A Roadmap for Improving the Manufacture of Automotive Heat Exchangers through Value Stream Mapping

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Kate Lusiba

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Supervisor: Mr Mendon Dewa ______________ **Date:** ______________

Co-supervisor: Bloodless Dzwairo (DTech Eng: Civil) [redacted] **Date:** 5/7/2019.

Declaration

I hereby declare that this study is my own work and it does not contain material that has been published already or written by another student or researcher. This material has not been accepted for any award of any former degree at Durban University of Technology or any other educational institution. Furthermore, I declare that the academic content of this theory is my own creation of work. The study company support or contribution made has been clearly acknowledged in the thesis.

[redacted]

Kate Lusiba (20920608)

Date: __10/07/2019__________

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Abstract

Lean manufacturing is an optimum approach for the reduction and elimination of waste within an organization. The case study company is based in South Africa and produces heat exchangers through main processes or fractals, which include pre-assembly, core building, brazing and final assembly. A walk through the plant showed that there was a large amount of inventory awaiting final assembly and that the brazing furnace often waited for material from core building. This was an indication that there could be an imbalance between the three fractals in terms of cycle time. Thus, the aim of this study was to improve the manufacturing processes for heat exchangers at the automotive manufacturing company through the deployment of value stream mapping, subsequent line balancing and developing a roadmap for reduction of waste. The case study research strategy was adopted for the study since it provided an in-depth view of phenomena.

The first objective was to outline the production flow for the manufacture of automotive heat exchanger parts. The method used was a walk through the plant and observations were made to gain an understanding of the production steps from logistics production planning to shipping of the finished goods, and subsequently to a mapping-out of the production process flow was undertaken. The results showed that there was a large amount of inventory awaiting final assembly and that the brazing furnace often waited for material from core building. It was concluded that there was need to conduct a detailed process analysis to identify sources of waste.

The second objective was to conduct value stream mapping for assessing the value- and non-value-adding activities in the manufacture of automotive heat exchangers components. A value stream map was developed through walking to Gemba and mapping out the production process, collecting data and pinpointing waste activities or areas to be improved. The kaizen flashes from the value stream map also revealed that operators were not fully utilizing the capacity of the bottleneck workstations. It was concluded that two instead of one planning points, and inefficiency at assembly were root causes of the high work-in-process level.

The third objective was to conduct a line balancing analysis for the three production fractals. The method used was a Pareto analysis for evaluating the products, analysing the product mix and line balancing analysis of the production line. The results revealed that the furnace was run on two shifts while the subsequent assembly and preceding core building were running on three shifts causing a work-in-process build-up, thereby resulting in line imbalance. It was concluded that it was imperative to change the scheduling approach, and adopt one that prioritised and spread the cores that had relatively short cycle times, and also reduce downtime, change-over time as well as additional time for scrap and defects, and a future-state balance chart revealed that the fractals imbalance had been reduced.

The fourth objective was to develop a roadmap for reduction of waste in the manufacture of car heat exchangers components. The method used was to develop proposals and assess the feasibility and cost implications of implementing each option.

Recommendations were made for continuous process improvement and a roadmap for reduction of waste was proposed. In order to improve the output of assembly, training for the operators was recommended since it would also enable the removal of the second planning point at assembly. Further research could also be conducted to develop an optimal scheduling algorithm for allocation of products to work centres to ensure high utilization of work centres and reduce work-in-process inventory.

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List of Acronyms

#Var	Number of Variants
AM	Aftermarket
ASSY	Assembly
AT	Additional Time
AT_C	Additional Time due to changeover
AT_D	Additional Time due to downtime
AT_Q	Additional Time due to quality issues
CAC	Charge Air Cooler
CB	Core Builder/ Core Building
CO	Change-over
cond.	Condenser
COT	Change-over Time
COT	Change-over Time
CT	Cycle Time
CIP	Continuous Improvement Program
CTT	Customer Takt Time
CTT_p	Process-Specific Customer Takt Time
CW	Calendar Week
EC	Engine Cooling
Evap.	Evaporator
FIFO	First In First Out
HTR	High Temperature Radiator

HV	High Volume
HVAC	Heating, Ventilation and Air Conditioning Unit
IMH	Internal Material Handling
JIT	Just-In-Time
KPI	Key Performance Indicator
LPG	Liquefied Petroleum Gas
LS	Lot Size
LT	Leak Testing
LTR	Low Temperature Radiator
LV	Low Volume
MRP	Material Resource Planning
Nocolok	Non corrosive lock, name of brazing flux
OE	OEM
pcs.	Pieces
PDCA	Plan, Do, Check, Act
PT	Processing Time
Rad	Radiator
resp.	Respectively
Silflux	Brazing flux that is applied onto parts as a coating
SMED	Single Minute Exchange of Die
TPM	Total Productive Maintenance
TPS	Toyota Production System

TXV	Expansion Valve
VCP	Value Creation Process
VOL	Volume
VSA	Value Stream Analysis
VSM	Value Stream Map
WA	Weighted Average
WIP	Work In Progress
MTM	Methods Time Measurement

CHAPTER 1 : INTRODUCTION

1.1 Introduction

Globalization has brought many advantages to globally operating companies including a plethora of different suppliers to choose from in the global marketplace. By exploiting this opportunity, the buyer can obtain an optimum product for the best price, whereas the supplying organisation is subject to intensified competition. As a result, it is very important for suppliers to enhance their competitiveness and this can be accomplished through lean manufacturing and supply.

Globally, many organisations have tried to implement lean manufacturing, and about 4% succeeded and 96% failed (Burdg 2010). The case study company based in South Africa specializes in vehicle air conditioning and engine cooling systems. It is among the global original equipment manufacturer (OEM) leaders for passenger cars and commercial vehicles, output radiators, heaters, condensers, charge air coolers and evaporators, and were determined to reduce or eliminate process waste.

One of the tools that support successful organisations in achieving their business goals is through Lean manufacturing. Lean manufacturing improves business performance, reduces costs and eliminates waste (Lasnier 2007). The case study company adopted lean principles and is currently striving to maintain and improve the system. This thesis focuses on comprehending the production processes for the manufacture of automotive heat exchanger components, deployment of Value Stream Mapping (VSM), line-balancing analysis and mapping continuous improvement initiatives. This chapter outlines the problem statement, aim of the study and its significance, as well as the structure of the dissertation.

1.2 Problem Statement

Organisations that do not synergistically streamline their processes would produce finished products at the pace that is misaligned to customer demand, with more process waste such as high work in process inventory and poor space utilisation (Kumar et al. 2006). The case study company is based in South Africa and it manufactures automotive heat exchangers. Three main processes (also referred to as fractals) are required to produce the heat exchangers: core building, brazing and final assembly. During the study, a walk through the plant for a week revealed that there was a large amount of inventory awaiting final assembly and the brazing furnace often waited for material from core building. This scenario led to an increase in the space required for post-braze First-in-First-Out (FIFO) lanes and higher operating costs, hence the need to conduct value stream mapping in order to identify and reduce waste. It was hypothesized that value stream mapping would reveal the amount of waste that needed to be eliminated, leading to the development of a roadmap that would lead to process improvement.

1.3 Aim of the Study

The aim of this study was to improve the manufacturing processes for heat exchangers at an automotive manufacturing company, using value stream mapping, line balancing and developing a roadmap for the reduction of waste.

1.4 Specific Objectives

The specific objectives of this research are:

- To outline the production flow for the manufacture of automotive heat exchanger parts
- To conduct value stream mapping for assessing the value-adding and non-value-adding activities in the manufacture of automotive heat exchanger components
- To conduct a line balancing analysis for the three production fractals
- To develop a roadmap for reduction of waste in the manufacture of car heat exchanger components.

1.5 Research Methods

The case study research strategy was adopted for this study. The methodology that was adopted included the development of a current state value stream map, identification of the value-adding activities and non-value-adding activities, assessment of the non-value-adding activities in the manufacture of car heat exchanger components, and the development of a plan for the future state value stream map. In this study, the research methods used for the study were as follows:

- For objective one, a walk through the plant was done and observations were made to gain an understanding of the production steps from logistics production planning to shipping of the finished goods and subsequently a mapping out of the production process flow for the case study company.

- For objective two, the method used was a value stream map that was developed through walking to Gemba and mapping out the production process, collecting data (machine loading, labour time, machine time, cycle time, etc), and pinpointing waste activities or areas to be improved.

- For objective three, the method used was Pareto analysis for evaluating the products, analysing the product mix, product movement and line balancing analysis of the production line.

- For objective four, a qualitative and economical evaluation for improvement opportunities was undertaken and proposals were developed for continuous improvement initiatives.

1.6 Research Scope and Limitations

This research scope embraced the three production fractals of heat exchangers that include core building, brazing and final assembly and well as planning for production of these heat exchangers. This research was limited to the case study company based in South Africa and situated in the central east part of the country on the coast of the Indian Ocean.

1.7 Significance of the Study

The case study company has implemented lean production and is striving to become one of the green companies in South Africa. However, there is room for improvement and the research pinpoints the areas for improvement in the system as well as potential solutions and makes recommendations that will benefit the case study company. The research publication also adds more information to the body of knowledge regarding the manufacture of automotive heat exchangers.

1.8 Dissertation format

Chapter One – Introduction: This chapter focuses on presenting the study outline, which consists of the study background, research problem, aim of the study, research objectives, research questions, research scope and limitations, significance of the study, dissertation format and a conclusion.

Chapter Two – Literature Review: This chapter provides a theoretical concepts base supporting lean manufacturing tools and techniques.

Chapter Three – Case Study Company Background: This chapter presents the background of the company and furthermore describes the manufacturing processes.

Chapter Four – Research Methods: This chapter focuses on the methodology that was adopted for the study as well as ethics considerations.

Chapter Five – Results and Discussion: This chapter focuses on the results and a discussion of the research. The key elements discussed include production process flows, line balancing analysis, assessing value-adding and non-value-adding activities, balancing chart and value stream mapping.

Chapter Six – Summary and Conclusions: This chapter provides the summary and conclusion of the study, makes recommendations and outlines the roadmap for reduction of waste.

1.9 Conclusion

This chapter outlined the research framework, problem and background of the study. The key elements of the study included research objectives, research methods, research scope and limitations, significance of the study and the dissertation format of the study. The following chapter gives a detailed literature review on Lean Manufacturing, the Toyota production system and Lean tools such as kaizen. 5S, Value stream mapping, and Single exchange of dies.

CHAPTER 2 : REVIEW OF LEAN MANUFACTURING TECHNIQUES

2.1 Introduction

This chapter presents the background literature on the theory and understanding of the foundational concepts of lean manufacturing. The principles of lean production aim at the reduction of wastes, which is also the goal of the thesis. This chapter commences with the rise of lean manufacturing and the Toyota production system, and then deals with lean principles, types of wastes and lean tools.

2.2 The Rise of Lean Manufacturing

Lean production methods were pioneered by Toyota in Japan (Hines et al. 2011), and lean thinking banished waste and created wealth in organisations. An organisation needs to understand the customer's requirements and what the customer values in order to implement lean manufacturing successfully. The seven wastes defined by Japanese Toyota manager Taiichi Ohno include waste of inventory (stock on hand), waste of processing, waste of movement (motion), waste of overproduction, waste of time on hand (waiting), waste in transportation and waste in making parts that are defective. Zarbo (2012) described "Lean" manufacturing as an automobile industrial production method of the Toyota Mechanical Company that several organisations had tried to replicate for over the past thirty years. There was a need for the straight extrapolation or equivalent of Toyota's manufacturing foundation production systems of efficiency and production practice in order to achieve the benefits of Lean manufacturing in an operational environment.

Mohan (2011) defined lean manufacturing as a production technique that stresses the minimization of all the resources that are required to produce some output. It pertains to pinpointing and eliminating non-value-adding activities, making sure that the work team or employees are multi-skilled, as well as utilising flexible machinery. It is crucial to understand that the roots of lean manufacturing lie in the Toyota Production System. Toyota initiated the production methods by making sure that basic principles were followed, as established by Henry Ford on a mobile assembly line. Ford emphasized the importance of generating a continuous material flow, standardizing ways of carrying out activities, and eliminating waste from a process. Ford’s company managed to manufacture millions of black Model-Ts despite using inefficient batch production approaches of manufacturing large lot sizes of work-in-process inventory and pushing each product to the next phase of production, without consideration of the demand required (Dennis 2016).

Cummings and Worley (2014) pointed out that the Toyota Production System (TPS) was created as a solution to the problems that characterise an enterprise. Awad (2016) mentioned that Jidoka is one of the oldest production methods and the conception is grounded on producing high quality products from the manufacturing process through the utilisation of man and machinery to support the processing of multi-products. This production process idea was started in the Toyoda Spinning and Weaving organisation of which Sakichi Toyoda was the founder (Loyd 2016). Sakichi created an automatic loom that came to a standstill every time it detected a damaged thread in the system, and the loom would trigger stopping the process from making rejects. Thereafter, in 1924, Sakichi made an automatic system that permitted a single man to run multiple equipment. Sakichi used the rights to produce the loom outside Japan and in the end sold it to Platt Brothers Ltd. in England. The funds were then partly utilized to establish an automotive company that was shortly thereafter changed to a different business in 1937 and the company was managed by Sakichi’s son, Kiichiro Toyoda (McCarthy and Rich 2015).

