; however, these variations should be kept within stable / controlled limits. Customers care about the quality, not the methods of production (Pyzdek & Keller, 2014). Six Sigma emphasises that out-put parameters that affect the consumer are critical. There is no use compromising on quality in order to increase production figures (Pyzdek & Keller, 2014).

Six Sigma is a data driven (scientific engineering) approach that emphasises the ability of the process to produce a consistent outcome, by reducing defects and producing measurable financial results (Bateh & Farah, 2017; Pirasteh, 2010; Pyzdek & Keller, 2014). This is done by using a set of mathematical tools that underpin the fluctuation, evaluate the differences and set new tolerance indexes (Kumar *et al.*, 2018). Management can then start predicting outcomes, when outcomes are unsatisfactory, associated tools are used to further understand the influencing parameters (Arumugam *et al.*, 2016). The assumption is that the program is designed to reduce defects and variations in production, which ultimately lower cost, save time and improve customer satisfaction, thus solving process problems (Ansar *et al.*, 2018).

When a process is investigated it produces a re-evaluation of most of the value-added status of items, this may mean that some items are discontinued or refined. Once re-evaluation of elements starts, the process becomes predictable, minimising opportunities for mistakes in the flow of production (Pyzdek & Keller, 2014). Flow is considered the time of raw material in-put up to the out-put of a sealable product. Anything that restricts the flow causes variation and reduces output volume; thus, the organisation has more money tied up in in-process inventory and the time it takes for the organisation to see any profit is increased, resulting in slower reaction time in responding to customer needs (Hernandez, 2017; Pyzdek & Keller, 2014; Sproull, 2009a).

Aberdeen Group is a technology driven research business that participates and directs value-chain fact-based research globally (Easton & Rosenzweig, 2012). According to their Lean Six Sigma Benchmark Report, which was based on a survey done in 2006, 52% of the respondents

claimed to have implemented Six Sigma, whereas 37% had used both Lean and Six Sigma initiatives. However, less than 16% of the Six Sigma respondents (companies) stayed true to the rigorous programme and these companies produced 40% more savings, on average, than the rest of the population (Easton & Rosenzweig, 2012).

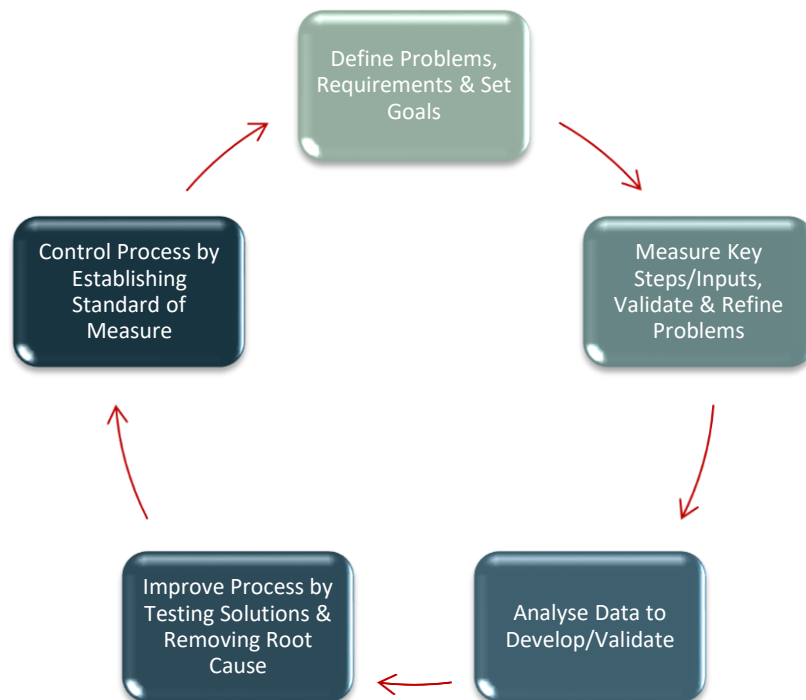
This indicates that Six Sigma is not just about defects and reducing the number of mistakes, it is about the organisation's bottom line and how it may improve turnover, reduce costs and empower employees. The Six Sigma tool known as DMAIC (an abbreviation of define, measure, analyse, improve and control) is a reactive approach to reducing errors in five steps.

2.4.3 The focussing steps

This improvement methodology, also known as DMAIC, articulates a five-step process that aims to eliminate process variation (De Mast & Lokkerbol, 2012; Munro *et al.*, 2015):

- Define the project objectives and customer deliverables.
- Measure the process performance and quantify the problem.
- Analyse and determine the root cause of the defects.
- Improve the process by eliminating defects with implemented changes.
- Control and maintain the improved process performance.

Figure 2-7 Six Sigma DMAIC improvement cycle



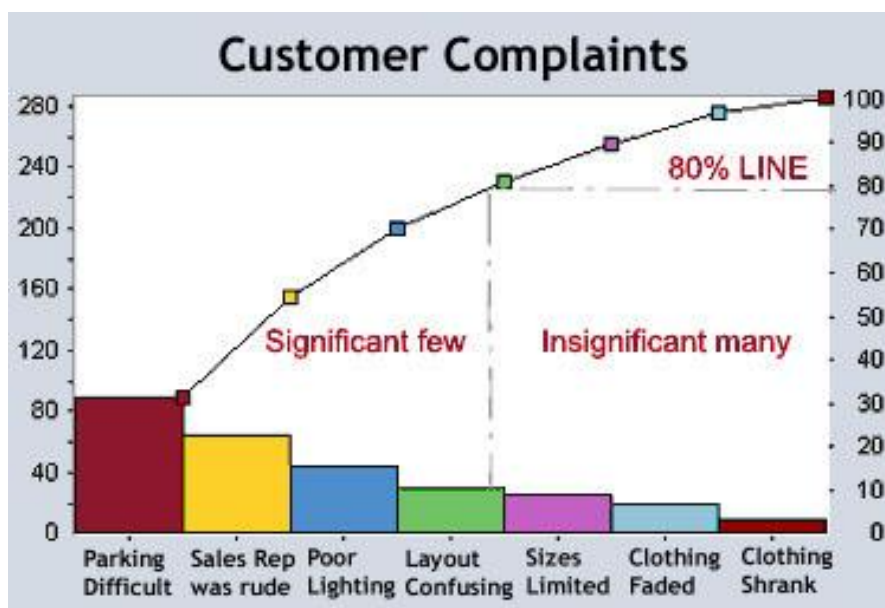
Source: Adapted from the ultimate improvement cycle by Bob Sproull (2009:6).

2.4.4 Six Sigma tools and techniques

2.4.4.1 Pareto Chart

This type of chart is named after Vilfredo Pareto. It is represented as a bar chart that includes a line graph (Gitlow *et al.*, 2015). A Pareto chart can be used when analysing data about the frequency of problems in a process or when there are many problems or causes and the intention is to focus on the most significant one (Conger, 2015). This Six Sigma analysis tool is frequently used to decide where to apply initial efforts in order to have the maximum effect (Conger, 2015; Rouse, 2013).

Figure 2-8 Example of Pareto chart



Source: (Rouse, 2013)

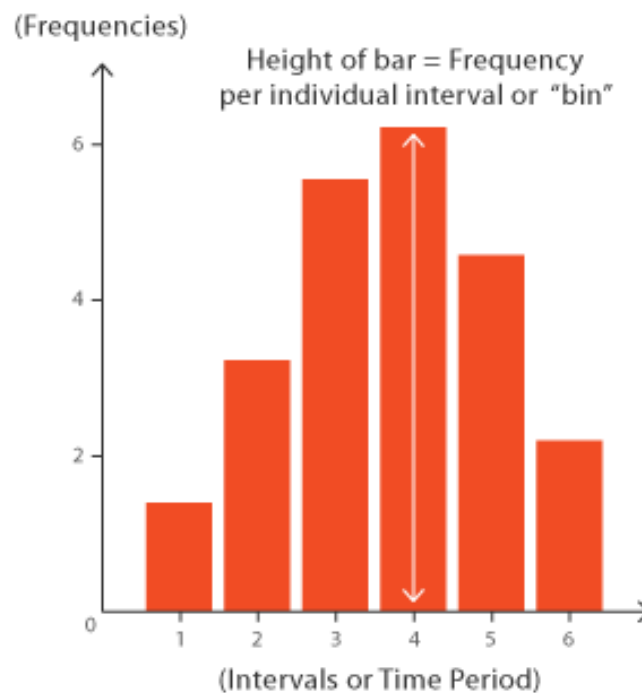
2.4.4.2 Voice of customer (VOC)

This type of analysis evaluates the customers' needs both current (stated needs) and latent (unstated needs). VOC analysis helps capture the needs of customer through stated verbatim comments and translating it into customer needs and product output characteristics (Ansar *et al.*, 2018; Evans & Lindsay, 2014).

2.4.4.3 Histograms

A graphical method used to represent the distribution of data over a continuous interval or certain time period. The data value are grouped into ranges and shown as bars. Each bar in a histogram represents the tabulated frequency at each interval (Cox *et al.*, 2016). Histograms provides an estimate as to where values are concentrated, what the extremes are and whether there are any gaps or unusual values (Cox *et al.*, 2016).

Figure 2-9 Example of histogram

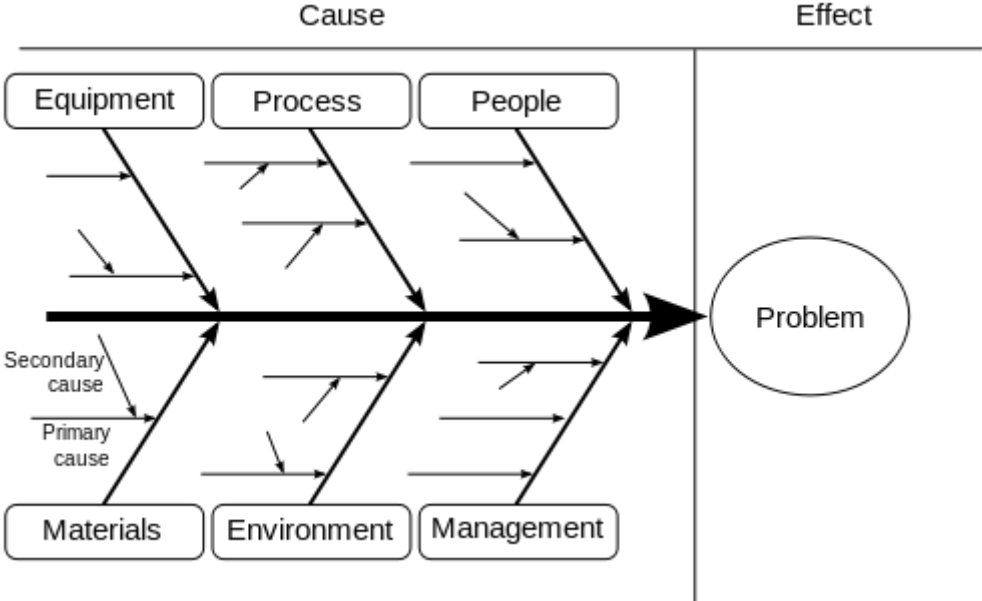


Source: (Rouse, 2013)

2.4.4.4 Cause and affect analysis

This technique help identify all the likely causes of a problem to assist the continuous improvement project to focus on the main cause of the problem first time round (Pyzdek & Keller, 2014; Voehl *et al.*, 2016). The technique was developed by Professor Ishikawa and is also referred to as the Ishikawa or fishbone diagram (Pyzdek & Keller, 2014). The cause and affect technique combine brainstorming with a type of mind map, which pushes the team to consider all possible causes to a problem, rather than just the most obvious ones (Koripadu & Subbaiah, 2014).

Figure 2-10 Example of cause and effect diagram



Source: (Wade, 2018)

2.5 Integrated Theory of Constraint, Lean and Six Sigma (iTLS).

2.5.1 Introduction

Developed by Reza M Pirasteh and Robert E, Fox in the book titled “Profitability With No Boundaries”, the book combined the concepts of theory of constrain, lean and six sigma which was referred to as an acronym iTLS. (Nelson & Sproull, 2015) found that a continuous improvement processes such as TOC, Lean and six sigma have been applied in a range of organizations to improve their profitability and efficiencies. (Pirasteh, 2010) did a scientific research to determine the effects and contributions of these approaches and in addition measured an integrated approach applying the three methodologies. The study found that iTLS projects produced more than four times the benefits of either lean, TOC or six sigma projects alone. The application of the iTLS methodology research results additionally showed that the invested capacities and resources were transformed into steady production flow (Demchuk & Baitsar, 2014). The iTLS methodology is a fairly recent methodology, which was published and patented in 2010 (Pirasteh, 2010). According to Sproull (2009a), iTLS is a new generation of continuous improvement models and rationally join the three most influential continuous improvement philosophies, techniques and tools. It harmonises, integrates and synchronises the three methods in a synergic mixture that produces substantial higher financial results (Pirasteh, 2010; Sproull, 2009a). The methodology is a management philosophy that allows the formation of more lasting

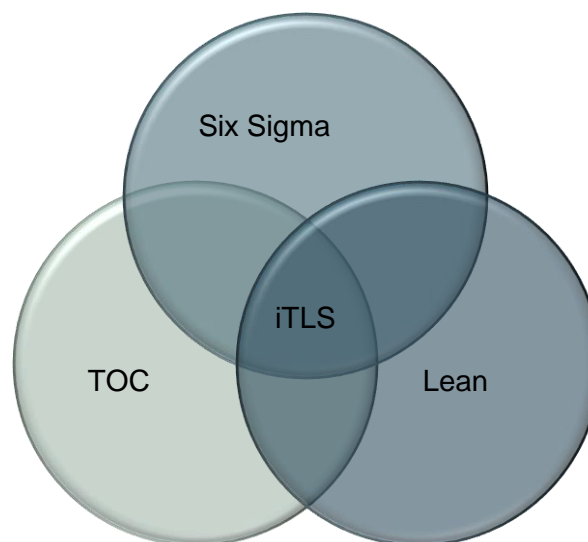
solutions to problems. (Pirasteh, 2010) research into iTLS found that it recognises inconsistency and attempts to control processes statistically. It is a methodology to recognise the actual problem, establishing importance, clearly defining the real requirement, and applying useful solutions (Demchuk & Baitsar, 2014; Pirasteh, 2010; Sproull, 2009a).

2.5.2 The methodology

The iTLS system is combined to create improvements that not only increase bottom line, but seeks to improve the health of the organisation as well as the competitiveness by supporting different situations with specific tools for that situation (Sproull, 2009a). Each step in the process of the methodology produces an outcome, which is to be used in the next step (Pirasteh, 2010):

- TOC is applied to achieve maximum throughput by creating universal alignment, and focusing on specific leverage points.
- Lean is applied at that specific leverage point, in order to reduce the lost opportunity that the waste represents.
- Six Sigma is applied to the leverage points to reduce variation in the process and ensure consistent results.

Figure 2-11 iTLS, six sigma, lean and TOC



Source: Adopted from Pirasteh (2010)

Each of the methodologies discussed can be presented as casually interdependent; for example, identifying constraints in a system (Stock) and reducing waste (Lean) both improve the flow (De Mast & Lokkerbol, 2012). Once the flow is streamlined, a predictable process output can improve

the product variation (Six Sigma). The sigma tools and metrics are used to understand the nature of sources of variability, how these affect the desired outcomes, as well as the settings needed to reduce the variability to an acceptable level for the customer (Ansar *et al.*, 2018). The constraint tools can be used to examine cause-and-effect relationships to identify root causes with respective repercussions, listing all possible causes and effects will ultimately lead to all ineffective resource uses being addressed (Pirasteh, 2010). This will prevent the same problems from occurring in the future. The Lean tools are used to understand, verify, modify and document the operational processes, in order to pull the demand (Hernandez, 2017).

Considering the above-mentioned tools and techniques, the below table provides a summarising list of each respective methodology ideology versus the integrated methodology and its continuous improvement strategic objectives.

Table 2-1 Methodology ideology and objectives

Theory of Constraint	Lean Manufacturing	Six Sigma (6σ)	iTLS
<ul style="list-style-type: none"> • System constraint focus • Process focussed • Id system constraints • Exploit constraints • Fast throughput • Emphasis on speed and volume • Process interdependence • Minimal worker input • Improved quality 	<ul style="list-style-type: none"> • Flow focussed • Customer focussed • Identify value stream • Decrease cycle time • Eliminate waste • High value steps • Reduce process flow • Process efficiency at leverage points • Less inventory 	<ul style="list-style-type: none"> • Problem focussed • Customer Focussed • Reduce process variation • Uniform process output • Increase effectiveness • Eliminate defects • Less waste • Less inventory • Fast throughput 	<ul style="list-style-type: none"> • Holistic process focussed • Customer focus • Bottom-line focus • variation reduction • consistent output • predictable output • waste reduction • streamline the flow • Reduce constraints • Improve throughput • Improved tuning • Less inventory

Source: compiled from (Goldratt & Cox, 2016; Nave, 2002; Pirasteh, 2010; Sproull, 2012)

2.5.3 Why use the integrated theory versus single methodologies

When choosing an improvement methodology, consideration must be given to what would be best for the organisation and the situation, as well as how the methodology will integrate into the culture of the organisation. Resources, training and investment all contribute to such a decision.

Simply choosing an improvement methodology to reduce only one issue (such as process time) may result in insignificant outcomes.

(Sproull, 2009a) highlights that there are many reasons for individual initiatives to fail, e.g.: the available resources of the company cannot meet the needs of the scope; companies tend to fail in recognising the leverage point and they fail to focus on the right problems. Sproull (2009a) believes that TOC, Lean and Six Sigma (the theories themselves) are not the problem, the problem is with the implementation of these approaches: it is a question of planning, execution, focus and leverage. For example, some Lean initiatives attempt to eliminate waste from their value chain, but are disappointed when the estimated waste reduction does not have the expected impact on their bottom line. The same can be said with some Six Sigma initiatives, where the company tries to eliminate all forms of variation, but it does not have the expected impact on the bottom line. With TOC, the functional lower boundary of inventory is zero, when zero inventory is reached, there is nothing left to yield. Lowering the inventory can lead to a substantial saving; however, it is a once-off occurrence. Operating expense reduction, a favourite of many Six Sigma and Lean initiatives, again has a lower limit, and once that functional limit is surpassed, this initiative may debilitate the company, rather than strengthen it (Sproull, 2009a).

iTLS is unique in the sense that it is a global approach that aims to close the gaps that exist in continuous improvement methodologies by combining fail-safe tools in an effective sequence. According to Pirasteh (2010) and Sproull (2009a), iTLS can be applied in all process operations-based projects or activities; however, this is no easy task. First, an understanding is required of what has to be addressed, and then the following: establish a project plan and mission; analyse the existing characteristics and performance; formulate solutions and base decisions on factual information, in order to ensure that all resources are exploited to maximise throughput and achieve strategic and tactical objectives. IBM (Agostinho *et al.*, 2016) stated that early adopters of continuous improvement processes, who work their way through industry, cultural and organisational barriers, such as structure, leadership and timing are experiencing notable financial and production performance results:

- Increased organisation agility and responsiveness to market, regulatory, opportunity and requirement changes through adaptive business architecture.
- Improved ability to monitor, detect and respond to difficulties by using real-time-data, which in turn quantifies into reduced process and analysis costs.
- Improved tuning processes that lead to enhanced ability to innovate.

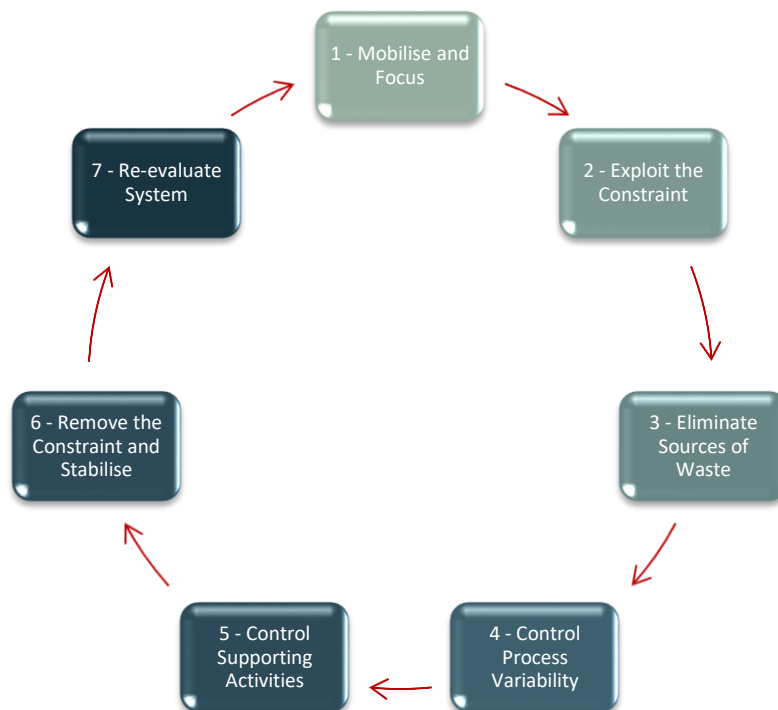
- Higher levels of component re-use (waste reduction) has led to lowered technical implementation costs and lead times as improving processes become easier and more cost effective.

2.5.4 The focussing steps

According to Pirasteh (2010), the combined iTLS approach attempts to optimise the continuous improvement process using the following seven step process:

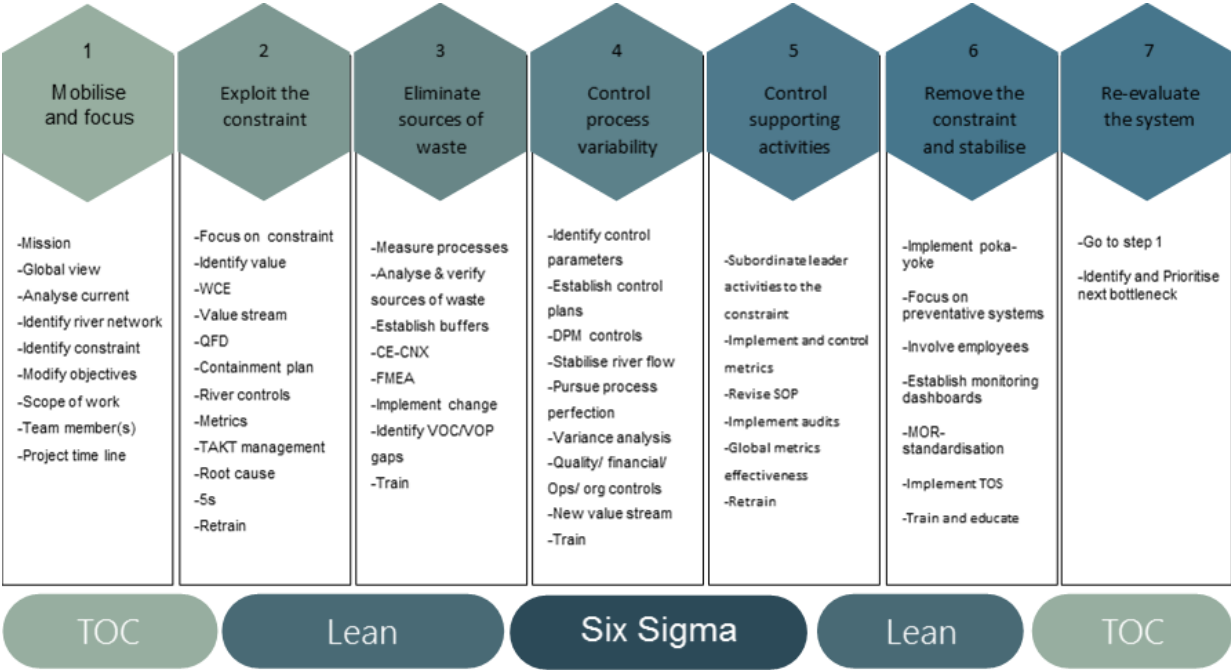
- Mobilise and focus
- Exploit the constraint
- Eliminate sources of waste
- Control process variability
- Control supporting activities
- Remove the constraint and stabilise
- Re-evaluate the system

Figure 2-12 iTLS seven step improvement cycle



Source: Adapted from the ultimate improvement cycle by Bob Sproull (2009:17).

Figure 2-13 Synergy between methodology and objectives of each step of iTLS



Source: Compiled from (Pirasteh, 2010; Sproull, 2012)

2.5.4.1 Mobilise and focus

The first step is based on TOC principles to identify the exact constraint. This is the most critical step, since the application of the iTLS system is highly dependent on successful identification to achieve the most effective results (Pirasteh, 2010). In order to ensure that the correct improvement initiative is followed, resource utilisation should be economised. The iTLS sequence applies TOC techniques to ensure the global optimisation is considered and explores the problem by assessing the organisation overall performance (Sproull, 2009a). The objective of this step is to identify the most restrictive bottleneck in the entire value stream that restrict throughput (Pirasteh, 2010). Just like a chain has a weakest link, there will always be a resource in the process that restricts the system from maximising its yield. According to Goldratt and Cox (2016), the bottleneck is the best starting point for any improvement initiative, since it offers the greatest opportunity to increase revenue in a fairly short period of time. This step focuses on reviewing and validating the problem definition. It is important to accurately recognise what the problem is, so that proper boundaries and scope can be established (Demchuk & Baitsar, 2014). In most organisations, resources need to be shared between manufacturing and improvement efforts; therefore, it is important not to waste these resources and to focus them on projects that would positively impact throughput (Goldratt & Cox, 2016). The nature of the constraint should also be

determined in this step by means of a cause and effect analysis. At this step in the process, it is important to understand the following:

- Why the change is occurring?
- What specifically is going to change?
- What is the expected outcome?

A detailed project charter should be developed and must include the following information:

- Business need
- Project description
- Strategic plan
- Management approval

At this stage a project timeline and baseline plan need to be established along with a project team.

2.5.4.2 Exploit the constraint

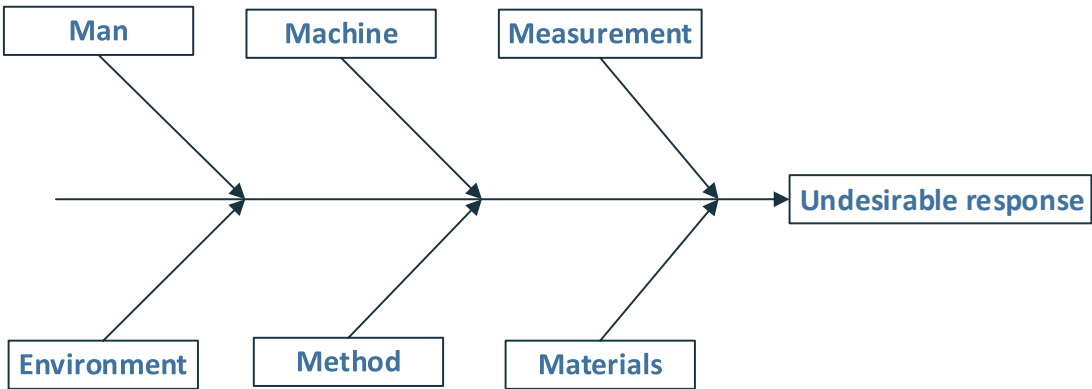
Once the restrictive link in the organisation is identified, the mobilised teams should develop a specific plan to improve the rate at which product flows through this bottleneck (Goldratt & Cox, 2016). Customer value needs to be specified, in order to remove non-value adding production activities from consuming resources (Pirasteh, 2010). Value-stream mapping is a technique used at this step to visually depict the current flow of process steps and sequence of events (Pinto *et al.*, 2018b). The goal is to achieve maximum throughput at the bottleneck by eliminating non-value-adding activities, which can easily increase capacity by 20% (Schmidtke, 2015). A wasteless value stream can streamline the process reducing inventory, queues and work-in-process (WIP). The 5S approach needs to be applied at this stage to impart order and discipline into the process activities (Bicheno & Holweg, 2000). A pull system needs to be employed at this point to guarantee that the products are only manufactured to meet customer requirements (Ivanov *et al.*, 2017). The intention is to produce the correct quantity, at the expected delivery time, to be delivered accurately to the customer and address.

2.5.4.3 Eliminate Sources of Waste

At this stage, significant process changes are identified and need to be implemented. It is important to involve all stakeholders, since several organisational aspects may be impacted (Dumitrescu & Dumitrache, 2011). The team involved needs to challenge all existing assumptions, in order to find an appropriate solution. At this stage, poor practices, bad habits, unrelated measurements, nasty surprises and limiting or lacking policies are indicated (Easton &

Rosenzweig, 2012). By making use of the root cause analysis process, non-value-adding activities can be clearly understood and prevented (Mann, 2014). Cause and effect analysis, e.g. using a fishbone diagram is a useful tool to clearly identify and quantify sources of waste and variability (Demchuk & Baitsar, 2014). The fishbone diagram draws certain input variables, such as the 6M's: man, machine, method, materials, measurement and Mother Nature or environment (Ansar *et al.*, 2018). All process variables should be considered and organised under these categories.

Figure 2-14 Cause and effect diagram



Source: (De Mast & Lokkerbol, 2012)

In this step, tens to hundreds of variables could be identified; so to ease the investigation of each variable for the team, a screening process must first be applied. Tools such as Pareto, the five why's and CNX analysis could be used. According to Patel *et al.* (2015), CNX is used to identify constants the, Noise (N) and X factors (X). Constants represent items that a controllable and is quantitatively constant. The noise variable is uncontrollable and appears randomly in the process. X factors are the suspected variables that cause the undesirable effect in the process. These are usually variables that are not well measured with limited understanding on their behaviours or attributes.

After the C and N variables are screened out, the team must investigate the X factors and assign answers using a failure mode effect analysis (FMEA). The FMEA considers each variable by frequency of occurrence (OCC), severity (SEV) and probability of escaped detection (Detrixhe) and uses the value of the risk priority number (RPN) to quantify the combined effect of these dimensions (Shah & Patel, 2018).

Equation 1 Risk priority number

$$RPN = (OCC) \times (SEV) \times (DET)$$

Source: (Shah & Patel, 2018)

2.5.4.4 Control Process Variables

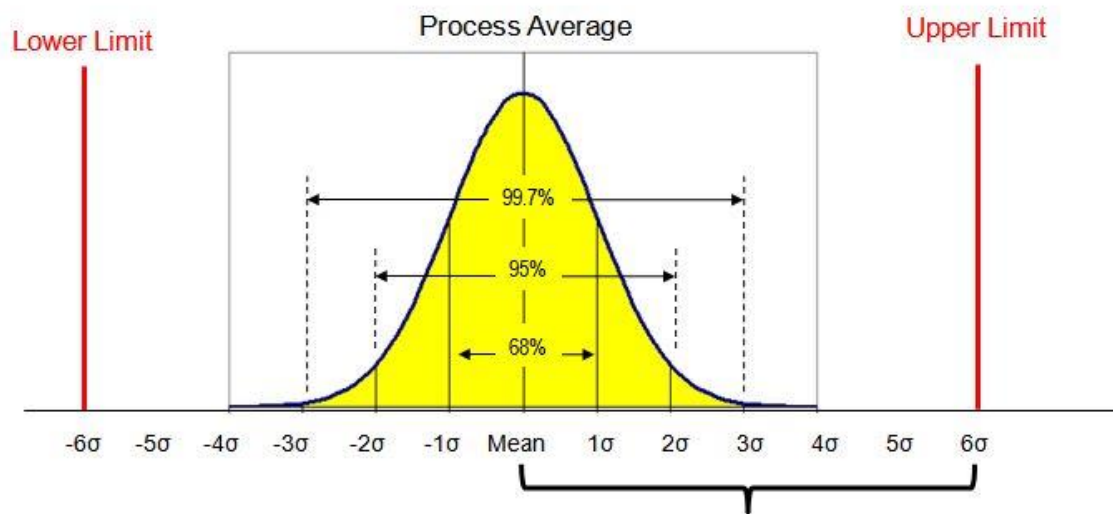
At this stage process input variation that consistently perform outside the customer requirements need to be established by using Six Sigma tools and techniques (Pirasteh, 2010). The required nominal defined by your customer specifications should be the same as the process mean. Any process spread and variable will result in an error in the process and needs to be squeezed enough around the process mean (Sproull, 2009b). The narrower and denser the manufacturing shape that is delivered, the more accurately the process is performing. Process control limits needs to be set far enough from customer specifications to provide a buffer for random fluctuations. This buffer space is dependent on the voice of customer (VOC) and the practical feasibility to achieve it (Nelson & Sproull, 2015). In Six Sigma methodology, the buffer space is measured in sigma (σ). The aim is to pursue perfections and this is done by fitting as much manufactured product between the process mean and the specified boundaries (Evans & Lindsay, 2014).

Table 2-2 Sigma level compared to defects, per million

σ Capability	Defects per million (DPM)
6	3.4
5.5	32
5	233
4.5	1350
4	6210
3.5	22750
3	66810
2.5	158687
2	308770

Source: (Furterer, 2014)

Figure 2-15 Sigma level bell curve



Source: (Smith, 2018)

It is necessary to compare voice of customer (VOC) to voice of process (VOP), in order to quantify process capabilities and determine the gaps (Furterer, 2014). With the help of Six Sigma techniques, these gaps need to be systematically removed, so as to minimise variation (Pirasteh, 2010).

2.5.4.5 Control Supporting Activities

Once the ideal process variable setting is established, it is important to create standard operating procedures (SOP) and other control mechanisms to ensure the critical factors remain consistent over time (Sproull, 2009a). Statistical process analysis and control is required along with prevention device such as poka-yoke and the rapid problem-solving worksheet (Furterer, 2014). The employees involved in the process need to be part of the team that will be responsible for resolving the variation. This will instil ownership in these employees, since they will participate in problem identification and finding a solution (Fletcher, 2018). Controlling the supporting activities is a vital stage in the process, which ensures sustainability of continuous improvement. The quality and discipline required to follow the process plays a crucial role in error reduction and it is recommended that recognition programs be establish for work teams to sustain this step (Tyagi *et al.*, 2015). Control charts and the problem-solving worksheets should be visible on the takt boards. Production managers need to review the takt boards daily to determine if any management intervention is required (Shah & Patel, 2018). Quarterly review of the rapid problem-solving worksheets could add value to other areas as best practices can be shared.

Figure 2-16 Rapid problem-solving worksheet

Problem:				
Root cause: 1. Why? 2. Why? 3. Why? 4. Why? 5. Why?	Plan to resolve: Containment	Responsible	Member	Date
Operator: Supervisor: Quality:	Prevention / Poka-yoke	Schematic		

Source: (Pirasteh, 2010)

2.5.4.6 Remove the constraint and stabilise

Process performance dashboard and takt boards gives the workers understanding on how their work is being measured. Key performance indicators (KPI) need to be explained and should highlight targeted quality, costs and performance (Pirasteh, 2010). Workers involved will have the information required to identify any performance gaps in the metrics. As this is a crucial stage, it would be sensible to link it to an incentive scheme (Sproull, 2009a). The dashboard should indicate real time information providing the cross functional team with information such as global, throughput and other critical performance measures. It is important to involve the human resources (HR) as an active member of the iTLS activities. HR can assist in ensuring that all improvement processes are harmonised with the company’s policies and procedures. This integrations can connect worker performance measures to incentives, promotions and compensation (Sproull, 2009a).

2.5.5 Linked to the study

The iTLS methodology concentrates on the all-round reduction of restraints, waste and variations assuming it in-turn manifests itself into primary and secondary results that are tangible (Pirasteh, 2010). For example:

- Focusing on variation reduction will result in more consistent and predictable process output, which can be measured with basic statistical engineering – and thereby improving quality.
- Focusing on waste reduction will improve and streamline the flow. Any unnecessary product touch-time results in more in-process inventory costs and less profit.
- Focusing on constraints will improve throughput volume. The constraint is the problem, and should thus be the focus.