Zarbo (2012) posited that several good management practices that reinforced an efficient production culture were adapted fromHenry Ford’s Production System. These included:

- Toyota’s line-level organisational formation for quality improvement using group team leaders and individual team members aligned with occupation cells.
- Group members are given the power to represent their team in client or supplier gathering work passes across work cells, units, departments, and hospitals

- Process developments that are not led by team leaders as per the Toyota way, but by authorized health care group members.

Al-Haddad (2014) posited that the empowerment of knowledgeable persons for system improvement needs leaders to adopt the Deming management style instead of simply implementing the principles and tools of the Toyota's production system. One of the best approaches to adapt to future change is to create solid knowledgeable teams that are able to tackle challenges that may seem impossible at first sight. ReVelle (2016) found that Toyota did not have it easy in the business world as it lacked space, funds and the big volumes of one type of vehicle and therefore an efficient system that responded flexibly to consumer demand was required.

2.3 Toyota Production System

Mohan (2011) revealed that the Toyota Production System (TPS) was developed to be competitive on the world market; in particular, the system was in competition with Henry Ford's perception of manufacturing but addressed specific circumstances in Japan. Throughout the years of trial and error on the production line, Toyota revealed that it was able to simultaneously achieve low cost, high quality and just-in-time (JIT) deliveries by cutting down the production flow through waste elimination. This concept was different from the past mass manufacturing paradigm.

The main focus of TPS was to shorten the production flow and ensure that the line was waste free, eliminating anything that gets in the way of a smooth flow. Alabi (2016) idealised a hypothetical perfect state of continuous one-piece flow process. While this ideal state was hardly grasped, experts of TPS had a clear understanding that direct performance of the system would improve only if the system moved in the direction of continuous flow through waste elimination.

Naresh (2011) explained TPS in more detail and in Figure 2.1 it is shown that TPS was a philosophy and combination of various sub-systems to attain a common goal of efficiency improvement and waste decrement. Just-in-Time (JIT) is a technique used to manage inventory and eliminate the inventory build-up in production (Soliman 2017). The JIT system sends small deliveries of stock just when they are needed, and an ideal state one-piece flow is to manufacture one part at a time, with the drumbeat, or pace, emanating from the takt time, or customer demand. Eliminating buffer stock or having smaller safety stock is one method that reveals all the hidden waste. This supports the Jidoka concept, which stops the production process when problems occur so that the workers can address the problems instantaneously and thereafter restart production (McLean 2017).

Figure 2.1 shows the case study company's production system. It is different from the Toyota Production System house but also has the vision of zero defects, one-piece flow and 100% value added on top, which is similar to TPS. It has an additional layer on the roof that displays the strategy to achieve the vision. The first supporting wall is also JIT but the second wall of the house is "Failure-free-Production" instead of Jidoka. In addition, the centre of the house is different from TPS as it also contains continuous improvement but it does not embrace humans and the elimination of non-value adding elements.

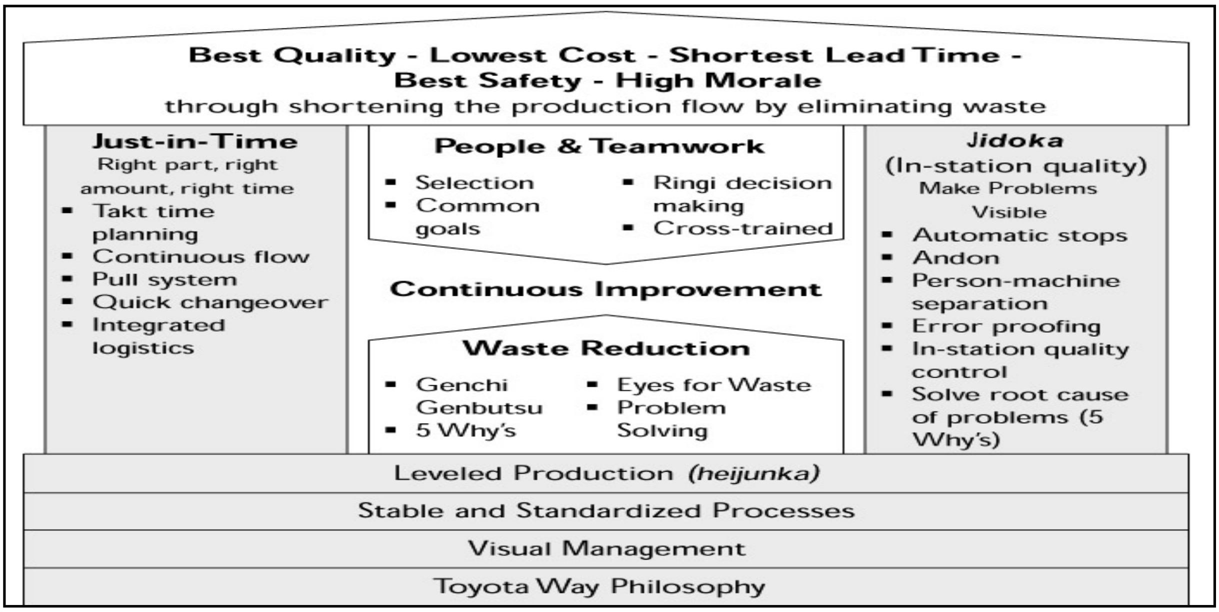


Figure 2.1: Toyota Production System

Source: (Naresh 2011)

Qualification, TPM, visual management, standardised work and process planning and technology transfer form the foundation of the company's production system. The employees within the company understand that the lean tools interact with each other and that the use of a single tool might not be successful.

Naresh (2011) explained that the house foundation determines the strength of the entire house. Working with smaller inventory and production stoppage in a line when problems occur is the root to weakness or instability in a system, leading to a sense of urgency from the employees. If there is an unplanned machine breakdown, the maintenance department is normally always available and have a planned scheduled in place to fix machines under preventative maintenance, as the buffer stock is used to supply the customer. In lean philosophy, as an operator stops the machine or equipment to sort out a problem, other machines or operations will also stop instantaneously due to no inventory. If a breakdown occurs, it creates a crisis, and therefore there is always a sense of urgency to sort out problems together as a team to get the equipment in a working state as soon as possible (Dennis 2016).

Jaca *et al.* (2014) indicated that the main objectives of the Toyota Production System are to produce products that meet world class quality standards, ensuring that customers' expectations are met, and to tailor an image of business responsibility within the manufacturing industry. The Toyota Production System has in the past had fundamental aims that are consistent with the objectives and principles below as discussed by Jayamaha *et al.* (2014):

- Ensuring the provision of quality service to the customer that meets world class standards.
- Providing employee development supported by trust, common respect, and collaboration.
- Ensuring cost reduction by eliminating waste and increasing profit.

In this thesis, there will be no differentiation between the Lean principles and production methods since they are similar, regardless of whether they are applied to the production or to the whole value chain.

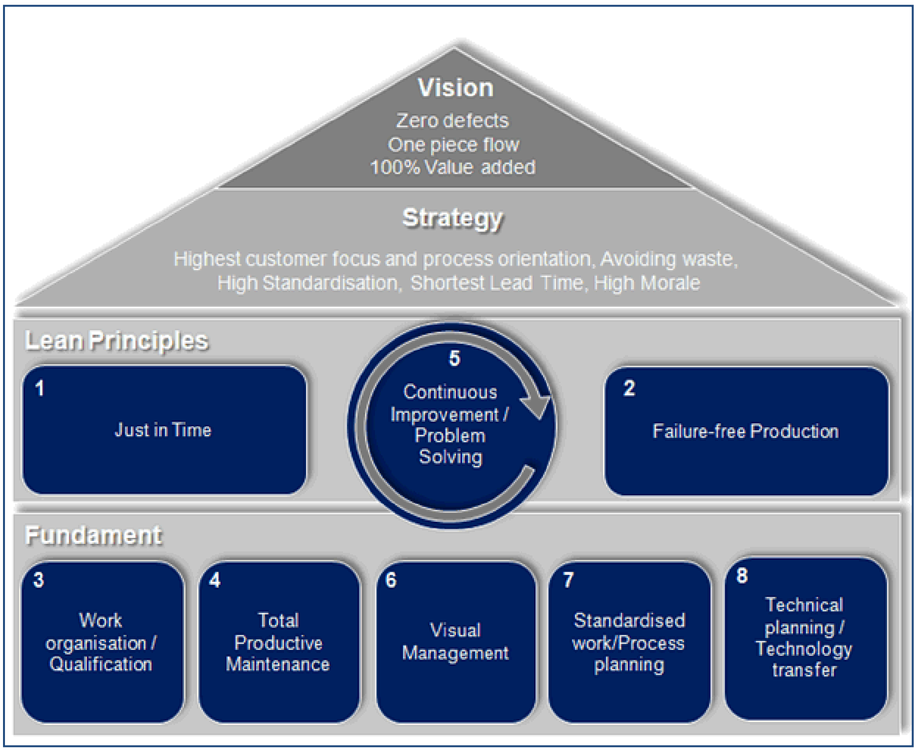


Figure 2.2: Case study in-house production system

2.4 Lean Principles

The main five principles of Lean are as follows:

- Pinpoint the entire steps essential to plan, order and produce the product throughout the entire value stream while minimising non-value-adding waste.
- Manufacture the exact quantity required by the customer.
- Specify value-adding and non-value-adding tasks from the customer's perspective
- Always strive for perfection by continuously eliminating waste as it is revealed in the system.
- Ensure that only operations that add value to the process without interruptions and backflows are being created (Hines *et al.* 2011).

The Lean principles are fundamental to eliminating waste and are quite easy to memorize and it is essential to use them as a guide for a business that is implementing Lean.

2.5 Value-adding and non-value adding activities

A casual observation or evaluation of a process can reveal wasteful activities from processes, and activities can be distinguished as either Value-Adding (VA) or Non-Value-Adding (NVA) activities as shown in Figure 2.3. However, even though some activities may be perceived as NVA activities, such activities may be crucial for ensuring compliance with certain regulatory requirements or standards and these activities are called Essential Non-Value-Adding (ENVA) activities.

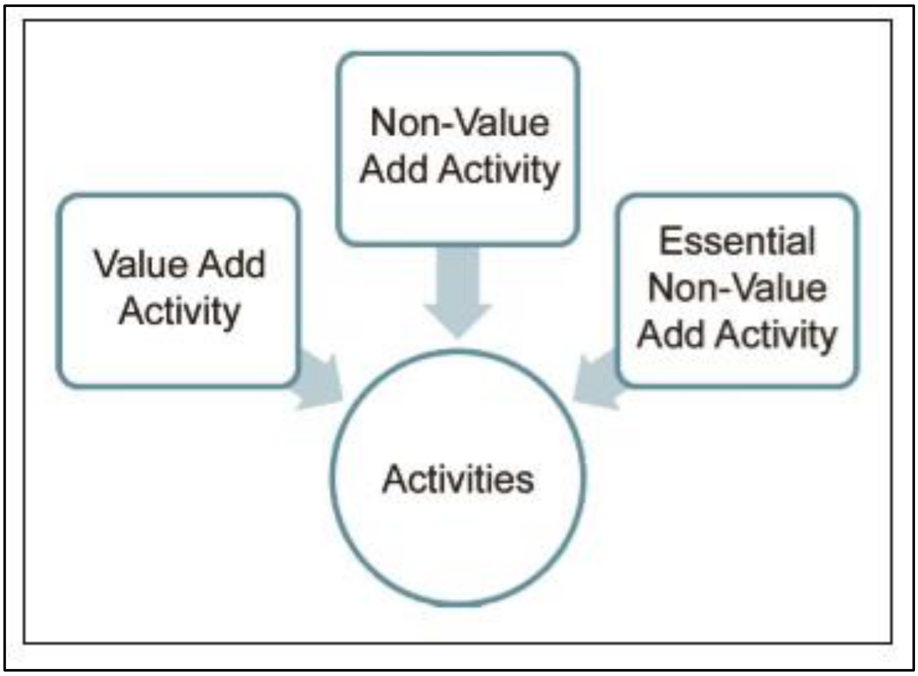


Figure 2.3: Different categories of activities

Source: (Benson 2011)

2.6 The Eight Wastes of Lean Management

There are eight sources of waste that include inventory, over-production defects, waiting, transportation, motion, incorrect use of staff and their skills, and over-processing (The Centre for Management & Business Development).These sources of waste include the following:

- Inventory – Inventory is any excess products held in stock that are not directly needed by the customer. Therefore, the stock on hold, if not in production use, takes up a lot of space, resulting in increased inventory costs and high possibilities of having obsolete stock while stored (Chen and Xu 2015). Most companies that have implemented Lean ensure that they install IT systems to control their inventory to ensure that money is not wasted on unnecessary resources, components or products (Bhasin 2015).

- Over-production – Over-production takes place when an organisation produces more than what the customer needs. This means producing parts that are not ordered or producing more than what is needed at that time. Over-production is the worst of all the types of waste since it has a knock-on consequence of increasing all the other types of waste. Thangarajoo and Smith (2015) stated that over production amplifies costs of inventory, defective parts, unnecessary transportation, waiting time and avoidable motion.