Taking into account the service and product configuration at face value to improve the process and system, the selected chemical packaging plant can possibly benefit with the integrated iTLS methodology in the following ways:

- TOC can create systematic alignment and focus on leverage points to achieve maximum throughput of the chemical product. The throughput of the chemical packaging bags are limited by the performance of the eight automated packaging units and their operators, who do not seem to perform optimally.
- Lean techniques can be applied to reduce the lost opportunity that waste and storage represent. One outsourced pack line operator is designated to each packaging unit, which could indicate wasteful use of resources when investigated.
- Six Sigma tools are deployed to reduce variation and ensure consistent results in the chemical colour, properties and contamination, in order to minimise customer complaints.
- As a holistic view: Improved ability to monitor, detect and respond to difficulties can yield faster response times to bottle-necks / waste, improved tuning processes, and lower implementation costs - thus ultimately reducing production time and cost. These are savings that can be passed on to the client for a better customer-focussed approach.

2.5.6 A Case study of iTLS implementation (Sproull, 2012).

A global electronics manufacturing company based in California decided to hire consultants to deploy a continuous improvement methodology at their 21 plants (Sproull, 2012). The company employed 45 000 staff of which 211 team leaders were frustrated with the then 'current state' of plant production projects. Due to growing demand from its main customers for lower prices and higher quality, upper management tried to maintain a steady culture of continuous process improvement, but failed to realize the tangible benefits. Their fragmented approach (at separate

plants) to using lean, theory of constraint (Stock), just in time (JIT) as well as six sigma (6σ) was aimed at exposing and eliminating constraints. Both lean and six sigma were locally deployed and returned some success values however, management felt that a combined and integrated approach could yield even better results, giving their global footprint of 21 plants (Sproull, 2012).

The company's consultants designed an integrated methodology experiment that could complement the existing lean and six sigma practices now known as iTLS. Each production facility (plant) was capable of prototyping, designing, manufacturing and distributing products. iTLS was deployed as a pilot programme, and data collected for more than two years. Each plant had a methodology assigned to them that complemented their unique local preferences and experience within a specific approach. According to Sproull (2012) the methodologies were assigned as follows:

- Six Sigma was applied to 11 plants
- Lean was assigned to four plants
- TLS was assigned to six plants

Throughout the pilot programme, the plants completed a total of 105 projects. Each project was documented and tasks studied. Trainers and plant personnel were unaware of the comparative study so as to remove potential bias. Verifiable financial benefits were the chosen criteria of efficiency, as most organizational leaders are accustomed to being judged on financial measurements.

Other key measurements used as drivers for project selection were process indicators such as: on-time delivery, inventory reduction, scrap expense, cycle time reduction, customer returns as well as warranty costs.

Applying the TLS model

The order of action starts off with the application of the TOC management philosophy, in order to identify possible and existing constraints:

1. Identify the constraint.
2. Exploit the constraint.
3. Subordinate any other actions to the said constraint.
4. Elevate the constraint.
5. Avoid undesirable lethargy.

This identifies the problem at the systems level, after which a problem definition was created to address the specified bottleneck. Here, the first four steps of the Lean process (six steps) are applied, as they identify waste and assist users to target ways to achieve improvement.

1. Specify the value.
2. Identify the process value stream of creating and delivering goods.
3. Cause value to flow uninterrupted.
4. Allow the client to pull value from the producer.

In conjunction with the above steps, the Lean 5S's should be considered, i.e.: sort, simplify, scrub, standardise, sustain. Using the 5S's brought order and discipline to the process, and helped sustain the gains achieved. A value stream mapping process that is used to create a "wasteless" value stream is supposed to simplify actions, in order to eliminate extraneous queues, and minimise inventory and work in progress.

Next, pull systems should be implemented that ensure material is only issued once a signal comes from the user. The end result should be products developed to customer requirements in the correct amount, at the correct time and delivered to the correct location, using an established process flow. Process variables should be performing consistently and repetitively with negligible variability. This leads up to Lean's last two steps, Step 5 and Step 6:

5. Pursue perfection
6. Implement with agility

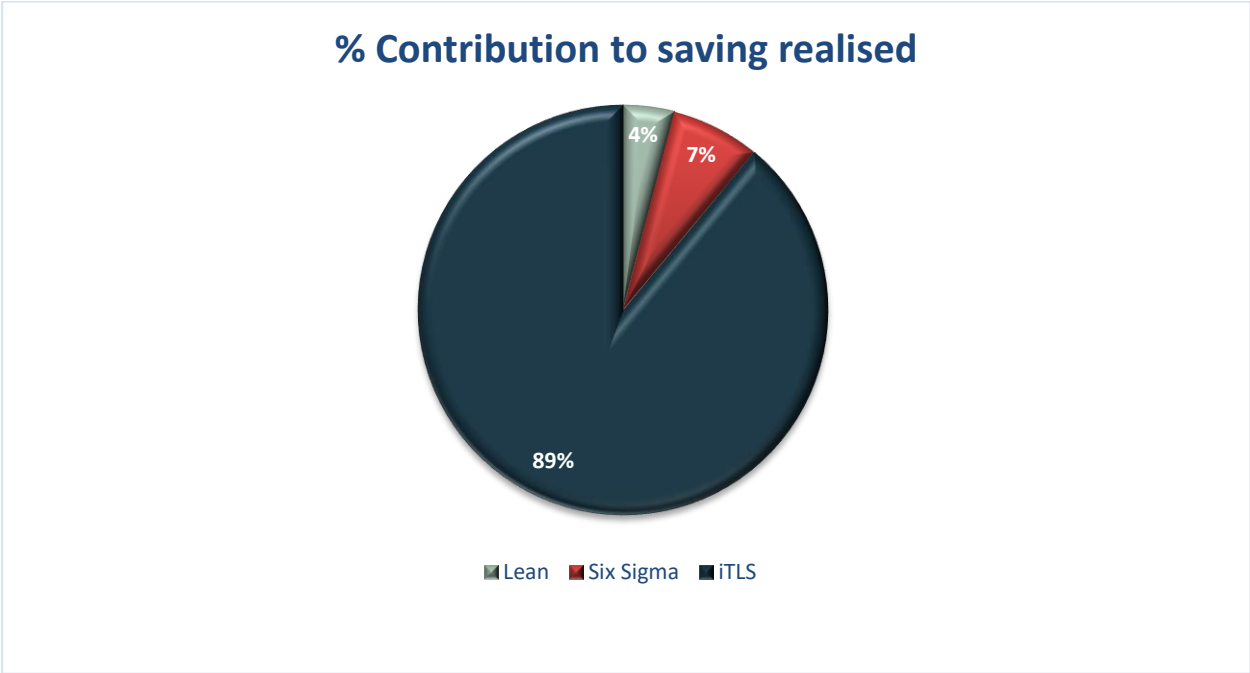
Six Sigma's "design-measure-analyse-improve-control" should be applied at this stage to pursue perfection. This would enable workers to: isolate the sources of deviation that were identified: systematically minimise and then

remove those variations. Design of experiments may be required during this stage as a quality management technique used to assess the result of the changes to any input process variables – cause and effect experiments. These experiments will assist in determining optimal settings for critical influences.

Penultimately, once the most favourable settings have been established, operating procedures and control mechanisms need to be put in place. The poka-yoke, or other mistake-proofing methods should be implemented as an early warning system that aids in sustaining the process gains and prevent process variability. Statistical process controls and techniques should also be applied during these final stages, so as to monitor and adjust operations.

Lastly, process audit measures should be designed and put in place for continual performance measurement as part of a preventative action plan.

Figure 2-17 Case study: Percentage contribution to saving realised



Source: (Sproull, 2012)

Which method was most effective?

The various Lean and Six Sigma projects were compared. It was established that there was no noteworthy statistical difference between the financial benefits. The iTLS projects yielded more than four times the financial benefits of either Lean and Six Sigma. The plants that used iTLS were able to do more projects in the same amount of time, as there was less re-working to be done.

Relative effort expended by the implementers of the methodologies was measured and the results showed that the iTLS projects had only trained three people per project, as opposed to Lean and Six Sigma's eight people per project (on average). Therefore, it delivered four times the financial benefits with half the training investment, which is a substantive saving in terms of investment. iTLS was responsible for 89% of the savings reported, in spite of being used at less than 30% of the production plants. Six Sigma came in at second place with a 7% saving; Lean came last, with a mere 4% saving.

2.6 Chapter conclusion

In this chapter, an overview of three foundational methodologies namely: Theory of Constraints, Lean manufacturing and Six Sigma has been discussed along with the integrated iTLS methodology. Under TOC we found that it is a methodology used to focus the team on the single most contributing factor limiting the organisation from achieving its goal. This was found to fit in well with the iTLS as it provides a good starting point from where the team can proceed to improve the throughput of the entire organisation. The Drum-Buffer-Rope tool was discussed to provide more insight on how to improve throughput. The lean manufacturing methodology highlighted the house of lean and an overview was provided on selected lean tools such as: value stream mapping, the culture of Kaizen, eight forms of waste, 5S, Just-in-time and the overall equipment effectiveness.

Lean principals are implemented in the iTLS process to guide the improvement initiatives by identifying waste in the organisation and reducing or eliminating it. Six sigma's data driven approach was discussed which emphasised on a process of consistency. The Pareto, voice of the customer, histograms and cause and effect analysis was assessed. The six sigma is used in the iTLS to pursue perfection and to protect the organisation from falling back into old process or procedures. The iTLS methodology was introduced and an evaluation was done on how the discussed three methodologies fits into the process. An enlightenment was given on the benefits of iTLS compared to single methodologies. Each of the seven iTLS process steps was discussed in detail. A case study was the presented of an iTLS application versus lean and Six Sigma, which showed the huge benefits of iTLS.

CHAPTER 3: RESEARCH DESIGN

Figure 3-1 provides an outline of Chapter 3 and how it has been laid out.

Figure 3-1 Chapter layout



Source: Author (van Wyk, 2018)

3.1 Introduction

A research design outlines the process to be followed by the researcher for collection, measurement and analysis of data (Bell *et al.*, 2018). This blueprint of the logical progression of the investigation ensures that the research problem is addressed, whilst adhering to ethical standards and standards for data validity and reliability.

3.2 Research approach

A multi-level longitudinal technical analysis was conducted, as the same repeated measures were scrutinised over three performance indicators with multiple data collection points. Monthly performance, quality and production values were analysed from two fiscal years, i.e. July 2016 to June 2018. Therefore, the time series of 24 months or waves of measurements exceeds the minimum sampling time series of 20 waves for a longitudinal analysis (Trochim & Arora, 2016:6).

Quantitative research methods were mainly used in this research, due to statistical values used, which are fixed and measurable. According to Silverman (2016:56), quantitative research is conclusive in its purpose, as it is used to quantify a problem, discover patterns, produce comparisons, generalise data and categorise solutions, in order to prevent problems from re-occurring.

Quantitative research aims to provide reliable projectable results in order to limit variables and establish cause and effect within extremely controlled conditions which can be directly aligned with iTLS methodology resolves (Bloomberg & Volpe, 2018). It also aims to test, measure and improve any such theories or hypotheses. The basic diagram below indicates the course of action that should lead to the answer of the research question.

Figure 3-2 Research approach followed



Source: van Wyk (2018)

To further extend on the course of action diagram, a list explaining the process of the research design is provided regarding how data will be interpreted by incorporating both the iTLS methodology and the internal reports:

- Problem identification.
- Identify suitable methodology.
- Create a theoretical framework from the literature study, which will support the phenomenon.
- Research approach: a multi-level longitudinal study will be done.
- Data collection: Internal secondary data.
- Statistical methods - systematic review
 - Interpret the mean / median and generate and generate percentiles, where necessary.
 - Generate bar charts to see patterns of logged reasons of defects / bottlenecks / waste.
- Interpretation of data:
 - Identify the constraint with regard to TOC by analysing the actual daily production reports.
 - Identify sources of waste with regard to Lean by analysing OEE Report and QAQC Rejection Logbook.
 - Identify Process Variability with regard to Six Sigma by analysing the Customer Complaints Report.
- Answer research question and draw conclusions.
- Develop recommendations and state possible solutions.
- Propose an implementation plan for the study.

3.3 Data collection

According to Lewis (2015), data consists of fact or figures, either numeric or non-numeric, that can be used to draw conclusions. The nature of data can be described as either quantitative or qualitative: quantitative represents counts in either discrete or continuous form. Discrete data is the term used to describe data that is numeric and has a finite number of possible values; it therefore describes the type of data used in this study, as the number of production runs cannot be infinite. Its level of measurement can be referred to as Direct Interval Measurements, as all data collected shows meaningful intervals between measurements, but no true starting point (zero) (Taylor *et al.*, 2015). Therefore, the first sample of data to be used in this study can be described as: discrete quantitative internal secondary data that have a finite number of possible values, that are physically measurable quantities of volume and mass, and which are considered to be continuous (Quinlan, 2018 #104).

The internal data are collected in the form of statistical reports that are directly linked to the planned, rejected, re-melted and actual manufactured chemical product produced according to client orders. A population refers to the complete set of data elements that will be used. A sample is a portion of the population selected for analysis - in this case it is the selected reports. According to (Quinlan *et al.*, 2019), a statistic is the characteristic of a sample, presumably measurable. Fortunately, the internal data collected had already been passed through a statistical process, as it was collected from the primary source using OEE and SAP systems.

Computerised systems measure input and output constantly, and this datum is sent to computers, where it is collectively measured and statistically modelled into organised (understandable) units, such as tonnage and volume. Because the data is continually measured and stored, it can be referred to as historical data (Gandomi & Haider, 2015) . Data is mainly be displayed in percentages on charts for easy understanding. The secondary internal data was accessed through the organisation's intranet service, by signing into the collective data reports from different departments; the production planning details were obtained from the production management team of the solidification and packaging plant. The mass balance, OEE and rejection logbook were gathered from the industrial engineering section at the packaging facility. The customer complaints data was obtained from the Quality Department, which services the entire business.

3.4 Sampling

This study will analyse internal company data reports of the selected chemical packaging facility (secondary data). The aim was to analyse the secondary data through the iTLS methodology, in order to: identify and quantify bottlenecks (Stock), wastages (Lean) and variation issues (Six Sigma) and to then to assess the root cause, and determine possible recommendations and solutions for conclusion purposes. Therefore, the statistical sample consisted of the following:

- The Actual Daily Production Report. This report is compiled daily by the production foreman and indicates why daily production schedules were not fulfilled.
- Scheduled production plan from the sales department. This report indicates amounts and product category is required per order.
- Mass Balancing and Rejection Dashboard to compare what was supplied to the facility in comparison to what percentage was rejected versus what percentage was actually delivered.
- Overall Equipment Effectiveness Report (OEE) to measure the performance of the eight automated packaging stations with regards to; rejections per station, idle time, availability and break-downs. What could have been packed and what was actually packed (total production values) over the two-year (24 month) period.
- QAQC Rejection Logbook to analyse exact reasons for rejections and overall quality defects of the facility. The data was captured from the daily reports of the operators on a worksheet.

The sampling strategy will consist of systematic sampling. Systematic due to the fact that the internal data is collected and presented systematically (numeric data that have and present meaningful intervals such as fiscal years and monthly reports) (Sekaran & Bougie, 2016).

3.5 Data analysis

According to Hair Jr *et al.* (2015), researching secondary data should be done before researching primary data as a way to gather insight and understanding of the subject to be studied. It is easily obtainable, cheaper and involves less time. All six reports are separate units of analysis and each serves as a parameter to the study population, however, they are generalised and must be grouped, correlated and amalgamated further for the purpose of this study, and in order to draw conclusions regarding the research question. A percentage is a parameter to the study population (eight automated pack lines) and not a statistic. A parameter is a characteristic of the population (the site) whereas a statistic is a characteristic of a sample – in this case, the selected reports/

The OEE will be used as the main unit of analysis, the meta-data in the other five reports was used to substantiate, prove, fill in gaps where necessary, and give reasons for defects, so as to obtain a complete picture of the sample population.

According to Vinodh and Ruben (2015), OEE measures three critical factors namely availability, performance and quality to provide an accurate picture of the effectiveness of the manufacturing process. There is a simple way to calculate the OEE (Vinodh & Ruben, 2015):

Equation 2 OEE

$$OEE = Availability \times Performance \times Quality$$

Source: (Tang, 2017)

The ratio of Run Time to Estimated/Planned Production Time equals to the Availability measured.

Equation 3 OEE: Availability

$$Availability = RunTime \div ProductionTime$$

Source: (Tang, 2017)

Ideal Cycle Time is obviously the fastest time it could take to manufacture the goods.

Equation 4 OEE: Performance

$$Performance = (IdealCycleTime \times TotalGoodsCount) \div RunTime$$

Source: (Tang, 2017)

Quality takes into account good parts, produced parts that meet quality standards with first-time run, as well as parts that need rework.

Equation 5 OEE: Quality

$$Quality = GoodCount \div TotalCount$$

Source: (Tang, 2017)

Knowing how the OEE and primary nature of production losses are measured, comparison and analysis can be done on consecutive data per pack line, as per the following example;

Other statistical controls, tools and techniques (iTLS) used within the data analysis will include the following:

- Arrhythmic Mean: The average. It simulates a list of numbers (in this case manufactured tonnage) divided by the number of items on the list (in this case eight automated packing machines). This will give the average tons produced by the pack line over the interval times measured. The average is to be combined with the product specification upper and lower limits, that determine whether the product is in or out of spec. This forms part of the standard deviation which will be described below.
- Standard Deviation (six sigma): the distance/difference for each measured value in the data set from the mean/average. This difference is known as the residual. The summation of the squared residuals is divided by the number of samples minus one, then, finally the square root is calculated. Standard deviation forms the basis for six sigma and the number of errors allowed in the process should continue to decrease.

Equation 6 Standard deviation

$$\sigma = \sqrt{\frac{\sum (x - \bar{x})^2}{n}}$$

σ = standard deviation

\sum = sum of

x = each value in the data set

\bar{x} = mean of all values in the data set

n = number of value in the data set

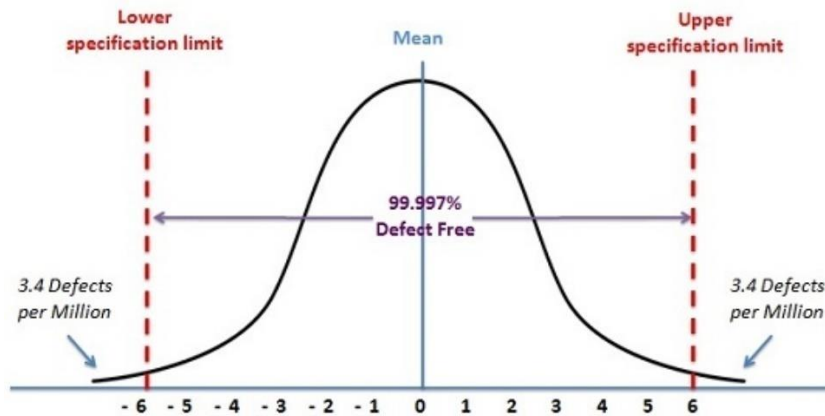
Source: (Koripadu & Subbaiah, 2014)

The narrower the specification limits, the less room for deviation (Bateh & Farah, 2017). A product specification may be written as follows: 10 ± 2 mm. The first number (10) denotes the average, the second number (2) denotes the error permissible from the average/mean. Therefore, the product upper limit would be 12 and the lower limit would be eight.

- Distribution, (six sigma) upper & lower limit bell curve: Normal Gaussian distribution is the most common frequency distribution one will come across. The centre line is the mean/average with half of the measurements (deviations produced) are above and other half is below. The curve, which is bell shaped, getting closer to zero yet never quite reaches the line. The wideness of the curve is determined by the standard deviation as discussed above, so too the upper and lower limits. Three sigma is the benchmark for acceptable standards in manufacturing quality since the 1920s, this may be a valuable standard when considering the chemical packaging facilities' limits.

Even though three sigma may state that customer satisfaction will be 99.74%, in real life it is only about 93% (Mitra, 2016)

Figure 3-3 Six Sigma Bell Curve



Source: (Demchuk & Baitsar, 2014)

- Defects per unit and per million opportunities (DPU and DPMO – six sigma):
 An end product (unit), in this case one ton of chemical product produced to client requirements-, may have different types of defects. Whereas when an item is defective, it is not acceptable and is rejected. In some instances, flaws may be acceptable; however, in the selected packaging plant, any of these flaws identified, the product will be rejected, as it constitutes a defective product. This means that there is only one opportunity of defects per unit (per ton) in the sample. To calculate the ratio of defects per million opportunities one needs the total number of defects found in the sample (total amount of tons produced over the two-year period) and divide that by the total defect opportunities as listed above multiplied by one million. The calculation can be seen in image ... below. The DPMO yield indicates the sigma level of the plant in terms of image ... where for example 2σ signifies 69.15% of goods produced to quality standards.

$$DPMO = \left(\frac{\text{total number of defects found in a sample}}{\text{total number of defect opportunities in the sample}} \right) \times 1,000,000$$

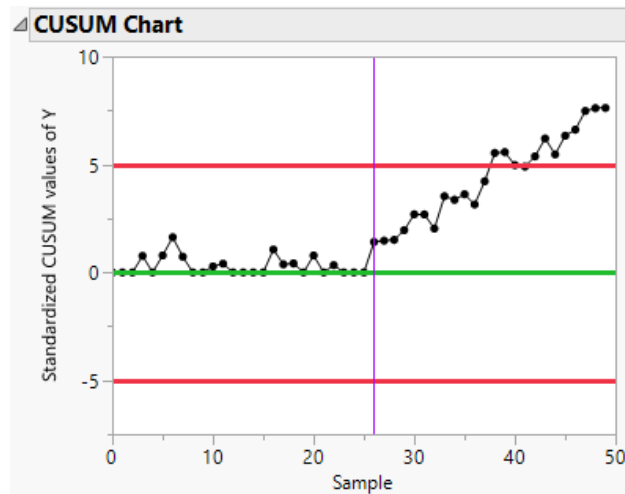
Table 3-1 Sigma level, DPM and Yield

Sigma Level	Defects per Million	Yield
6	3.4	99.99966%
5	230	99.977%
4	6,210	99.38%
3	66,800	93.32%
2	308,000	69.15%
1	690,000	30.85%

Source: (Alsyouf *et al.*, 2018)

- Measures of Dispersion (six sigma tool): refers to the extent to which data is distributed around a central value, which describes the variability of the sample population. Relative measures of dispersion are the coefficients of range; dispersion; and quartile deviation.
- Cumulative Deviation/Cumulative Sum (CUSUM) control chart (lean tool): This statistical quality control chart is used to monitor change within a process where the mean is the specification of a quality target value. Upper and lower control limits are the deviation limits that are estimated. When an out-of-control process crosses these boundaries, an assignable cause can be expected. Using the planned vs actual tonnage packaged, this chart can generate this chart to show the cumulative information of previous and current samples taken at given times, in this case hourly packaged rates over a monthly basis over a fiscal two-year period - in order to identify out-of-control progressions in the process mean. On an excel spreadsheet deviation is planned tonnage minus the actual tonnage and cumulative deviation is adding the current period deviation to the preceding deviation. In doing this, one will be able to see whether deviations are growing, stagnating or decreasing.

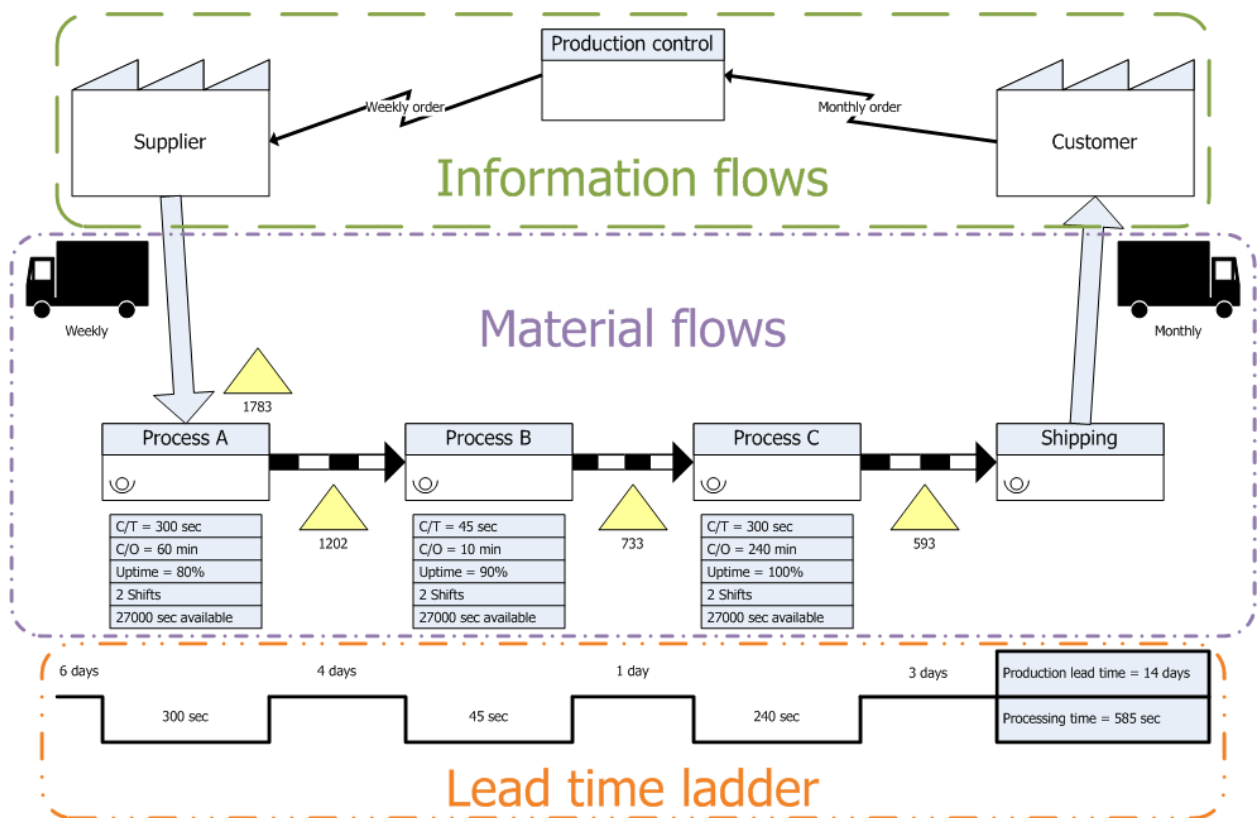
Figure 3-4 Cumulative sum control chart



Source: (Conger, 2015)

- Mass Balancing (Stock): Mass balance accounts for all materials in a process, as it considers input, output and the distribution of substances between streams within the process. Also referred to as material balance, it accounts for mass flows, materials entering and leaving the system.
- Pareto Chart (Six Sigma tool): When analysing a broad range of causes of problems in a process (automated pack line), a Pareto chart is used to look at the frequency of problems (rejections) and where they occur the most, by looking at specific components. The chart is named after Vilfredo Pareto and is represented as a bar chart that includes a line graph. The descending bars indicate the individual values (measurement tool, in this case percentage of rejection rates) related to specific problems identified, and the cumulative total represents the line. The principle of factor sparsity states that, with a large number of events, approximately 80% of the effects originate from 20% of the causes. This is why it is also known as the law of the vital few.
- Process flow diagram (lean): Is a visual way to identify activities that do or do not add value.
- Value stream map (lean): this is another visual indication of the steps taken from product creation to delivering it to end customer. The inputs for a VSM include all the resources you leverage to produce a product. The value adding steps, as well as the attendant non-value adding steps as indicated on a map of the process flow as shown in figure X.

Figure 3-5 Example of Value Stream Map



Source: (Mason *et al.*, 2015)

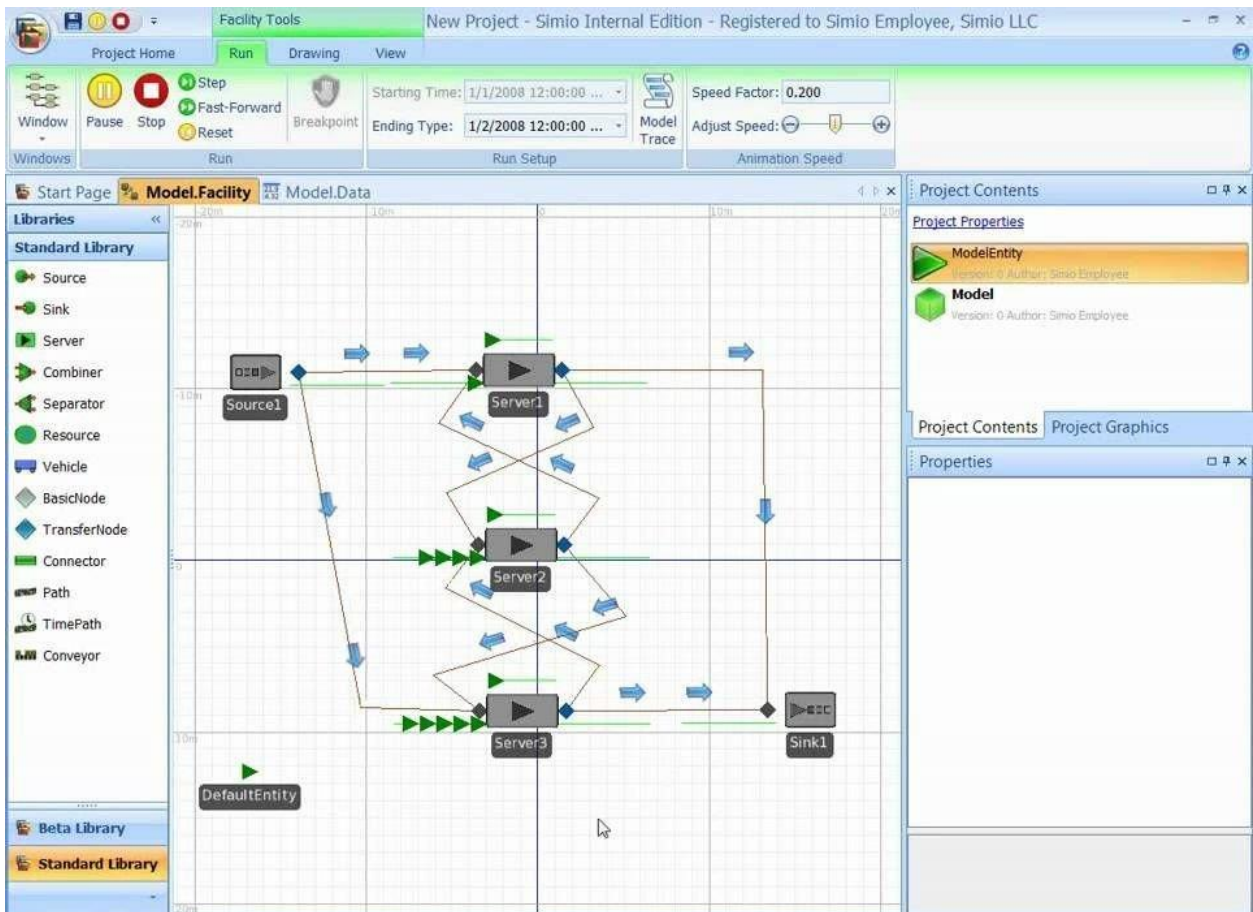
Histograms (Six Sigma tool): A graphical method used to represent the distribution of data over a continuous interval or certain time period. The data value is grouped into ranges and shown as bars. Each bar in a histogram represents the tabulated frequency at each interval. Histograms provides an estimate as to where values are concentrated, what the extremes are and whether there are any gaps or unusual values.

Conveyor simulation (TOC tool): Development of a simulation model was a result of a need to conduct throughput analysis on the system. A simulation model was developed in order for the effect of conveyor system on throughput to be analysed. Simio Simulation Software was selected because:

- Creating new objects or modifying an existing object does not require advanced object-oriented programming skills.
- The cost of student licence was low
- Learning material is freely availability.
- Full features are available in student's version

Simio is a simulation software that simulate the facilities capabilities. The technology’s primary Simulation Module delivers an authentic object-based 3D model that can highlight any constraint in the system.

Figure 3-6 Example of Simio software simulation program



Source: (Pegden, 2018)

3.6 Conclusion

In this chapter, the research design was discussed, highlighting that the study involved multi-level longitudinal analysis. The data collection and sampling sections indicated that the process entailed six sampling sources in the organisation and that the data used is secondary data. This statistical sampling strategy was used to systematically collect and present the data. The data analysis reflected on a range of tools and techniques that were used as part of the analysis phase of this study. The analysis and results are discussed in the Chapter 4.

CHAPTER 4: RESULTS AND FINDINGS

Figure 4-1 provides an outline of Chapter 4 and how it has been laid out.

Figure 4-1 Chapter layout



Source: Author (van Wyk, 2018)

4.1 Introduction

This chapter details the results and findings of the research conducted on a selected packaging facility. The main objective was to identify any inefficiencies related to waste, throughput and quality using the literature study in Chapter 2 as the basis. The research design was determined to statistically evaluate the secondary data gathered from the facility – as indicated in Chapter 3. This chapter provides an evaluation of three areas of focus, namely waste, quality and throughput. It ends with a chapter conclusion.

4.2 Evaluation of waste

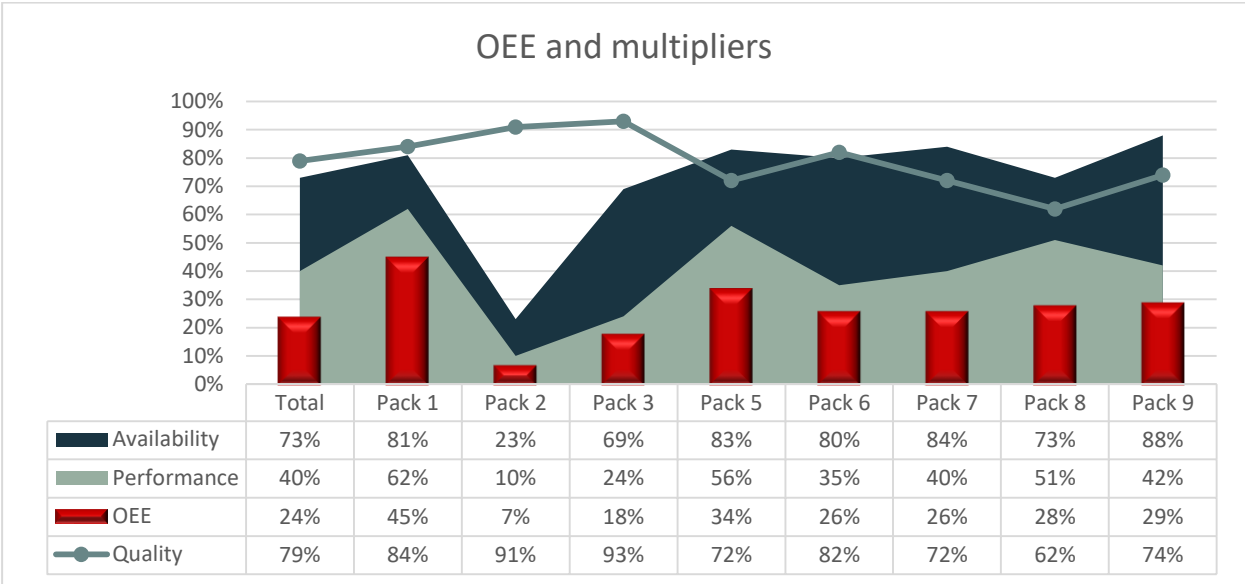
In order to identify if the packaging facility operates with a focus on value added operations, an evaluation was done by means of selected Lean tools. Overall equipment effectiveness (OEE) and eight forms of waste were statistically evaluated against the conditions of performance.

4.2.1 Overall equipment effectiveness

The manufacturing facility makes use of software and data collected directly from the bagging machines and robots. The OEE software took samples every second and the data received from this system was summarised into hourly rows and then grouped into monthly rows, according to each packaging line. See Annexure B. From the results, it was found that the OEE software was not functioning as per design, with the only accurate variable that could be used being availability of machines. The performance column (actual), scheduling (plan) and number of rejections (scrap) for each packaging machine were inserted into the calculations manually. The data was retrieved from the actual daily production report, the scheduled production plan and the QAQC rejections logbook, respectively. The number of samples amounted to 116 640 000 cells and this was summarised into 4 723 cells.

Figure 4-2 show the results of this analysis of the OEE and its multipliers. The data indicated that: bagging station one performs the best of the eight automated machines, at 45% OEE; bagging station 2 performs the worst, at 7% OEE. The entire packaging facility’s manufacturing effectiveness is equal to 24% OEE.

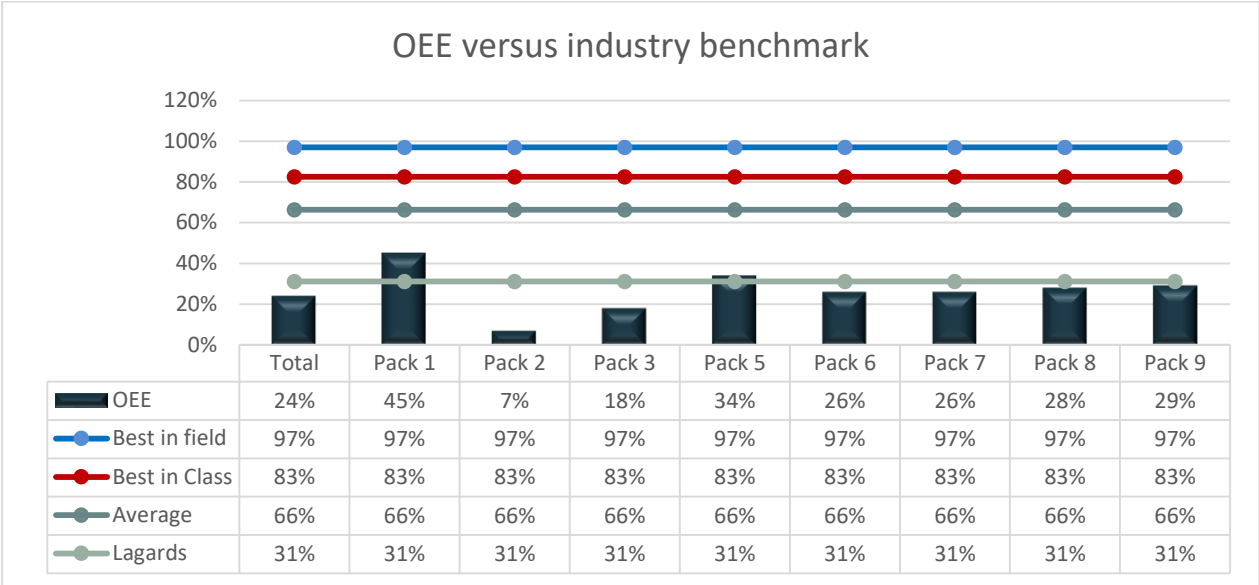
Figure 4-2 OEE performance per packaging line and its multipliers



Source: (van Wyk, 2018)

By comparing the outcome (24% OEE) to industry benchmarked packaging plant, the results show that the facility is operating at below the lowest performer’s level -labelled laggards in Figure 4-3 (Sage, 2018). The research done by (Sage, 2018) indicates that 29.9% of all packaging facilities operate below 31% OEE. 44.9% of the company’s achieved a 66% OEE and 25.2% of companies are performing at OEE values between 83% and 97%. This indicates that the facility is performing at a level below the industry average.

Figure 4-3 OEE compared to industry benchmark

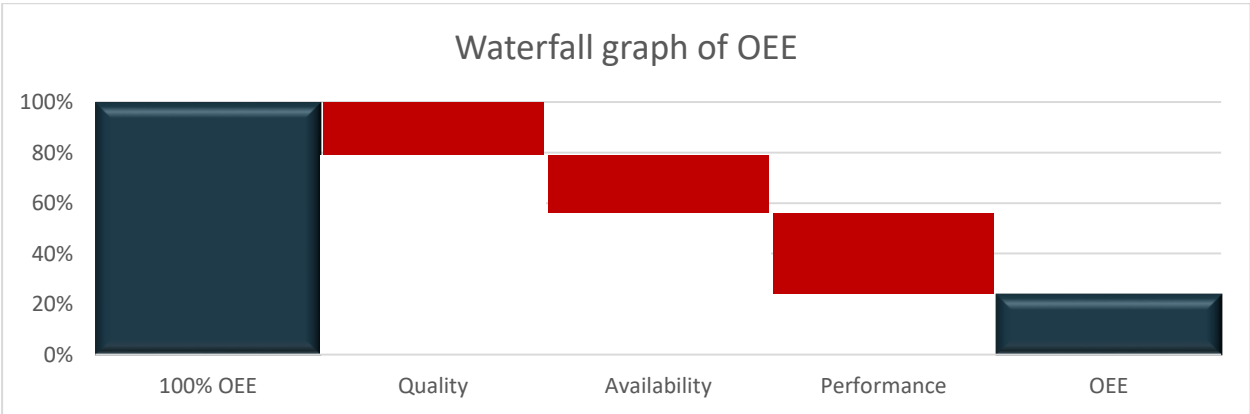


Source: (Sage, 2018; van Wyk, 2018)

The biggest contributor to the low OEE score is performance. The waterfall graph provided in Figure 4-4 shows that performance accounts for the largest portion of the total. In order to drill down into the results, each multiplier of the OEE equation was evaluated. The formula for calculating the OEE is shown below (Equation 2 OEE).

$$\% OEE = (\% Availability) \times (\% Performance) \times (\% Quality)$$

Figure 4-4 Waterfall graph of OEE



Source: (van Wyk, 2018)

4.2.1.1 Availability

Availability of the facility was 70%. Availability measures the time the machine was available to be run. A score below the benchmark of 90% indicates a high downtime figure. Downtime can result from a number of breakdowns or long set-up and adjustment time periods. Downtime is a waste that does not add value to the customer. The selected packaging facility's availability was calculated using the following formula:

Equation 7 OEE: Availability equation of facility

$$\% \text{ Availability} = \frac{(\text{Machine uptime})}{(60)} \times 100$$

Source: (Tang, 2017)

The availability is highly dependent on the production plan, as cleaning and maintenance activities are scheduled according to non-productive periods. In order to accurately evaluate the availability, equipment availability should be assessed when it is planned to manufacture product. By comparing the formula to the research done by (Tang, 2017), it was found that the availability should only include the time that the machine is scheduled, planned or assigned to run. This can be done by comparing availability to days when production was planned.

4.2.1.2 Performance

Performance recorded the lowest score of the OEE multipliers at 40%. The industry benchmark for performance is 95% and a score of 40% indicates that there is a large amount of waste in the system. Low performance specifies wastes such as idling, reduced speed and stoppages. When considering the performance multiplier, we need to distinguish what variable is impacting the overall value. The formula used was:

Equation 8 OEE: Performance equation of facility

$$\text{Performance \%} = \frac{(\text{Actual product packed})}{(\text{Design capacity}) \times (\text{Availability})} \times 100$$

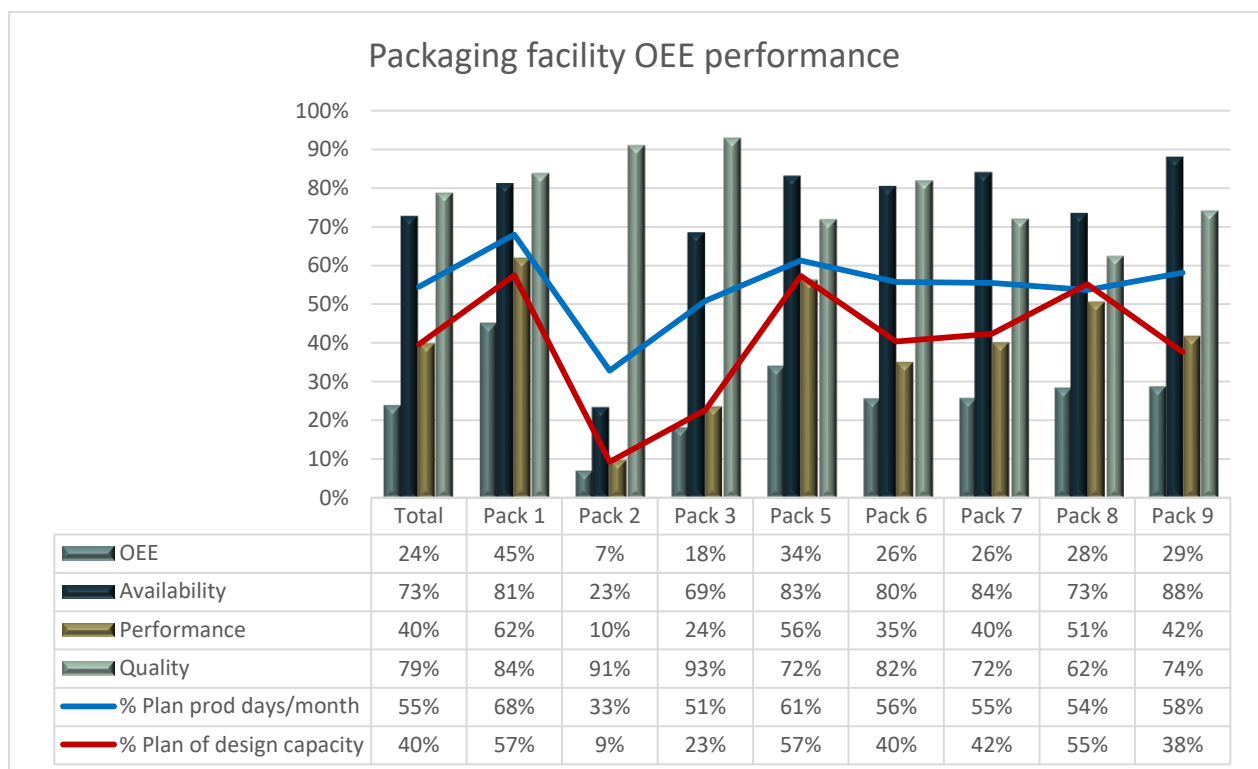
There three variables:

- The design capacity variable ranges from 23.5 to 34.5 tons per day according to each machine's designed ability. This is a fixed value in the company's OEE equation, as it is determined by the designed intent of each piece of equipment.
- The availability variable is discussed in paragraph 4.2.1.1

- The final variable is the actual product packed. It was measured by logging each bag that is filled by the bagging machine. If the machine was not scheduled to manufacture any product, this variable would be low.

Thus, if the production plan schedule is low, it will affect two of the variables in the performance equation, namely availability and packed product. The percentage planned manufacturing days per month for overall utilisation is 55%. The percentage production plan was found to be at an overall rate of 40% of its design capacity. This indicate that the facility is idling, performing only approximately half of the time and doing so at a low yield. In Figure 4-5 it can be seen that the production plan in days and capacity has a direct relation to the performance. This confirms that the packaging system is capable of performing at a higher rate and that the demand needs to be increased, as low production performance having a serious impact on the effectiveness of the equipment.

Figure 4-5 Packaging facility OEE performance per packaging line



Source: (van Wyk, 2018)

The facilities OEE system measures on a continuous basis in an environment with excessive capacity. This measurement is of less value, since the equipment is not used for the purpose for which it was designed, but rather for the purposes for which it was planned to be used. It was then determined that the OEE calculations used should be re-calculated using only the days on

which production was planned. This would deliver a more accurate evaluation of the waste within the facility.

4.2.1.3 Quality

The quality performance achieved a mean of $\bar{x} = 79\%$. Bagging machine 8 performed the worst, at $\bar{x} = 62\%$; bagging machine 3 performed the best, at $\bar{x} = 93\%$. The score indicates the percentage of quality throughput, and a low score would indicate waste due to quality losses. The formula used to calculate the quality factor is as follows:

Equation 9 OEE: Quality equation of facility

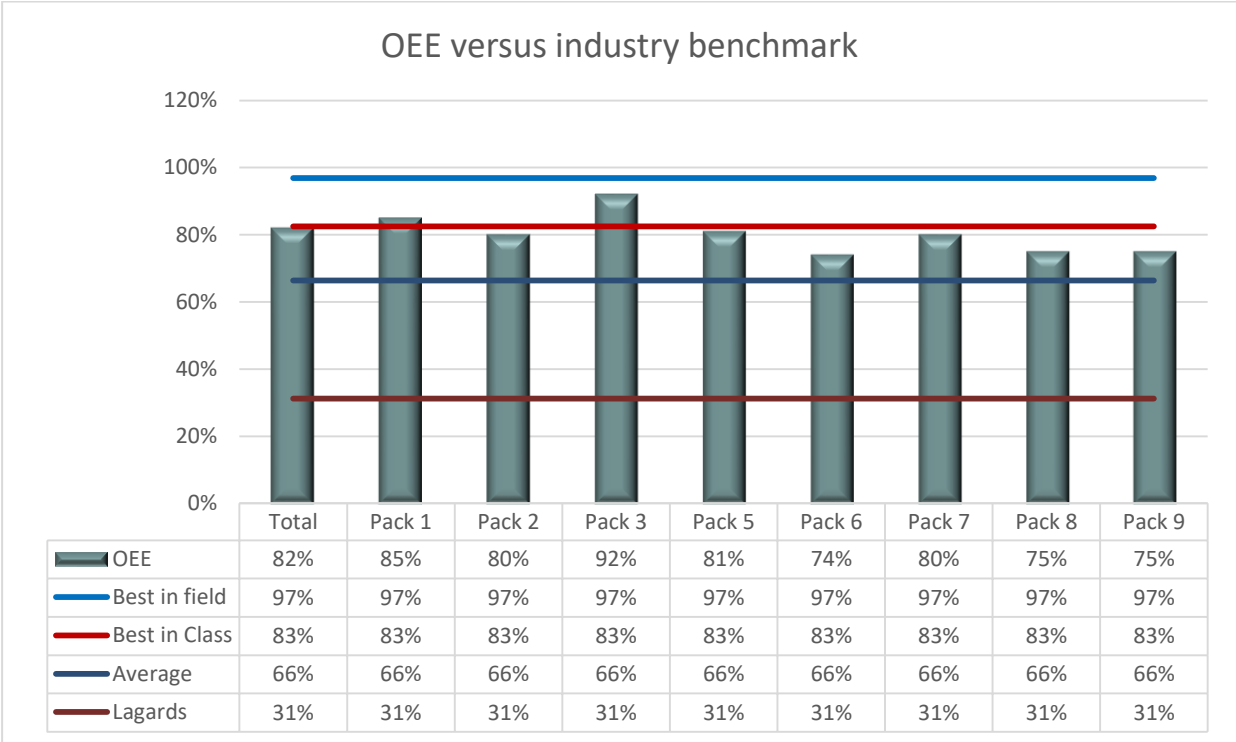
$$Quality \% = 100 - \left[\frac{(Product\ Rejected\ in\ Tons)}{(Product\ packed\ in\ Tons)} \times 100 \right]$$

Source: (Tang, 2017)

4.2.1.4 Overall Equipment Effectiveness according to planned rates

To identify if the performance is effective, when compared to planned rates, a new calculation was done to only include only the days on which production was planned. This drastically improved the OEE value of the facility to $\bar{x} = 82\%$ as Figure 4-6 indicate. Bagging station 6 performed the poorest at $\bar{x} = 74\%$; however, bagging station 3 surpass bagging station 1 with regard to effectiveness. Overall, the OEE score of 82% is just below the best-in-class benchmark of 83%. This is a regarded as an accurate reflection of the facility overall effectiveness.

Figure 4-6 Recalculated OEE compared to industry benchmark

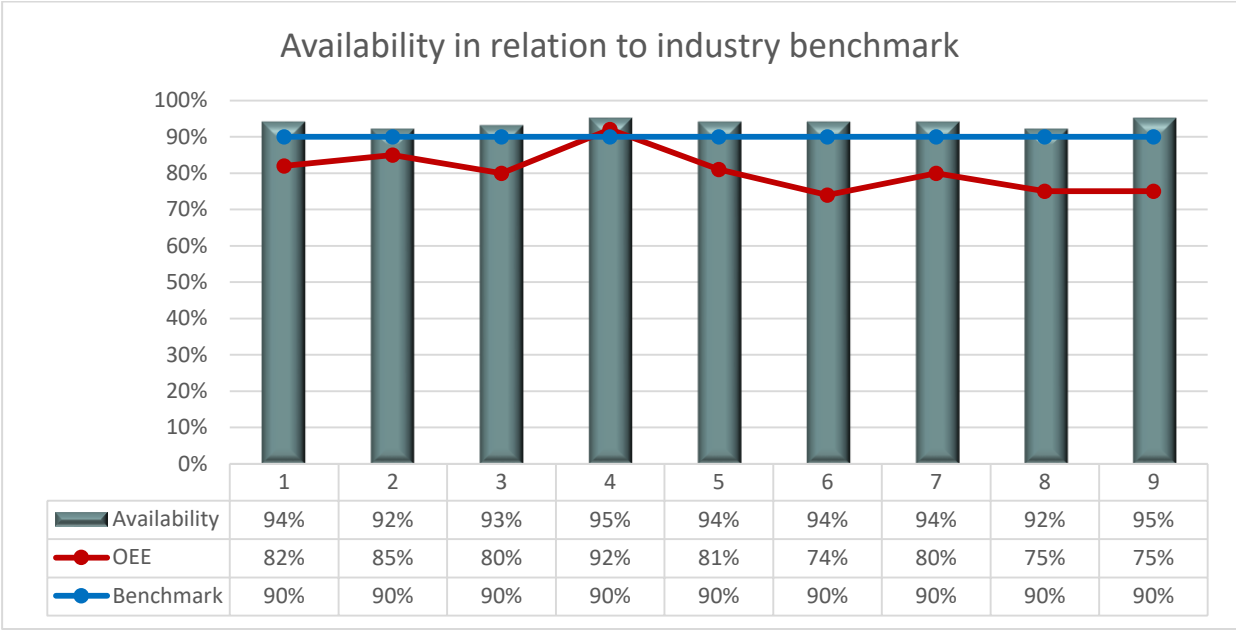


Source: (Sage, 2018; van Wyk, 2018)

Availability

Availability of the equipment achieved an overall mean of $\bar{x} = 94\%$ (Figure 4-7). This indicate that when the equipment needs to manufacture a product, it is not plagued by breakdowns or slow set-up periods. In relation to the 90% industry benchmark, the facility performed 4% higher and none of the automated packaging machines went below the value. This result shows that there is no waste with regard to downtime of equipment.

Figure 4-7 Availability in relation to industry benchmark

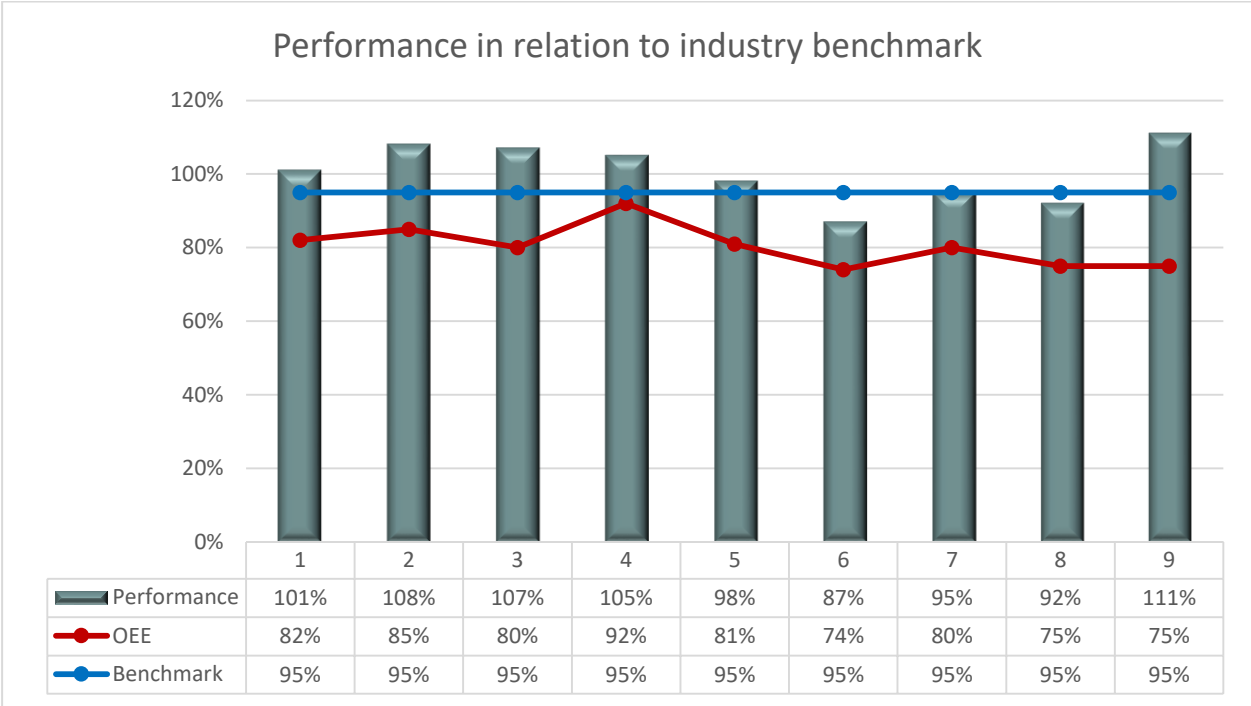


Source: (Sage, 2018; van Wyk, 2018)

Performance

The performance of the equipment increased to an overall mean of $\bar{x} = 101\%$ as Figure 4-8 indicate. The performance is evaluated as exceptional and is 6% above the industry bench mark. A score that is higher than 100% is possible, if the equipment produces more than it is capable of doing during the available periods. This suggests that waste due to speed of manufacturing is not a concern.

Figure 4-8 Performance compared to industry benchmark

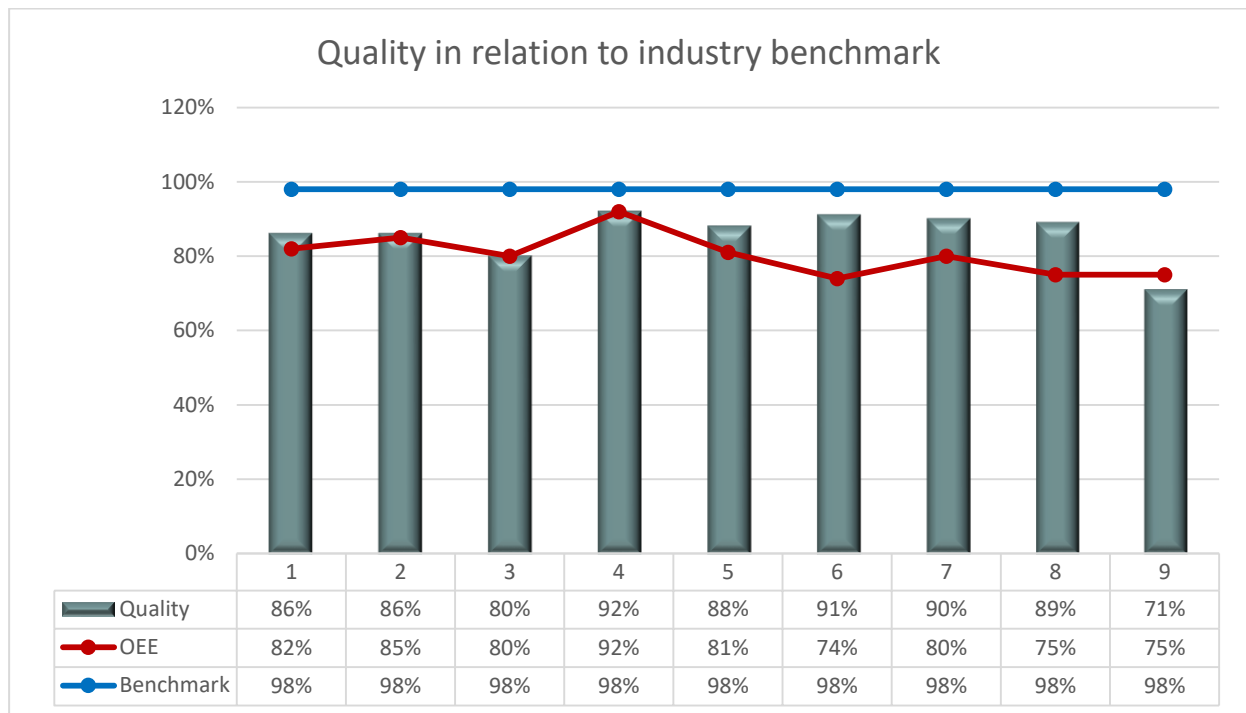


Source: (Sage, 2018; van Wyk, 2018)

Quality

Even though quality improved overall, from a mean of $\bar{x} = 79\%$ to $\bar{x} = 86\%$, this was the OEE multiplier that scored the lowest. It was also evaluated to be 13% below the industry benchmark of 99% (Figure 4-9). This indicates that there is waste in terms of quality performance. The result is that throughput is reduced, as quality loss will restrict the production yield.

Figure 4-9 Quality compared to industry benchmark



Source: (Sage, 2018; van Wyk, 2018)

4.2.1.5 OEE findings

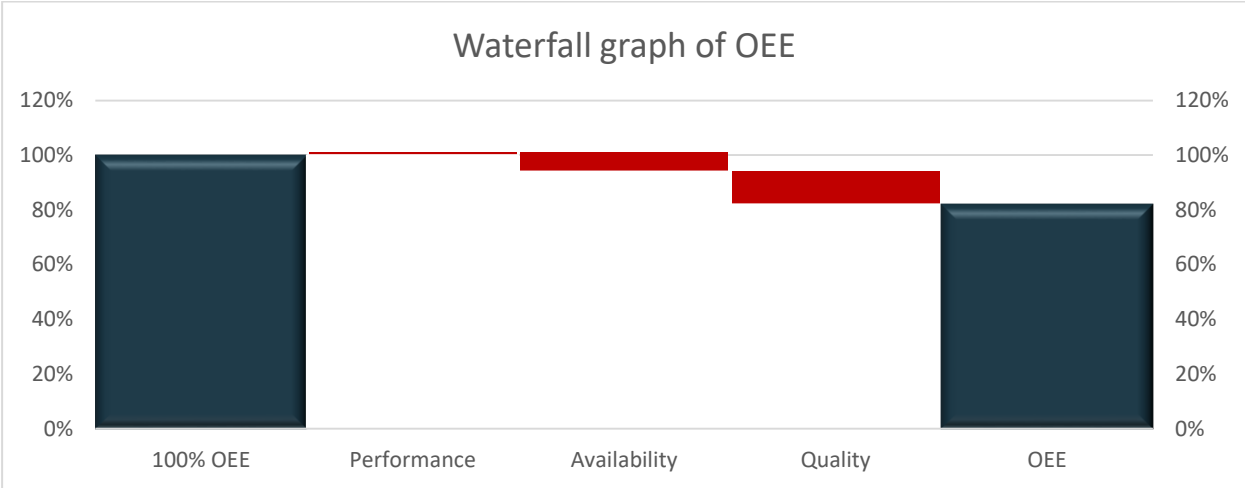
It was found that the OEE software used by the facility has two variables that are measured incorrectly, namely: performance and quality. It was also discovered that the OEE calculation of the facility takes unplanned periods into account. This contributed to a skewed result with regard to the effectiveness of the equipment, signifying low performance and availability. The OEE was calculated by only considering planned production rates, which revealed above-industry-benchmark performance and availability scores. This revealed that the biggest waste was a result of quality losses. This is also indicated in the waterfall graph in Figure 4-10. The quality losses measured in the OEE analysis only refers to bagging machine rejections. Quality losses also result in restricted flow of the process as scrapped product need to be re-worked.

Equation 10 Throughput

$$\text{Throughput} = \text{Actual production} - \text{Quality losses}$$

Source: ((Sage, 2018)(van Wyk, 2018)

Figure 4-10 Waterfall graph of recalculated OEE performance



Source: (van Wyk, 2018)

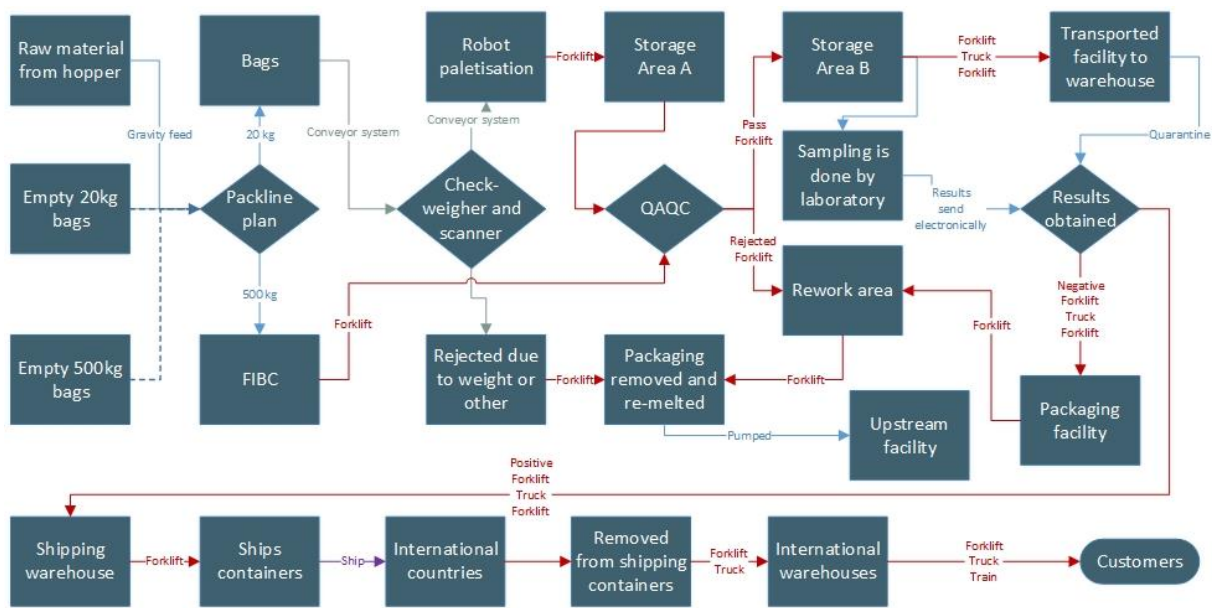
4.2.2 Lean’s eight forms of waste

According to Charron *et al.* (2014), non-value adding activities, also known as muda, account for 95% of all costs in non-Lean manufacturing facilities. These non-value adding activities can be evaluated as eight forms of waste. The eight forms of waste are, transport, inventory, motion, waiting, over-production, over-processing, defects and skills. Each of these are evaluated to identify the extent of the waste problem at the selected packaging facility.

4.2.2.1 Transport

A process flow diagram is used to depict the transport of products within the packaging facility. It was found that each pallet of product was transported 47 times before it reaches the customer. Each time a product is moved, there is an opportunity risk of it being damaged or deteriorating in quality. Transportation does not transform the product in any way, but results in cost being added to the process. However, it does play a big role in the supply chain, as shown in Figure 4-11. The cost of the forklifts, trucks, drivers and warehouse are all ultimately relayed to the customer, even though this does not add value for them.

Figure 4-11 Packaging facility process flow diagram

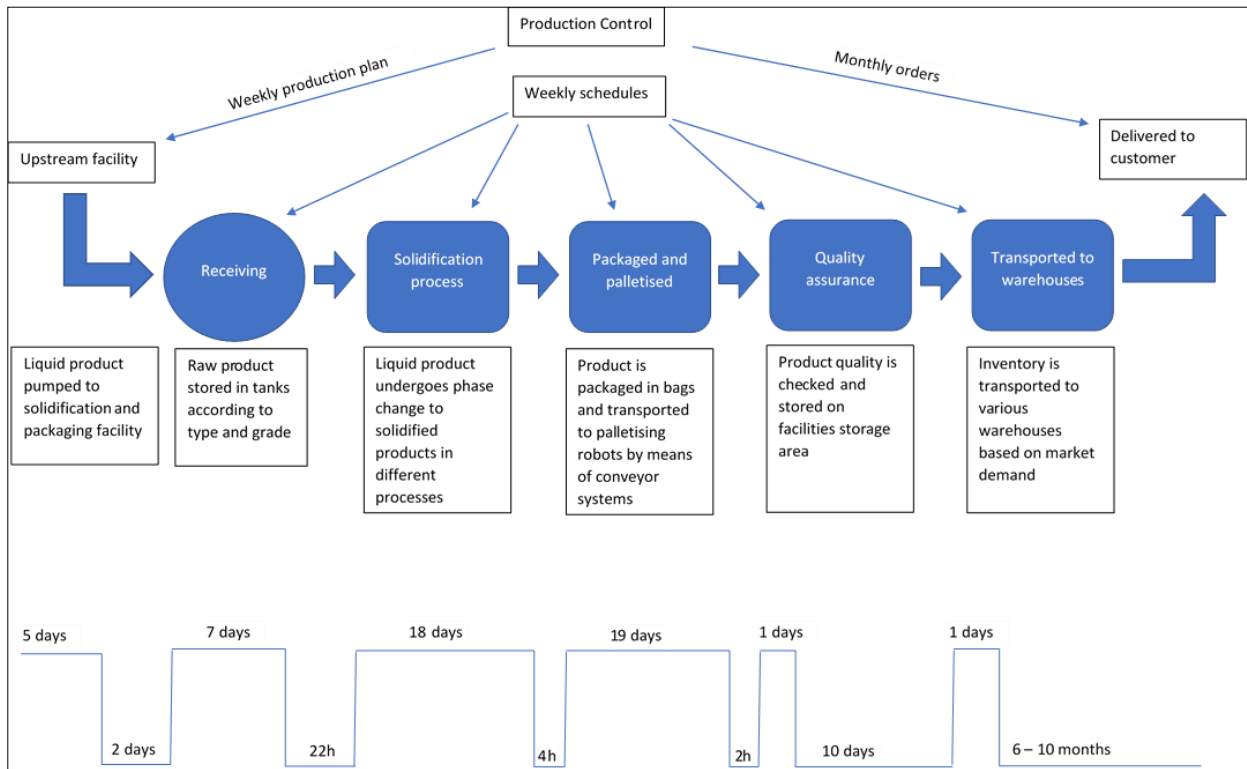


Source: (van Wyk, 2018)

4.2.2.2 Inventory

Excess inventory is related to over-production. The results of the cumulative deviation analysis (Figure 4-24) indicated that the facility is highly inconsistent in its production to planning targets and this results in excess inventory in the company's warehouses. The Lean tool and Value Stream Mapping were used to depict the packaging facility process. Given the evaluation shown in Figure 4-12 it is apparent that the inventory periods were recorded in months and not in days, as with the rest of the map. The company makes use of a push system and is highly dependent on the Marketing Department to sell all products manufactured.