- Waiting – Waiting can be noted as queuing and can occur because most downstream activities in manufacturing are dependent on the operations that are upstream. The idle downstream material is usually used for activities that are not value-adding, resulting in overproduction (Harish and Selvam 2015). When resources, equipment, information or workers hold up the production line for some reason, production costs will increase and time is wasted and that adversely impacts profitability.

- Defects – Santos, Wysk and Torres (2014) described defects as parts that do not meet the customer specifications. Defective parts result in reworks and rejects that lead to costly production processes. Defects are triggered by poor production processes as an outcome of machine breakdown or human error. Reworking or reprocessing takes extra time and hence increases the finished product cost. Rejecting or discarding products incurs extra costs and excessive resources usage that affects the production line.

- Transportation – Tesfaye (2014) defined transportation waste as any material, objects, parts and finished goods movements that are unnecessary, leading to a waste of time, resources and money. Unnecessary transport is generally compared to unnecessary movement, which falls under motion waste and that results in parts damage and product failure. Goods movement also affects the IT inventory control system.

- Motion – Motion relates to the additional steps taken by operators and equipment thereby wasting operator's effort and time. Unnecessary movement results from poor basic procedures and training, and poor work process design (Hirano 2016).

- Incorrect use of staff and their skills – If the skills and abilities of staff are not utilized properly, the result is loss of business time and failure to use operator's skills and suggestions, and leads to fewer or missed opportunities of improvement and education. Staff need to be integral to the entire manufacturing process (Karodia, Cowden and Kum 2014). The operators on the shop floor can come up with ideas to eliminate sources of waste. Engagement can improve the processes and develop the staff's skills continuously.

- Over-processing – Morgan and Brenig-Jones (2015) stated that over-processing is the unnecessary steps taken in the production process. This also refers to extra processes such as re-working and re-processing. The other meaning of over-processing is producing products, or an output, exceeding the customer's specifications. In most cases, this takes place due to malfunctioning machinery, faults during re-processing, poor information transfer, ineffective methods and not using the customer's requirements as a point of reference (that includes in-house customers downstream in the process).

2.7 Lean Manufacturing Tools and Techniques

When applied correctly, Lean manufacturing tools will result in positive outcomes. Using the Lean tools makes it easy to tackle the source of waste when identified, just by selecting the suitable Lean tool to eliminate or reduce waste. Sharma *et al.* (2013) discussed the tools, and each tool contains a unique approach to waste elimination. Lyons *et al.* (2013) also stated the key Lean manufacturing principles, that is, the alignment of production to demand, waste elimination, suppliers' integration and the innovative participation of the labour force in continuous improvement activities.

The Lean tools and techniques that are related to the task of this thesis are discussed below. Firstly, value stream analysis and balancing charts are those methods that can help to visualise and analyse processes. Thereafter, two possibilities of categorizing and prioritising products or problems are discussed as this helps to concentrate on major issues. Finally, possibilities of putting the pull principle into practice are illustrated with the aim of being able to compare that with the situation at the case study company.

2.7.1 Kaizen

Nicholas (2016) described Kaizen as a philosophy of continuous improvement, also known as one of the terms used by the Japanese for long-term improvement by connecting everyone from top managers down to the shop floor workers. Sandeepsoni *et al.* (2015) also posited that Kaizen became one of the essential Lean tools for the success of Kaizen production, quality and process improvement projects in any kind of manufacturing industry. Kaizen becomes a success through team work and industry goals are achieved efficiently. Quality departments can be introduced as facilitators for continuous improvement to ensure that the projects are on track through team effort. In manufacturing, Kaizen narrates finding and eliminating waste in equipment, employees and production processes.

Kaizen may also include Kanban, a simple parts-movement system whereby cards and packaging are used to take the parts from one point to another on the manufacturing line. Kaizen practice is an everyday process, in which the purpose goes further than simple productivity enhancement. It is one of the processes that humanizes the workplace and when completed correctly, Kaizen teaches individuals exactly how to execute experiments in their day-to-day jobs using the systematic technique and also to learn how to identify and eliminate waste from the system. The Kaizen process may also be used to provide a more humane approach to employees and increasing the business productivity (Vorne Industries Inc 2011).

A typical Kaizen cycle may include the following:

- Standardizing operations and activities.Chen, Li and Shady (2010) posited that standard process routine templates are used to display the time relationship between the employee(s) and manufacturing systems. Routine templates require information such as the time taken by a worker to walk during production, processing time for the machine and manual operation times. Operations that are manual are those tasks that require workers to perform the task between processing cycles, for example offloading/ loading, de-burring, and inspection checks. Information is collected and presented in graphics to show exactly which activities the employee(s) and machines are performing throughout a cycle.
- Operation measurement (measures cycle time and total amount of in-process inventory).
- Innovation to meet requirements or specifications in order to increase productivity.
- Gauging measurements compared to specifications
- Standardizing the improved and new operations.

Kaizen can be implemented through the “Plan Do Check Act” (PDCA) cycle. The logic and benefits of Kaizen for every improvement need to be carefully assessed before implementation. The “5 whys?” concept is used to achieve this and all scheduled improvements require going through “why?” questioning on five levels to make sure that the value and common sense of the improvement is understandable. This decreases the chances of making unjustifiable changes to systems.

Advantages of Kaizen include:

- Teamwork, Increased Efficiency, Employee Satisfaction, Improved Safety
- Kaizen philosophy improves – Quality of product, Capital usage, Production capacity, Utilization of space, Communications.
- Kaizen provides speedy outcomes.

Gonzalez, Rodrigo Valio Dominguez and Manoel Fernando (2016) defined continuous improvement as a method of incremental, concentrated and continuous improvement connecting the whole business. Gonzalez, Rodrigo Valio Dominguez and Manoel Fernando (2016) indicated the characteristics of innovation programmes; improvement ideas are centralized and controlled in a Production System Efficiency (PSE) department, which is a crucial tenet of Kaizen activities in the business.

Figure 2.4 shows the key tenets of continuous improvement and these include management systems, employees, group work, and culture. A continuous improvement-oriented culture, knowledge sharing and learning culture are the essential elements of organisational culture.

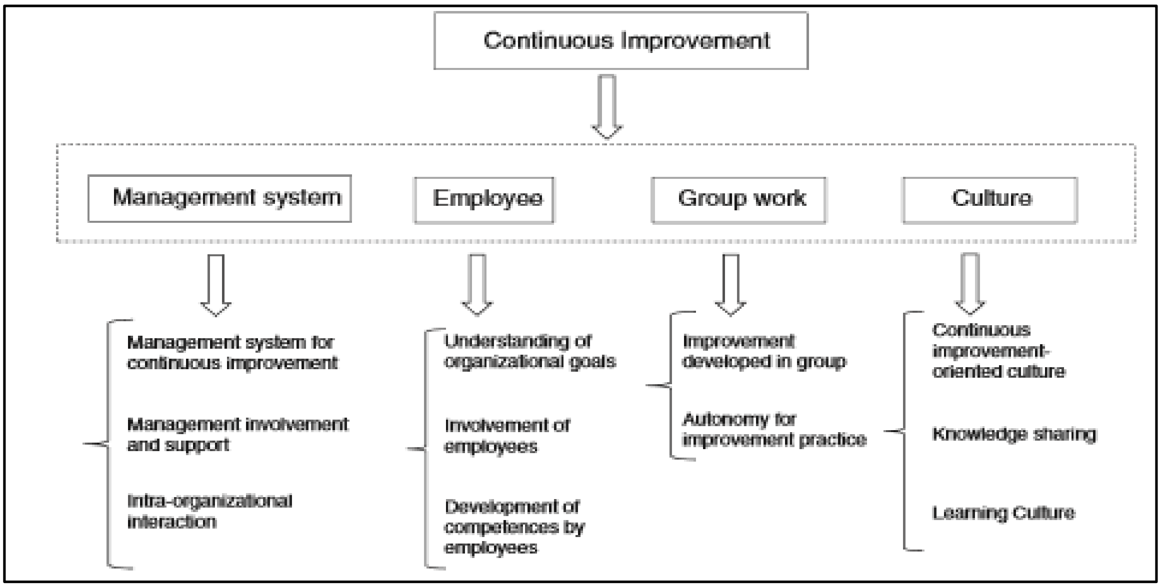


Figure 2.4: Organisational capabilities for continuous improvement

Source: (Gonzalez, Rodrigo Valio Dominguez and Manoel Fernando 2016)

2.7.2 One-piece Flow

Continuous flow or One-piece flow processing is an idea that means items are repositioned and processed straight from a single processing step to the succeeding step, a single piece at each time. One-piece flow aids resource utilization to the maximum, reduces lead times, and pinpoints communication and obstacles in-between operations. Sundar, Balaji and Kumar (2014) explained that a pull system enables the manufacturing of goods based on what the customer orders or calls off. The success of the pull system is dependent on moving manufactured goods in small batches (moving towards one-piece flow wherever feasible), ensuring that the process pace is measured to takt time (in order to prevent the overproduction waste). The Kanban system is used to send a signal for refill or when a part is required and flattening of output mix and quantity is required.

The One-Piece flow manufacturing method takes into consideration the factor of time to set up and make-to-order procedure, sequencing, and consequently production scheduling (Chryssolouris 2013). The workers are assigned a recurring sequence of loading and offloading equipment tools. Flexible line manning is one of the important flow lines in which the equipment is organized in a U-shape cell. Uddin (2015) indicated that as soon as changeover activity or activities occur in a U-shape cell, with one-piece flow, the manufacturer starts producing parts as soon as the Kanban tag for parts is shown.

2.7.3 Jidoka

Jidoka is also identified as built-in-quality and Swart (2016) defined Jidoka as a second system support. Jidoka allows the separation of man and equipment in a workplace. The meaning of Jidoka in Japanese is work autonomation. Toyota defines it in a similar way, adding what is recognized to be fundamental in portraying characters of “kanji”.

Ward and Sobek II (2014) mentioned that the Toyota Production System (TPS) aims for processes that are able to make an intelligent judgement and stop automatically at the first indication of an unusual state or problem such as defects. This automatic shutdown function helps to stop defective parts from evading the downwards stream, injury prevention, restrictions on damaged machines, and therefore permits an enhanced view of the current state as problems come into sight. Therefore, to bring a machine to a standstill is a better signal to indicate a problem than to continue with production, which will only cause additional waste. Separation of the human element from the machines is the second element of Jidoka since the machinery comes to a standstill when a problem occurs and it is not necessary for individuals to monitor the machinery. Jidoka allows workers not to be tied to the machinery and having to keep an eye on the machines and the workers are thus utilised in a value-added way. This skill of separating humans from machines is an essential enabler for work standardisation to thrive. It is a reflection of Toyota and demonstrates respect for employees.

Brown (2016) defined Jidoka directly from the English translation meaning "humanised automation" or “intelligent automation". Jidoka also refers to shutting down a manual line when something in the process goes wrong. The production methods used by mass manufacturers in America which were seen to be out of control when it came to waste. Waste is called “Muda” in Japanese, meaning all activities of production that only add cost but do not add value. For example, inventory, excess in people and machines are forms of waste that may exist in a plant. In order to prevent errors from increasing, a invented a system of placing a cord on top of every work station in the production facility and encouraged employees to stop the entire assembly cell instantaneously if a problem was discovered.

2.7.4 Productivity

Burke (2013) explained productivity as improvements in efficiency that may result in overproduction, which is one of the worst wastes and redirects the company's overall efficiency in the wrong trend. Keohane and Olmstead (2016) stated that the improvement in efficiency demonstrates the value of reducing costs and when performing an evaluation of efficiency, the required manufacturing quantity is the main factor. One also has to think through how the required parts may possibly be produced with less labour-hours and whether it is achievable in the best possible time. Other key issues under productivity include:

- **Apparent Efficiency and True Efficiency** - Apparent efficiency is attained when the quantity of production is increased within the same labour-hours but not taking into consideration the exact quantity of the saleable product (Keohane and Olmstead 2016). True efficiency is achieved by producing parts that can be saleable (saleable quantity) within less labour-hours. True efficiency contributes to a huge cost reduction and increased production quantity, and takes into consideration the methods of boosting production within the existing labour-hours. On the other hand, to sustain or reduce production quantity, one should consider methods of increasing efficiency by reducing labour-hours. Efficiency is utilised in different ways as a norm for assessing productivity using labour or machines.

- **Total Efficiency** - When looking for options to increase company efficiency through eliminating waste, efficiency should be analysed for each process and the plant as a whole (Pan *et al.* 2015). It is crucial to implement efficiency improvement projects from the lowest level to the highest level of a system in order to have improved efficiency for the total system.