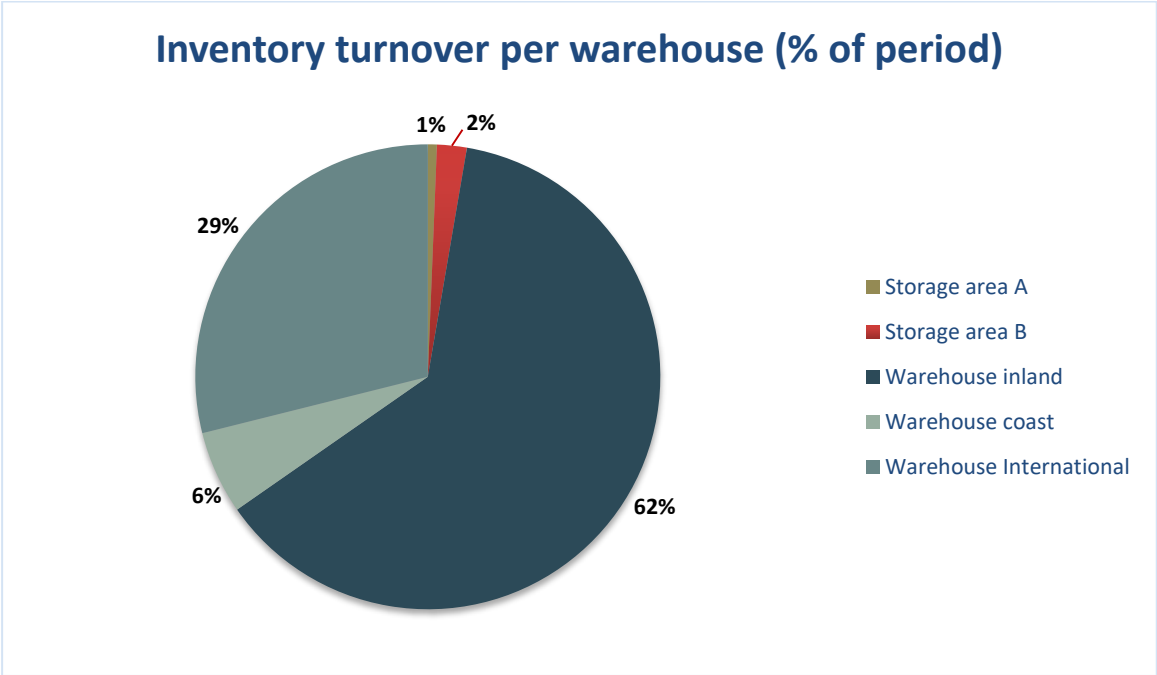
Figure 4-12 Packaging facility value steam map



Source: (Athuraliya, 2018; van Wyk, 2018)

To further investigate this, inventory turnover of each warehouse was evaluated. It was found that the local inland warehouse holds the majority of the inventory for periods exceeding 10 months (Figure 4-13). Slow turnover of inventory results in significant storage cost, and this over-stocking may imply weak sales and over-production. According to Lean principles, excess inventory tends to hide problems such as defects, production imbalance, equipment downtime, long set-up times, and late deliveries (Ohno, 1988).

Figure 4-13 Inventory turnover per warehouse



Source: (van Wyk, 2018)

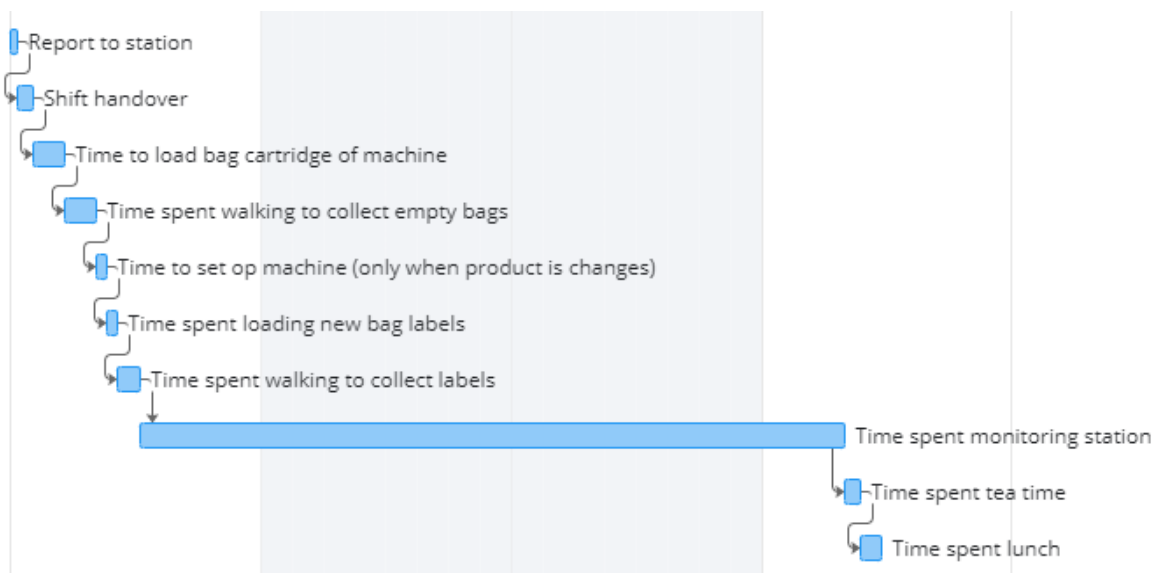
4.2.2.3 Motion

A floor plan of the packaging facility was drawn and can be seen in Figure B-11 in Annexure B. No ergonomic problems could be identified that were due to bending, lifting, reaching and stretching. Each packaging line has an operator that monitors the performance and fills the machine with empty bags and new labels. The empty bags are light in weight (65 grams per bag) and therefore collected 100 at a time and placed at a comfortable level. The floor plan is shown in scale and it indicates the significant walking distances (in purple) that the operator covers to collect empty bags, new labels and control room instructions, and to use the amenities and restrooms. Each trip results in an unmanned packaging line, which can be a number of minutes each time.

4.2.2.4 Waiting

According to the company operating procedure, each packaging line needs to be manned by an operator that monitors the automated machine. According to Pinto *et al.* (2018a), this is a waste of a resource, as the person merely watches a machine, while standing around waiting for the next process step. The automated pack line can operate for six hours without any interference required if fully loaded with labels and empty bags. With one pallet being wrapped every six minutes (maximum capacity) and one every hour based on minimum historic rates the forklift driver collecting the pallet at the final stage to transport it to area – only 5 meters away - which means wasting a considerable amount of time waiting for product. Ten pack line operators and five forklift drivers are at work at any time of the day (two 12-hour shifts) all year round (365 days) and their waiting time is highly dependent on the production throughput. The OEE analysis detailed in section 4.2.1.2 showed that: the facility's production plan only uses 55% of available work time; during this time, the facility only performs at 40% of its capacity. This indicates that a many of the packaging line and forklift operators will be idling for most of their work shift. Based on the operating procedure for the automated bagging machines, a time evaluation bar chart was drawn – see Figure 4-14. It indicates that most of the packaging line operators' time is spent monitoring a reliable and over-performing machine while they themselves are idling.

Figure 4-14 Bar chart time evaluation of packaging line operator

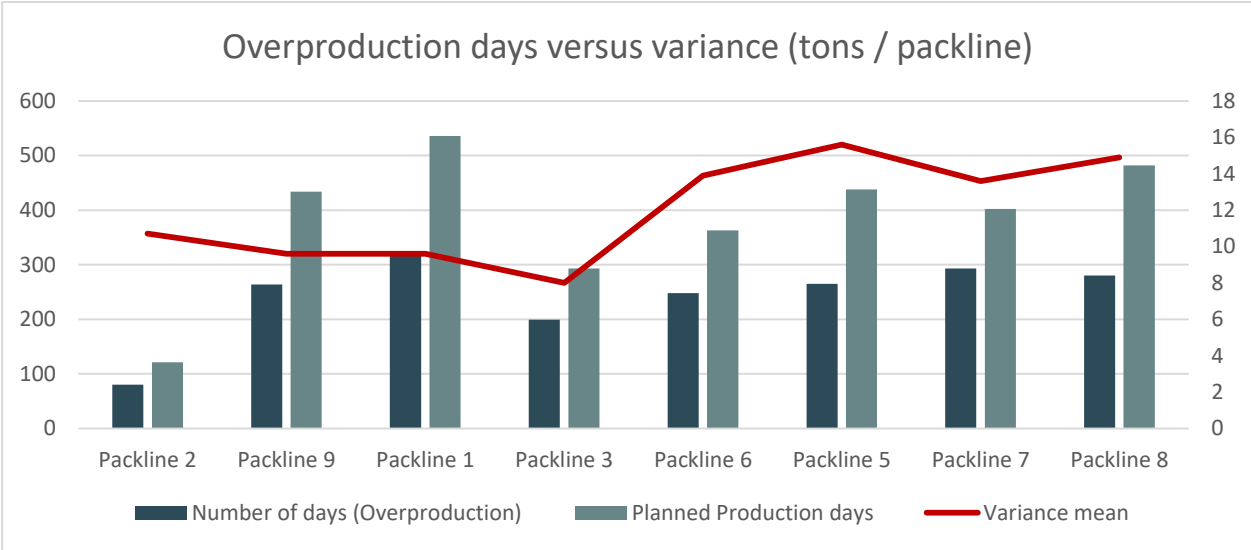


Source: (van Wyk, 2018)

4.2.2.5 Over-production

Over-production was measured in terms of days during the study period (Figure 4-15). The results indicate that over-production occurs $\bar{x} = 64\%$ of the time and the overall facility over-produce $\bar{x} = 11.99$ tons of product or $\bar{x} = 600$ packaged bags. The results also indicated that for the 536 production planned days, the packaging facility only made target 4% of the time. According to Lean principles, over-production prohibits the smooth flow of product and actually degrades quality and productivity. The over-production translates into high inventory, which was identified in the section on 4.2.2.2.

Figure 4-15 Amount of over-production produced in relation to planned days

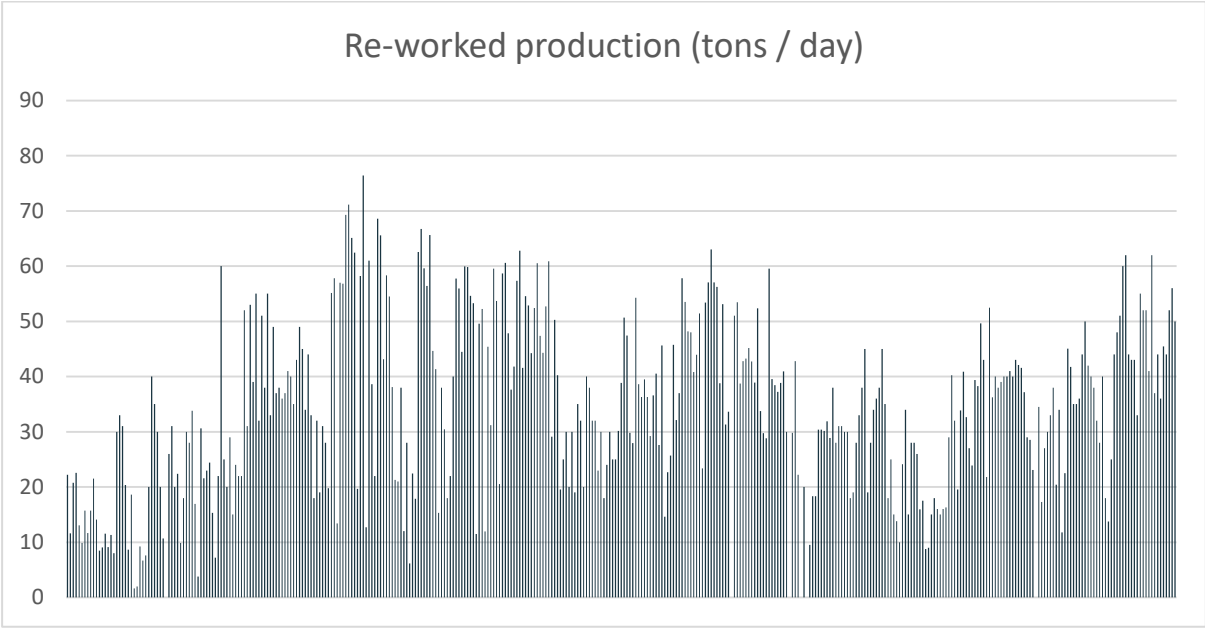


Source: (van Wyk, 2018)

4.2.2.6 Over-processing

To evaluate the non-value adding processing of the facility, re-working was measured. The amount of re-melted product over the 24-month period is shown in Figure 4-16. A mean of $\bar{x} = 34$ tons of product is re-melted and transferred in liquid form to the upstream feeding facility. If the product had been manufactured correctly the first time, no product would have needed to be re-worked. The re-working impacts negatively on both the facility under study, as well as the upstream feeding facility.

Figure 4-16 Re-worked production

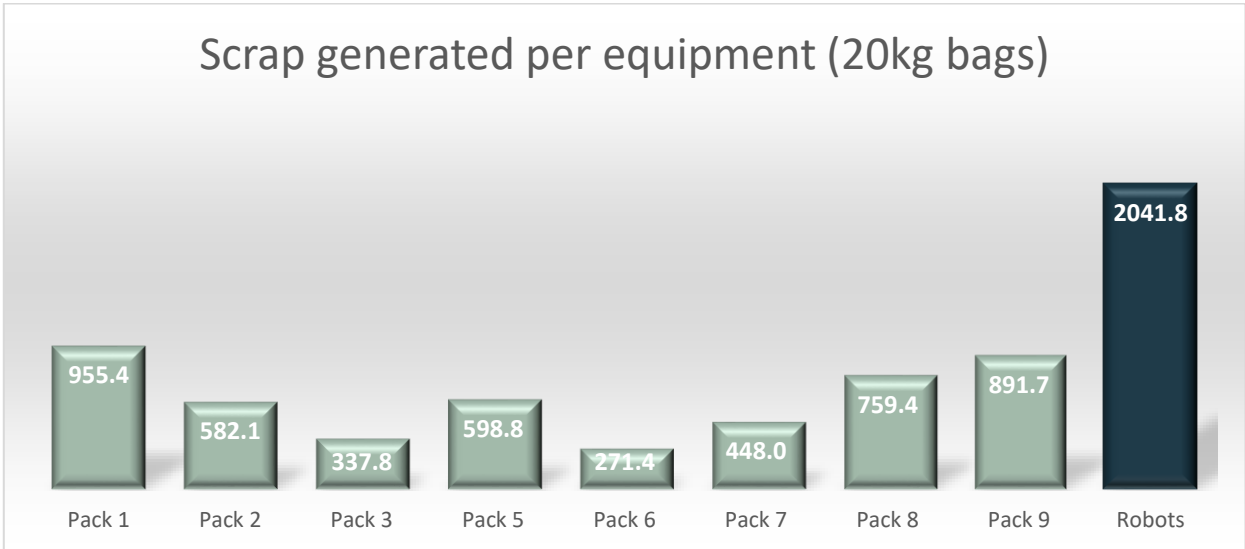


Source: (van Wyk, 2018)

4.2.2.7 Defects

Number of rejections per packaging line machine were evaluated (Figure 4-17) and the results suggested that robot rejections generated far more (2041.8 bags) incidents than the bagging machines. Bagging stations 1 and 9 had the highest rejections, at 955.4 bags and 891.7 bags, respectively. The packaging line rejections were due to the machine loading the bag either over or under the required weight. Robot rejections occur when the robot cannot identify the bag. This could be due to an incorrect, misaligned or unreadable label on the bag. The robot also rejected bags if it received bags from a packaging line that it was not busy palletising. The number of bag rejections identified in this evaluation was high: a total of 8996 bags were rejected and re-worked.

Figure 4-17 Scrap generated per equipment

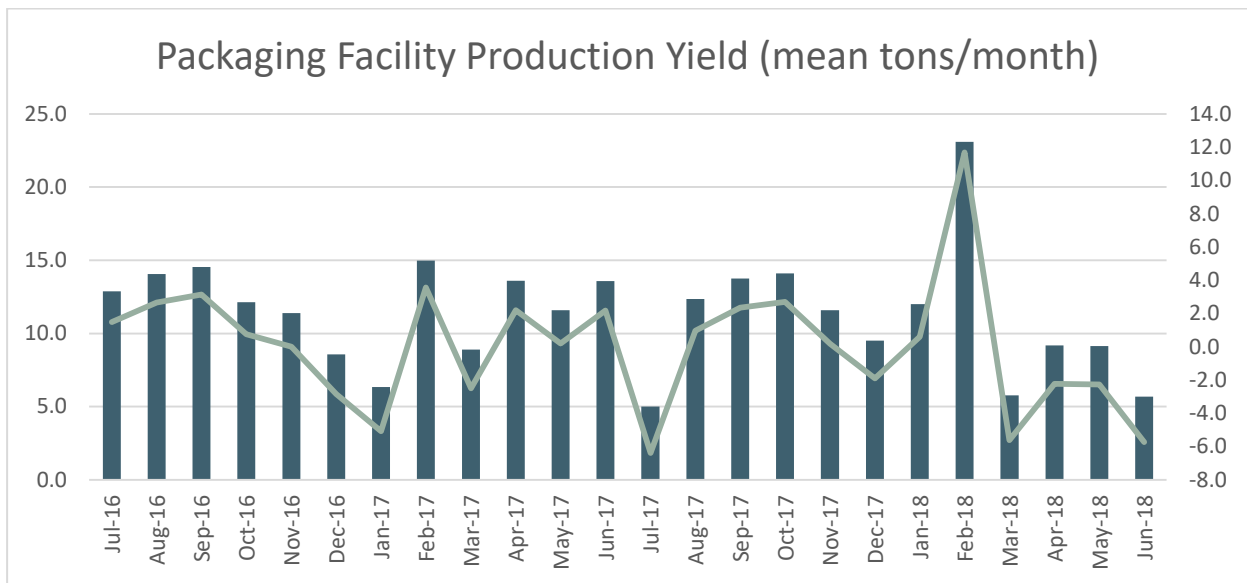


Source: (van Wyk, 2018)

4.2.2.8 Skills

People are the most important asset of any organisation and therefore an organisation should strive to live in the spirit of Kaizen (continuous improvement). A broad assumption was made with regard to wasted skills: a company that truly utilises the skills and creativity of its people will be able to show improvement in throughput. In Figure 4-18, it can be seen that production yield has not improved on a consistent basis. The chart shows that moderately lower yields are experienced in the final quarter of FY18. This result is regarded as an indication that the skills of the operators are not fully utilised to improve production rates or to eliminate defects.

Figure 4-18 Packaging facility production yield

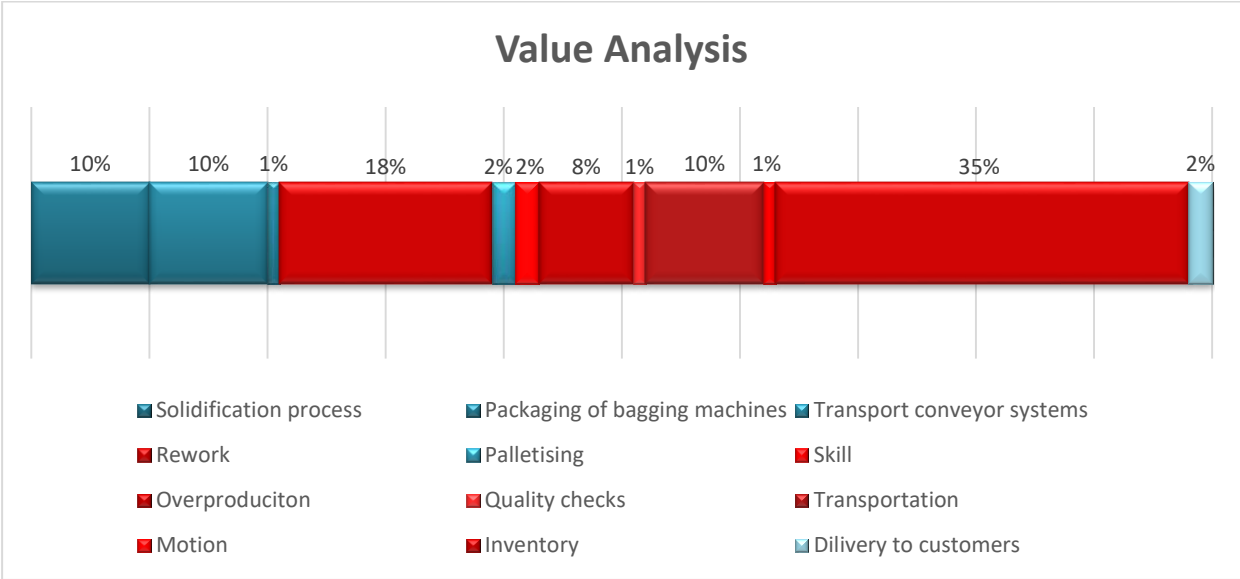


Source: (van Wyk, 2018)

4.2.2.9 Findings on eight wastes

By means of a process flow diagram, it was identified that the facility transports the products excessively. A value stream map and inventory turnover highlighted the slow turnover of the final product in the local warehouse. Based on the facility floor plan, high motion waste was identified, in the form of walking. It was found that each packaging line operator spends most of his productive working hours watching the automated bagging machines. Additionally, due to the low production periods and rates, they also waste a lot of time idling. The production variation to plan showed that the facility over-produces most of the time and this has a direct link to the high inventory levels. The amount of re-melted scrap pointed out the high re-work waste, which not only impacts the packaging facility's throughput performance, but also the upstream feeding plant. A value analysis was then done, as shown in Figure 4-19. This shows that only 25% (blue) of the facility's efforts contribute to value adding. In contrast, 75% is regarded as non-value adding and is a direct reflection of the amount of waste generated by the facility.

Figure 4-19 Value analysis of entire packaging facility



Source: (van Wyk, 2018)

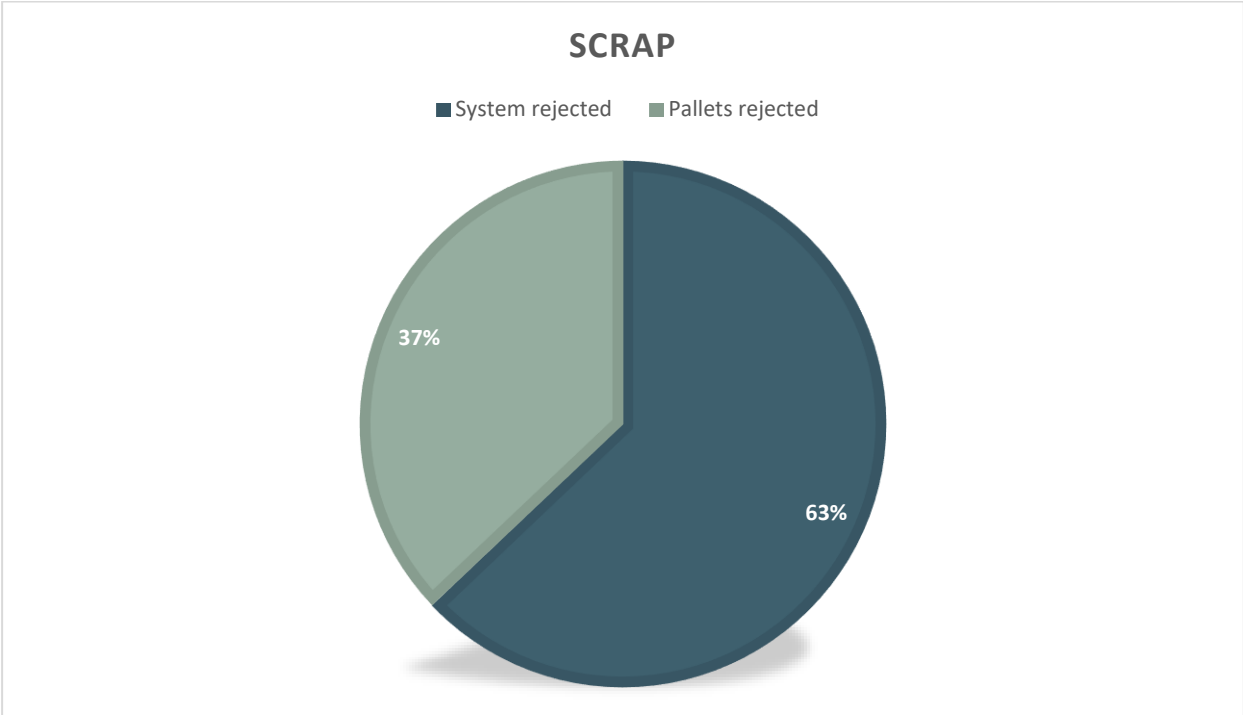
4.3 Evaluation of quality

The evaluation of quality was done on the packaging facility by reviewing the overall rejections. From this evaluation, the Six Sigma tool known as the Pareto chart was drawn, in order to identify the biggest quality concern. The number of defects per million operations were then calculated and the sigma level was determined. The VOC was developed and the findings on quality then documented.

4.3.1 Overview of total quality rejections

The rejection logbook data was used to identify the number of defects of the facility over the 24-month study period. The rejection logbook gathered a vast amount of information. The 38 806 cells captured, detailed the amount scrapped per packaging machine per day and the type of defect that caused the scrapping. This was then shortened to the days of all months (1466 cells), as detailed in Annexure A. The summary in percentage scrap of product by the packaging system is measured in relation to the scrap generated by rejection during quality checking after the product has been palletised. This is shown in Figure 4-20. It indicates that the majority of scrap produced at the facility is a result of high level of pallet rejection, at a mean of $\bar{x} = 62.91\%$.

Figure 4-20 Scrap with packaging system compared to scrap with palletisation



Source: (van Wyk, 2018)

Table 4-1 **Rejection logbook - pallet rejection section** give an example of the quality assurance pallet rejection section of the rejection logbook of the plant (one-month period). The example show that the pallet could possibly be rejected by the quality assurer for four reasons.

Table 4-1 Rejection logbook - pallet rejection section

PALLETS									
REASONS FOR REJECTION	Pack 1	Pack 2	Pack 3	Pack 5	Pack 6	Pack 7	Pack 8	Pack 9	TOTAL
Double labels	0	0	0	0	0	0	0	0	0
Overhang	4	0	18	25	26	6	8	0	87
Bottom sheet	2	0	4	16	18	13	6	0	59
Broken / leaking	136	0	34	78	86	136	49	0	519
Total pallets rejected	142	0	56	119	130	155	63	0	665

Source: Internal rejection logbook data of company (2018)

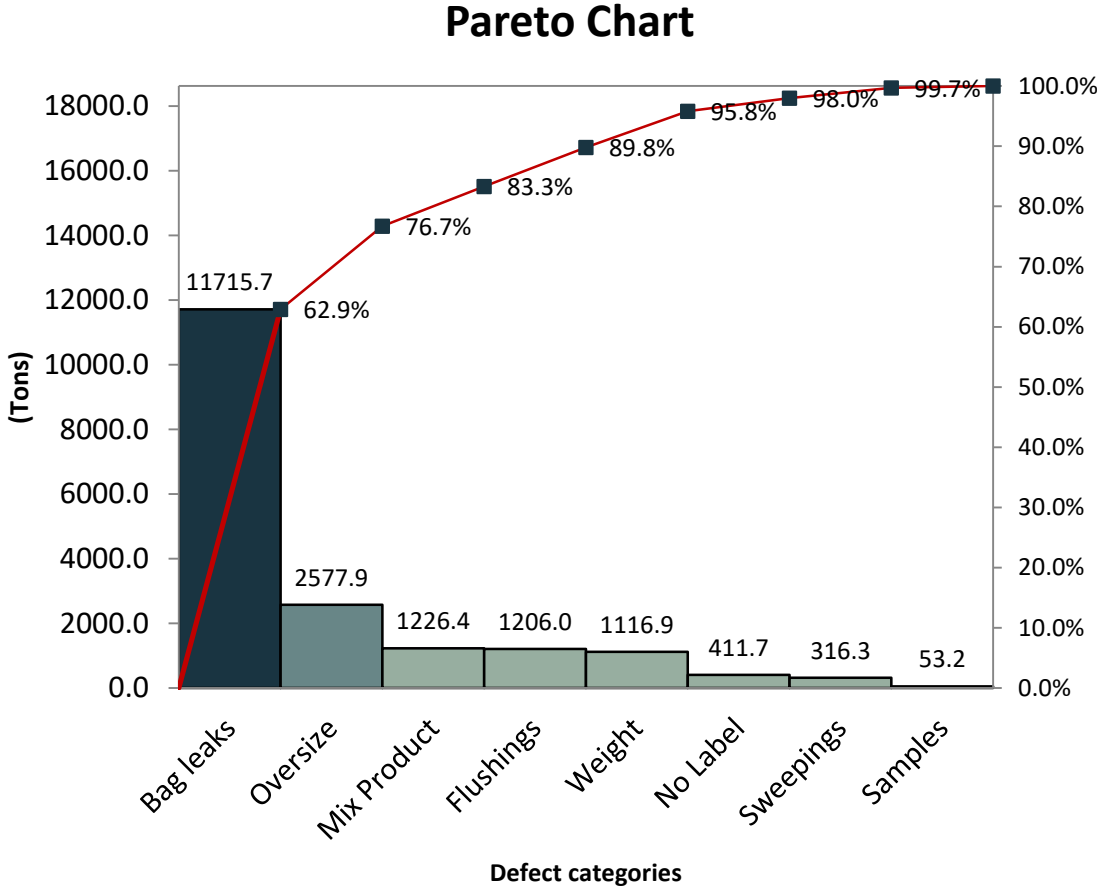
4.3.2 Pareto chart

To classify the application of the most value adding project as part of the identification phase of the continuous improvement process, a Pareto chart was drawn using the results of the quality rejection logbook (Figure 4-21). It visually distinguishes the trivial many from the vital few, highlighting that the biggest contributor to rejections at the facility is bag leaks. Bag leaks occur when a single bag leaks product in an already wrapped pallet, as the company's internal standards require that the pallet be rejected due to poor quality – and the entire pallet of thirty-five bags needs to be scrapped. This causes a large amount of good quality packaged product to be wasted (62.91% of all product that is scrapped). The Pareto analysis offers an objective basis for selecting the key concern. From this analysis, the greatest improvement is bag leaks, with 585 785 bags or 11 715.7 tons being rejected during the study period.

Rejections by the robot and bagging machine combined only amounted to 8% of the defective products. All product is sieved before being packaged to prevent over-sized product from entering the bag. Over-sized product amounts to 19% of all scrap generated. The high number of over-size product could be a result of the way the raw material solidifies and forms the product. Flushing amounted to 7% of the total scrap generated in the facility. At the event of a product change, the solidification process is flushed to clean old product from the system.

This product might contaminate the new batch, and in order to guarantee the product qualities, the SOP required that two tons of product be flushed before the bagging machines could start producing. When taking the total flushing figure (1206 tons) and dividing it by two (2 tons), the result is 603 product changes. When this was compared to the daily production plan, it was discovered that only 240 product changes were made during the period. This indicates that an average of 5 tons of product is wasted during product change periods. This is a manual process that is controlled by the production operator of the solidification plant and indicates that the operator is not complying with the SOP. As a result, two-and-a-half times more waste is produced than what is required.

Figure 4-21 Pareto chart of defect categories



Source: (van Wyk, 2018)

4.3.3 Sigma level

To determine the Sigma level of the facilities, the number of deviations per million opportunities were calculated. The results showed that the packaging facility is operating at a 2.87 Sigma level, which totals 84 761 defective bags per million operations. The formula used is as follows:

Equation 11 Defects per million opportunities

$$DPMO = \frac{(number\ of\ defects\ X\ 1000\ 0000)}{[(number\ of\ defect\ oppertunities\ per\ unit)X\ (Number\ of\ units)]}$$

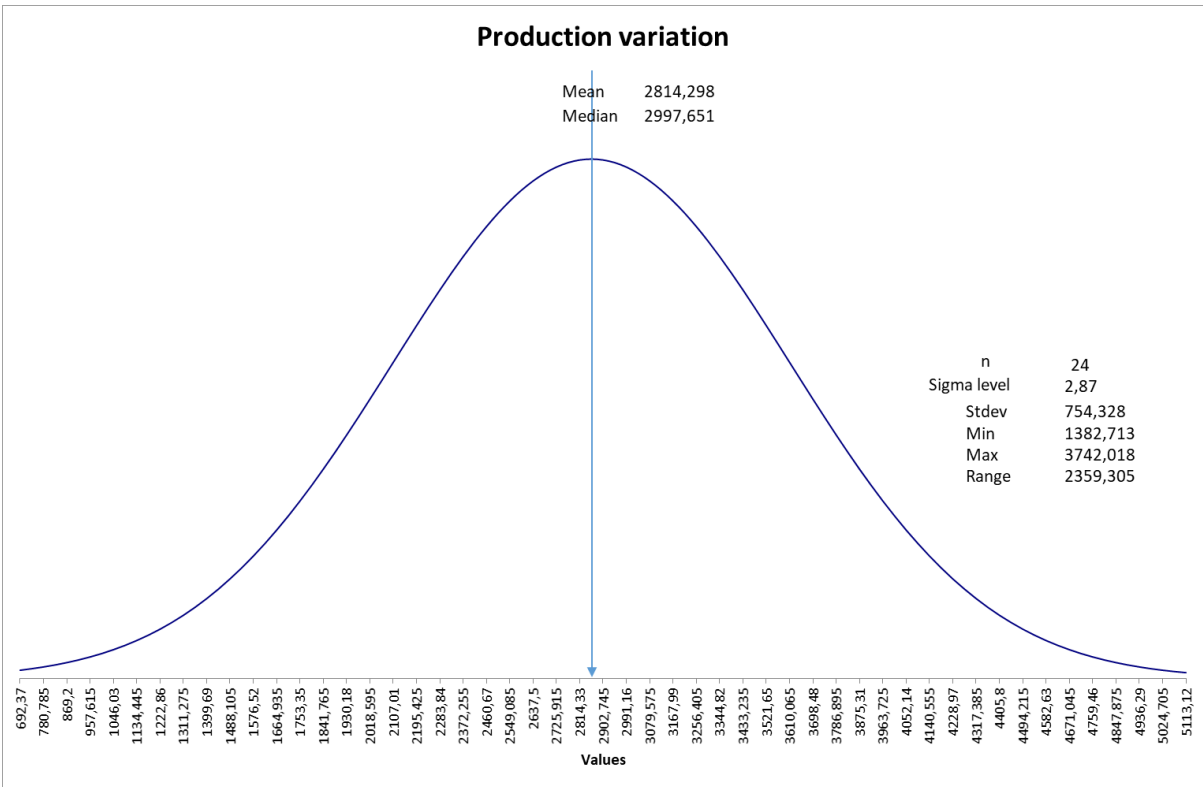
$$DPMO = \frac{(5278\ tons\ X\ 1000\ 000)}{[(1)\ X\ (62265)]} = 84\ 761\ defects\ per\ million$$

84 761 defects per million = 2.87 Sigma Level

Source: (Cox et al., 2016)

The standard deviation of SD = 754.33 was calculated (using the OEE data provided in Annexure A) as a statistical measure, as shown in Figure 4-22. The mean was calculated to be $\bar{x} = 2814.3$ and the rest of the normal probability distribution is shown. The calculated defects and sigma level of the study period is also depicted in the graph. Most companies operate between 3 and 4 sigma level. According to Conger (2015) sigma levels of less than three is not desirable. (Conger, 2015) further stated that companies with less than three sigma levels would not be able to survive in a competitive marketplace. A 2.87 sigma level indicates that the packaging facility is doing things right 80.56% of the time. Six Sigma represents the level of perfection towards which a company should aim. If a company achieves Six Sigma, it will have a 99.99966% throughput and 3.4 defects per million opportunities.

Figure 4-22 Production variation graph



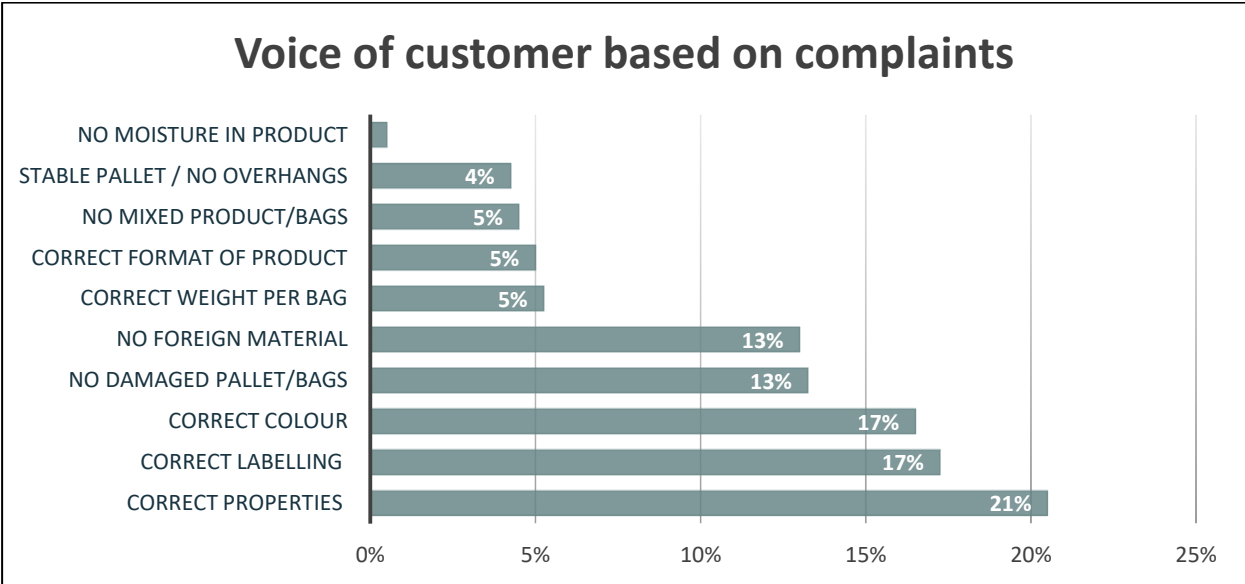
Source: (van Wyk, 2018)

4.3.4 Voice of customer

To align the improvement initiatives with what the customer needs are, a voice of customer analysis was conducted. This was a reactive study done on historic customer complaints received over the study period. The results are shown in Figure 4-23. The requirements are only based on

quality concerns as this is the only aspect that the facility can have direct control over. The results suggest that a strong focus should be placed on the quality control of the facility, as wrong properties, incorrect labelling, the wrong colour, damaged pallets and contamination were found to be customers' greatest concerns.