2.7.5 5S

Melton (2005) shared the same ideas as Agrahari, Dangle and Chandratre (2015) who listed the 5S activities as:

- Seiri (Sorting) - separate needed tools and materials from those not needed and eliminate the obsolete materials.
- Seiton (Straighten out) - organize tools for ease of usage.
- Seiso (Shining) – clean up
- Seiketsu (Standardize) - perform the above frequently (maintain the system).
- Shitsuke (Sustain) - practise the routine of succeeding with the first four 5Ss

2.7.6 Work Standardisation

Naresh (2011) described work standardisation as being significant for waste reduction or elimination of muda. Standardized tasks or activities basically ensure that each job is carried out in an organized and identical way, regardless of the people that work on it. When the work is standardized the quality of the output stays the same even if the operator has changed the position in the process. In the Toyota way, every single operator follows the identical processing steps at all times. This includes the time required to complete a job, and the arrangement of steps followed for each activity. It is crucial to make sure that balancing of the line is taken into consideration and achieved, unnecessary work-in-process (WIP) stock is minimized and activities that add no value are reduced.

Standardization is one of the tools that can be applied in an organisation for continuous improvement. One of the least used lean tools is work standardization, yet it is the most powerful tool. In standardization, recording or documenting the current best method is essential; documents that are utilised must be standardized, and that is the foundation of kaizen or continuous improvement. As the standard is enhanced, the latest standard becomes the baseline for more improvements, and improving standardized work is a never-ending, continuous process. Continuous improvement or kaizen philosophy emphasizes that there is always room for improvement. It decreases the variation of the process, improves the products and processes quality. The housekeeping or 5S method has a contribution in work standardisation, which is utilised in organisations to eliminate waste at the workplace. The 5S method must be included in the processes of standardisation and lean workplace (MĺÍkva *et al.* 2016)

Dennis (2016) defined standardization as an important element for Jidoka and Just-In-Time (JIT). Uniformity in methods is essential to limit process variation and achieve efficient production in a well-timed manner. Much documentation exists to channel workers, document standardized methods and define processes and training of the work teams. The standardized work chart and quality inspection worksheet are the commonly used documents in the production space.

The standardized work chart is mainly focused on repetitive individual motion that links the job elements into an effective work sequence with no waste (Scott and Davis 2015). It is also furthermore utilised as a visual control tool for top management and supervisors to simply spot a problem that may occur in the system. In addition, this document is utilised as one of the tools for continuous improvement and as a work instruction manual for operators.

Scott and Davis (2015) stated that the quality inspection worksheet provides the definition of the quality checks that should be carried out by the operators in the production area. It gives instructions on which critical areas must be inspected in order to meet the required specifications. When the inspection system is utilised, it pinpoints where the quality information is captured, the frequency of quality checks, and what actions the inspector should take when there is a problem.

For the case-in-point scenario, the company uses work organisation/ qualification to:

- Ensure that all new employees go through a standardized induction programme including organisational vision and other relevant topics.

- Train all employees in organisational elements, lean principles and the 7 kinds of waste.
- Identify training needs for all employees.
- Ensure training programmes are planned and executed.
- Update qualification matrices periodically.
- Involve operators in improvement projects and organisational activities.
- Standardize and document shift change activities.

2.7.7 Just-In-Time

Harish and Selvam (2015) defined Just-In-time (JIT) as a method of managing inventory whereby small shipments of stock are distributed as soon as they are required. Just-In-time strives to minimize the stock levels in an organisation.

Crandall and Crandall (2015) mentioned that JIT philosophy is grounded on producing and supplying the required products only, within the required time and in the required quantity, utilizing the least possible needed resources. In an ideal world, the exact quantity of parts is manufactured and shipped straight away as soon as the orders are received from the customer. The upstream processes and suppliers deliver just the required amount of parts once the process downstream requires them. When the JIT philosophy is applied, no stock on hold is needed.

JIT systems pinpoint the unseen problems in the value process sequence and reduce the production waste in the system while concurrently increasing the throughput. Although JIT production systems appear to be interesting and have fewer complexities, coordination is required with the supply chain to avoid delays in production. Eliminating all work-in-process (WIP) inventory is not feasible in a realistic world. The solution to producing efficiently is constantly decreasing the quantity in the system.

There is a common reaction to act in response to problems by building up a safety stock based on an estimation of defective parts or rejects, employee absenteeism and breakdown of equipment. Toyota, on the other hand, is opposed to using buffer stock to respond to problems. Keeping excessive stock results in a range of hidden production waste issues and it becomes impossible to establish a strong structure at a workplace.

The safety stock utilised to offset production halts caused by defective parts or machinery breakdowns hides the fact that there are problems in the system. This prevents the need to predict problems, improve the operational rate and prevent the repetition or recurrence of breakdowns and defects from being detected. JIT manufacturing aids in pinpointing opportunities for making the processes perfect rather than making room for inventories (Rahmani and Nayebi 2014). The Pull system is one of the important elements of JIT thinking.

Parts are manufactured by a single process in conventional production systems, as defined by the production plan, and parts are supplied to the subsequent processes even though there is no need for those parts in the system (Dennis 2016). A push system would suffice if parts were manufactured according to plan throughout the entire process. However, when the production line comes to a standstill because of a single process that is experiencing sizeable problems, the other machines directly connected to the problematic line will be affected by either a shortage or a backup of parts (Drew, McCallum and Roggenhofer 2016).

According to Malakooti (2013), the pull system removes poor production planning, which is excessive production or under-production through restrictive manufacturing of the parts required by the succeeding downstream process. A very good example of a pull system in action is a standard vending machine. As shown in Figure 2.5, the consumer is pulling the exact items required at that time and in the required quantity. The trigger to the supplier is the empty spaces in the vending machine, therefore only the items pulled by the customer are replaced or filled up.

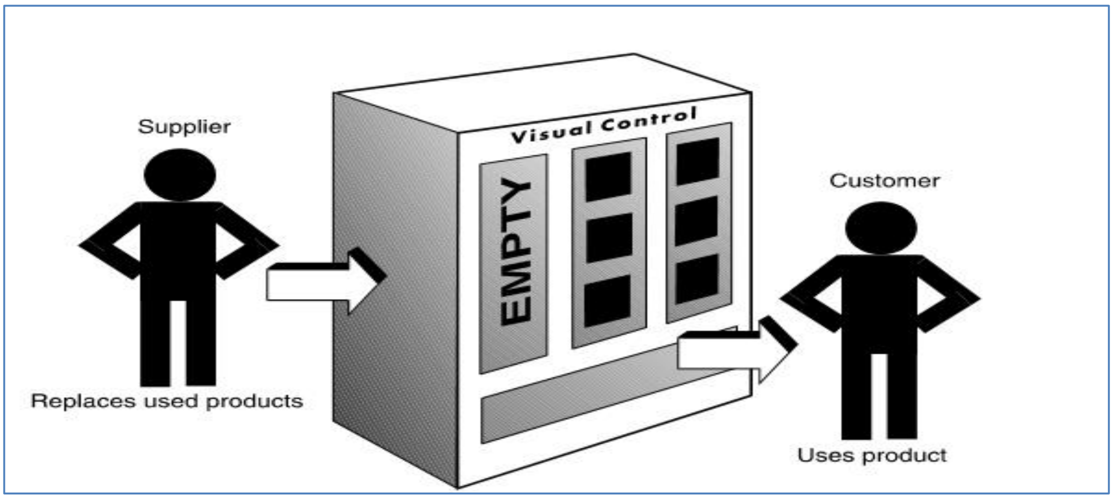


Figure 2.5: Preceding process (Pull System)

Source: (Gousios *et al.* 2015)

For a preceding process to produce the required number of products, it is essential that all the production processes have the required resources, for example, materials, people and equipment, in order to produce the items just as they are needed. When the downstream process call-offs are inconsistent in time and quantity, the upstream process must in proportion drop or up the production for the compensation of irregularity.

When implementing JIT, some lean tools are incorporated automatically as in the case study company to produce and deliver Just-in-Time. This is accomplished by ensuring the following:

- Calculating customer takt time of each process step.
- Integrating all product families in VSD.
- Identifying the pacemaker and control production only at this point.
- Levelling the production according to a defined sequence (Heijunka).
- Making sure that all pre-processes are controlled by FIFO lanes or Kanban supermarkets.

- Applying single piece flow wherever possible.
- Developing and using returnable packaging for easy handling and ergonomic withdrawal of material.
- Ensuring that supplied material at work stations does not exceed two hours of production, otherwise the two-box-principle is used.
- Using VSM/VSD to prioritize CIP activities and reduce lead time.
- Defining and controlling the whole supply chain (transportation of goods, packaging, delivery frequencies, supplier integration etc.).

2.7.8 Kanban

Rahman, Sharif and Esa (2013) defined a Kanban system as a strategy utilised in manufacturing in organisations that have adopted lean production to reduce costs and minimise inventory. Nevertheless, the implementation of the Kanban system is not practised widely by manufacturing industries. The Kanban system is utilised as an inventory level controller of buffer stock in production. The Kanban system sends a signal to the upstream machine as soon as the buffer stock reaches the set maximum level, therefore the machine stops manufacturing that specific type of part. A visual signal or trigger that is used to send information when a part is required in the system is called a Kanban (Fontanot, Haase and Sala 2014). The Kanban system is usually identified by a card that goes through the processes, sending information about the materials required for replenishment (Cimorelli 2013).

2.7.9 Value Stream Mapping

Value Stream Mapping (VSM) is a visual technique used to map the flow of information and material required to manage the activities carried out by organisations manufacturing products, suppliers and distributors to send finished goods to customers. Chen, Li and Shady (2010) posited that VSM is made up of all the materials and information needed for the manufacturing of a specific item and to show how the information flows throughout the system of production. VSM basically translates the value stream data into a map or diagram in which the current or future state of the production system is represented. As the term indicates, a current state VSM represents the flow of information and materials in the current process. A future state VSM shows a more perfect future state where there is no waste in the production system.

Santamaria (2013) studied VSM and defined it as a one of the visual tools that utilizes lean manufacturing for identifying and analysing all the production activities, from planning to shipment of the products. A value stream map makes it easy to identify improvement opportunities that have a high impact on the entire production process. The VSM tool examines the current and future process map layout of the value chain, and this makes it feasible to keep records of the current state and the actual process that will be enhanced, as well as the succeeding state, or the future state, which is the ideal world of production with all the improvements achieved. The VSM is a chart that consists of symbols and icons that explains the two different types of flows. The first flow is the information flow from logistics planning, and it contains the customer call-offs or orders up until the production commences. The second flow is the material flow in production, which takes into consideration all the production processes required to produce good parts up until the product is sent to the customer.

Performance measurement is allocated to all manufacturing processes that reveal and display the status of the existing processes and generally include setup time, cycle time and baseline shift, number of operators in a shift, scrap rate, machine availability, efficiency and machine downtime. As soon as the performance measurement is in place and drawn according to the VSM, opportunities for improvement are pinpointed in line with the impact they have on cost reduction, increasing flexibility and enhancing quality and productivity. Lastly, a future state is drawn in order to aid with visualizing the future process when the opportunities of improvement are implemented.

Sundar, Balaji and Kumar (2014) defined value stream as a set of defined actions needed to get a specific product through the three critical tasks management of any organisation, and these include management of information, physical transformation and problem solving. Dal Forno *et al.* (2014) mentioned that VSM aids the identification of value-adding activities in a value stream and waste removal, which is a non-value-adding activity.

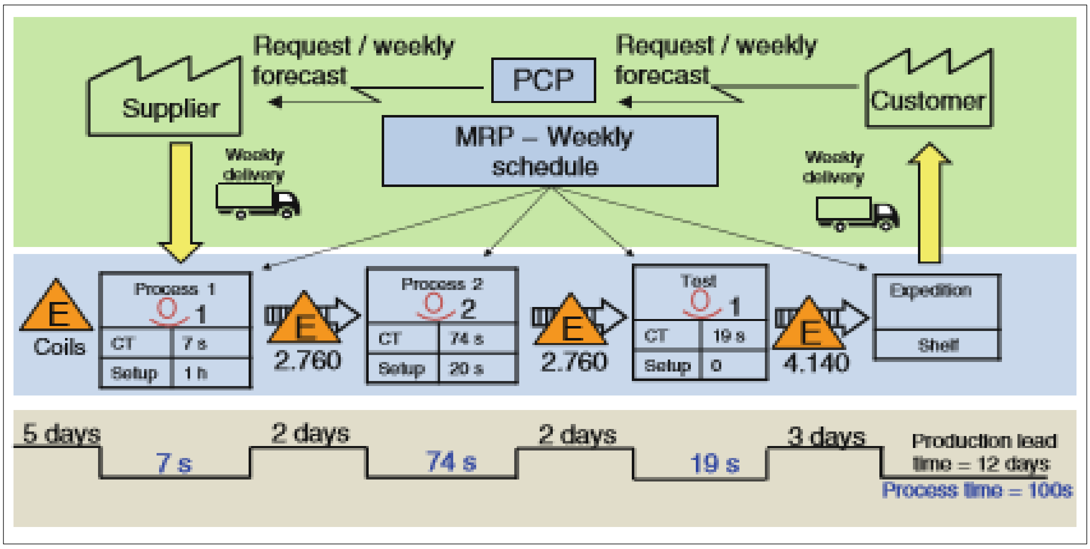


Figure 2.6: Example of Value Stream Mapping

Source: (Dal Forno *et al.* 2014)

A subsequent step in VSM is developing a future state map supported by the improvements generated from the current state. The information availability in the VSM assists and confirms the decision of implementing lean techniques and can in addition keep the organisations motivated during the actual implementation phase with the aim of getting the desired outcome. The inventory, processing time, waiting time and lead time is clearly indicated in the VSM and it also shows the process flow in which bottleneck processes and cycle time can be sorted out against takt time.

2.7.10 Poka-Yoke

Santamaria (2013) defined the poka-yoke as a concept designed wisely in order to avoid system faults during operation. Other researchers describe the poka-yoke as an ant-brainless, which gives safety assurance to the users when using the machines and processes, and hence, the occurrence of accidents is prevented. The engineer Shigeo Shingo introduced Toyota to these inventions in the 1960s within the Toyota Production System. Even though poka-yoke existed in the past, the engineers introduced it into their Toyota Production System. Figure 2.7 shows the various types of errors that may possibly occur in a process.

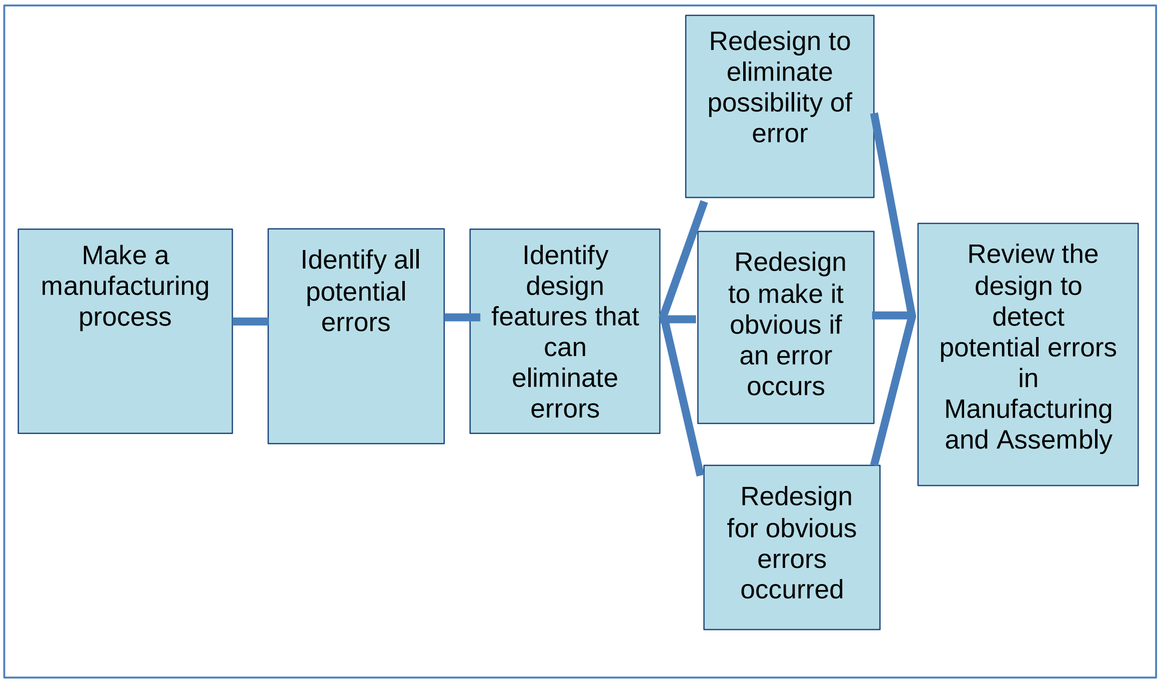


Figure 2.7: Different errors that can occur during a process

Source: (Santamaria 2013)

2.7.11 Line Balancing

Lam *et al.* (2016) defined line balancing as a technique utilised to minimize imbalance between workloads and workers in order to achieve the run rate that is required. Consequently, the analysis of the line must be in terms of assembly process, layout of workstations and the cycle time of the workstations. A multiple activity chart is utilised to measure the cycle time at the work space with integration of an operator and the machine, and it can be described as an operator and machine chart.

Sundar, Balaji and Kumar (2014) indicated that the task time variation is primarily due to a human being's instability with respect to work rate, skilfulness and motivation as well as the failure sensitivity of complicated processes. These sources of inconsistency are minimized by controlling the moving cost of machine and men. The worker walking time and variation of operator and machine cycle time results in line imbalance. Furthermore, line imbalance is created by the change-over time for mixed model lines. Based on customer call-offs or orders, the number of operators and machines at the workstation are increased or reduced with the aim of overcoming the line imbalance. Man and machine flexibility is achievable through open information and material flow in the production process.

2.7.12 Takt Time

Womack and Jones (2015) stated that levelling out production quantity means that a single part must be produced in a certain period of time and this time is called takt time. It originates from the customer requirement that is the average quantity. Sundar, Balaji and Kumar (2014) described takt as the rate of recurrence of a part or item that must be manufactured in order to meet customer demand. Takt time is determined by the daily production demand ─ when there is an increase in demand, takt time decreases, but when there is a decrease in demand it increases. The significance of performing takt time measurements emanates from the costs due to manufacturing customer products in advance, which is characterised by increasing space for storing parts and the retrieval of finished products, as well as early buying of raw materials. Early wages expenditure, the cost of wasted opportunities to manufacture other products and costs of capital for excessive capacity are also reduced if takt time is taken into consideration.

Takt time is calculated using the available time for production for a period of time and customer demand for a specific time as shown in the following equation.

$$Takt\ time = \frac{Available\ Time}{Customer\ Demand}$$

Elmoselhy (2013) mentioned that the calculation of the number of parts to be produced using takt time makes it simple to manage the equipment, available labour hours and additional factors essential for value-adding production. If a single type of part is produced, the level production is feasible by levelling that single quantity. When multiple types of parts are produced it is then essential to consider all the products in order to avoid the waste that results in inefficiency.

The levelling of product types means that the required production quantity proportions for all types will have to be produced in series (Black and Kohser 2017). One of the examples is when the production quantity ratio for outputs A, B and C is 3:2:2 respectively, and different types will be manufactured successively as per the following order A A A, B B,C C, A A A, B B, C C and so on. Production that is performed using this approach makes it feasible to pull parts from a preceding process with no additional stock, labour hours and equipment required for the prior process (Mitra 2016).

2.7.13 Single Minute Exchange of Die (SMED)

Moreira and Garcez (2013) defined Single Minute Exchange of Dies (SMED) as a Japanese process-based advanced method that consists of the separation and change of the internal setup processes into outside operations. External setup time means any process time that is taken before a machine comes to a stop, while internal set-up time is any tasks done during machine running time, which is considering change-over time. SMED makes it feasible for a company to react to variations in demand and results in lead time reduction plus elimination of waste during change-over activities.

Ani and Shafei (2014) described SMED as a process founded in the 1980s to counter the challenge of available time loss due to time spent on the change-over processes. Change-over process time includes changing operation sequences, and machine or tool programming based on what the process requires during change-over from one model to another model mainly for mixed production of parts. SMED practice is a systematic approach that aids in reducing change-over time or set-up time.

2.7.14 Continuous Flow vs Batch Processing

Lee *et al.* (2015) described batch and continuous manufacturing as:

- Batch manufacturing: the raw material(s) is charged before the start of processing and the product is discharged at the end of processing. In batch production there are stages that a part goes through before it becomes a finished product as shown in Figure 2.8(a).

- Continuous manufacturing is when the material(s) and product are continuously and simultaneously charged into and discharged from the system as shown in Figure 2.8(b).

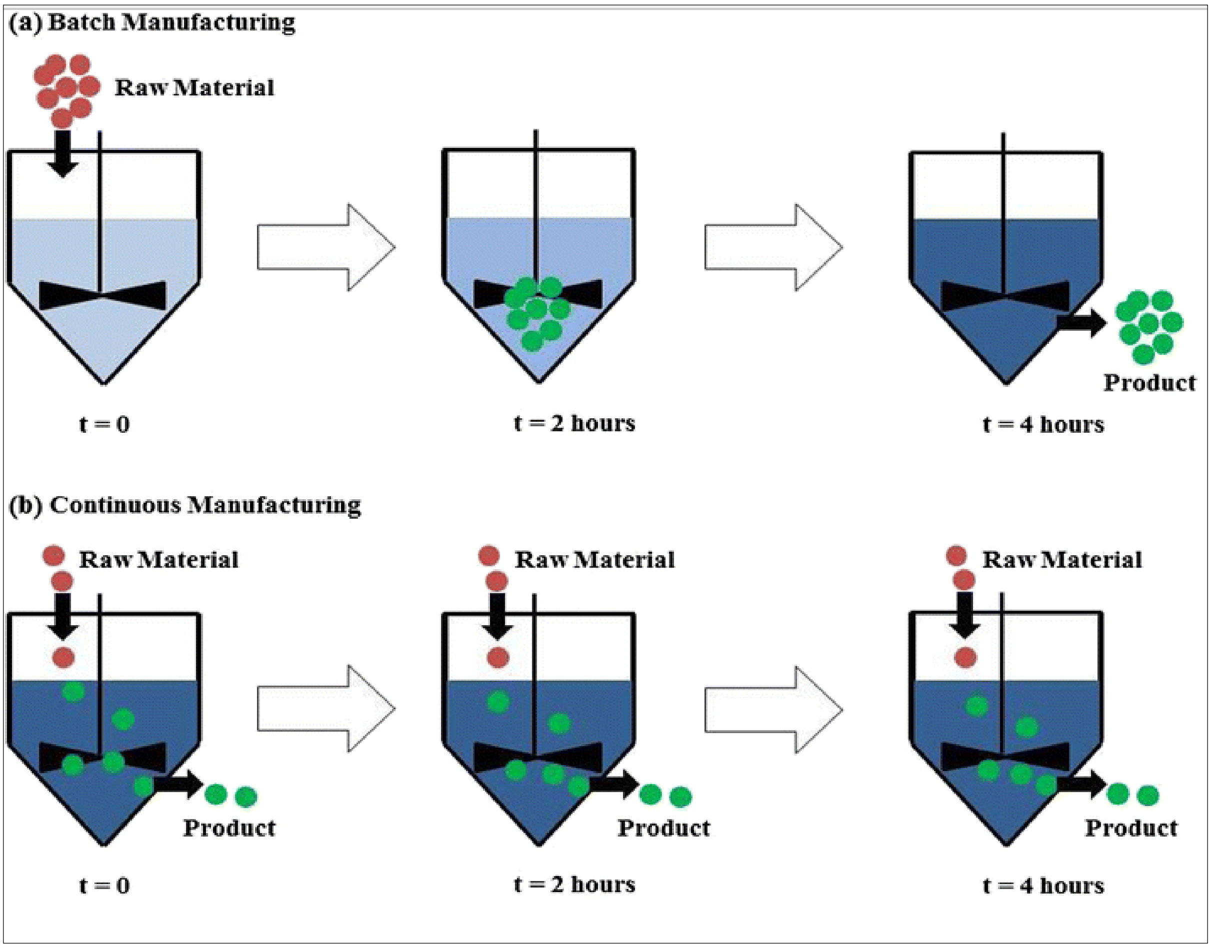


Figure 2.8: Batch and Continuous manufacturing

Source: (Lee *et al.* 2015)

Batch and continuous manufacturing can be useful to sole unit processes or an entire manufacturing process made up of a series of unit operations. In batch manufacturing, materials from one phase are generally tested offline according to the in-process requirement and stored before they are moved to the next processing step. If the in-process material cannot meet quality specifications, it may be thrown away or, if possible, re-processed prior to moving to the next process step.

In continuous manufacturing, materials manufactured during each process step are sent right away and continuously to the subsequent station for further processing. Each processing step is required to consistently produce an intermediary material or product with acceptable quality characteristics. Continuous manufacturing, compared to batch manufacturing, hence often includes an upper level of process plan to ensure acceptable process control and product quality.

2.7.15 Costs of Carrying Inventory

Carrying inventory for finished goods has the advantage of being able to deliver customer orders at short notice. However, carrying inventory costs the company a lot of money and Soliman (2017) defined the cost of carrying inventory as a collection of:

- Inventory costs, for example, the cost of assets or capital.
- Renting of space used for the inventory, depreciation, costs of utility, goods insurance, levies or tax, etc.
- Item handling costs.
- Deteriorating and outdated items costs.

In addition, the tied-up money influences the company's liquidity. Nevertheless, carrying inventory does not only have financial disadvantages. On the other hand, high levels of inventory hide failure-prone processes, inflexibility and unbalanced capacity, and thus these issues cannot be improved. On the other hand, high inventory levels can enable on-time delivery and constant utilization of capacity and it can compensate for downtime. Depending on the viewpoint, high work in process can be seen to be positive as it compensates for other issues in the production or conversely, it can be seen as negative as the issues cannot be fixed if they are not visible.

2.8 Conclusion

This chapter focused on the background to the study and the theory of the foundational concepts was presented for the reader to have more understanding of the research objectives. This chapter commenced with the rise of lean manufacturing, and proceeded to look at the Toyota production system, lean principles and its impact on the quality of the product, types of waste and lean tools. VSM was identified as a one of the visual tools utilized in lean manufacturing to identify and analyse all the production activities from planning to shipment of the products. Hence, VSM would be adopted for developing a roadmap for improving the manufacture of automotive heat exchangers at the case study company. It was also noted from the literature review that, based on customer demand, the number of operators and machines at a workstation in the case study company could be increased or reduced with the aim of overcoming the line imbalances. The organisation was also incurring high inventory costs and work in progress handling costs. The next chapter outlines the background to the company and the manufacturing processes.