Figure 4-23 Voice of customer, based on historic complaints



Source: (van Wyk, 2018)

4.3.5 Finding on quality

The overall quality rejection evaluation showed that the defects generated were mostly a result of complete packaged product being rejected. A Pareto analysis showed that bag leaks amounted to the largest number of scraps, and this was identified as the best area to focus on, in order to achieve the greatest success in improving variations in the process. The Pareto analysis also showed that the facility has high scrap generation due to over-sized products being manufactured, as well as flushing. Further investigation into the amount of flushing showed that the process operator flushes on average two and a half time more product that what is required by the company's SOPs.

The packaging facility sigma level was calculated to be 2.87, which is assessed to be uncompetitive in a high rival market. The facility produces 84 761 defects for every million operations. This is a good indication that there is much room for improvement with regard to quality. The last Six Sigma tool used was a reactive evaluation to understand what quality requirements the customer expect. It was found that correct product properties, accurate labelling,

the right colour product, no contamination and packaging that is not damaged are the most important quality areas.

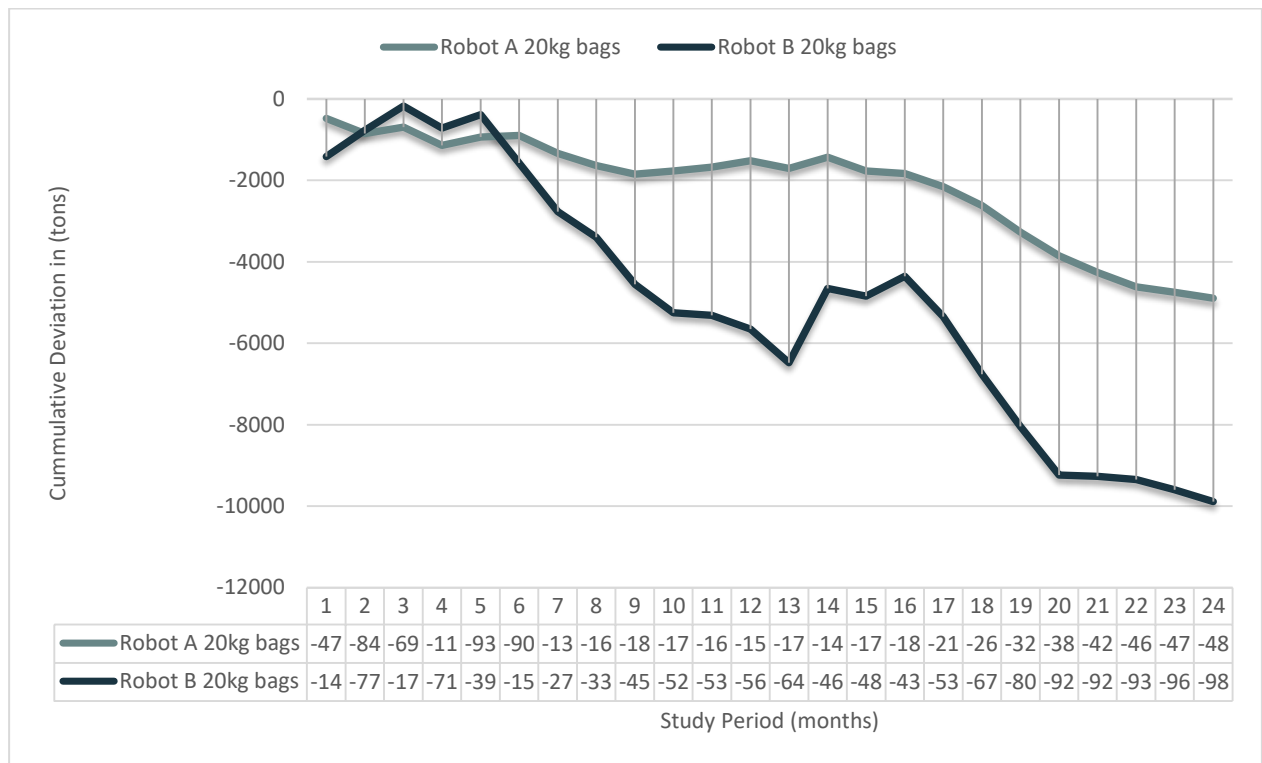
4.4 Evaluation of throughput

Cumulative deviation was evaluated in this section to determine if the facility is over-producing or under-producing and if it balanced out over time. Product design capacity was evaluated by visually comparing the overall process to its historic highest throughput. A histogram was then drawn to identify if the planned rates were realistic in terms of the capability of the installed equipment. A simulation was then done based on historic and design data to show any bottlenecks in the conveyor system. A holistic evaluation was done of the entire facility to pin down the most restrictive problem that the plant is currently facing. The finding of the throughput analysis was then highlighted.

4.4.1 Cumulative deviation

The production plan is scheduled based on forecast demands. Products are therefore produced and “pushed” into the market for the Marketing Department to sell. The facility makes use of large warehouses across the world. The production plan indicates how much, in tons, of each product needs to be manufactured per day. The packaging facility manufactures according to the production plan and any deviation from this plan indicates a variation from the process. Production data was analysed in order to determine the extent of this problem. The first step was to determine cumulative deviation of actual production from plan, in order to gain an understanding of whether the production plan was met over long periods. The results indicate that both robot A and robot B constantly exceeded the 20 kg production plan - this was demonstrated by the cumulative deviation trend that falls throughout the entire period of consideration. A negative result indicate that the actual produced products exceed the planned produced products for that particular month.

Figure 4-24 Cumulative deviation of overall throughput of robot A & robot B

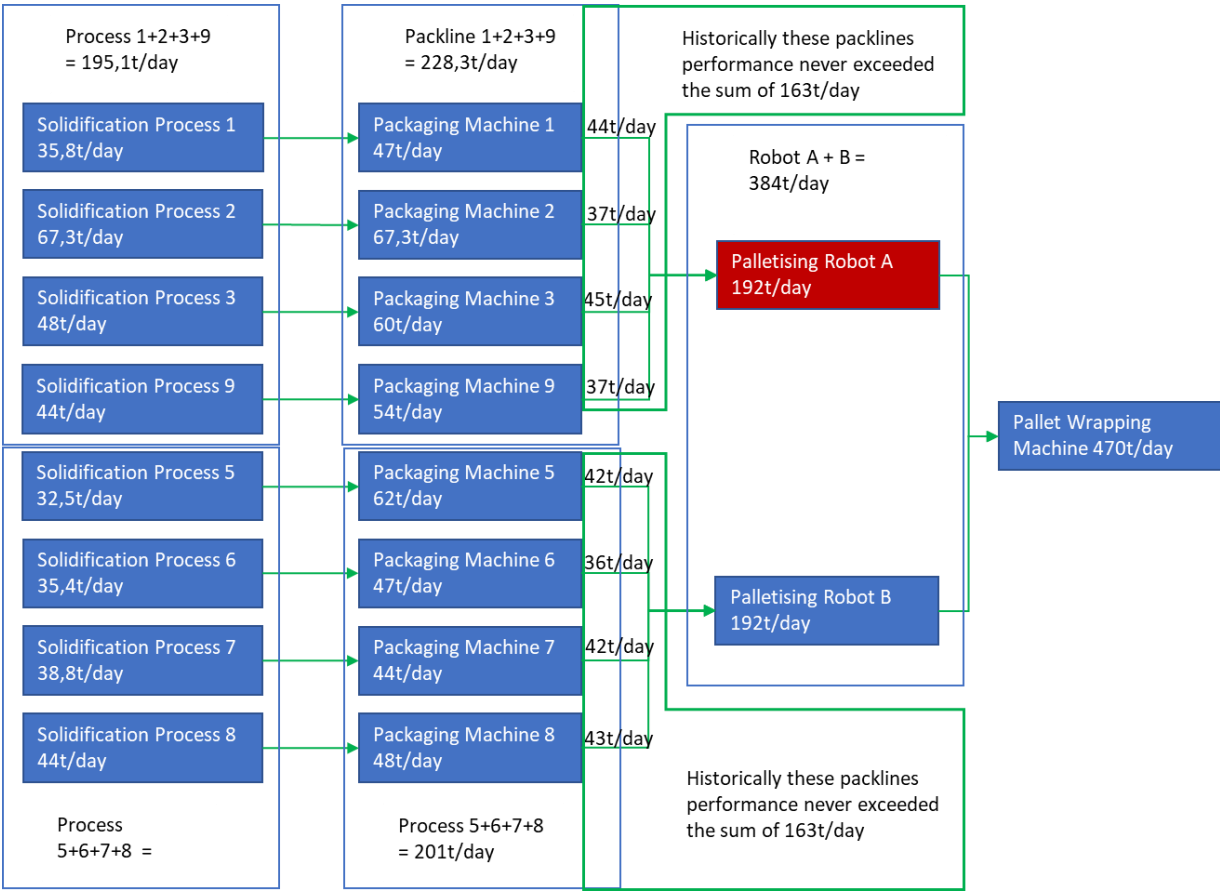


Source: (van Wyk, 2018)

4.4.2 Production design capacity

To determine if there was any constraint in terms of throughput, the historic maximum rate was calculated. The design capacity of the solidification process, bagging station, robots and pallet wrapping machine was then gathered from the equipment data sheets. A process overview was then drawn in Figure 4-25. The figure indicates that the pallet wrapping machine capability of 470 t/day is rated much higher than what the combined robots are capable of producing at 384t/day. This is also the case with the packaging machine, which is capable of running at a combined rate of 228.3t/day (packaging line 1, 2, 3 and 9) and 201t/day (packaging line 5, 6, 7 and 8) in relation to its feeding solidification process of 195.1t/day and 150.7t/day, respectively. It was identified that robot A is under-designed, with a capacity of 192t/day should its feeding packaging machine 1, 2, 3 and 9 be required to perform at designed rates 201t/day.

Figure 4-25 Process overview with design capabilities compared to historic maximum performance

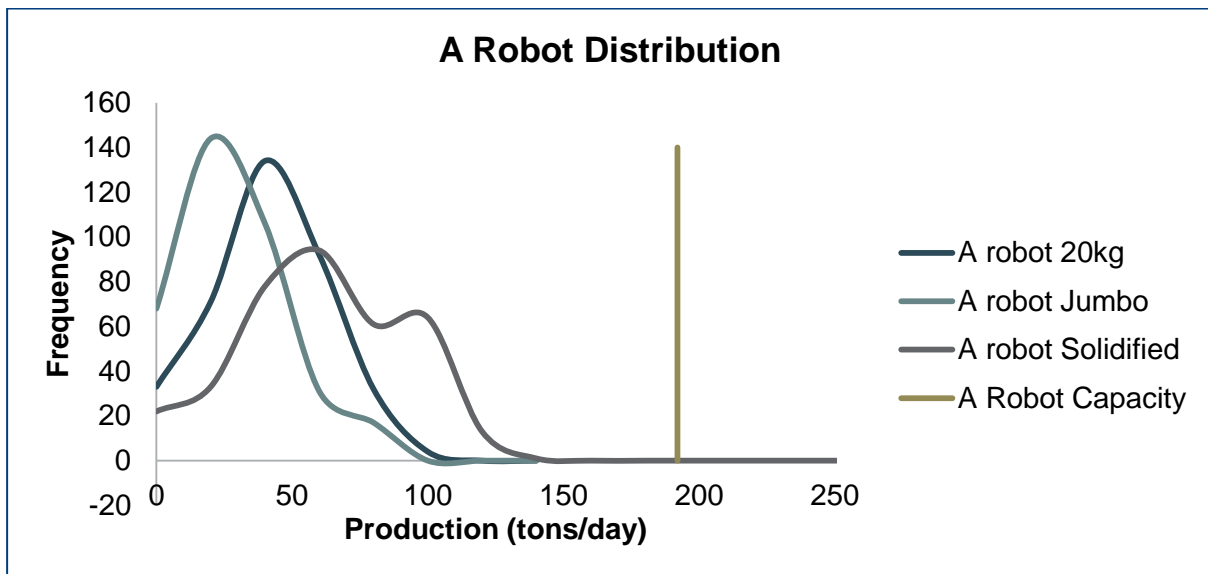


Source: (van Wyk, 2018)

Frequency distribution was determined for planned and actual production rates at each of the palletising robots. The resulting frequency distribution curves were then compared to capacities of each palletising robot and the combines capacities of solidification equipment that are dedicated to each robot.

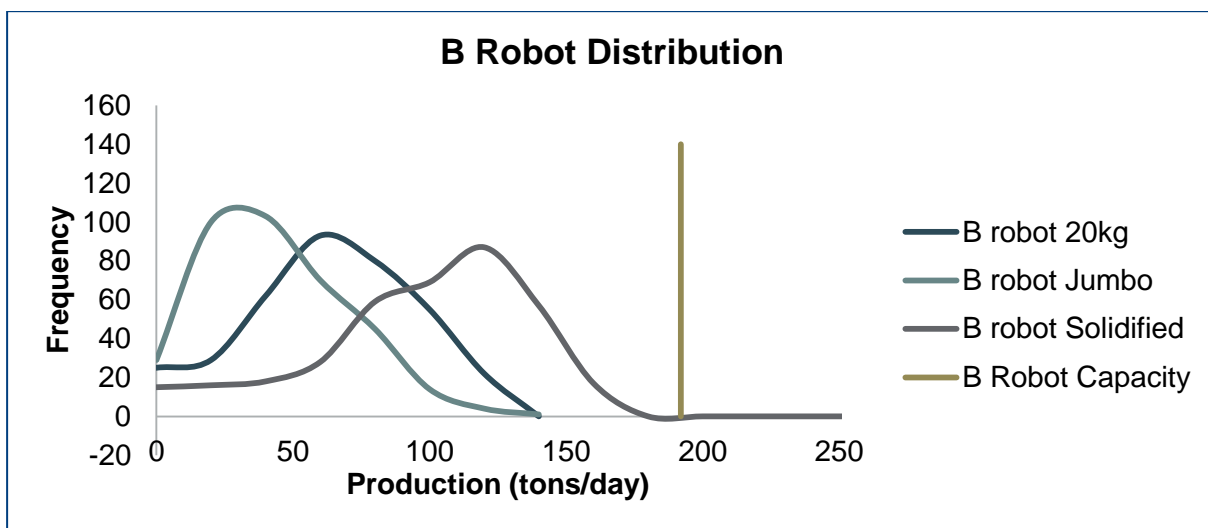
Performance of the entire packaging systems, relative to the capacity of the robots and solidification system, was analysed and the results are presented in Figure 4-26 and Figure 4-27.

Figure 4-26 Distribution - robot A



Source: (van Wyk, 2018)

Figure 4-27 Distribution – robot B



Source: (van Wyk, 2018)

In Figure 4-26 and Figure 4-27, it can be seen that:

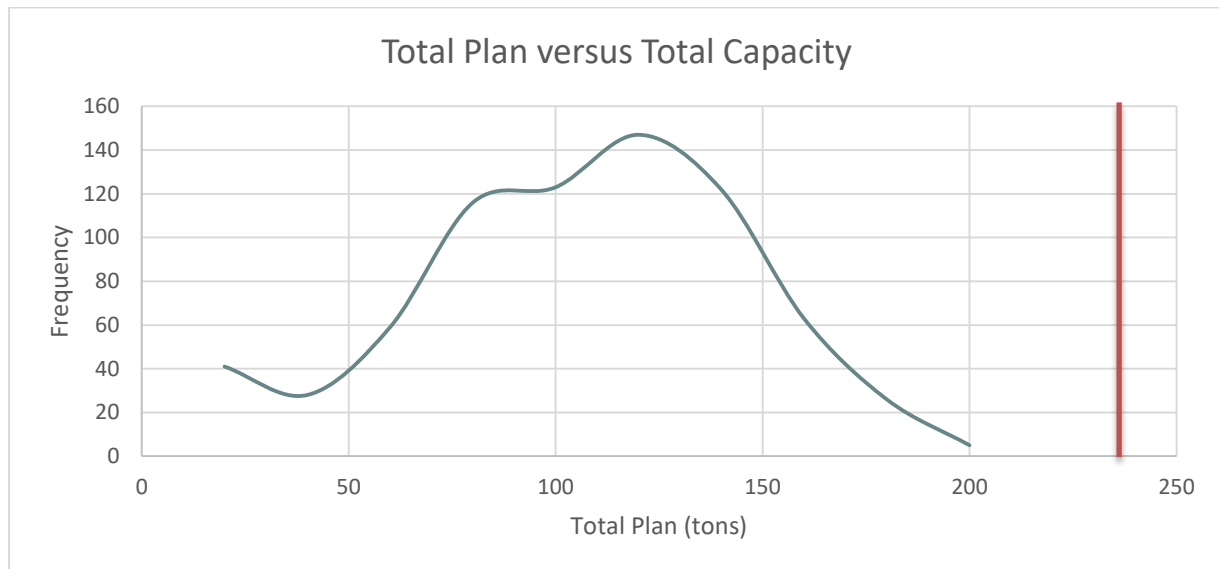
- Both robots are palletising at a rate that is much lower than their capacity.
- Total solidification figures are lower than the palletising capacities.
- Robot A is expected to have a utilisation figure of more than 100%.

- Robot B is expected to have a utilisation figure that is much lower than 100%.
- Overall, no constraints were identified in terms of throughput capacity.

4.4.2.1 Production histogram

A production histogram in Figure 4-28 shows comparison between frequency distribution of production plan over the period of consideration against total production capacity. In Figure 4-28, it can be seen that: the mode is approximately 120; this mode occurs at a frequency of 147 when the plant was planned to be online for 536 days, i.e. 55% of the time. This means that the Planning Department planned for the plant to operate at approximately 40% of its total capacity.

Figure 4-28 Histogram that compares distribution of production plan to total production capacity



Source: (van Wyk, 2018)

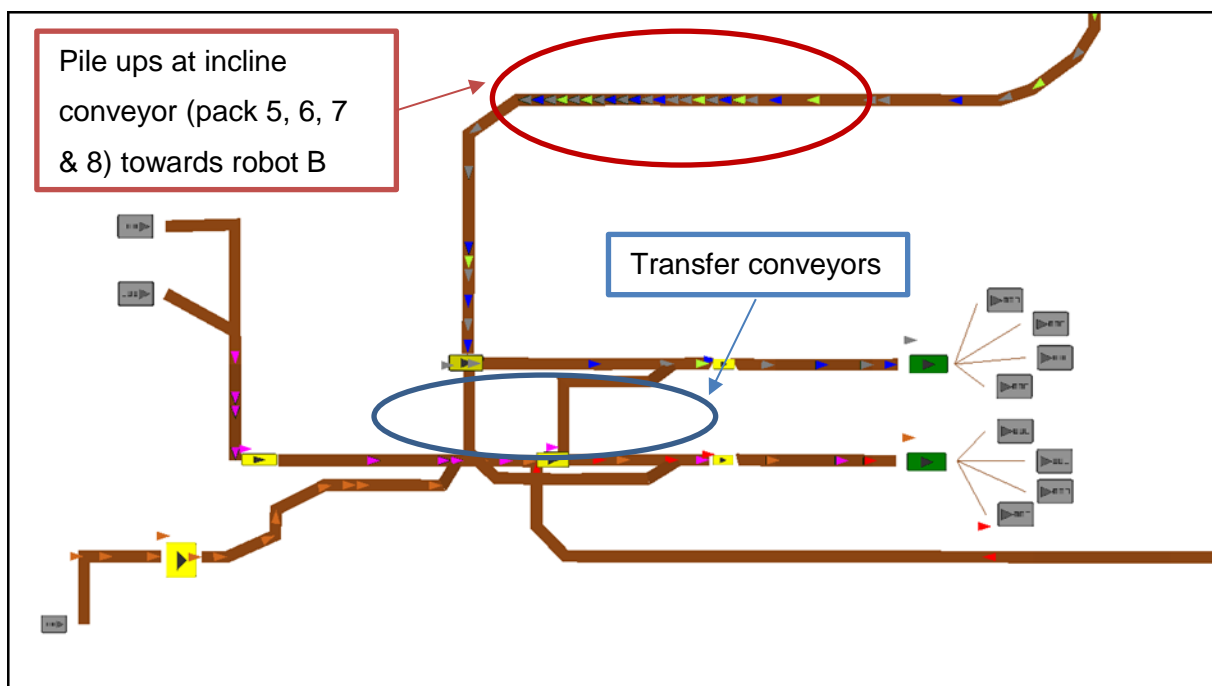
In Figure 4-28 it can be seen that the plan is generally for between 60 and 160 tons per day. Furthermore, the plant operates at rates between and 250 tons per day only 14% of the time.

The information presented in this sub-section indicates that the plant is consistently under-utilised and that the planning department is constantly planning lower production rates. However, the design capabilities are evaluated as being suitable for the facility's requirements.

4.4.2.2 Conveyor throughput simulation

Conveyor system throughput was analysed using a discrete event simulation model that was developed as part of this investigation. The simulation model was built using equipment data sheets, and validation was performed by comparing simulation results to historic performance data. The simulation was performed based on maximum historic production rates to determine if any conveyor system constraints could be identified. The simulation run started with an empty system; therefore, a warm-up period of 10 hours was used, in order to ensure that the simulation results were only applicable to steady state. The model was then run for a further 24 hours for purposes of generating results. Based on the results in Figure 4-29 the simulation gives an accurate representation of how the conveyor system is performing.

Figure 4-29 Conveyor simulation results



Source: (van Wyk, 2018)

The results indicate that packaging lines 5, 6, 7 and 8 are constrained heavily, even though the palletising robot that is dedicated to them has a far higher capacity than their combined capacity. The under-performance can be contributed to its series configuration design of conveyor system at these packaging lines. The series configuration can be seen in the packaging line floor plan in Annexure B and the three-dimensional simulation model in Annexure D. As can be seen in Figure 4-29, the rest of the packaging lines can operate close to their desired throughputs. This indicates that when the palletising robot operates at the desired rate, the conveyor system interactions do not have a significantly negative impact on throughputs. However, when the rate was compared to the designed capacity, it was found that there were performance limitations.

Table 4-2 Simulation throughput results with observation

Object Name	Design Value (bags/day)	Category	Statistic Type	Simulation results (bags/day)	Comments
Pack 1	2537	Throughput	Total	2528	Not affected much by low robot service time
Pack 2	4767	Throughput	Total	130	Set high bagging rates but had the least number of bags
Pack 3	3400	Throughput	Total	1785	Took priority over Pack 2
Pack 5	2302	Throughput	Total	262	Lowest priority at the shared feed conveyor belt
Pack 6	2510	Throughput	Total	1206	Took priority over Pack 5
Pack 7	2748	Throughput	Total	1552	Took priority over Pack 5 & 6
Pack 8	3118	Throughput	Total	3092	Took priority over Pack 5, 6 and 7
Pack 9	3117	Throughput	Total	1789	Lowest priority at the shared feed conveyor belt

Source: (van Wyk, 2018)

Further observations that were made from the simulation were, as follows (and are included in Table 4-2):

- Packaging line 3 took priority over packaging line 2 at the feed conveyors.
- Pack 2 had the highest capacity; however, it had the lowest number of palletised bags.
- Pack 8 took priority over packs 5, 6 and 7, while pack 5 had the lowest priority at the shared feed conveyor belt.
- Pack 1 was not affected much by high production rate or robot service time.

Full validation results can be found in Annexure E. The Annexure shows only throughput related results, because throughput was the focus of this investigation.

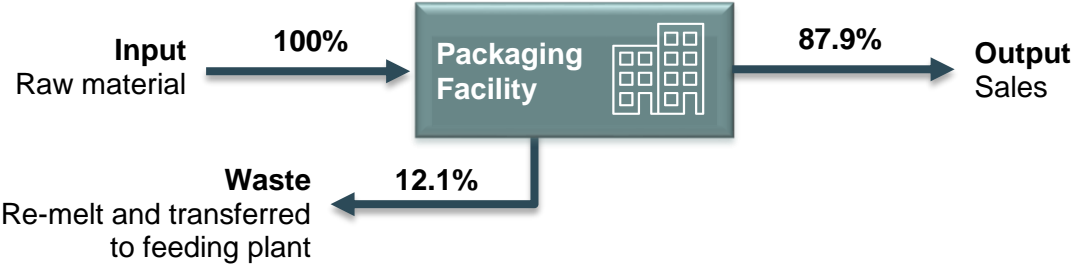
Based on the results, a change was made to introduce a buffer to packaging line 5, 6 and 7 output to allow one bag to be stored and to allow the bagging station to fill a bag while the conveyor belt is not free. This change was simulated and it was found that it would enable the solidification systems to operate at 99% throughput. The buffer capacity option has the potential to enable the operation of solidification units at 100% of their capacity; however, this is not practically possible because the operations policy does not allow for utilisation of cross conveyors – see Figure 4-29. These were designed to transfer bagged products between the robots, should this be required.

Without the cross conveyors, robot A is expected to have a utilisation figure above 100%, which is not physically possible. The simulation was then done to enable the cross conveyor to operate in the system. The results showed that, when the cross conveyors are used, the system can enable the sharing of loads between the robots, which results in healthy utilisation. Therefore, it would enable the solidification and packaging facility to perform at 100% of its throughput capacity.

4.4.3 Holistic evaluation of the system

To mobilise and focus resources on the correct area, TOC principles were used to investigate the problem from a holistic viewpoint. The organisation’s mass balance average throughput was evaluated and the results are shown in Figure 4-30. The mean output of the packaging facility is measured as the number of packaged pallets sent to customers over the study period. The study was evaluated over a 24--month period and the results reflect a mean value of each of the constructs. The results showed that the packaging facility’s throughput is $\bar{x} = 87.9\%$. This is a percentage reflection of how much product was delivered to customers, on average, over the study period. The waste generation of the facility was evaluated to be $\bar{x} = 12.1\%$. This amount only measures the product loss and does not account for the man-hours, inventory, packaging and utility cost of steam, nitrogen and electricity and the cost of re-melting, transferring and solidifying the product again. The facility re-melted all bags rejected from the pack line and the pallets rejected by the quality control department. The material is sent back to the upstream feeding plant in liquid form, for it to be processed and returned. The returned product is then solidified and packaged.

Figure 4-30 Holistic view based on mass balance results



Source: (van Wyk, 2018)

The evaluation shows that waste is a factor that is hindering the facility from achieving its goal. According to L'Agiliste (2018) a bottleneck is a resource with a capacity less than or equal to

demand. The throughput of this facility is constrained by waste, which is reducing the organisation's yield and ultimately limiting the company from achieving its goal.

4.4.4 Throughput findings

The cumulative deviation analysis found that: the facility is continuously over-producing product; over the study period this over-production resulted in excess throughput and inventory build-up. A process throughput overview indicated that robot A is under-design of the facility performance at designed rates; this was confirmed by the simulation analysis of the conveyor system. A histogram of the robot distribution showed that both robots palletised at rates much lower than their capacity historically. The production plan versus capacity histogram showed that the planning department schedule low rates most of the time. A simulation model of the conveyor system indicated that the packaging systems dedicated to robot B are under-performing, due to the conveyor series configuration. A buffer was then simulated, which allowed the packaging machines to store one bag while filling another. This enabled the machine to fill backs without being delayed by the conveyor system and improved the throughput of the to 99%. It was also found that the transfer conveyor of the facility was not used. But when this was brought into the simulation, it yielded a 100% conveyor throughput. A holistic evaluation was conducted, using the overall mass balance data. It was identified that the biggest constraint limiting the throughput of the facility is the high amount of waste product being generated.

4.5 Conclusion

In this chapter, the results and findings were discussed to highlight the inefficiencies in the packaging facility. The waste was evaluated with selected Lean Manufacturing tools, namely: OEE and the eight forms of waste. It was identified that the waste is a concern and that the process includes a number of non-value adding tasks. The quality evaluation was done making use of Six Sigma tools, such as the Pareto analysis and VOC. The facility sigma level was calculated and identified to be so low that if more competitors were to manufacture the same product, the facility would not be able to compete in terms of quality. The throughput analysis indicated that the facility design is capable of meeting the design capabilities, with some recommended solutions from the simulation analysis. The biggest constraint in the entire system was identified as the amount of waste that is limiting the throughput of the plant.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Figure 5-1 provides an outline of Chapter 5 and how it has been laid out.

Figure 5-1 Chapter layout



Source: (van Wyk, 2018)

5.1 Introduction

The primary objective of this study was to identify inefficiencies related to waste, throughput and quality in the selected packaging facility. A literature study was performed on the conception model of the iTLS methodology. This was explained in Chapter 2. Chapter 3 details the research design and how the quantitative research was performed using secondary process data. In Chapter 4, the results of the study were provided given. The final chapter aims to draw conclusions from the results presented in Chapter 4. Following on from the conclusions, recommendations are offered based on the insight gathered from the literature study. The success of the study is critically evaluated against the primary and secondary objectives that were established in Chapter 1. Recommendations are made for further research endeavours related to the topic of iTLS improvement methodology. A proposed implementation plan is provided, based on the results, findings and recommendations of this research. The chapter concludes with the overall study conclusion.

5.2 Conclusions on findings

The results of the study in Chapter 4 aimed to identify if there are any inefficiencies related to waste, throughput and quality within a selected chemical packaging facility by analysing it against iTLS methodologies. The conclusions are discussed below in terms of each topic.

5.2.1 Identification of waste

All eight Lean waste items described in the literature study were evaluated in Chapter 4, and it was identified that the facility has:

- High transport cost, with a single pallet transported 47 times before it reaches the customer.
- High inventory cost, with slow turnover in its warehouses.

- Motion waste, in the form of walking, due to equipment layout.
- Long waiting losses, due to the low production rate of facility.
- High amount of re-work, which causes over-processing losses.
- Over-production losses, due to deviation from the production plan.
- Excessively high defects and scrap rates.
- Low utilisation of skills and expertise of employees.

In this manufacturing facility, a range of waste situations were identified by reviewing the information evaluated. Waste is not adding any value to the customer. Each of the waste situations identified need to be translated to the customer, since the organisation operates on a make-sell concept. The higher the cost of waste within the facility, the higher the price of the end product paid by the customer. The facility will eventually not be competitive in the market, if these waste parameters continue to grow in size. The OEE tool used was found to be inaccurate.

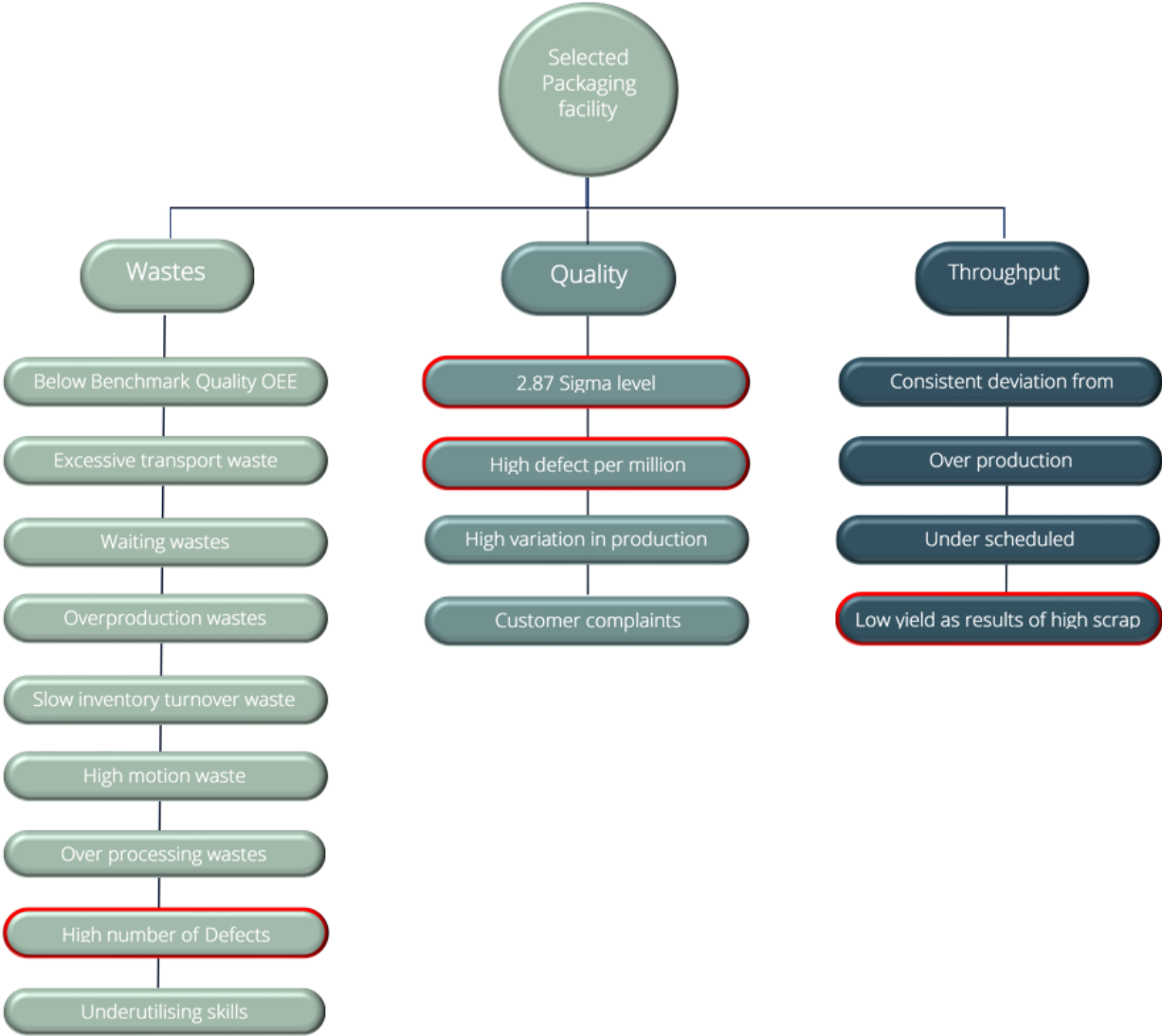
5.2.2 Identification of quality variation

A six-sigma level calculation indicated that the facility is operating at a 2.87 sigma level. This indicate that the facility has a high level of variation in its production process. The results also indicated that 84 761 defects are generated for every million opportunities. A Pareto analysis was conducted on the rejection logbook and found that the biggest contributor to the high-quality variation was the leaking bags inside a wrapped pallet. The VOC evaluation indicated that most customer complaints were a result of incorrect product density.

5.2.3 Identification constraints

Constraints are regarded as anything that is limiting the company from achieving its goal of making money. It was found that the excessively high scrap generated within the facility is limiting the throughput. The performance was evaluated in relation to planned production days and found to perform well. The conclusion was drawn that the lower production plan is resulting in lower performance - and thus lower throughput of the facility. A simulation analysis was conducted and the conveyor configuration was identified as being the biggest constraint within the conveyor system. A simulation test was then done to include a buffer and the cross conveyor of the system, which resulted in a 100% throughput.