CHAPTER 3 : CASE STUDY COMPANY BACKGROUND

3.1 Introduction

This chapter outlines the background of the company and its manufacturing processes. The study was conducted on manufacturer of car heat exchangers, specialising in vehicle air conditioning and engine cooling systems. The main products include Radiators (Rad), Heaters, Condensers (Cond.) Charge Air Coolers (CAC) and Evaporators (Evap). The factory consists of three different stages of manufacturing and preassembly of components.

The case study company based in South Africa is an international automotive supplier. The corporation offers products in the traditional product areas of engine cooling and air conditioning for both passenger and commercial vehicles as well as cooling modules for vehicles with alternative drive systems such as battery cooling.

3.2 Plant Overview

Figure 3.1 shows an overview of the case study plant layout. Highlighted in blue are the core building lines, with a total of thirteen stations, from which a matrix is built, that is, a combination of different small components assembled together. All the small components are provided from the core building supermarket, which is next to the core building lines on the plant layout. A few components come from within the case study plant, which is the building adjacent to the EC plant. Lines one to six produce similar radiators and the remaining seven lines produce different components – condensers, Low Temperature Radiators (LTRs), Evaporators (Evaps) and Charge Air Coolers (CACs). The Low volume Hand lines mainly produce low volume parts and CACs. Generally, it is the norm that operators are responsible for the quality of their individual work.

After core building, the products go on a trolley into the First-In-First-Out (FIFO) lanes (number 1 on Figure 3.1) in front of the heating section and this is dependent on the model. A steel jig with a nitride coating, is comprised of wires that hold the parts together. The parts are fed through a furnace that is about 65 metres long and divided into several sections. Brazing takes roughly 60 to 110 minutes depending on the model and product type. Two operators unload cores from the end of the furnace and put the steel jig on a trolley and the brazed products are placed on a separate trolley. The number of heated parts is scanned into the system when a trolley is finished, which means the heated quantity is fed back to the SAP system (software used for planning).

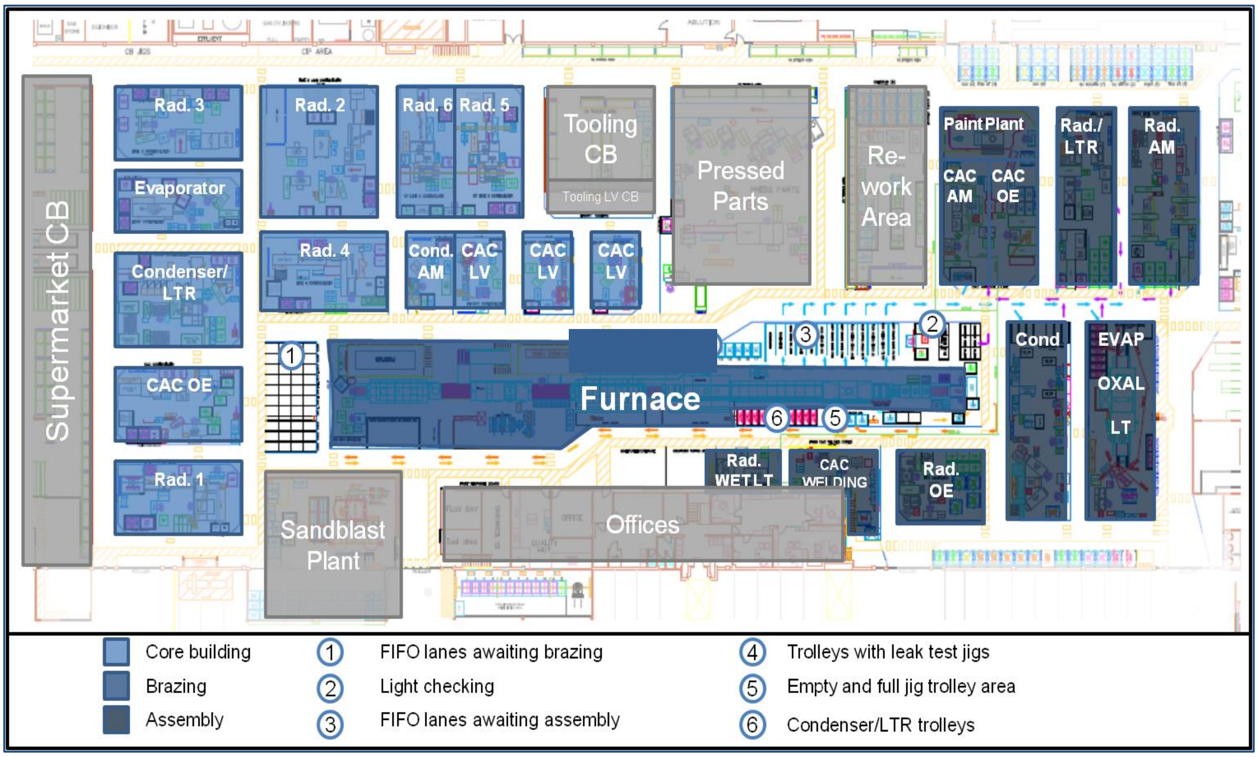


Figure 3.1: Case study plant layout overview

(Source: Developed by author)

The products are then sent to the main assembly stations and products without aluminium side plates go to the light check station (number 6 in Figure 3.1). The operator checks that there are gaps between the tubes and the aluminium side plates by holding the part over on a light of a camera. After that, the trolleys are stored in the FIFO lanes next to the brazing line (number 4 on Figure 3.1).

Products with side plates are supposed to go either directly to the assembly lines or to the hold area (number 5 on Figure 3:1) and wait for further processing there. Those products are LTRs, condensers and evaporators. The condensers and evaporators are moved to the Rad./LTR line whereas CACs and radiators go to the Radiator/Low

Temperature Radiator line as well as to the CAC OE, CAC AM, Rad. OE, Rad. WET LT and CAC Welding line. In this study, the term OE refers to Original Equipment, while OEM refers to Original Equipment Manufacturer; and in this context it refers to parts that go to the Original Equipment Manufacturer as a service delivery in contrast to Aftermarket (AM) parts. The three basic processes that characterise the engine cooling plant include core building; brazing and assembly.

3.2.1 Core Building

Core building is the first production step at the case study plant. All core build lines require two operations, that is, building of the matrix and pre-assembly parts where the covers and side plates are pressed onto the matrix. Evaporators require a third step where tubes have to be fitted onto the side plates. After that, parts are stacked in a jig ready for the heating process. One component is produced on-line by a specific machine, which forms the airways out of an aluminium coil and cuts them into the right lengths.

There are six radiator lines as indicated in Figure 3:1. Due to the different ages of the machines and volumes, the core building lines have different degrees of automation. Radiator line 1 and line 4 are fully automatic, which means that components are stacked automatically and pushed to the core building machine. Here the operator inserts side plates and covers. Then, the machine presses the side plates and covers onto the part. The operator then puts the jig onto the part and later unloads the jig and part from the machine and packs the parts on a trolley. In addition, the machine has to be loaded with tubes when the stock in the machine is cleared.

Line 2 and line 3 are semi-automatic and two operators work on this line – one operator operates the airway machine and the matrix machine and the second operator operates the actual core builder. The fin machine inserts the fin automatically onto a tray that has slots for each airway and at the same time the operator fills the tube stacking machine with tubes. Subsequently, the tube stacking machine spreads the tubes on the matrix machine so that the operator can then insert the airway in-between the tubes by tilting the tray. Depending on the size of the product the operator might need to insert a second tray. When the matrix is completed, the bail holding the tubes is released and the operator pushes the matrix of airways and tubes together and hands it over to the second station. The headers are pressed onto the matrix and the tubes get flared at the same time at the second station. After that, the worker can remove the whole core from the core building machine. In order to do this without the airways and the side plates falling apart the operator has to use a jig or strips of sheet metal and bolts – depending on the model – to hold the parts together.

Lines 5 and 6 are also fully automatic but use the tray system for the airways like lines 2 and 3. The difference is that the tray tilts automatically and inserts the airways into the gaps between the prepared tubes. The operator only has to insert side plates and covers and pushes the button for the machine to press them onto the part.

The Condenser/ LTR line works like the radiator lines 2 and 3 but the difference is that LTRs and condensers do not get headers pressed onto the sides of the matrix but side plates. In addition, at the condenser line there is a pre-assembly line for manifolds. However, this line is only used for certain products as most of the manifolds are supplied pre-assembled.

The CAC OE line is also semi-automatic and resembles line 2 and line 3 although there are two core building machines fed by one airway machine and tube stacker. The process of building the matrix is basically automatic. The tube stacker drops a tube and the airway machine shoots the airway on top of it and then the stacker drops another tube. When a matrix is finished, an operator takes a jig to remove the matrix from the tube stacker and then puts the matrix into the pre-assembly machine. The process at the CAC core building machine is the same as at lines 2 and line 3.

As stated previously in this chapter, the evaporator line requires a third step in order to prepare the part for heating. However, the first step here is also to have the matrix built by stacking airways and tubes manually. This is performed by two operators simultaneously. The next step is the core build (pre-assembly) machine where the side plates are pressed on the matrix. One worker operates this machine. After that, the additional step of fitting the pipes on the side plates is performed by an operator with the help of a machine. The same operator then puts the part into the jig on the trolley.

Most of the previously described lines were designed to produce high volume parts. Very low volume aftermarket parts run on the three CAC LV lines. At those lines, one operator per line builds the cores manually. Those lines are very flexible since they consist of interchangeable units, one core builder table and one fin machine (both units are on wheels). Consequently, change-over times are very short because the only thing that needs to be done is to put the right fin machine into place and to put the right core builder into place. There is no change of tools at the CB and no change of form rolls at the airway machine as the entire unit is moved in or out of the line. Of course, cycle times are longer, compared to the HV lines due to the manual processing.

Like the CAC LV lines, the Condenser LV line is also entirely manual. The difference in relation to the other three is that the core builder is not on wheels so there is a little less flexibility. As previously indicated, the thirteen core building lines are different from each other because of the different products and because of the different ages of the machines. As a result, the tools of the different fin machines and core builders are in most cases not interchangeable. After core building, the products go to the furnace (heating machine) in order to be brazed.

3.2.2 Brazing

The next step after core building is brazing. All brazed parts go through the heating machine, which is divided into six different zones. The zones are connected by a conveyor. Brazing, which is joining components with an additional alloy that has a lower melting temperature than the components themselves, takes place in the fifth zone. The components of the heat exchangers have an aluminium silicon cladding to allow the brazing process. However, before the actual heating process the parts have to pass through other zones.

The first section is the degreaser where the oil forming from the airways and pressed parts evaporates as forming oil would hamper the heating process. After that, the parts go through the coating where heating coat is sprayed on the parts. The chemical prevents corrosion and supports the heating process. For some products, extra coating is added manually after the coating zone.

Having passed the coating process the products go to the dryer where the coat dries. Then the products enter the preheat zone in order to be preheated to about 550ºC. Like the degreaser and the dryer, the preheat zone is heated with LPG.

After preheating, the cores go into the electrical coating zone where the joining of components happens at a temperature range from 600 to 650 ºC. In order to prevent oxidation of the aluminium, the coating zone contains a constant level of nitrogen and so does the preheat zone.

The last zone cools the product with fans to enable the operators to unload the conveyor at the end of the heating machine manually. Figure 3.2 gives a bird's-eye view of the brazing and the different zones.

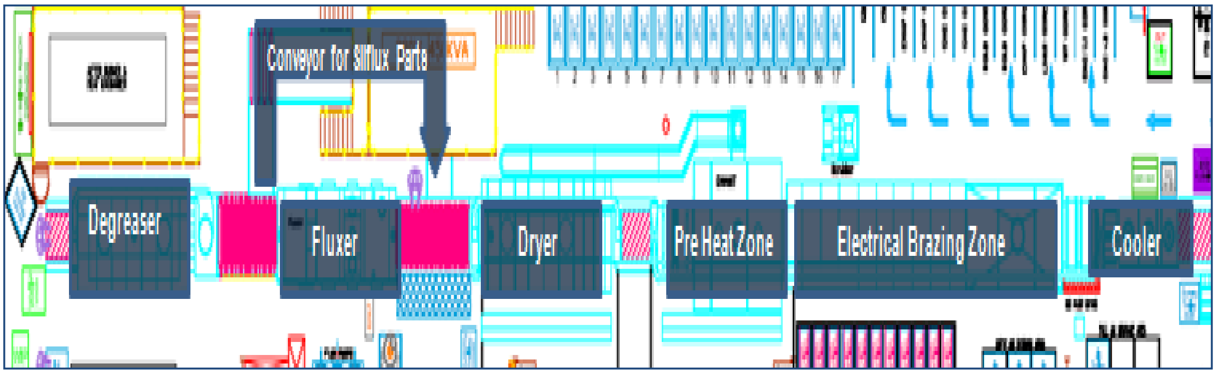


Figure 3.2: Bird's-eye view of the Heating machine with different Zones

(Source: Developed by author)

The furnace currently runs at three different profiles as there are different products to be brazed. The profiles are different in terms of belt speed and the temperatures in the zones. Mainly the thickness of the product dictates which brazing profile to apply. Some products therefore pass the furnace double-stacked.