Figure 5-2 Identified inefficiencies in packaging facility



Source: (van Wyk, 2018)

5.3 Recommendations

Based on the above conclusion the following recommendation was developed:

5.3.1 Recommendation 1 – Improve the effectiveness of OEE

The packaging facility performance measurement tools namely:

- OEE needs to be corrected to accurately track improvement initiatives. The performance and quality variables of the software are measuring incorrect values. This tool is already installed and if it records the metrics accurately, the facility would be able to identify losses, benchmark progress and improve the productivity of the manufacturing equipment.

- The quality rejection logbook involves a manual process that still makes use of data capturers to document all the scrap. It is recommended that the facility install a bar-coded scanner that links to the rejection logbook and OEE software. This can accurately capture the data in terms of where and why the defect occurred.

5.3.2 Recommendation 2 – Implement visual controls

Performance dashboards are not being displayed. This is an important recommendation, as it will allow workers to quantify performance and enable accountability for the larger organisation. The equipment be installed at the packaging lines to give the operators a visual indication of how each of their bagging machines are performing. Only a few meaningful metrics can be displayed.

5.3.3 Recommendation 3 – Reducing waste and variation

Eight waste items were identified during the study and the following is recommended:

- The facility’s “push” system philosophy needs to be changed to a “pull” system. It is recommended that a Kanban system be employed to merge the material requirements planning (MRP) with a RFID chip per pallet. This would allow the facility to only manufacture based on orders or to ensure a predetermined minimum stock level at the warehouse. The current over-production situation is contributing negatively and resulting in a number of non-value adding waste elements. For example, the over-production results in high inventory, which in turn results in excessive transport costs or defects due to damage during transportation. A pull system could reduce waste drastically, but the lowered inventory levels would expose other inefficiency problems that would need to be resolved.
- Reduce the number of packaging line operators. This would reduce the waste contributed due to waiting. It is also recommended that the skills of these operators be developed using a continuous improvement approach to drive a culture of eliminating defect wastes. If the packaging machines were close together, motion losses would be drastically reduced if one operator monitors four bagging machines and has all the required raw materials delivered to each machine, e.g. bags and labels.

5.3.4 Recommendation 4 – Address core problem

The company should re-pack pallets that have been rejected due to bag leaks. The facility discards a full pallet of product in the event of one bag leaking; therefore, re-packing the pallet would not only limit the amount of scrap generated drastically, but would also reduce operating

cost contributing to re-work. However, this can be done manually by operators or capital could be invested in a separate palletising area.

5.3.5 Recommendation 5 - Develop standardised work-methods

Updating the SOP and retraining the operators on the control parameters. A high scrap level is generated due to human interface issues that deviate from the SOP. Over-weight and under-weight rejections are a result of incorrect packaging line input settings during product change; over-sized product is a result of incorrect adjustments at the solidification system; and the high flushing figure was identified as being two-and-a-half times greater than what was expected.

5.3.6 Recommendation 6 – Optimise the constraint buffer

Install a buffer on packaging lines 5, 6 and 7 to allow a bag to be stored while another is being filled. This is to compensate for the conveyor that is not available for the machine to release the bag and results in the machine being delayed. Additionally, it is recommended that the cross conveyor be brought back into operation to allow the robots to share loads. This would improve the conveyor throughput to 100% and would increase the redundancy of the system.

5.3.7 Recommendation 7 – Identify customers value

Conduct market research on the VOC. The current market research is reactive and is only focused on complaints. The slow inventory is an indication that the demand for the product is not high, and by capturing customers' expectations, preferences and aversions, better align with the company's continuous improvement initiatives can be achieved.

5.3.8 Recommendation 8 – Power of involvement

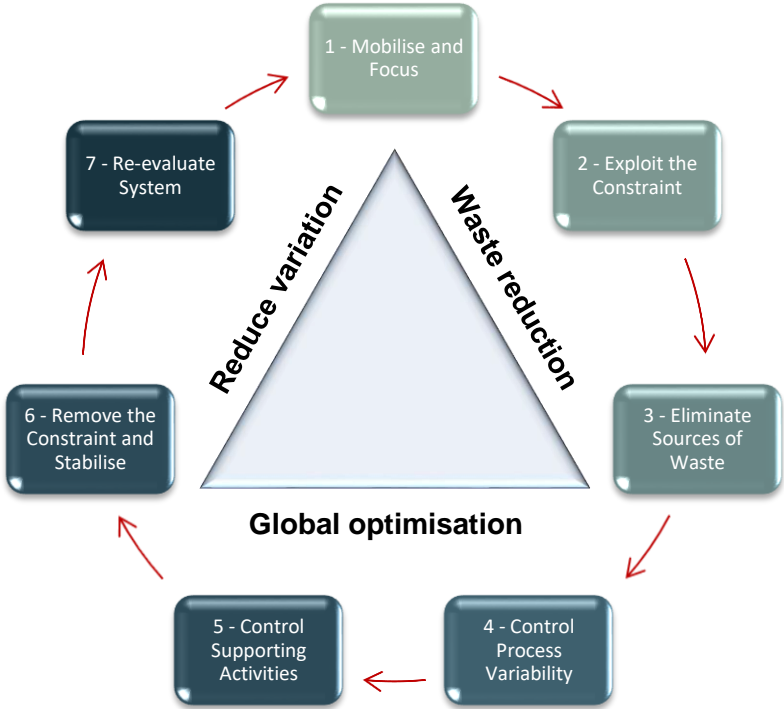
Development of the company's staff in relation to continuous improvement initiatives. If staff are trained to identify and resolve issues, they would become more aware of non-value adding processes. Continuous improvement project leaders need to be well educated in the iTLS methodology and must be able to transfer their knowledge during each project. By developing the people and continuously improving its processes the facility can drive a culture of Kaizen.

5.3.9 Recommendation 9 – Sustain by implementing iTLS

Based on the methodology and steps researched in section 2.5.4, it is recommended that the company implement a systematic process called iTLS, as it provides the plant with techniques and tools to increase system throughput, lower cost, and improve responsiveness and quality. The findings of the study pointed out that the facility could benefit greatly from a process such as iTLS, since all three focus areas were identified as a concern. (See Figure 5-3.)

The following seven continuous improvement steps are suggested as a solution to address the identified inefficiencies of the plant. The seven steps include the required input information, the tools and techniques to be used and what is expected to be delivered by each step.

Figure 5-3 iTLS model for packaging facility



Source: Adapted from (Pirasteh, 2010; Sproull, 2012)

I. Step 1: Mobilise and focus

The study findings exposed the core problem at the facility. The results could be used or the company's continuous improvement team could re-evaluate the findings with more current data. The input requirements established for the organisation were formulated based on the literature study undertaken, which was regarded as the seen "tool box" to achieve the output of the step. The proposed input tools and output requirement are shown in Figure 5-4.

Figure 5-4 Step 1 Mobilise and focus

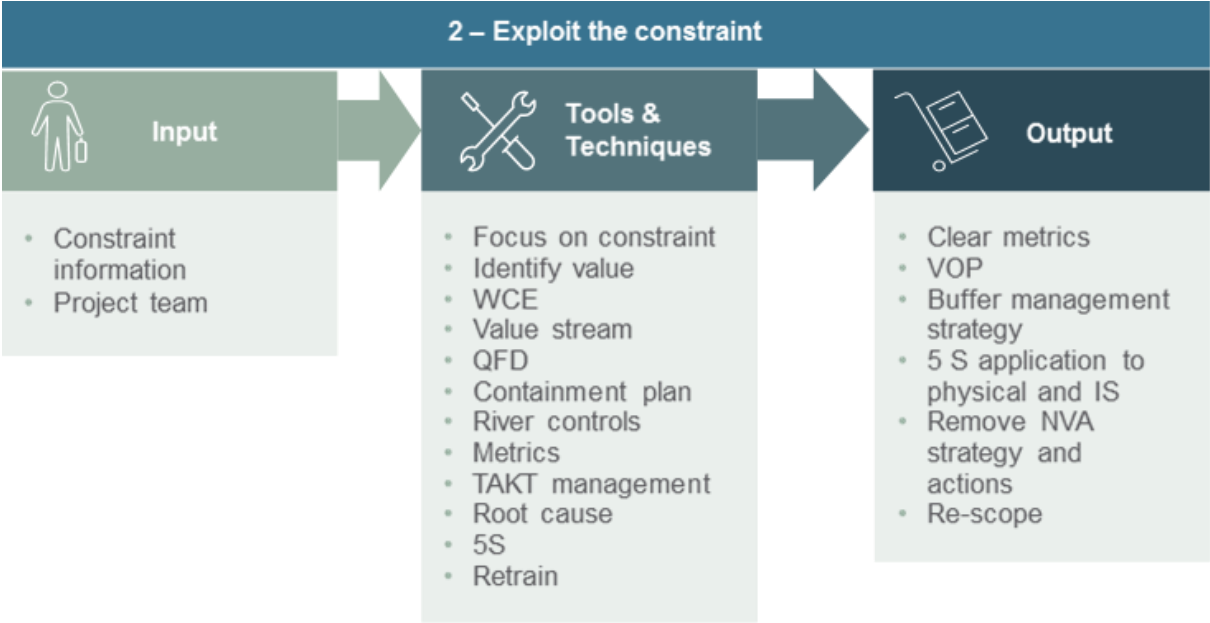


Source: Adapted from (Goldratt & Cox, 2016; Nave, 2002; Pirasteh, 2010; van Wyk, 2018)

Step 2: Exploit the constraint

At this point a number of improvements can increase the current performance throughput of the constraint. The data analysis done in the previous step is used to determine the most appropriate action. With the selected project team in place and the constraint having been identified, all efforts should be directed towards dealing with it. The type of constraint will determine the tools and techniques applied. The proposed input, tools and techniques, as well as the expected outputs are shown in Figure 5-5.

Figure 5-5 Step 2 Exploit the constraint

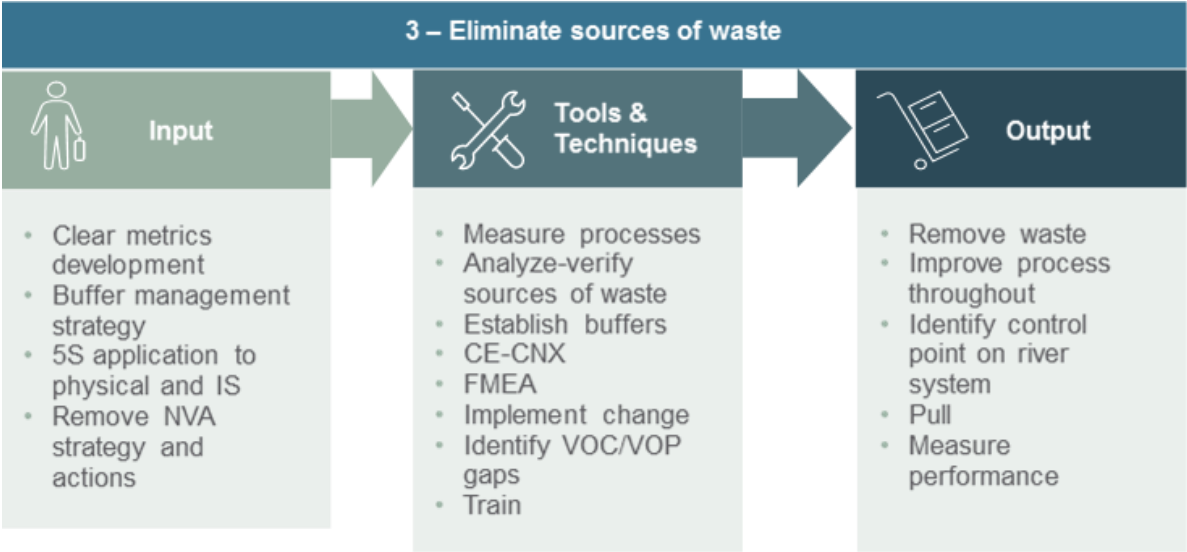


Source: Adapted from (Demchuk & Baitsar, 2014; Goldratt & Cox, 2016; Pirasteh, 2010; van Wyk, 2018)

Step 3: Eliminate sources of waste

At this stage, the established measurements need to be assessed. It was found in this study that the OEE measurement was done incorrectly, therefore, it is recommended that it be revised. This need to be accurate for this step of the process as the benefits of the improvement needs to be traced to ensure that wastes regression doesn't occur. Proven Lean tools, such as the failure mode and effect analysis, could be used to help address the gaps between what the customer expects (VOC) and what the facility can deliver. A number of waste items were identified in this study and applying this step could lead to a further increase in throughput and a reduction in operating expenses and high inventory costs. The process should focus on being demand driven and this step should help establish the "pull".

Figure 5-6 Step 3 Eliminate sources of waste

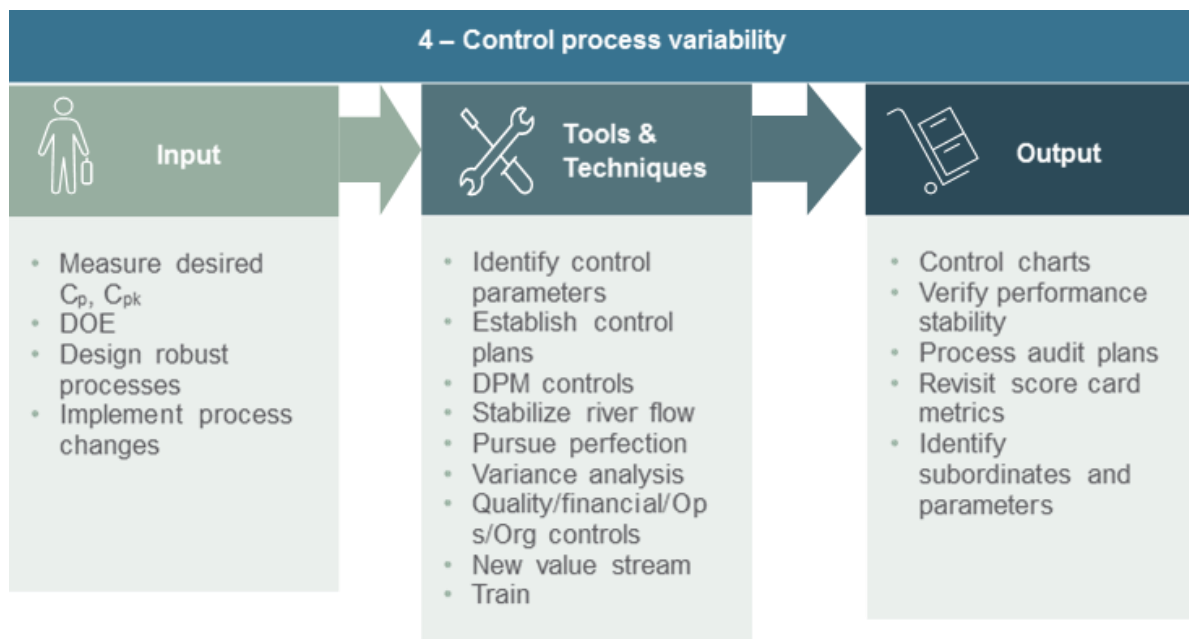


Source: Adapted from (Bicheno & Holweg, 2000; Demchuk & Baitsar, 2014; Pirasteh, 2010; van Wyk, 2018)

Step 4: Control process variability

With most improvement initiatives, there is a tendency for the initiative to dissipate over time; therefore, it is important to include a step to control the variability. By applying Six Sigma tools and techniques at this stage, the process is as error-free as it can be made, as per requirements. The upper and lower limits of the process need to be pinned and the process variability should be squeezed around the process mean. This step would help drive the narrow process spread required to control the number of defects to an acceptable standard. Figure 5-7 show the recommended requirements and tools for this step.

Figure 5-7 Step 4 Control process variability



Source: Adapted from (Conger, 2015; Pirasteh, 2010; Sproull, 2012; van Wyk, 2018)

Step 5: Control supporting activities

Once the process variability settings are established, it needs to be controlled. This step recommends that the SOP be revised and other control metrics be implemented.

Figure 5-8 Step 5 Control supporting activities

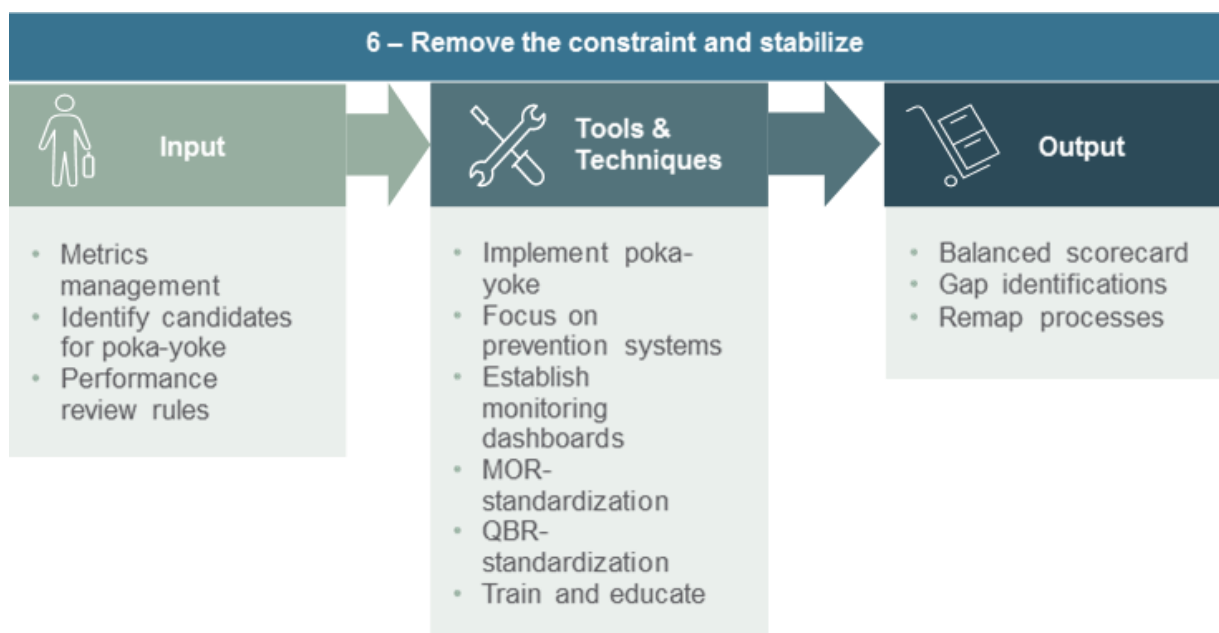


Source: Adapted from (Pirasteh, 2010; van Wyk, 2018; Voehl *et al.*, 2016)

Step 6: Remove the constraint and stabilise

In this step, the identified process constraint no longer poses a threat to the process throughout. Fail-safe parameters need to be established to ensure control over the variability. All workers need to receive training on problem-solving. Incorporated dashboards for monitoring reasons is establish. The evaluation of the continuous improvement efforts fits into this step, i.e. determine how much did the hard work paid-off.

Figure 5-9 Remove the constraint and stabilise

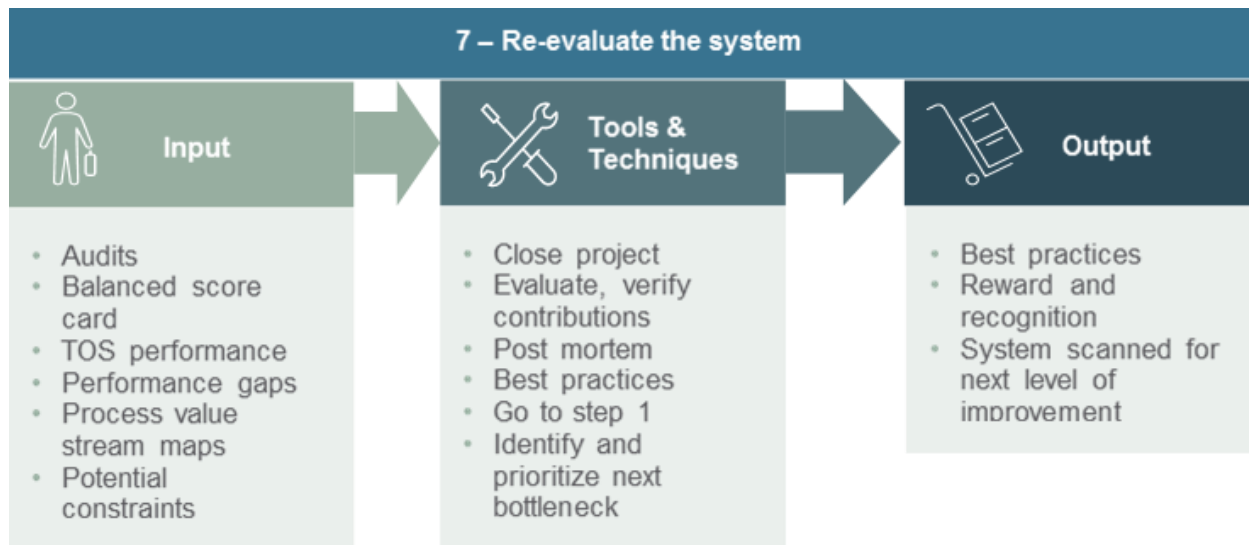


Source: Adapted from (Pirasteh, 2010; van Wyk, 2018; Vinod *et al.*, 2015)

Step 7: Re-evaluate the system

During this step, the project team needs to re-evaluate the initiatives and system performance against the global benchmark. A post-mortem need to be done and stakeholder buy-in is required. The lessons learned from the research project need to be documented and shared within the organisation. The process needs to be scanned to determine the next area of improvement. A recognition and reward system could be established to give workers incentive to continually drive the process.

Figure 5-10 Re-evaluate the system



Source: Adapted from (Conger, 2015; Sproull, 2012; van Wyk, 2018)

5.4 Evaluation of the study

The determination of success of the study depends on a critical evaluation of the achievements of the primary and secondary objectives, as detailed in section 1.4 of Chapter 1.

5.4.1.1 Primary objective

The main objective of this study was to identify inefficiencies related to waste, throughput and quality in the selected facility, by utilising continuous improvement tools and techniques of the iTLS methodology.

To gain an appreciation of the iTLS methodologies, tools and techniques used to identify inefficiencies, a literature study was conducted. It evaluated the steps of theory of constraint, Lean and Six Sigma and how these steps and tools are integrated into the iTLS process. Evaluation of how these tools practically fit into a facility was described in the research design; based on these tools, the results and findings were derived in Chapter 4. Inefficiencies related to waste, quality and throughput were identified and recommendations were provided.

Based on the above, it is determined that the primary objective was achieved.

5.4.1.2 Secondary objective

The secondary objectives of the study were:

- To apply TOC, Lean and Six Sigma evaluation techniques to a selected packaging facility.
- To verify if the existing performance measuring tools used is accurate.
- To provide the facility with a recommended iTLS methodology implementation plan.

A literature review on the performance measuring tools was done and, based on the research done, a research design was determined, as indicated in Chapter 3. From the results obtained (Chapter 4), the OEE data indicated that the information was sampled incorrectly. The OEE method used in the facility was also found to be unfit, as it measures continuously, irrespective of whether the machine being measured is scheduled to run or not. It was found that the facility measuring instrument used for performance measurement was inaccurate.

In the recommendation portion of this chapter, a step-by-step process is provided to guide the plant through the iTLS methodology process. An implementation plan was proposed 5.3.9 it provides a structured plan of how to implement the improvement initiative.

It is, therefore, concluded that both the secondary objectives were met.

5.4.1.3 Research Question

The above objectives aided in answering the research question:

Can the iTLS continuous improvement methodology provide a solution to the problems of constraint, wastage and process variation at a selected packaging facility?

The literature review gave a structured solution on how the iTLS methodology can benefit three areas of inefficiencies in a manufacturing facility. Based on the finding on the case study done in the literature review (section: 2.5.6), it was also found that implementing such a methodology can provide a sustainable solution. The main objective of the study identified that the facility is producing faced with problems such as constraint, wastage and process variation. Based on the study findings it was evaluated that the iTLS continuous improvement methodology could provide a fitting solution to the selected packaging facility.

5.4.1.4 Limitations

- There are statistical model restraints due to the IP governing the product grades and forms. This result will be that all data on products will be converted and expressed per packaging line.
- IP limitations: the company name and name of the specific plants may not be published.
- A limitation exists in the accuracy of the data collected by the Overall Equipment Effectiveness Report, as it reflects hourly intervals. This can be problematic, as there are idle times as a result of inspections, routine maintenance and breakdowns, when no pallets are packaged. This results in inaccurate per-hour-packaging quantities in the data model.
- A data model limitation exists when clients do not report all quality issues; this may reduce the number of quality reports charted.

5.5 Suggestions for further research

Further research into the continuous improvement process known as iTLS is suggested, even though this is a fairly new methodology (2010). Aspects that could be explored include:

- Additional research can be done to determine the validity of the findings in this research by replicating the same approach in another packaging facility.
- A similar longitudinal study can be done by conducting the same research on the same packaging facility used for this analysis in five years' time and then assessing the success of the iTLS implementation and whether the same findings apply or if new findings arise.
- A qualitative longitudinal study on the impact of the iTLS on the performance of a production industry.
- A critical evaluation of the change management process required to successfully sustain the iTLS methodology culture after implementation.
- A case study on the implementation of iTLS methodology compared to similar industries that does not make use of the methodology.

5.6 Overall conclusion

The selected packaging plant was chosen for the study as it was suspected that the facility manufactures its products ineffectively. A literature study was conducted, which pointed out the advantages of using a combined methodology called iTLS, rather than using the foundational methodologies independently. Selected tools and techniques from the different methodologies were used to discover that the facility does perform inefficiently. The overall scrap generation of the facility was found to be the biggest constraint. Applying the iTLS process to this facility would

improve both this constraint, as well as other contributing issues, such as the large amount of non-value-adding processes and variations in the manufacturing process.

The study provided conclusions on the findings and recommendations linked to the literature study. The research value of this mini-dissertation lies in the unique combination methodology that is ground-breaking in nature. The application of iTLS as a systematic continuous improvement process could deliver the benefits of improved throughput, lower waste and more consistent quality. It is a process that, if implemented correctly, could provide a company with the required focus and tools to be competitive in the global marketplace.

As Edward Deming (2018) stated:

“it is not enough for everyone to do his best. Everyone is already doing
his best. Efforts, to be effective, must go in the right direction. “

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ANNEXURE A: OVERALL EQUIPMENT EFFECTIVENESS DATA

Table A-1 Overall equipment effectiveness data for Packaging line 2

Description	Packaging line 2											
	Availability % per 24h	SMALL BAGS					JUMBO BAGS			Scrap		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Small bags Rej	%	
July '16 total		377,50	498,60	-121,10	1054,00		177,70	164,70	13,00	44,90		
\bar{x}	94,8%	12,18	16,08	-3,91	34,00	50%	5,73	5,31	0,42	1,45	86,38	41,0%
Aug '16 total		498,70	172,10	326,60	1054,00		562,60	854,50	-291,90	55,95		
\bar{x}	92,1%	16,09	5,55	10,54	34,00	29%	18,15	27,56	-9,42	1,80	73,07	19,6%
Sep '16 total		327,20	333,00	-5,80	1020,00		365,10	391,40	-26,30	43,44		
\bar{x}	96,4%	10,91	11,10	-0,19	34,00	42%	12,17	13,05	-0,88	1,45	56,89	22,8%
Oct '16 total		612,50	429,80	182,70	1054,00		74,10	164,50	-90,40	74,14		
\bar{x}	91,8%	19,76	13,86	5,89	34,00	72%	2,39	5,31	-2,92	2,39	84,80	55,8%
Nov '16 total		344,70	337,60	7,10	1020,00		64,30	168,50	-104,20	60,84		
\bar{x}	91,5%	11,49	11,25	0,24	34,00	45%	2,14	5,62	-3,47	2,03	74,44	30,5%
Dec '16 total		0,00	0,00	0,00	1054,00		351,00	170,50	180,50	28,35		
\bar{x}	47,7%	0,00	0,00	0,00	34,00	0%	11,32	5,50	5,82	0,91	8,55	0,0%
Jan '17 total		140,40	0,00	140,40	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	0,6%	4,53	0,00	4,53	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Feb '17 total		0,00	0,00	0,00	952,00		0,00	0,00	0,00	0,00		
\bar{x}	0,0%	4,83	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Mar '17 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	0,0%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Apr '17 total		0,00	0,00	0,00	1020,00		0,00	0,00	0,00	0,00		
\bar{x}	21,8%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
May '17 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	0,2%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Jun '17 total		0,00	0,00	0,00	1020,00		0,00	0,00	0,00	0,00		
\bar{x}	0,1%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Jul '17 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	0,0%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Aug '17 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	0,0%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Sep '17 total		0,00	0,00	0,00	1020,00		0,00	0,00	0,00	0,00		
\bar{x}	0,4%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Oct '17 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	0,4%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Nov '17 total		0,00	0,00	0,00	1020,00		0,00	0,00	0,00	0,00		
\bar{x}	6,5%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Dec '17 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	3,3%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Jan '18 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	2,5%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Feb '18 total		0,00	0,00	0,00	952,00		0,00	0,00	0,00	0,00		
\bar{x}	3,2%	0,00	0,00	0,00	66,90	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Mar '18 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	2,9%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Apr '18 total		0,00	0,00	0,00	1020,00		0,00	0,00	0,00	0,00		
\bar{x}	3,1%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
May '18 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,00		
\bar{x}	2,1%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Jun '18 total		0,00	0,00	0,00	1020,00		0,00	0,00	0,00	0,00		
\bar{x}	1,9%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	100,00	0,0%
Overall		2301,0	1771,1	529,9	24820,0		1594,8	1914,1	-319,3	307,6		
\bar{x}	23%	49,60	38,10	11,40	534,77	0,10	34,31	41,18	-6,87	6,62	91,01	0,07

Table A-2 Overall equipment effectiveness data for Packaging line 9

Description	Packaging Line 9											
	Availability % per 24h	SMALL BAGS					JUMBO BAGS			Quality		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Scrap	%	%
July '16 total		560,40	439,60	120,80	1054,00		186,60	95,40	91,20	91,81		
x̄	98,7%	18,08	14,18	3,90	34,00	45%	6,02	3,08	2,94	2,96	71,54	32,0%
Aug '16 total		434,70	496,20	-61,50	1054,00		138,60	297,90	-159,30	108,18		
x̄	97,1%	14,02	16,01	-1,98	34,00	61%	4,47	9,61	-5,14	3,49	68,11	40,2%
Sep '16 total		481,20	439,60	41,60	1020,00		224,70	174,00	50,70	43,42		
x̄	95,9%	16,04	14,65	1,39	34,00	46%	7,49	5,80	1,69	1,45	85,84	38,0%
Oct '16 total		269,00	218,30	50,70	1054,00		608,10	582,20	25,90	167,17		
x̄	96,1%	8,68	7,04	1,64	34,00	34%	19,62	18,78	0,84	5,39	36,46	12,0%
Nov '16 total		48,00	147,70	-99,70	1020,00		799,20	360,90	438,30	78,42		
x̄	95,9%	1,60	4,92	-3,32	34,00	40%	26,64	12,03	14,61	2,61	82,54	31,4%
Dec '16 total		277,40	217,70	59,70	1054,00		335,80	498,60	-162,80	59,81		
x̄	83,6%	8,95	7,02	1,93	34,00	59%	10,83	16,08	-5,25	1,93	81,35	39,8%
Jan '17 total		116,80	89,60	27,20	1054,00		640,20	613,80	26,40	85,90		
x̄	77,9%	3,77	2,89	0,88	34,00	38%	20,65	19,80	0,85	2,77	76,96	22,7%
Feb '17 total		160,60	0,00	160,60	952,00		350,40	292,70	57,70	0,00		
x̄	96,7%	9,37	3,08	5,74	34,00	0%	12,51	10,45	2,06	0,00	100,00	0,0%
Mar '17 total		478,80	298,20	180,60	1054,00		87,40	52,80	34,60	120,51		
x̄	96,2%	15,45	9,62	5,83	34,00	44%	2,82	1,70	1,12	3,89	30,10	12,8%
Apr '17 total		510,00	582,00	-72,00	1020,00		120,00	127,00	-7,00	21,26		
x̄	98,7%	17,00	19,40	-2,40	34,00	58%	4,00	4,23	-0,23	0,71	95,87	54,7%
May '17 total		120,00	196,00	-76,00	1054,00		618,00	570,00	48,00	6,56		
x̄	98,4%	3,87	6,32	-2,45	34,00	45%	19,94	18,39	1,55	0,21	96,65	42,6%
Jun '17 total		448,00	460,00	-12,00	1020,00		0,00	26,00	-26,00	31,94		
x̄	94,3%	14,93	15,33	-0,40	34,00	50%	0,00	0,87	-0,87	1,06	92,21	43,3%
Jul '17 total		0,00	30,00	-30,00	1054,00		789,00	153,00	636,00	31,46		
x̄	70,1%	0,00	0,97	-0,97	34,00	18%	25,45	4,94	20,52	1,01	5,33	0,7%
Aug '17 total		329,00	475,00	-146,00	1054,00		183,00	206,00	-23,00	71,58		
x̄	99,0%	10,61	15,32	-4,71	34,00	56%	5,90	6,65	-0,74	2,31	52,26	29,1%
Sep '17 total		840,00	657,00	183,00	1020,00		0,00	131,00	-131,00	71,74		
x̄	98,8%	28,00	21,90	6,10	34,00	67%	0,00	4,37	-4,37	2,39	86,40	57,6%
Oct '17 total		840,00	707,00	133,00	1054,00		0,00	155,00	-155,00	48,41		
x̄	98,4%	27,10	22,81	4,29	34,00	70%	0,00	5,00	-5,00	1,56	89,26	61,9%
Nov '17 total		791,00	620,00	171,00	1020,00		0,00	136,00	-136,00	50,46		
x̄	83,5%	26,39	20,74	5,65	34,00	68%	0,00	4,55	-4,55	1,68	81,58	46,4%
Dec '17 total		752,00	647,00	105,00	1054,00		70,00	121,00	-51,00	55,12		
x̄	96,1%	24,26	20,87	3,39	34,00	63%	2,26	3,90	-1,65	1,78	70,89	43,2%
Jan '18 total		806,00	664,00	142,00	1054,00		6,00	78,00	-72,00	81,18		
x̄	96,3%	26,00	21,42	4,58	34,00	65%	0,19	2,52	-2,32	2,62	85,37	53,2%
Feb '18 total		594,00	510,00	84,00	952,00		83,00	190,00	-107,00	95,30		
x̄	90,7%	46,71	38,72	7,99	66,90	55%	3,07	8,98	-5,91	5,88	42,13	21,0%
Mar '18 total		420,00	188,00	232,00	1054,00		0,00	44,00	-44,00	41,74		
x̄	37,9%	13,55	6,06	7,48	34,00	19%	0,00	1,42	-1,42	1,35	50,99	3,7%
Apr '18 total		56,00	13,00	43,00	1020,00		0,00	0,00	0,00	1,76		
x̄	94,1%	2,24	0,61	1,63	34,00	2%	0,00	0,05	-0,05	0,10	97,98	1,8%
May '18 total		0,00	0,00	0,00	1054,00		0,00	0,00	0,00	0,58		
x̄	97,4%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,02	98,13	0,0%
Jun '18 total		0,00	0,00	0,00	1020,00		0,00	0,00	0,00	0,00		
x̄	18,3%	0,00	0,00	0,00	34,00	0%	0,00	0,00	0,00	0,00	99,94	0,0%
Overall		9332,9	8095,9	1237,0	24820,0		5240,0	4905,3	334,7	1364,3		
x̄	0,88	201,45	174,70	26,73	534,77	42%	112,75	105,59	7,15	29,41	74,08	29%

Table A-3 Overall equipment effectiveness data for Packaging line 1

Description	Packaging Line 1												
	Availability % per 24h	SMALL BAGS					JUMBO BAGS				Quality		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Scrap	%	%	
July '16 total		425,50	199,70	225,80	818,40		109,70	196,20	-86,50	19,12			
x̄	91,0%	13,73	6,44	7,28	26,40	48%	3,54	6,33	-2,79	0,62	65,50	28,7%	
Aug '16 total		162,20	116,80	45,40	818,40		353,60	445,40	-91,80	8,33			
x̄	94,7%	5,23	3,77	1,46	26,40	32%	11,41	14,37	-2,96	0,27	78,32	23,8%	
Sep '16 total		288,70	355,90	-67,20	792,00		241,40	137,40	104,00	20,61			
x̄	83,5%	9,62	11,86	-2,24	26,40	57%	8,05	4,58	3,47	0,69	84,00	39,9%	
Oct '16 total		435,80	420,70	15,10	818,40		52,20	91,20	-39,00	27,80			
x̄	97,8%	14,06	13,57	0,49	26,40	54%	1,68	2,94	-1,26	0,90	80,64	42,6%	
Nov '16 total		199,30	175,20	24,10	792,00		287,90	212,20	75,70	18,11			
x̄	79,7%	6,64	5,84	0,80	26,40	43%	9,60	7,07	2,52	0,60	75,86	26,1%	
Dec '16 total		351,90	409,20	-57,30	818,40		37,20	17,40	19,80	9,50			
x̄	98,7%	11,35	13,20	-1,85	26,40	51%	1,20	0,56	0,64	0,31	97,88	49,0%	
Jan '17 total		486,20	332,40	153,80	818,40		24,10	7,20	16,90	15,24			
x̄	64,7%	15,68	10,72	4,96	26,40	65%	0,78	0,23	0,55	0,49	90,36	38,0%	
Feb '17 total		351,90	242,50	109,40	739,20		139,40	84,60	54,80	13,19			
x̄	63,6%	28,46	19,52	3,91	26,40	60%	4,98	3,02	1,96	0,47	88,19	33,6%	
Mar '17 total		556,10	572,90	-16,80	818,40		62,50	40,20	22,30	33,73			
x̄	95,1%	17,94	18,48	-0,54	26,40	77%	2,02	1,30	0,72	1,09	94,04	68,7%	
Apr '17 total		459,00	543,00	-84,00	792,00		170,00	164,00	6,00	14,81			
x̄	94,9%	15,30	18,10	-2,80	26,40	81%	5,67	5,47	0,20	0,49	88,60	68,5%	
May '17 total		729,00	764,00	-35,00	818,40		31,00	25,00	6,00	32,19			
x̄	97,2%	23,52	24,65	-1,13	26,40	96%	1,00	0,81	0,19	1,04	95,20	88,7%	
Jun '17 total		520,00	937,00	-417,00	792,00		394,00	0,00	394,00	16,33			
x̄	64,2%	17,33	31,23	-13,90	26,40	121%	13,13	0,00	13,13	0,54	98,21	76,5%	
Jul '17 total		438,00	211,00	227,00	818,40		129,00	28,00	101,00	8,96			
x̄	75,9%	14,13	6,81	7,32	26,40	41%	4,16	0,90	3,26	0,29	75,58	23,3%	
Aug '17 total		535,00	668,00	-133,00	818,40		0,00	40,00	-40,00	54,02			
x̄	91,9%	17,26	21,55	-4,29	26,40	89%	0,00	1,29	-1,29	1,74	73,55	60,3%	
Sep '17 total		848,00	697,00	151,00	792,00		60,00	52,00	8,00	43,30			
x̄	98,4%	28,27	23,23	5,03	26,40	96%	2,00	1,73	0,27	1,44	92,79	87,4%	
Oct '17 total		258,00	205,00	53,00	818,40		586,00	829,00	-243,00	51,00			
x̄	56,8%	8,32	6,61	1,71	26,40	89%	18,90	26,74	-7,84	1,65	79,76	40,2%	
Nov '17 total		670,00	607,00	63,00	792,00		0,00	17,00	-17,00	39,00			
x̄	84,0%	21,88	19,79	2,09	26,40	51%	0,61	1,41	-0,80	1,31	93,97	40,2%	
Dec '17 total		425,00	207,00	218,00	818,40		142,00	190,00	-48,00	65,27			
x̄	60,7%	13,71	6,68	7,03	26,40	9%	4,58	6,13	-1,55	2,11	72,61	4,1%	
Jan '18 total		478,00	313,00	165,00	818,40		374,00	352,00	22,00	69,63			
x̄	68,6%	15,42	10,10	5,32	26,40	60%	12,06	11,35	0,71	2,25	51,93	21,5%	
Feb '18 total		606,00	543,00	63,00	739,20		12,00	33,00	-21,00	61,39			
x̄	94,6%	36,43	28,45	7,98	51,95	69%	12,84	12,79	0,06	4,37	85,31	55,3%	
Mar '18 total		91,00	98,00	-7,00	818,40		0,00	1,00	-1,00	5,25			
x̄	38,8%	2,94	3,16	-0,23	26,40	19%	0,00	0,03	-0,03	0,17	99,24	7,4%	
Apr '18 total		546,00	474,00	72,00	792,00		0,00	0,00	0,00	11,12			
x̄	94,2%	17,71	15,39	2,32	26,40	72%	0,00	0,00	0,00	0,36	97,35	65,7%	
May '18 total		873,00	821,00	52,00	818,40		0,00	28,00	-28,00	64,30			
x̄	95,3%	28,16	26,48	1,68	26,40	106%	0,00	0,90	-0,90	2,07	89,64	90,5%	
Jun '18 total		343,00	235,00	108,00	792,00		398,00	379,00	19,00	23,75			
x̄	63,6%	11,97	8,43	3,54	26,40	0%	12,84	12,25	0,58	0,83	62,44	0,0%	
Overall		11076,6	10148,3	928,3	19272,0		3604,0	3369,8	234,2	726,0			
x̄	81%	238,99	218,80	20,09	415,23	62%	77,81	72,75	5,06	15,67	83,79	45%	

Table A-4 Overall equipment effectiveness data for Packaging line 3

Description	Packaging Line 3												
	Availability % per 24h	SMALL BAGS					JUMBO BAGS				Quality		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Scrap	%	%	
July '16 total		526,70	406,70	120,00	818,40		0,00	0,00	0,00	8,64			
\bar{x}	92,6%	16,99	13,12	3,87	26,40	61%	0,00	0,00	0,00	0,28	91,76	51,8%	
Aug '16 total		694,20	578,40	115,80	818,40		0,00	0,00	0,00	7,92			
\bar{x}	94,2%	22,39	18,66	3,74	26,40	75%	0,00	0,00	0,00	0,26	97,26	68,3%	
Sep '16 total		257,00	336,70	-79,70	792,00		0,00	0,00	0,00	3,69			
\bar{x}	90,7%	8,57	11,22	-2,66	26,40	48%	0,00	0,00	0,00	0,12	98,67	43,3%	
Oct '16 total		352,40	145,60	206,80	818,40		0,00	0,00	0,00	2,55			
\bar{x}	46,0%	11,37	4,70	6,67	26,40	40%	0,00	0,00	0,00	0,08	98,15	18,3%	
Nov '16 total		497,40	317,80	179,60	792,00		0,00	0,00	0,00	40,59			
\bar{x}	96,1%	16,58	10,59	5,99	26,40	46%	0,00	0,00	0,00	1,35	76,52	34,1%	
Dec '16 total		400,40	301,70	98,70	818,40		0,00	0,00	0,00	7,67			
\bar{x}	98,2%	12,92	9,73	3,18	26,40	38%	0,00	0,00	0,00	0,25	97,69	36,0%	
Jan '17 total		225,00	282,80	-57,80	818,40		0,00	0,00	0,00	2,01			
\bar{x}	98,6%	7,26	9,12	-1,86	26,40	35%	0,00	0,00	0,00	0,06	99,23	34,3%	
Feb '17 total		0,00	0,00	0,00	739,20		0,00	0,00	0,00	0,00			
\bar{x}	32,7%	7,74	9,73	0,00	26,40	0%	0,00	0,00	0,00	0,00	100,00	0,0%	
Mar '17 total		0,00	0,00	0,00	818,40		0,00	0,00	0,00	0,00			
\bar{x}	34,2%	0,00	0,00	0,00	26,40	0%	0,00	0,00	0,00	0,00	100,00	0,0%	
Apr '17 total		348,00	385,00	-37,00	792,00		0,00	0,00	0,00	9,17			
\bar{x}	88,4%	11,60	12,83	-1,23	26,40	69%	0,00	0,00	0,00	0,31	82,12	49,8%	
May '17 total		0,00	17,00	-17,00	818,40		0,00	0,00	0,00	0,00			
\bar{x}	52,8%	0,00	0,55	-0,55	26,40	33%	0,00	0,00	0,00	0,00	100,00	17,5%	
Jun '17 total		0,00	0,00	0,00	792,00		0,00	0,00	0,00	0,00			
\bar{x}	0,1%	0,00	0,00	0,00	26,40	0%	0,00	0,00	0,00	0,00	100,00	0,0%	
Jul '17 total		0,00	0,00	0,00	818,40		0,00	0,00	0,00	0,00			
\bar{x}	0,0%	0,00	0,00	0,00	26,40	0%	0,00	0,00	0,00	0,00	100,00	0,0%	
Aug '17 total		0,00	0,00	0,00	818,40		0,00	0,00	0,00	5,99			
\bar{x}	79,1%	0,00	0,00	0,00	26,40	0%	0,00	0,00	0,00	0,19	80,67	0,0%	
Sep '17 total		0,00	0,00	0,00	792,00		0,00	0,00	0,00	0,00			
\bar{x}	99,4%	0,00	0,00	0,00	26,40	0%	0,00	0,00	0,00	0,00	100,00	0,0%	
Oct '17 total		211,00	348,00	-137,00	818,40		0,00	0,00	0,00	10,13			
\bar{x}	87,1%	6,81	11,23	-4,42	26,40	89%	0,00	0,00	0,00	0,33	79,89	61,8%	
Nov '17 total		177,00	111,00	66,00	792,00		0,00	0,00	0,00	10,03			
\bar{x}	89,0%	5,93	3,94	1,99	26,40	4%	0,00	0,00	0,00	0,33	73,95	2,6%	
Dec '17 total		0,00	0,00	0,00	818,40		0,00	0,00	0,00	0,55			
\bar{x}	92,5%	0,00	0,00	0,00	26,40	0%	0,00	0,00	0,00	0,02	98,23	0,0%	
Jan '18 total		0,00	0,00	0,00	818,40		0,00	0,00	0,00	0,50			
\bar{x}	67,2%	0,00	0,00	0,00	26,40	0%	0,00	0,00	0,00	0,02	98,40	0,0%	
Feb '18 total		249,00	75,00	174,00	739,20		0,00	0,00	0,00	4,03			
\bar{x}	94,6%	8,03	2,42	5,61	51,95	5%	0,00	0,00	0,00	0,15	97,66	4,2%	
Mar '18 total		48,00	21,00	27,00	818,40		0,00	0,00	0,00	0,00			
\bar{x}	15,6%	1,55	0,68	0,87	26,40	0%	0,00	0,00	0,00	0,00	100,00	0,0%	
Apr '18 total		264,00	147,00	117,00	792,00		0,00	0,00	0,00	16,68			
\bar{x}	80,5%	8,57	4,76	3,80	26,40	26%	0,00	0,00	0,00	0,54	64,93	13,6%	
May '18 total		123,00	102,00	21,00	818,40		0,00	0,00	0,00	4,07			
\bar{x}	96,5%	3,97	3,29	0,68	26,40	1%	0,00	0,00	0,00	0,13	94,80	1,2%	
Jun '18 total		0,00	0,00	0,00	792,00		0,00	0,00	0,00	0,00			
\bar{x}	18,4%	0,13	0,11	0,02	26,40	0%	0,00	0,00	0,00	0,00	99,83	0,0%	
Overall		4373,1	3575,7	797,4	19272,0		0,0	0,0	0,0	134,2			
\bar{x}	69%	94,24	77,13	17,15	415,23	24%	0,00	0,00	0,00	2,89	92,91	18%	

Table A-5 Overall equipment effectiveness data for Packaging line 6

Description	Packaging line 6											
	Avail-ability % per 24h	SMALL BAGS					JUMBO BAGS			Scrap		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Quality		
July '16 total		711,90	578,10	133,80	861,80		78,60	98,70	-20,10	19,10		
\bar{x}	92,5%	22,96	18,65	4,32	27,80	69%	2,54	3,18	-0,65	0,62	93,39	59,6%
Aug '16 total		536,80	595,00	-58,20	861,80		249,10	355,20	-106,10	5,17		
\bar{x}	89,8%	17,32	19,19	-1,88	27,80	72%	8,04	11,46	-3,42	0,17	99,43	64,4%
Sep '16 total		580,90	624,40	-43,50	834,00		143,50	202,20	-58,70	23,81		
\bar{x}	94,4%	19,30	20,76	-1,46	27,80	79%	4,89	6,89	-2,00	0,77	88,46	66,1%
Oct '16 total		407,30	410,10	-2,80	861,80		83,70	99,00	-15,30	39,85		
\bar{x}	89,7%	13,14	13,23	-0,09	27,80	52%	2,70	3,19	-0,49	1,29	70,83	32,9%
Nov '16 total		310,00	628,00	-318,00	834,00		110,00	113,00	-3,00	23,33		
\bar{x}	90,3%	10,42	20,68	-10,26	27,80	80%	3,64	3,75	-0,11	0,79	94,50	68,0%
Dec '16 total		300,00	439,00	-139,00	861,80		269,00	22,00	247,00	11,17		
\bar{x}	77,9%	9,68	14,16	-4,48	27,80	53%	8,68	0,71	7,97	0,36	94,54	38,9%
Jan '17 total		248,00	77,70	170,30	861,80		218,20	241,50	-23,30	10,23		
\bar{x}	79,0%	8,00	2,51	5,49	27,80	9%	7,04	7,79	-0,75	0,33	84,64	6,2%
Feb '17 total		252,00	216,20	35,80	778,40		46,20	27,60	18,60	19,00		
\bar{x}	94,5%	16,39	9,97	6,42	54,70	28%	8,76	9,05	-0,29	0,95	83,31	22,1%
Mar '17 total		176,00	131,60	44,40	861,80		102,40	75,60	26,80	7,95		
\bar{x}	70,7%	5,68	4,25	1,43	27,80	18%	3,30	2,44	0,86	0,26	82,24	10,3%
Apr '17 total		560,00	442,00	118,00	834,00		150,00	182,00	-32,00	25,17		
\bar{x}	87,7%	18,25	14,40	3,85	27,80	55%	4,95	5,95	-1,00	0,82	81,32	39,1%
May '17 total		305,00	276,00	29,00	861,80		266,00	192,00	74,00	42,20		
\bar{x}	83,2%	9,84	8,90	0,94	27,80	33%	8,58	6,19	2,39	1,36	84,51	23,4%
Jun '17 total		559,00	284,00	275,00	834,00		26,00	65,00	-39,00	19,15		
\bar{x}	81,3%	18,35	9,45	8,90	27,80	36%	1,12	2,30	-1,18	0,66	66,24	19,3%
Jul '17 total		0,00	8,00	-8,00	861,80		0,00	0,00	0,00	8,76		
\bar{x}	70,8%	0,00	0,26	-0,26	27,80	1%	0,00	0,00	0,00	0,28	71,73	0,5%
Aug '17 total		270,00	269,00	1,00	861,80		94,00	68,00	26,00	14,28		
\bar{x}	92,3%	8,71	8,68	0,03	27,80	32%	3,03	2,19	0,84	0,46	66,78	20,0%
Sep '17 total		470,00	462,00	8,00	834,00		164,00	60,00	104,00	20,97		
\bar{x}	91,5%	15,44	15,18	0,26	27,80	57%	5,39	2,01	3,38	0,69	76,69	40,3%
Oct '17 total		221,00	207,00	14,00	861,80		341,00	288,00	53,00	13,19		
\bar{x}	88,8%	7,13	6,68	0,45	27,80	25%	11,00	9,29	1,71	0,43	84,04	18,7%
Nov '17 total		253,00	236,00	17,00	834,00		156,00	133,00	23,00	8,58		
\bar{x}	77,8%	8,39	7,83	0,56	27,80	31%	5,39	4,59	0,80	0,29	86,01	20,8%
Dec '17 total		147,00	7,00	140,00	861,80		676,00	505,00	171,00	15,38		
\bar{x}	76,2%	4,74	0,23	4,52	27,80	1%	21,81	16,29	5,52	0,50	53,22	0,5%
Jan '18 total		520,00	175,00	345,00	861,80		123,00	505,00	-382,00	12,21		
\bar{x}	76,4%	16,77	5,65	11,13	27,80	22%	3,97	16,29	-12,32	0,39	72,03	11,8%
Feb '18 total		379,00	116,00	263,00	778,40		50,00	204,00	-154,00	5,19		
\bar{x}	62,8%	29,54	9,57	19,97	54,70	15%	5,71	23,69	-17,98	0,57	93,90	9,0%
Mar '18 total		277,00	123,00	154,00	861,80		78,00	78,00	0,00	16,76		
\bar{x}	61,3%	8,94	3,97	4,97	27,80	15%	2,52	2,52	0,00	0,54	81,61	7,5%
Apr '18 total		357,00	235,00	122,00	834,00		0,00	0,00	0,00	11,89		
\bar{x}	67,0%	11,80	7,71	4,10	27,80	30%	0,08	0,08	0,00	0,40	93,03	18,7%
May '18 total		195,00	130,00	65,00	861,80		93,00	30,00	63,00	4,95		
\bar{x}	65,4%	6,29	4,19	2,10	27,80	16%	3,00	0,97	2,03	0,16	92,79	9,9%
Jun '18 total		152,00	117,00	35,00	834,00		532,00	474,00	58,00	17,16		
\bar{x}	67,4%	5,11	3,91	1,20	27,80	15%	17,26	15,32	1,94	0,56	70,90	7,1%
Overall		8187,9	6787,1	1400,8	20294,0		4049,7	4018,8	30,9	395,4		
\bar{x}	80%	176,67	146,19	30,48	437,81	35%	87,36	86,98	0,38	8,52	81,92	26%

Table A-6 Overall equipment effectiveness data for Packaging line 5

Description	Packaging line 5											
	Availability % per 24h	SMALL BAGS					JUMBO BAGS			Scrap		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Quality		
July '16 total		468,70	395,40	73,30	728,50		78,60	40,80	37,80	33,70		
\bar{x}	98,0%	15,12	12,75	2,36	23,50	54%	2,54	1,32	1,22	1,09	78,51	41,7%
Aug '16 total		410,10	431,20	-21,10	728,50		249,10	190,80	58,30	10,61		
\bar{x}	91,6%	13,23	13,91	-0,68	23,50	61%	8,04	6,15	1,88	0,34	96,75	54,0%
Sep '16 total		309,30	457,60	-148,30	705,00		143,50	299,40	-155,90	52,23		
\bar{x}	89,9%	10,40	15,21	-4,81	23,50	71%	4,89	9,86	-4,97	1,70	58,07	37,1%
Oct '16 total		428,20	387,10	41,10	728,50		83,70	268,50	-184,80	37,76		
\bar{x}	73,8%	13,81	12,49	1,33	23,50	57%	2,70	8,66	-5,96	1,22	64,62	27,4%
Nov '16 total		354,00	476,48	-122,48	705,00		240,00	60,00	180,00	30,03		
\bar{x}	91,2%	11,86	15,77	-3,91	23,50	73%	7,83	2,21	5,61	1,01	57,43	38,4%
Dec '16 total		478,00	465,00	13,00	728,50		197,00	36,00	161,00	18,54		
\bar{x}	84,2%	15,42	15,00	0,42	23,50	68%	6,35	1,16	5,19	0,60	94,27	54,0%
Jan '17 total		185,00	257,20	-72,20	728,50		218,20	371,60	-153,40	5,94		
\bar{x}	68,9%	5,97	8,30	-2,33	23,50	38%	7,04	11,99	-4,95	0,19	88,40	23,3%
Feb '17 total		629,30	350,00	279,30	658,00		46,20	25,80	20,40	24,00		
\bar{x}	91,2%	26,46	20,78	5,68	46,24	58%	8,76	13,21	-4,45	0,97	91,00	48,1%
Mar '17 total		386,50	133,00	253,50	728,50		102,60	141,60	-39,00	27,16		
\bar{x}	35,6%	12,47	4,29	8,18	23,50	22%	3,31	4,57	-1,26	0,88	68,62	5,3%
Apr '17 total		524,00	423,00	101,00	705,00		212,00	180,00	32,00	43,16		
\bar{x}	88,2%	17,31	13,78	3,52	23,50	64%	6,95	5,95	0,99	1,42	60,41	33,9%
May '17 total		400,00	429,00	-29,00	728,50		316,00	276,00	40,00	44,72		
\bar{x}	89,3%	12,90	13,84	-0,94	23,50	66%	10,19	8,90	1,29	1,44	64,92	38,2%
Jun '17 total		382,00	386,00	-4,00	705,00		217,00	166,00	51,00	22,39		
\bar{x}	78,2%	12,74	12,90	-0,16	23,50	61%	7,33	5,64	1,69	0,77	82,95	39,5%
Jul '17 total		527,00	280,00	247,00	728,50		128,00	34,00	94,00	16,24		
\bar{x}	50,8%	17,00	9,03	7,97	23,50	37%	4,13	1,10	3,03	0,52	60,05	11,4%
Aug '17 total		327,00	584,00	-257,00	728,50		104,00	33,00	71,00	26,60		
\bar{x}	99,2%	10,55	18,84	-8,29	23,50	84%	3,35	1,06	2,29	0,86	53,18	44,1%
Sep '17 total		486,00	584,00	-98,00	705,00		164,00	100,00	64,00	34,06		
\bar{x}	89,4%	16,02	19,45	-3,43	23,50	87%	5,40	3,26	2,14	1,13	71,76	55,9%
Oct '17 total		430,00	437,00	-7,00	728,50		304,00	118,00	186,00	23,96		
\bar{x}	98,3%	13,87	14,10	-0,23	23,50	62%	9,81	3,81	6,00	0,77	67,39	41,0%
Nov '17 total		355,00	276,29	78,71	705,00		67,00	103,00	-36,00	26,77		
\bar{x}	85,7%	11,90	9,37	2,53	23,50	42%	2,48	3,45	-0,97	0,89	80,97	29,4%
Dec '17 total		435,00	293,00	142,00	728,50		62,00	62,00	0,00	19,50		
\bar{x}	87,8%	14,03	9,45	4,58	23,50	44%	2,00	2,00	0,00	0,63	49,58	19,0%
Jan '18 total		788,00	413,00	375,00	728,50		0,00	171,00	-171,00	34,35		
\bar{x}	90,7%	25,42	13,32	12,10	23,50	63%	0,00	5,52	-5,52	1,11	20,18	11,6%
Feb '18 total		260,00	275,00	-15,00	658,00		139,00	133,00	6,00	36,65		
\bar{x}	91,0%	34,63	22,85	11,78	46,24	47%	4,48	9,98	-5,50	2,37	61,00	26,1%
Mar '18 total		225,00	201,00	24,00	728,50		15,00	27,00	-12,00	13,94		
\bar{x}	53,5%	7,26	6,48	0,77	23,50	30%	0,48	0,87	-0,39	0,45	96,78	15,3%
Apr '18 total		405,00	457,00	-52,00	705,00		90,00	80,00	10,00	28,75		
\bar{x}	94,9%	13,30	14,95	-1,65	23,50	65%	2,92	2,61	0,31	0,94	82,65	50,7%
May '18 total		195,00	213,00	-18,00	728,50		93,00	57,00	36,00	13,50		
\bar{x}	85,8%	6,29	6,87	-0,58	23,50	31%	3,00	1,84	1,16	0,44	94,66	25,0%
Jun '18 total		438,00	438,00	0,00	705,00		218,00	189,00	29,00	30,07		
\bar{x}	86,3%	14,33	14,35	-0,02	23,50	66%	7,13	6,16	0,97	0,98	80,57	45,9%
Overall		9826,1	9042,3	783,8	17155,0		3487,9	3163,5	324,4	654,6		
\bar{x}	83%	212,05	195,01	17,04	370,09	56%	75,19	68,43	6,75	14,11	71,86	34%

Table A-7 Overall equipment effectiveness data for Packaging line 7

Description	Packaging line 7											
	Availability % per 24h	SMALL BAGS					JUMBO BAGS			Scrap		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Quality		
July '16 total		512,50	413,40	99,10	1069,50		332,20	402,00	-69,80	32,76		
\bar{x}	91,1%	16,53	13,34	3,20	34,50	72%	10,72	12,97	-2,25	1,06	38,54	25,2%
Aug '16 total		390,60	584,40	-193,80	1069,50		505,20	377,00	128,20	17,06		
\bar{x}	88,3%	12,60	18,85	-6,25	34,50	59%	16,30	12,16	4,14	0,55	92,41	47,7%
Sep '16 total		336,40	422,10	-85,70	1035,00		518,50	571,00	-52,50	22,64		
\bar{x}	93,1%	11,26	14,22	-2,97	34,50	75%	17,25	18,81	-1,56	0,75	89,83	62,5%
Oct '16 total		302,20	481,50	-179,30	1069,50		332,80	413,00	-80,20	25,01		
\bar{x}	89,3%	9,75	15,53	-5,78	34,50	15%	10,74	13,32	-2,59	0,81	69,69	9,2%
Nov '16 total		370,00	404,00	-34,00	1035,00		431,00	395,00	36,00	33,60		
\bar{x}	89,5%	12,25	13,53	-1,28	34,50	35%	14,25	13,17	1,08	1,11	59,98	19,0%
Dec '16 total		575,00	263,00	312,00	1069,50		367,00	540,00	-173,00	10,92		
\bar{x}	75,4%	18,55	8,48	10,06	34,50	19%	11,84	17,42	-5,58	0,35	81,84	12,0%
Jan '17 total		505,00	410,60	94,40	1069,50		177,30	282,40	-105,10	14,01		
\bar{x}	84,3%	16,29	13,25	3,05	34,50	53%	5,72	9,11	-3,39	0,45	90,08	39,9%
Feb '17 total		432,40	470,80	-38,40	966,00		106,40	123,80	-17,40	32,76		
\bar{x}	96,2%	30,76	29,63	1,14	67,89	74%	9,34	13,61	-4,27	1,52	86,33	61,3%
Mar '17 total		410,00	339,50	70,50	1069,50		428,00	481,80	-53,80	25,75		
\bar{x}	73,7%	13,23	10,95	2,27	34,50	40%	13,81	15,54	-1,74	0,83	74,37	22,1%
Apr '17 total		314,00	161,00	153,00	1035,00		520,00	586,00	-66,00	31,17		
\bar{x}	82,5%	10,56	5,55	5,01	34,50	30%	17,22	19,40	-2,19	1,03	29,94	7,5%
May '17 total		546,00	440,00	106,00	1069,50		369,00	387,00	-18,00	33,13		
\bar{x}	81,6%	17,61	14,19	3,42	34,50	28%	11,90	12,48	-0,58	1,07	56,12	12,9%
Jun '17 total		569,00	456,00	113,00	1035,00		378,00	384,00	-6,00	34,64		
\bar{x}	83,1%	18,92	15,17	3,76	34,50	19%	12,58	12,79	-0,21	1,15	65,11	10,2%
Jul '17 total		189,00	233,00	-44,00	1069,50		252,00	318,00	-66,00	37,13		
\bar{x}	64,8%	6,10	7,52	-1,42	34,50	41%	8,13	10,26	-2,13	1,20	24,33	6,4%
Aug '17 total		261,00	509,00	-248,00	1069,50		391,00	566,00	-175,00	18,92		
\bar{x}	92,4%	8,42	16,42	-8,00	34,50	14%	12,61	18,26	-5,65	0,61	66,10	8,7%
Sep '17 total		324,00	252,00	72,00	1035,00		632,00	629,00	3,00	24,92		
\bar{x}	91,3%	10,72	8,66	2,06	34,50	0%	20,79	20,88	-0,09	0,82	38,62	0,0%
Oct '17 total		462,00	563,00	-101,00	1069,50		376,00	616,00	-240,00	14,91		
\bar{x}	91,5%	14,90	18,16	-3,26	34,50	79%	12,13	19,87	-7,74	0,48	91,46	66,5%
Nov '17 total		698,00	526,00	172,00	1035,00		61,00	261,00	-200,00	34,13		
\bar{x}	84,6%	23,00	17,55	5,44	34,50	69%	2,36	9,06	-6,70	1,12	69,46	40,5%
Dec '17 total		935,00	664,00	271,00	1069,50		0,00	147,00	-147,00	100,16		
\bar{x}	84,8%	30,16	21,42	8,74	34,50	79%	0,00	4,74	-4,74	3,23	81,51	54,4%
Jan '18 total		601,00	713,00	-112,00	1069,50		0,00	258,00	-258,00	1,74		
\bar{x}	79,6%	19,39	23,00	-3,61	34,50	38%	0,00	8,32	-8,32	0,06	99,73	30,2%
Feb '18 total		556,00	346,00	210,00	966,00		334,00	637,00	-303,00	23,37		
\bar{x}	71,7%	37,95	34,90	3,04	67,89	29%	10,77	29,14	-18,37	0,81	82,77	17,0%
Mar '18 total		64,00	374,00	-310,00	1069,50		585,00	168,00	417,00	14,29		
\bar{x}	65,1%	2,06	12,06	-10,00	34,50	39%	18,87	5,42	13,45	0,46	83,10	21,3%
Apr '18 total		315,00	345,00	-30,00	1035,00		222,00	220,00	2,00	8,39		
\bar{x}	93,0%	10,23	11,52	-1,29	34,50	0%	7,77	7,27	0,50	0,29	86,82	0,0%
May '18 total		462,00	427,00	35,00	1069,50		238,00	105,00	133,00	27,32		
\bar{x}	87,9%	14,90	13,77	1,13	34,50	54%	7,68	3,39	4,29	0,88	85,43	40,3%
Jun '18 total		531,00	460,00	71,00	1035,00		13,00	19,00	-6,00	16,68		
\bar{x}	79,1%	17,61	15,28	2,33	34,50	4%	0,67	0,72	-0,06	0,57	85,79	3,0%
Overall		10661,1	10258,3	402,8	25185,0		7569,4	8887,0	-1317,6	635,4		
\bar{x}	84%	230,10	221,48	8,62	543,33	40%	162,98	191,57	-28,59	13,68	72,06	26%

Table A-8 Overall equipment effectiveness data for Packaging line 8

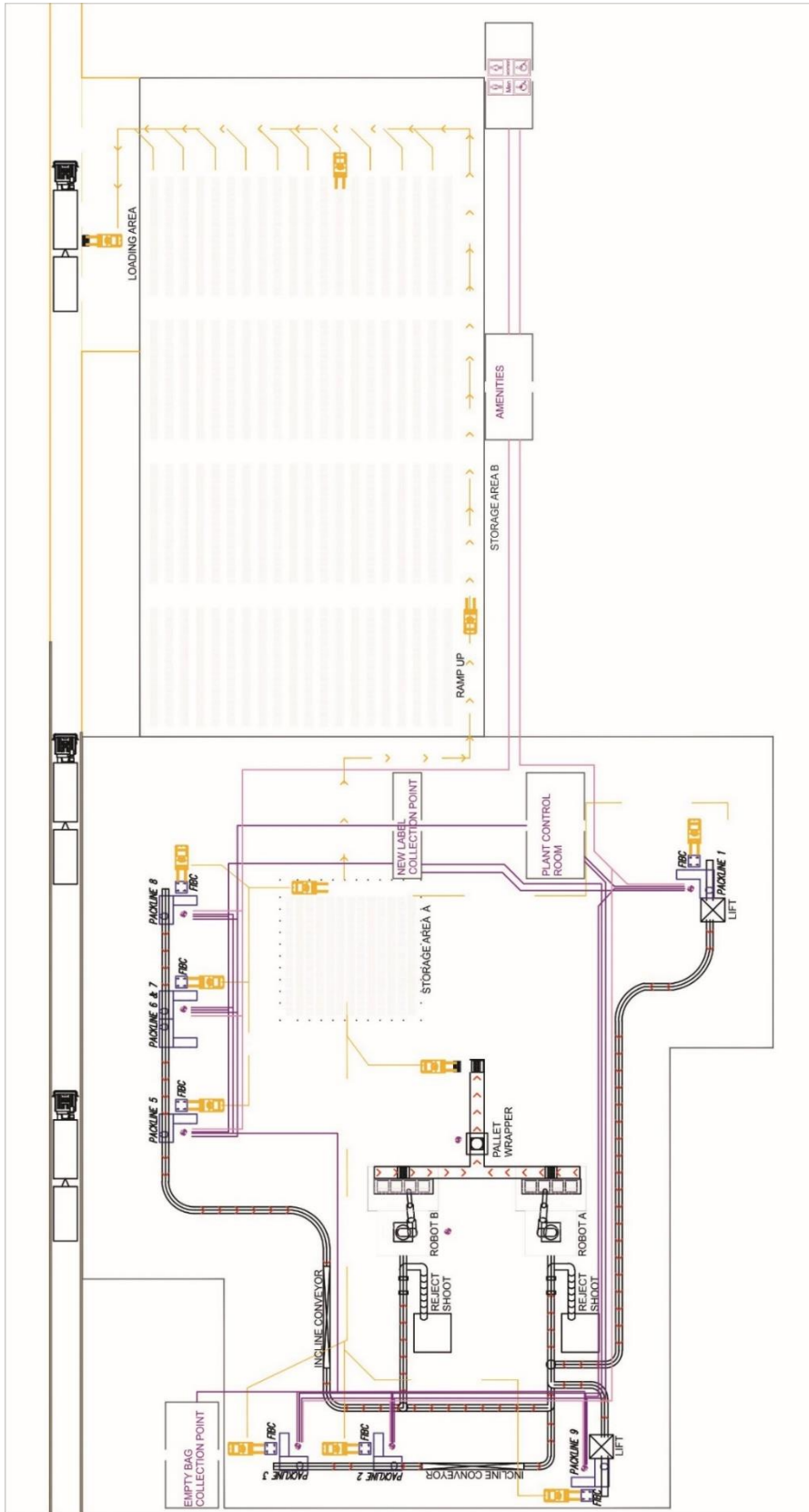
Description	Packaging line 8											
	Availability % per 24h	SMALL BAGS					JUMBO BAGS			Scrap		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Quality	%	
July '16 total		559,40	264,00	295,40	1069,50		552,00	521,00	31,00	35,24		
\bar{x}	87,1%	18,05	8,52	9,53	34,50	24%	17,81	16,81	1,00	1,14	60,58	12,6%
Aug '16 total		224,00	513,80	-289,80	1069,50		752,00	499,20	252,80	16,10		
\bar{x}	78,9%	7,23	16,57	-9,35	34,50	50%	24,26	16,10	8,15	0,52	96,91	38,4%
Sep '16 total		530,70	518,00	12,70	1035,00		369,00	652,80	-283,80	44,87		
\bar{x}	87,2%	17,35	17,24	0,11	34,50	58%	12,69	21,58	-8,89	1,46	60,48	30,5%
Oct '16 total		701,00	519,00	182,00	1069,50		366,00	221,00	145,00	45,40		
\bar{x}	79,7%	22,61	16,74	5,87	34,50	35%	11,81	7,13	4,68	1,46	48,88	13,6%
Nov '16 total		342,00	249,00	93,00	1035,00		543,00	779,00	-236,00	19,10		
\bar{x}	56,3%	11,76	8,57	3,19	34,50	44%	17,90	25,36	-7,46	0,66	62,70	15,4%
Dec '16 total		315,00	28,00	287,00	1069,50		521,00	1104,00	-583,00	53,73		
\bar{x}	83,8%	10,16	0,90	9,26	34,50	0%	16,81	35,61	-18,81	1,73	1,68	0,0%
Jan '17 total		478,50	119,40	359,10	1069,50		155,50	410,40	-254,90	17,45		
\bar{x}	12,6%	15,44	3,85	11,58	34,50	24%	5,02	13,24	-8,22	0,56	59,28	1,8%
Feb '17 total		596,60	679,00	-82,40	966,00		250,40	208,70	41,70	52,96		
\bar{x}	94,8%	35,18	27,07	8,11	67,89	67%	13,26	20,40	-7,14	2,29	79,24	50,3%
Mar '17 total		881,20	731,60	149,60	1069,50		160,70	292,80	-132,10	54,70		
\bar{x}	95,2%	28,43	23,60	4,83	34,50	84%	5,18	9,45	-4,26	1,76	67,36	53,7%
Apr '17 total		876,00	743,00	133,00	1035,00		148,00	251,00	-103,00	20,93		
\bar{x}	92,7%	29,18	24,73	4,45	34,50	82%	4,94	8,40	-3,46	0,73	94,42	71,4%
May '17 total		756,00	752,00	4,00	1069,50		301,00	295,00	6,00	73,09		
\bar{x}	87,5%	24,39	24,26	0,13	34,50	89%	9,71	9,52	0,19	2,36	31,86	24,7%
Jun '17 total		876,00	736,00	140,00	1035,00		155,00	141,00	14,00	62,43		
\bar{x}	84,2%	29,04	24,52	4,52	34,50	69%	5,31	4,86	0,46	2,09	71,26	41,3%
Jul '17 total		594,00	481,00	113,00	1069,50		290,00	249,00	41,00	37,16		
\bar{x}	54,6%	19,16	15,52	3,65	34,50	54%	9,35	8,03	1,32	1,20	61,91	18,3%
Aug '17 total		292,00	560,00	-268,00	1069,50		238,00	147,00	91,00	44,06		
\bar{x}	83,1%	9,42	18,06	-8,65	34,50	41%	7,68	4,74	2,94	1,42	43,31	14,7%
Sep '17 total		600,00	652,00	-52,00	1035,00		389,00	292,00	97,00	65,12		
\bar{x}	70,7%	19,66	21,61	-1,96	34,50	76%	12,80	9,57	3,22	2,15	57,01	30,8%
Oct '17 total		866,00	1030,00	-164,00	1069,50		296,00	195,00	101,00	31,35		
\bar{x}	96,2%	27,94	33,23	-5,29	34,50	96%	9,55	6,29	3,26	1,01	96,96	89,6%
Nov '17 total		468,00	384,00	84,00	1035,00		507,00	588,00	-81,00	26,26		
\bar{x}	54,6%	16,00	13,46	2,54	34,50	6%	16,66	19,17	-2,51	0,88	52,82	1,8%
Dec '17 total		600,00	539,00	61,00	1069,50		525,00	392,00	133,00	116,71		
\bar{x}	62,3%	19,35	17,39	1,97	34,50	53%	16,94	12,65	4,29	3,76	81,93	26,9%
Jan '18 total		749,00	698,00	51,00	1069,50		356,00	363,00	-7,00	37,76		
\bar{x}	81,9%	24,16	22,52	1,65	34,50	46%	11,48	11,71	-0,23	1,22	39,62	15,0%
Feb '18 total		860,00	750,00	110,00	966,00		39,00	178,00	-139,00	28,88		
\bar{x}	94,1%	53,88	47,79	6,09	67,89	72%	13,11	18,12	-5,01	2,23	72,81	49,5%
Mar '18 total		529,00	427,00	102,00	1069,50		0,00	22,00	-22,00	30,47		
\bar{x}	57,4%	17,06	13,77	3,29	34,50	65%	0,00	0,71	-0,71	0,98	83,57	31,2%
Apr '18 total		500,00	558,00	-58,00	1035,00		195,00	172,00	23,00	23,46		
\bar{x}	66,9%	16,68	18,44	-1,76	34,50	28%	6,29	5,57	0,72	0,79	78,73	14,6%
May '18 total		613,00	571,00	42,00	1069,50		194,00	199,00	-5,00	89,67		
\bar{x}	77,1%	19,77	18,42	1,35	34,50	52%	6,26	6,42	-0,16	2,89	83,99	33,7%
Jun '18 total		85,00	84,00	1,00	1035,00		806,00	923,00	-117,00	33,26		
\bar{x}	23,9%	3,38	3,30	0,08	34,50	0%	26,20	29,98	-3,78	1,17	12,32	0,0%
Overall		13892,4	12586,8	1305,6	25185,0		8108,6	9095,9	-987,3	1060,2		
\bar{x}	73%	299,74	271,39	28,35	543,33	51%	174,78	196,19	-21,41	22,85	62,48	28%