3.2.3 Assembly

After brazing the products are supposed to go into the post-heat FIFO lanes and then to their assembly line. Products without side plates pass light check before moving to assembly. CAC OE, CAC AM, Rad./ LTR, Rad.AM. and Rad.OE are the lines for products that have plastic tanks and therefore require congregating. Therefore, the lines consist of congregating machines and air leak testers. In addition to that, the CAC OE line has a paint station, as some CACs require coating. LTRs which do not require congregating just go through leak testing at the Rad./ LTR line.

Evaporators require more steps before they can be delivered to the customer. At the Evap. line they first pass the “curing station” where they get chemical treatment. After that the expansion valve is mounted onto the core at one work station. At the next workstation, the parts get leak-tested via helium leak-testing. Subsequent to that, at the last workstation the position of the pipes and the valve is checked, final inspection is done and the product is packed into the box.

Next to the Evap. line is the Cond. line where condensers are finally assembled and then leak-tested with the use of helium. Depending on the condenser - assembly means that the product probably just needs some mountings screwed onto it before it goes through to leak-testing but some products have to be flame-heated there as well.

The condenser line is a low volume line and so is the CAC Welding line. This line is dedicated to one CAC that has tanks that have to be welded onto the core. Contiguous to the CAC Welding line is the Rad. Wet LT line where radiator cores from part building line 5 and line 6 are leak-tested in a water tank because they are sold to the customer without plastic tanks. This line is a low volume line as well. At the end of main assembly, the parts are packed into the shipping boxes and the tow train picks them up and takes them to the finished goods warehouse.

3.3 Planning and Logistics

The production planning of the engine cooling factory is essentially determined by core building, which means core building is the drumbeat of the whole process. The planning department plans the core building process according to customer demand. Core building produces parts that are then moved to the FIFO lanes in front of the furnace. The furnace, which comprises the brazing process, brazes the product, and from brazing, the parts are supplied to the assembly lines. In this case study company the system used for production is a sequential pull system which allows for lower levels of inventory. The replenishment pull system and the drum buffer rope concept would not be practical as it would assume that the furnace, as a non-bottleneck workstation, can be switched on and off arbitrarily, which is not the case.

The planning department issues a second plan for assembly that, when possible, has the same sequence as the core building plan. The scenario does not fall in line with the idea of the sequential pull concept. Also, constraints that have to be considered when planning are the capacity of lines, available labour, material availability and obtainable brazing jigs. The core building lines and assembly lines are supplied with raw material by a tow train that goes from the stores in the adjacent building to the assembly area and from the core building to the core building supermarket.

Another tow train then delivers dollies with packaging material and takes the assembled and packed parts either to the finished goods warehouse or the aftermarket warehouse. OE parts go to the finished goods warehouse and are mostly shipped to the customer once or twice a week. Exceptions are OE radiators and LTRs as they are shipped almost daily. Parts that are designated for aftermarket go to the aftermarket warehouse. The AM department manages the stock and orders of the AM parts as customers sometimes order single parts but the EC plant has a higher minimum lot size.

3.4 Sustainability of Continuous Improvement Initiatives

This method describes the standard systematic, operation and organization of the Continuous Improvement Process at the case study company. This method was determined to sustain the continuous improvement initiatives. The continuous improvement process (CIP) ensures the continuity and sustainability of the development towards a lean organisation. All employees should improve their working processes continuously in small steps towards lean production.

3.4.1 Requirements for CIP sustainability

The requirements for CIP sustainability include the following:

- Organization, roles and responsibilities have to be defined.
- Skills and training requirements have to be fulfilled.
- Management by objectives: indicators and results have to be available.
- Follow-up actions: results, deviations, new actions, investments, costs, benefits.

3.4.2 Continuous Improvement Style at Case Study Company

The CIP cycle at the case study company shown in Figure 3.3 commences with leadership by example, followed by respect, empowerment and recognition, and ends with “keep getting better”. Leadership should inspire subordinates and must concentrate on the “how to”, not only the results. The Leader should respect and listen to subordinates, treat subordinates with courtesy and politeness, and listen to what others have to say.

“Go to Gemba” means that the leaders should go to where the work is being performed and observe and engage with those who are performing the work. Empowerment and support is characterised by increasing the capacity of individuals or teams to make decisions and support the implementation of necessary actions. Recognition is reinforcing the actions and desirable behaviours that the leader would want to see employees repeating. With the “Keep getting better” principle, employees should not be satisfied with the actual status quo. They should challenge the status quo every day and base their decisions on facts and data, and realise that it is vital to investigate deeply the root causes of problems.

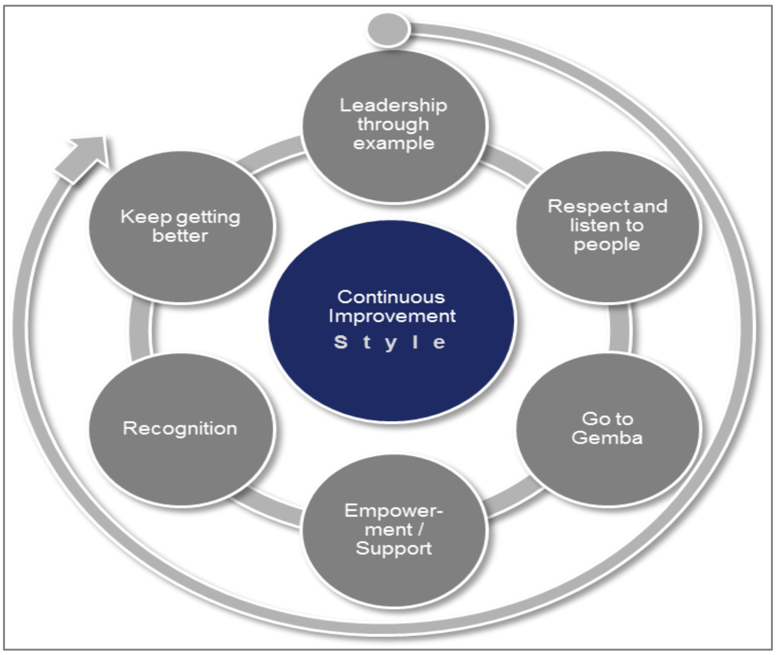


Figure 3.3: Continuous Improvement Style at Case Study Company

(Source: Developed by author)

3.4.3 Structure and Approach

The main factors that have to be considered for a successful lean implementation to avoid and reduce waste of all types through increasing the amount of added value include the following:

- Levelling the production using the lean tools such as kanban systems.
- Line balancing of all processes with orientation to the takt time of the customer.
- Implement value stream analysis to provide a clear picture of the relationship between cycle times and operations. Value Stream Mapping (VSM) and Value Stream Design (VSD) provide an overview of processes and help to identify waste.

As shown in Figure 3.4, Shop Floor Management helps with clear communication rules and a daily information flow for fast adjustments and reactions.

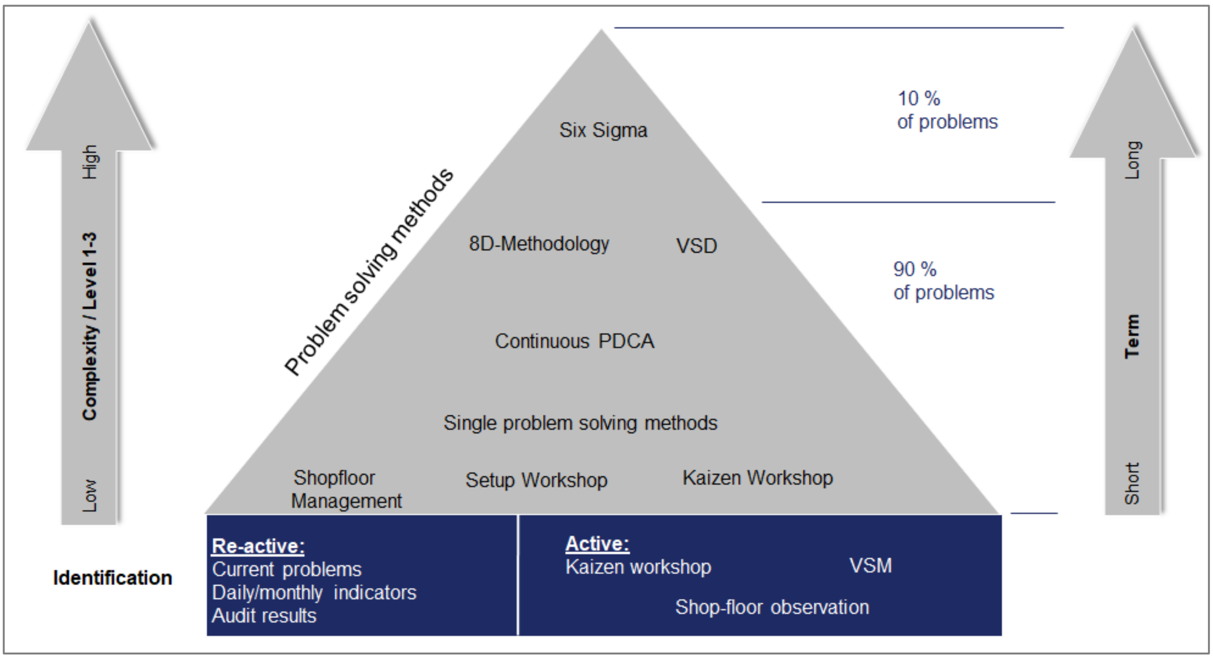


Figure 3.4: Structure and Approach

(Source: Developed by Case Study Company)

3.4.4 CIP Team's Developmental Approaches

The CIP Team's Development Approach is characterised by the following activities:

- Training to increase the team's knowledge in methodologies and tools.
- Target - The target is to achieve the right training for the right people and right tool for the right job.
- Practice: To get an experienced team that can easily decide on the right tools for each problem-solving project.
- Coach: The coaching process assists the team to become more skilled and confident to deal with the different types of waste or different opportunities.
- Follow results: The project results must be checked in each phase. This supports the team development and responsibility within the CIP activities.
- Train others: A well-developed team can better disseminate the acquired knowledge.

Figure 3.5: CIP Team's Development Approach

(Source: Developed by Case Study Company)

3.5 Conclusion

The aim of this chapter was to outline the background to the case study company and also give the reader a brief understanding of the manufacturing processes. The research was conducted on a manufacturer of car heat exchangers, and all the different types of lines, processes and products were explained. It was noted that the production planning of the engine cooling factory is crucial to improve the manufacture of automotive heat exchangers. It was also noted that the continuous improvement process ensures the continuity and sustainability of the development towards a lean organisation, and all employees should improve their working processes continuously in small steps and move towards lean production.

CHAPTER 4 : RESEARCH METHODS

4.1 Introduction

This chapter focuses on the methodology that was adopted for the study. The key elements of the methodology include understanding the different types of methodologies and then selecting the best methodology used to achieve the research objectives as well as the ethical considerations.

4.2 Research Design

Research design is a plan of what approach is to be used by the researcher to systematically conduct data collection and analysis to achieve the research objectives (DePoy and Gitlin 2015). Research method refers to how the research is carried out, including the philosophical and hypothetical assumptions that underlie the study, taking into account the insinuations of these assumptions for adopted systems (Cohen, Manion and Morrison 2013). There are two main types of research design that consist of positivist and phenomenological research strategies. Qualitative research places emphasis on articulated descriptions and human behaviour descriptions. Positivist research strategies include experimental design and surveys. Yin (2013) posited that a survey strategy is a positivist research strategy where studies are conducted on a population, and a sample is selected to make inferences about the population. Surveys normally use interviews and questionnaires with the purpose of determining the views, preferences, attitudes and perceptions of persons of interest to the researcher.

The phenomenological research strategies consist of action research, grounded theory ethnography and case study (Marshall and Rossman 2014). Case study research design includes observing a small group, project, organisation or company. Case studies are generally intensive research of the elements that added to the characteristics of the event under investigation. Case studies tell a story from multiple sources of information, generally in sequential order, in order to have supporting facts for the study being conducted. The data collection methods used in a case study research consist of questionnaires, documentary records, participant observation, direct observation, history/ records, in-depth interviews and focus groups. The case study design differs from other research strategies given that an attempt is made to study a multitude of elements by restricting the number of studies observed. Another differentiating feature is that a researcher tends to conduct an in-depth research of phenomena as they exist in their natural setting (Bryman 2016).

The case study research strategy was adopted for this study. In order to achieve the research objectives, the methodology that was adopted includes development of the current state value stream map; identification of the value-adding activities and non-value-adding activities; assessment of the non-value-adding activities in the manufacture of car heat exchangers components; and development of a plan for a future state value stream map. The first step in the methodology aimed to outline the production flow in order to have an understanding of the production steps from logistics production planning to shipping the finished goods. Process flow mapping is specific to the manufacturer of car heat exchangers components and takes note of concerns encountered when mapping the systems.