Table A-9 Overall equipment effectiveness data for entire Packaging line system

Description	Entire Pack line system											
	Availability % per 24h	SMALL BAGS					JUMBO BAGS			Scrap		OEE
		Plan	Actual	Variance	Design Capacity	%	Plan	Actual	Variance	Quality		
July '16 total		4142,6	3195,5	947,1	7474,1		1515,4	1518,8	-3,4	285,3		
\bar{x}	93%	16,7	12,9	3,8	30,1	53%	6,1	6,1	0,0	1,2	73,3	36,2%
Aug '16 total		3351,3	3487,9	-136,6	7474,1		2810,2	3020,0	-209,8	229,3		
\bar{x}	91%	13,5	14,1	-0,6	30,1	55%	11,3	12,2	-0,8	0,9	87,8	43,7%
Sep '16 total		3111,4	3487,3	-375,9	7233,0		2005,7	2428,2	-422,5	254,7		
\bar{x}	91%	12,9	14,5	-1,6	30,1	59%	8,4	10,1	-1,6	1,0	77,8	42,3%
Oct '16 total		3508,4	3012,1	496,3	7474,1		1600,6	1839,4	-238,8	419,7		
\bar{x}	83%	14,1	12,1	2,0	30,1	45%	6,5	7,4	-1,0	1,7	69,3	25,8%
Nov '16 total		2465,4	2735,8	-270,4	7233,0		2475,4	2088,6	386,8	304,0		
\bar{x}	86%	10,3	11,4	-1,1	30,1	51%	10,2	8,7	1,6	1,3	73,0	32,0%
Dec '16 total		2697,7	2123,6	574,1	7474,1		2078,0	2388,5	-310,5	199,7		
\bar{x}	81%	10,9	8,6	2,3	30,1	36%	8,4	9,6	-1,3	0,8	69,7	20,3%
Jan '17 total		2384,9	1569,7	815,2	7474,1		1433,5	1926,9	-493,4	150,8		
\bar{x}	61%	9,6	6,3	3,3	30,1	33%	5,8	7,8	-2,0	0,6	86,1	17,2%
Feb '17 total		2422,8	1958,5	464,3	6750,8		939,0	763,2	175,8	141,9		
\bar{x}	71%	19,9	15,0	3,9	44,7	36%	7,2	8,7	-1,5	0,8	91,0	23,2%
Mar '17 total		2888,6	2206,8	681,8	7474,1		943,6	1084,8	-141,2	269,8		
\bar{x}	63%	11,6	8,9	2,7	30,1	36%	3,8	4,4	-0,6	1,1	77,1	17,2%
Apr '17 total		3591,0	3279,0	312,0	7233,0		1320,0	1490,0	-170,0	165,7		
\bar{x}	82%	14,9	13,6	1,3	30,1	55%	5,5	6,2	-0,7	0,7	79,1	35,4%
May '17 total		2856,0	2874,0	-18,0	7474,1		1901,0	1745,0	156,0	231,9		
\bar{x}	74%	11,5	11,6	-0,1	30,1	49%	7,7	7,0	0,6	0,9	78,7	28,3%
Jun '17 total		3354,0	3259,0	95,0	7233,0		1170,0	782,0	388,0	186,9		
\bar{x}	61%	13,9	13,6	0,3	30,1	44%	4,9	3,3	1,6	0,8	84,5	22,8%
Jul '17 total		1748,0	1243,0	505,0	7474,1		1588,0	782,0	806,0	139,7		
\bar{x}	48%	7,0	5,0	2,0	30,1	24%	6,4	3,2	3,3	0,6	62,4	7,3%
Aug '17 total		2014,0	3065,0	-1051,0	7474,1		1010,0	1060,0	-50,0	235,4		
\bar{x}	80%	8,1	12,4	-4,2	30,1	40%	4,1	4,3	-0,2	0,9	67,0	21,1%
Sep '17 total		3568,0	3304,0	264,0	7233,0		1409,0	1264,0	145,0	260,1		
\bar{x}	80%	14,8	13,8	1,0	30,1	48%	5,8	5,2	0,6	1,1	77,9	29,9%
Oct '17 total		3288,0	3497,0	-209,0	7474,1		1903,0	2201,0	-298,0	193,0		
\bar{x}	77%	13,3	14,1	-0,8	30,1	64%	7,7	8,9	-1,2	0,8	86,1	42,4%
Nov '17 total		3412,0	2760,3	651,7	7233,0		791,0	1238,0	-447,0	195,2		
\bar{x}	71%	14,2	11,6	2,6	30,1	34%	3,4	5,3	-1,8	0,8	79,8	19,2%
Dec '17 total		3294,0	2357,0	937,0	7474,1		1475,0	1417,0	58,0	372,7		
\bar{x}	70%	13,3	9,5	3,8	30,1	31%	5,9	5,7	0,2	1,5	76,0	16,6%
Jan '18 total		3942,0	2976,0	966,0	7474,1		859,0	1727,0	-868,0	237,4		
\bar{x}	70%	15,9	12,0	3,9	30,1	37%	3,5	7,0	-3,5	1,0	70,9	18,3%
Feb '18 total		3504,0	2615,0	889,0	6750,8		657,0	1375,0	-718,0	254,8		
\bar{x}	75%	30,9	23,1	7,8	59,3	36%	6,2	12,8	-6,6	2,0	79,4	21,8%
Mar '18 total		1654,0	1432,0	222,0	7474,1		678,0	340,0	338,0	122,4		
\bar{x}	42%	6,7	5,8	0,9	30,1	23%	2,7	1,4	1,4	0,5	86,9	8,5%
Apr '18 total		2443,0	2229,0	214,0	7233,0		507,0	472,0	35,0	102,1		
\bar{x}	74%	10,1	9,2	0,9	30,1	28%	2,1	1,9	0,2	0,4	87,7	18,1%
May '18 total		2461,0	2264,0	197,0	7474,1		618,0	419,0	199,0	204,4		
\bar{x}	76%	9,9	9,1	0,8	30,1	32%	2,5	1,7	0,8	0,8	92,4	22,8%
Jun '18 total		1549,0	1334,0	215,0	7233,0		1967,0	1984,0	-17,0	120,9		
\bar{x}	45%	6,6	5,7	0,9	30,1	11%	8,0	8,1	0,0	0,5	76,5	3,7%
Overall		69651,1	62265,5	7385,6	176003,0		33654,4	35354,4	-1700,0	5277,7		
\bar{x}	73%	1457,54	1302,90	154,62	3682,71	40%	704,14	739,82	-35,68	110,43	78,76	24%

ANNEXURE B:PACKAGING FACILITY FLOOR PLAN

Figure B-11 Packaging facility floor plan layout



ANNEXURE C: REJECTION LOGBOOK

Table C-10 Rejection logbook for total scrap per packaging line (day per 24 month)

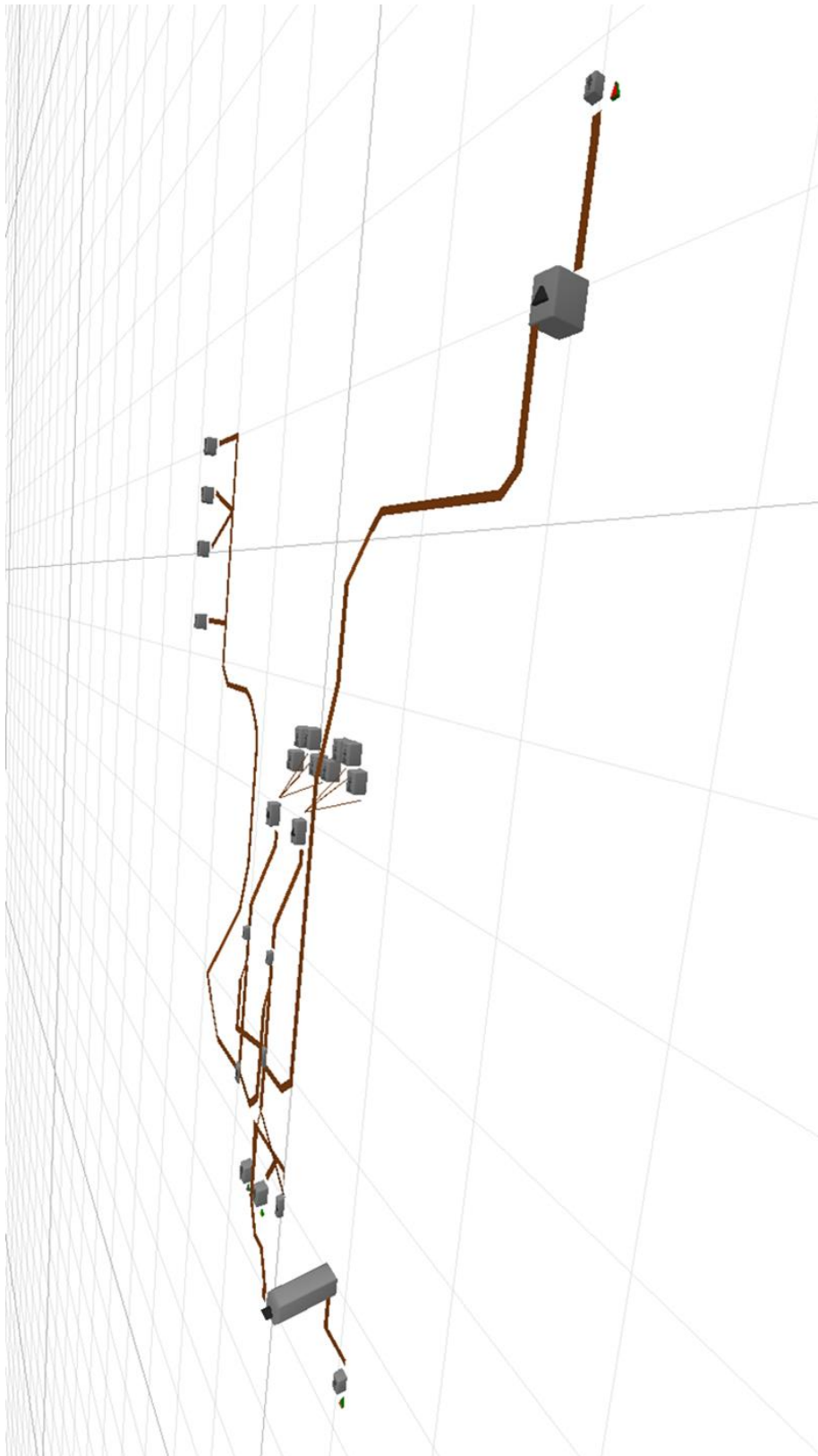
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Pack 1	30,471	25,08	19,553	26,613	22,597	37,55	26,024	32,445	31,17	31,079	43,665	39,023	45,582	45,068	36,225	34,594
Oversize	28,101	18,037	22,036	26,401	22,565	19,264	29,217	27,937	21,633	25,094	36,53	26,6477	37,912	25,38069	24,96055	26,825
Flushing	6,442	0	0	0,6	14,306	1,2	0	1,2	0,608	7,313	0	1,547	6,223	5,565	3,669	2,4
Sweeping	2,431	1,59	2,387	2,519	3,508	5,668	4,097	4,85	5,617	6,208	9,089	6,698	8,003	6,21	3,318	4,894
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21,65	14,561	16,703	21,349	15,868	15,844	18,196	19,874	21,315	20,768	29,586	22,295	28,57	22,80975	20,623	23,985
Pack 2	10,532	7,905	22,701	17,665	31,734	23,621	28,208	36,022	23,984	15,261	19,472	21,863	21,473	22,834	19,145	22,299
Oversize	9,389	6,068	21,048	13,742	26,108	21,638	27,109	31,72	22,1	14,803	18,914	20,581	20,908	21,606	18,169	20,789
Flushing	0	1,4	0	0,358	2,547	0,714	0	0	0	0	0	0	0	0	0	0
Sweeping	1,143	0,437	1,653	3,565	3,079	1,269	1,099	4,302	1,884	0,458	0,558	1,282	0,565	1,228	0,976	1,51
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10,532	6,505	22,701	17,307	29,187	22,907	28,208	36,022	23,984	15,261	19,472	21,863	21,473	22,834	19,145	22,299
Pack 3	12,551	10,038	3,891	2,791	10,231	14,107	6,313	19,96	19,161	15,826	14,203	16,346	9,575	14,592	6,437	13,085
Oversize	9,065	6,333	1,366	0	4,948	5,454	4,308	17,497	17,076	12,636	13,27	13,2	6,529	11,181	2,723	9,792
Flushing	2,563	0	0	4,206	0	3,977	0,6	2,097	0	0,7	0	1,2	0,6	0	6,699	1,469
Sweeping	0	1,189	3,075	2,241	2,227	2,976	1,405	1,387	2,219	2,035	2,13	1,802	1,91	2,194	0,603	0,574
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6,549	7,522	3,891	2,241	5,475	8,43	5,713	17,863	18,14	14,671	13,503	14,449	7,822	13,375	3,326	9,497
Pack 5	32,913	19,16	18,866	12,835	20,691	11,137	29,001	15,294	11,864	21,167	18,588	15,707	14,122	14,108	18,293	13,312
Oversize	12,413	4,539	8,646	8,939	9,333	9,193	7,23	10,919	6,672	10,244	8,498	10,73346	11,02331	6,473493	5,491524	6,296
Flushing	20,5	14,621	10,22	3,896	11,358	1,944	21,771	4,375	5,192	10,923	10,09	4,511	1,795	7,142	12,278	7,016
Sweeping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10,551	3,307	4,395	5,407	4,101	7,167	5,108	6,211	3,584	5,384	3,412	6,845	4,262	3,651	5,491	3,91
Pack 6	6,149	3,961	12,688	4,651	9,635	5,416	2,485	16,025	11,91	14,681	12,265	14,867	2,389	6,72	5,085	7,189
Oversize	6,149	1,34	7,062	4,651	3,458	2,902	2,485	4,602	6,26	4,562	6,034	6,183454	2,389	4,233	4,385	3,389
Flushing	0	2,621	5,626	0	5,697	2,514	0	11,423	5,65	10,119	6,231	8,23	0	2,487	0,7	3,8
Sweeping	0	0	0	0	0,48	0	0	0	0	0	0	0	0	0	0	0
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4,445	1,34	5,065	3,529	2,424	1,359	1,97	3,58	3,659	2,561	5,431	4,373	0,577	2,083	1,59	1,012
Pack 7	8,618	11,462	10,507	12,396	24,651	19,524	45,475	9,501	34,513	15,018	13,653	14,589	25,367	18,55	11,846	13,159
Oversize	1,69	5,648	19,289	4,545	8,229	7,615	5,216	8,35	9,335	5,595	5,043	4,278848	5,027	3,014	6,467157	3,136397
Flushing	20,598	45,658	5,611	7,851	16,422	11,909	15,747	1,151	11,508	9,423	7,61	7,986478	5	1,146	3,224	6,98664
Sweeping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0,65	0,724	2,003	0,513	7,75	4,96	3,444	4,441	2,605	2,773	2,791	1,458	2,487	1,627	4,3	1,657
Pack 8	21,44	17,025	17,655	18,571	36,18	14,119	27,178	21,063	10,91	26,555	11,231	24,008	32,022	68,406	18,036	13,945
Oversize	9,93	17,081	27,814	15,807	13,698	12,871	12,652	11,571	10,501	11,023	7,431	9,422341	9,281952	13,8563	10,02875	8,905
Flushing	22,337	44,188	7,848	8,03	11,541	1,248	14,526	12,017	0,409	15,532	3,8	16,16573	5,88	14,38757	5,86	5,04
Sweeping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5,456	5,413	7,725	5,168	8,917	6,831	7,366	7,55	6,984	3,357	3,087	4,321	4,665	8,154	5,928	3,478
Pack 9	31,574	32,301	26,937	33,504	30,307	35,939	33,832	28,337	25,687	26,325	29,329	35,017	33,202	31,153	28,387	29,769
Oversize	31,118	30,465	30,672	27,639	30,921	29,693	30,507	27,949	24,426	29,744	29,072	36,15731	29,31425	27,6842	26,911	32,08721
Flushing	0	0	0,65	2,146	0	1,2	4,367	0	0	0	0	0	0	1,202	0	0
Sweeping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,463	0
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21,261	22,444	18,266	18,952	17,921	21,057	20,829	18,659	16,397	18,296	17,881	22,596	18,971	18,359	17,864	20,259
ROBOTS	62,732	66,988	52,019	60,695	61,787	53,928	57,801	72,986	78,175	70,111	68,188	60,841	72,742	69,701	70,277	74,316
Sampling	1,7	1,1	1,88	1,595	1,89	1,565	1,56	1,555	1,41	1,66	1,485	1,755205	1,80527	1,9102	1,440011	1,50515
Sweeping	1,417	4,06	4,16	0,952	0	1,379	0	1,968	1,363	4,616	0,75	3,896	0	1,916	0,544	5,162
No Label	13,12	11,16	11,08	10,6	16,64	19,84	12,36	12,28	9,96	20,5	15,08	10,84	9,38	12,78	8,34	12,1
Weight	41,88	36,88	35,42	40,68	19,9	31,04	38,64	37,76	37,08	63,06	48,26	52,3	52,44	40,78	25,04	24,62
Bag Leaks	3,42	1,88	2,58	12,66	2,34	1,14	2,2	2,08	3,84	5,66	4,42	2,52	5,58	3	2,66	7,14
Mix produ	52,826	43,574	22,669	33,074	39,241	34,698	33,838	42,033	38,295	43,148	42,93	29,692	40,184	37,754	30,254	34,168

Table C-2 Rejection logbook for total scrap per packaging line (day per 24 month)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total
Pack 1	24,912	27,045	27,1096	42,159	46,622	25,433	37,456	28,541	28,433	44,563	17,481	23,751	19,73	18,486	16,926	955,3866
Oversize	20,822	32,083	29,6696	20,743	25,625	21,222	29,314	21,975	3,234	13,264	14,047	20,518	14,046	15,174	15,174	715,4515
Flushing	2,4	1,599	1,539	2,86	1,4	6,436	0,705	0	0	0,502	0	0	3,931	0	0,509	72,954
Sweeping	2,468	4,004	3,326	5,495	6,932	2,348	5,457	2,268	3,011	6,687	7,209	4,219	4,127	3,233	3,018	140,889
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14,778	16,934	19,9366	17,241	22,149	12,474	23,66	17,43	13,022	15,857	16,331	18,826	13,819	12,387	13,225	582,0664
Pack 2	24,758	18,056	15,184	22,879	25,771	5,728	14,866	14,797	17,344	21,681	45,267	25,947	31,935	34,182	31,134	694,248
Oversize	18,568	15,901	12,97	20,407	21,423	5,272	13,956	14,085	14,093	18,166	40,656	20,403	26,427	31,164	29,939	618,122
Flushing	1,578	0,925	0	1,257	0	0	0	0	0	1,205	0	0	0	0	0	9,984
Sweeping	4,612	1,23	2,214	1,215	4,348	0,456	0,91	0,712	3,251	2,31	4,611	5,544	5,508	3,018	1,195	66,142
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23,18	17,131	15,184	21,622	25,771	5,728	14,866	14,797	17,344	20,476	45,267	25,947	31,935	34,182	31,134	684,264
Pack 3	16,183	21,245	12,358	6,672	8,21	8,831	3,592	6,671	20,226	12,871	10,05	8,642	3,637	7,616	1,866	337,777
Oversize	9,777	15,586	9,826	0,452	4,997	2,058	2,935	6,545	8,619	10,246	8,687	3,055	3,328	5,791	1,24	228,52
Flushing	1,4	4,283	0	1,95	1,2	0	0	2,8	5,362	2,615	0	4,373	2,1	0	2,274	52,468
Sweeping	2,668	2,001	1,907	1,154	1,561	6,773	0,657	1,526	2,745	0	1,263	0,624	0,734	0	0,626	52,206
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12,445	16,962	11,733	4,722	6,558	8,831	3,592	6,671	11,364	9,556	9,36	3,679	3,637	5,091	1,866	268,534
Pack 5	22,141	15,672	21,538	18,057	28,458	25,326	24,091	18,593	17,556	11,696	32,98	23,481	22,531	22,132	7,454	598,764
Oversize	5,476	8,567	9,848	6,186	12,913	12,6	11,399	9,958	7,765	4,984	9,941	11,932	4,408	7,61	3,654	263,8848
Flushing	16,665	7,105	11,69	11,871	15,545	12,726	11,985	8,635	9,791	6,712	23,039	11,549	18,123	14,522	3,8	331,39
Sweeping	0	0	0	0	0	0	0,707	0	0	0	0	0	0	0	0	0,707
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4,352	6,427	7,097	4,375	9,182	7,946	8,842	6,448	7,199	4,214	9,007	10,032	2,849	7,125	1,488	179,369
Pack 6	8,82	11,776	14,596	7,757	8,915	4,701	10,727	11,946	10,836	9,675	7,888	15,333	3,976	4,646	3,705	271,413
Oversize	8,82	9,128	14,266	3,957	3,742	4,701	6,927	5,274	6,738	6,393	5,269	9,831	3,354	4,204	2,538	165,2265
Flushing	0	0,002648	0,33	3,8	5,173	0	3,8	6,672	4,098	3,282	2,619	5,502	0,622	0,442	1,167	102,6076
Sweeping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,48
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7,877	7,903	12,413	3,397	3,181	2,314	4,657	4,102	4,542	3,977	3,161	6,91	0,48	3,066	1,424	114,402
Pack 7	11,433	10,56	12,267	12,884	11,453	8,748	16,019	16,411	10,859	7,577	2,537	22,455	2,947	8,138	4,926	448,043
Oversize	3,271555	4,856017	5,599	2,566	6,693	1,411	7,075	5,55	3,798	4,077	1,504	13,223	2,947	3,118	1,334	169,501
Flushing	7,607	4,688	6,668	10,318	4,76	7,337	8,944	10,861	7,061	3,5	1,033	9,232	0	5,02	3,592	268,4521
Sweeping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2,699	2,684	2,584	1,44	5,414	1,046	3,699	2,433	1,584	2,121	0,939	5,841	2,316	3,118	0,736	82,837
Pack 8	28,033	40,047	35,458	32,706	21,353	36,054	23,897	15,169	14,066	17,327	27,676	41,775	19,467	15,799	12,231	759,402
Oversize	13,38836	14,28308	10,123	8,517	11,942	15,721	12,229	11,593	19,151	13,686	12,367	16,195	16,934	11,207	10,856	400,0658
Flushing	9,018273	21,49919	3,809	3,569	9,411	20,333	11,668	4,962	13,213	5,613	17,935	20,06	12,465	4,592	1,375	348,3318
Sweeping	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9,109	7,411	7,594	5,48	6,595	6,732	6,46	6,3	5,785	6,431	4,234	10,018	9,548	7,785	4,761	198,643
Pack 9	31,345	27,312	18,555	23,241	18,56	22,201	26,259	34,212	27,277	34,599	33,995	22,083	26,895	30,535	22,997	891,666
Oversize	30,04872	19,79195	21,521	21,521	18,608	17,751	33,137	26,789	33,375	28,909	25,942	23,355	28,562	28,816	22,543	855,0297
Flushing	0	0,462	0,567	0	0	1,199	6,2	0	1,24	0,578	0	0	0	0	0	19,811
Sweeping	0,56	0	0	0	0	0,36	0	0	0	0	0	0	0	0,554	0	1,937
Samples	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18,304	13,823	12,021	12,989	8,51	10,904	12,852	13,927	13,175	13,821	18,907	15,048	21,038	23,011	16,638	534,98
ROBOTS	69,433	69,048	86,362	77,842	79,715	77,572	64,605	64,194	63,544	63,26	63,118	57,25	64,366	53,502	34,74	2041,838
Sampling	1,78021	1,975255	1,59	1,525	2,2	1,92	3,445	1,925	1,55	1,81	1,835	1,535	1,8	1,63	0,82	53,1563
Sweeping	0	1,361	0,78	2,22	3,31	1,23	4,34	0,6	0	1,108	0,617	0	0,497	3,055	2,679	53,98
No Label	16,48	21,04	10,86	15,52	17,78	20,98	13	18,52	11,4	12,26	13,68	6,02	11,24	11,82	5	411,66
Weight	30,9	33,64	42,72	42,28	36,34	36,2	33,075	33,46	27,76	32,36	34,34	42,78	35,92	16,28	13,02	1116,855
Bag Leaks	1,4	2,76	1,88	2,22	2,54	10,78	3,32	2,98	3,68	5,5	2,46	3	7,747	3,96	1,52	118,867
Mix produ	40,14	44,034	47,961	47,193	50,096	49,139	38,848	43,749	44,898	46,404	40,447	32,841	45,996	33,692	22,629	1226,445

ANNEXURE D: THREE DIMENSION VIEW OF THE SIMULATION MODEL

Figure D-12 Three-dimension view of simulation model



ANNEXURE E : FULL THROUGHPUT RESULTS OF SIMULATION RUN

Table E-11 Full throughput results of simulation run

Object Type	Object Name	Category	Data Item	Statistic Type	Value
Conveyor	Antislip_A	Throughput	NumberExited	Total	6119
Conveyor	Antislip_B	Throughput	NumberExited	Total	6116
Conveyor	Conveyor1	Throughput	NumberExited	Total	3118
Conveyor	Conveyor10	Throughput	NumberExited	Total	6155
Conveyor	Conveyor11	Throughput	NumberExited	Total	6154
Conveyor	Conveyor12	Throughput	NumberExited	Total	6152
Conveyor	Conveyor13	Throughput	NumberExited	Total	6147
Conveyor	Conveyor14	Throughput	NumberExited	Total	6140
Conveyor	Conveyor15	Throughput	NumberExited	Total	6130
Conveyor	Conveyor16	Throughput	NumberExited	Total	6129
Conveyor	Conveyor17	Throughput	NumberExited	Total	6127
Conveyor	Conveyor18	Throughput	NumberExited	Total	6122
Conveyor	Conveyor19	Throughput	NumberExited	Total	6113
Conveyor	Conveyor2	Throughput	NumberExited	Total	3118
Conveyor	Conveyor20	Throughput	NumberExited	Total	6120
Conveyor	Conveyor21	Throughput	NumberExited	Total	6119
Conveyor	Conveyor22	Throughput	NumberExited	Total	6117
Conveyor	Conveyor25	Throughput	NumberExited	Total	6114
Conveyor	Conveyor3	Throughput	NumberExited	Total	5900
Conveyor	Conveyor32	Throughput	NumberExited	Total	6122
Conveyor	Conveyor36	Throughput	NumberExited	Total	6117
Conveyor	Conveyor4	Throughput	NumberExited	Total	5899

Conveyor	Conveyor41	Throughput	NumberExited	Total	1800
Conveyor	Conveyor42	Throughput	NumberExited	Total	1799
Conveyor	Conveyor43	Throughput	NumberExited	Total	1798
Conveyor	Conveyor44	Throughput	NumberExited	Total	1797
Conveyor	Conveyor45	Throughput	NumberExited	Total	1794
Conveyor	Conveyor47	Throughput	NumberExited	Total	3593
Conveyor	Conveyor48	Throughput	NumberExited	Total	2537
Conveyor	Conveyor49	Throughput	NumberExited	Total	2537
Conveyor	Conveyor5	Throughput	NumberExited	Total	6161
Conveyor	Conveyor50	Throughput	NumberExited	Total	2536
Conveyor	Conveyor51	Throughput	NumberExited	Total	2536
Conveyor	Conveyor52	Throughput	NumberExited	Total	2536
Conveyor	Conveyor53	Throughput	NumberExited	Total	2535
Conveyor	Conveyor54	Throughput	NumberExited	Total	2535
Conveyor	Conveyor55	Throughput	NumberExited	Total	2535
Conveyor	Conveyor56	Throughput	NumberExited	Total	2535
Conveyor	Conveyor57	Throughput	NumberExited	Total	2535
Conveyor	Conveyor58	Throughput	NumberExited	Total	2535
Conveyor	Conveyor59	Throughput	NumberExited	Total	2534
Conveyor	Conveyor6	Throughput	NumberExited	Total	6160
Conveyor	Conveyor60	Throughput	NumberExited	Total	2534
Conveyor	Conveyor61	Throughput	NumberExited	Total	2534
Conveyor	Conveyor62	Throughput	NumberExited	Total	2534
Conveyor	Conveyor63	Throughput	NumberExited	Total	2534
Conveyor	Conveyor64	Throughput	NumberExited	Total	2533
Conveyor	Conveyor65	Throughput	NumberExited	Total	1797
Conveyor	Conveyor66	Throughput	NumberExited	Total	1809

Conveyor	Conveyor67	Throughput	NumberExited	Total	1802
Conveyor	Conveyor68	Throughput	NumberExited	Total	1806
Conveyor	Conveyor69	Throughput	NumberExited	Total	1802
Conveyor	Conveyor7	Throughput	NumberExited	Total	6159
Conveyor	Conveyor8	Throughput	NumberExited	Total	6157
Conveyor	Conveyor9	Throughput	NumberExited	Total	6156
Conveyor	Flattener_A	Throughput	NumberExited	Total	6121
Conveyor	Flattener_B	Throughput	NumberExited	Total	6118
ModelEntity	Pack1Bag	Throughput	NumberCreated	Total	2537
ModelEntity	Pack2Bag	Throughput	NumberCreated	Total	4767
ModelEntity	Pack3Bag	Throughput	NumberCreated	Total	3400
ModelEntity	Pack5Bag	Throughput	NumberCreated	Total	2302
ModelEntity	Pack6Bag	Throughput	NumberCreated	Total	2510
ModelEntity	Pack7Bag	Throughput	NumberCreated	Total	2748
ModelEntity	Pack8Bag	Throughput	NumberCreated	Total	3118
ModelEntity	Pack9Bag	Throughput	NumberCreated	Total	3118
Server	A_Robot	Throughput	NumberExited	Total	6116
Server	B_Robot	Throughput	NumberExited	Total	6112
Server	Pack1_Bag_Lift	Throughput	NumberExited	Total	2536
Server	Pack2_TurnTable	Throughput	NumberExited	Total	1805
Server	Pack9_Bag_Lift	Throughput	NumberExited	Total	1801
Server	RobotA_TurnTable	Throughput	NumberExited	Total	6125
Server	RobotB_TurnTable	Throughput	NumberExited	Total	6121
Server	WeightCheck_A	Throughput	NumberExited	Total	6120
Server	WeightCheck_B	Throughput	NumberExited	Total	6117
Sink	Pack_1_Sink	Throughput	NumberExited	Total	2528
Sink	Pack_2_Sink	Throughput	NumberExited	Total	13

Sink	Pack_3_Sink	Throughput	NumberExited	Total	1785
Sink	Pack_5_Sink	Throughput	NumberExited	Total	262
Sink	Pack_6_Sink	Throughput	NumberExited	Total	1206
Sink	Pack_7_Sink	Throughput	NumberExited	Total	1552
Sink	Pack_8_Sink	Throughput	NumberExited	Total	3092
Sink	Pack_9_Sink	Throughput	NumberExited	Total	1789
Source	Pack1	Throughput	NumberExited	Total	2537
Source	Pack2	Throughput	NumberBalked	Total	4754
Source	Pack2	Throughput	NumberExited	Total	4767
Source	Pack3	Throughput	NumberBalked	Total	1603
Source	Pack3	Throughput	NumberExited	Total	3400
Source	Pack5	Throughput	NumberBalked	Total	2040
Source	Pack5	Throughput	NumberExited	Total	2302
Source	Pack6	Throughput	NumberBalked	Total	1294
Source	Pack6	Throughput	NumberExited	Total	2510
Source	Pack7	Throughput	NumberBalked	Total	1181
Source	Pack7	Throughput	NumberExited	Total	2748
Source	Pack8	Throughput	NumberExited	Total	3118
Source	Pack9	Throughput	NumberBalked	Total	1313
Source	Pack9	Throughput	NumberExited	Total	3117