4.3 Research method for objective 1

The first research objective was to outline the production flow for automotive heat exchanger parts. The method that was used to address the first research objective was to walk through the plant to have an understanding of the production steps from logistics production planning to shipping the finished goods and subsequently mapping out the production process flow for the case study company. Full production and sub-production process flows were then outlined for core building, pre-heating and assembly.

4.4 Research method for objective 2

The second research objective was to conduct value stream mapping for assessing the non-value-adding activities in the manufacture of car heat exchangers components. The method used to address this objective was to evaluate the production activities and zoom in to the areas that have non-value-adding activities also known as waste and come with ways to reduce waste.

4.5 Research method for objective 3

The third research objective was to conduct a line balancing analysis for the production fractals. The method used was to evaluate the products and the largest part of the total volume, and then analyse the product mix and movement.

4.6 Research method for objective 4

The fourth objective was to develop a roadmap for reduction of waste in the manufacture of car heat exchangers components. The method used was to develop proposals and assess the feasibility and cost implications of implementing each option.

4.7 Research framework

Figure 4.1 shows a schematic for the research framework that was adopted for developing a roadmap for improving the manufacture of automotive heat exchangers through value stream mapping.

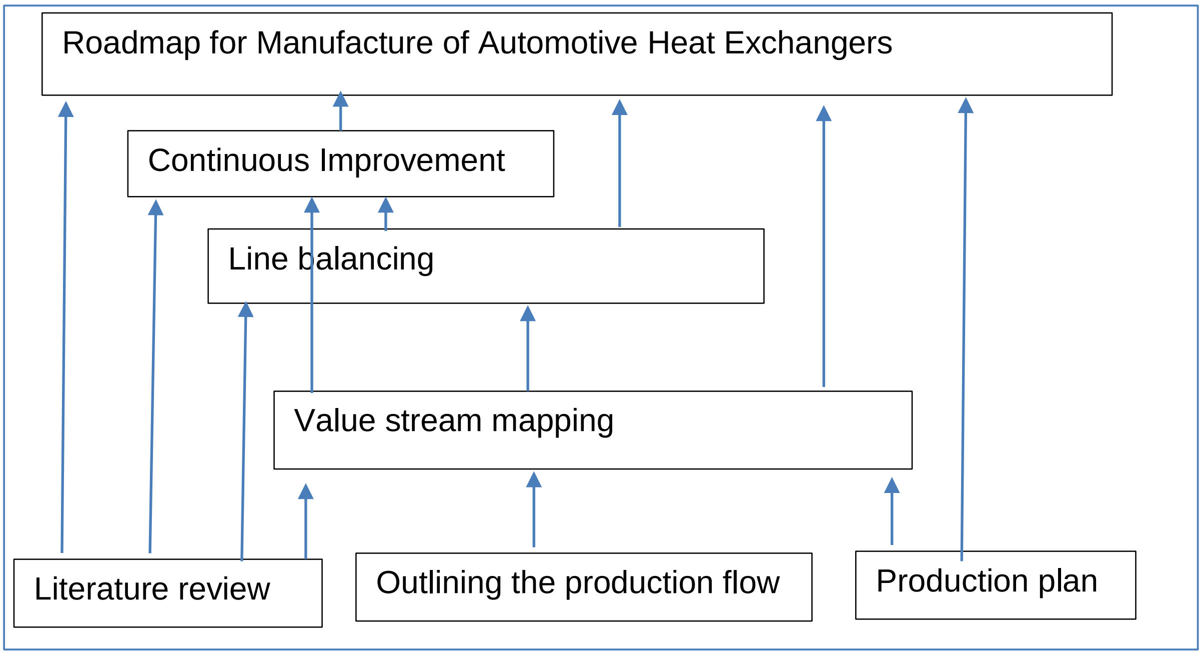


Figure 4.1: Schematic for research framework

It shows the interrelationships between the objectives of the study.

4.8 Ethical considerations

Ethics are defined as moral values that manage a human being's behaviour or the way they carry out activities/ tasks. It is one of the perspectives that deals with humanoid conduct and guides the standards of people's behaviour and relationships when conducting research (Wagner III and Hollenbeck 2014). Ethical issues are essential for any kind of research and reporting credible results is very important. It is a researcher's responsibility to decide on an appropriate method to use for collecting data and coming up with an understandable manner for presenting the research results (DePoy and Gitlin 2015). If this is not taken into consideration, it may perhaps lead to research misconduct.

The division of applied ethics has well established a set of guiding principles and laws that define the conduct intended for the research ethics. Research ethics is critical when conducting research and requires the researcher to protect their research participants, data and information.

Research ethics includes protecting participants by giving them enough information about the research and making sure that there is nothing hidden in order for the participants to make an informed and free choice on their contribution of information. Appendix 1 shows the ethics clearance certificate, and this is an indication that the researcher had to familiarise herself with all the ethical issues before conducting the study.

Shapiro and Stefkovich (2016) stated that human beings usually find it challenging when it comes to making ethical decisions. In this study, ethics were taken into consideration and embraced in the academic writing. It was seen as vital to maintain research ethics in accordance with the Durban University of Technology's policy whereby a post-graduate student's thesis should be checked for plagiarism using the Turnitin software. It is a requirement that all students must conform to 17% and less plagiarised material in order to be accepted for the research database. Appendix 2 shows a Turnitin report of 6% similarity index which is acceptable according to the institution's standard.

4.9 Conclusion

This chapter focused on the methodology that was adopted for the study and the ethical considerations. The case study research strategy was adopted for this study. In order to achieve the research objectives, the methodology that was adopted included the development of current state value stream map, identification of the value-adding activities and non-value-adding activities, assessment of the non-value-adding activities in the manufacture of car heat exchangers components, and development of a plan for future state value stream map. The next chapter focuses on the presentation of results and a discussion of the results.

CHAPTER 5 : RESULTS AND DISCUSSION

5.1 Introduction

This chapter focuses on the presentation and discussion of the research results. The key issues that are embraced in this chapter include production process flow, line balancing analysis, assessing value- and non-value-adding activities, balancing chart and value stream mapping.

5.2 Production Process Flows

This section addresses the first research objective, which was to outline the production flow for car heat exchanger parts. An appreciation of an overview of the production flow is crucial for subsequent analysis of value- and non-value-adding activities. Figure 5.1 shows the full production process flow at the case study company. It shows the production steps from logistics production planning to shipping the finished goods.

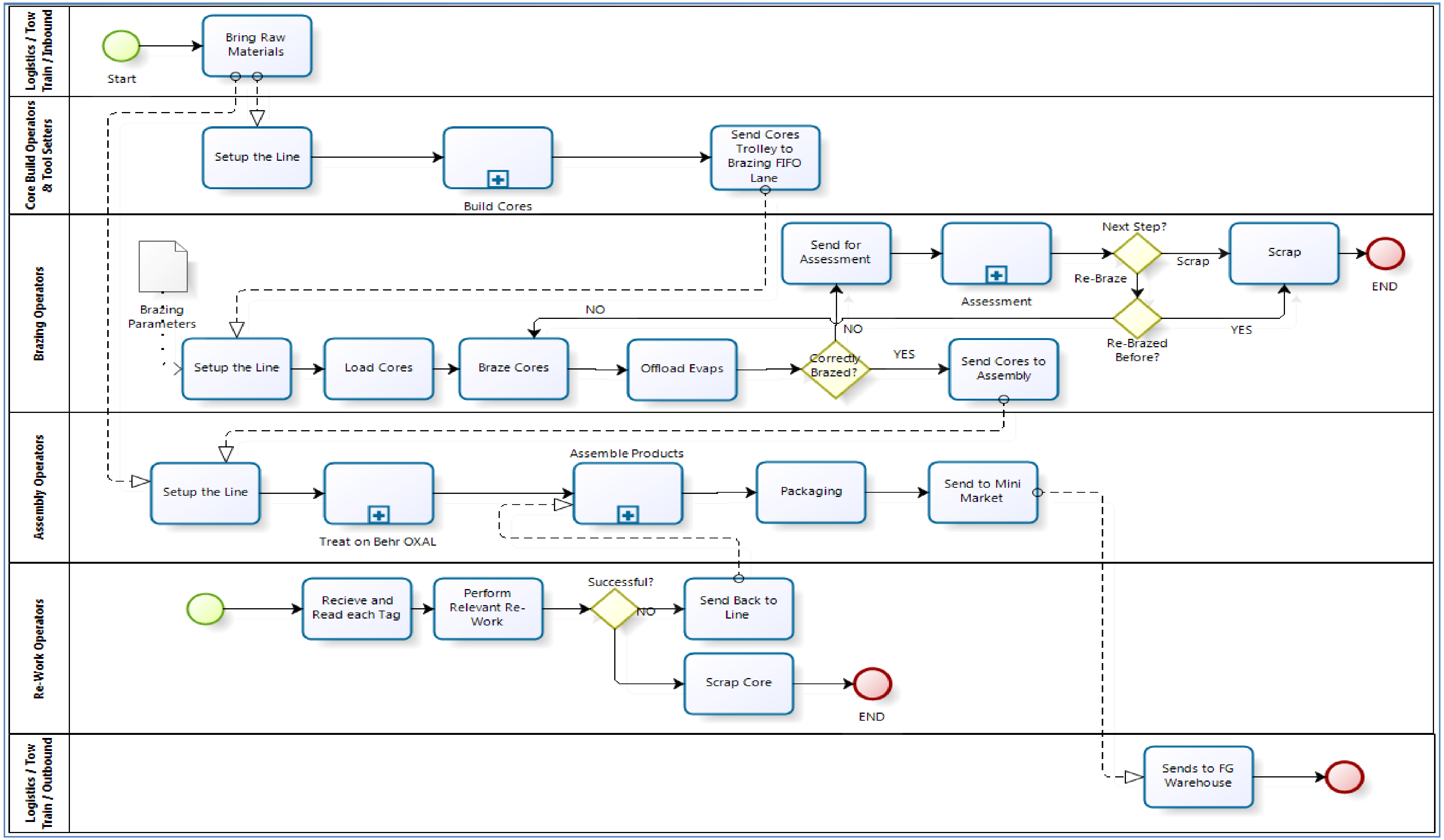


Figure 5.1: Full Production Process Flow

5.2.1 Sub-production Process Flow for Core Building

The process flow diagram in Figure 5.2 shows the sub-production line of core building, which is the first step of production on the engine cooling plant. This is the first stage of assembling single components into one sub-assembly, and building matrix, which is stacking fins and tubes together. Core building is where the headers or manifolds are hard-pressed into the matrix. Evaporators require a third step as the bended tubes have to be fitted on the manifolds. The parts are placed on the jig for brazing and then placed on a trolley, where the parts will be moved to the next station which is brazing.

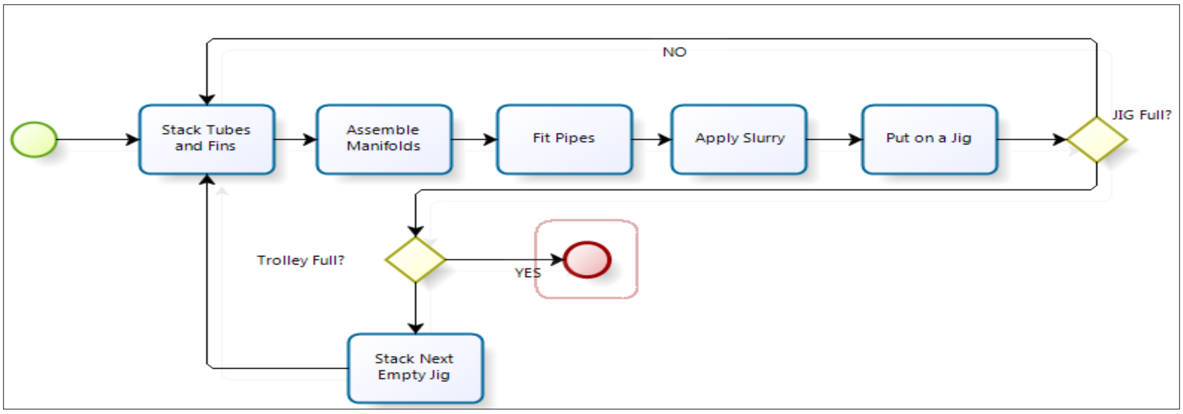


Figure 5.2: Sub-production Process Flow: Core Building

(Source: Developed by author)

Figure 5.3 also shows the assembly of components and building a matrix on the core building line.

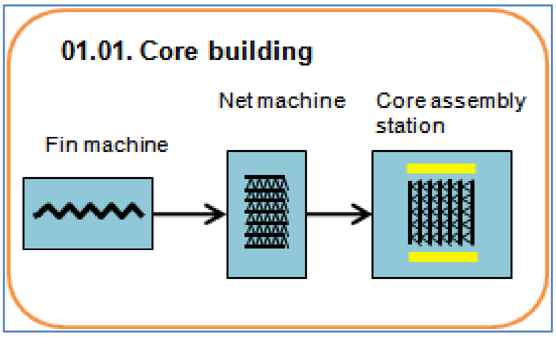


Figure 5.3: Core Building line - building a matrix

(Source: Developed by author)

5.2.2 Sub-production Process for Brazing Process

Figure 5.4 shows the sub-production line of the brazing process, which is the second step of production. All parts go through this step of production, where the brazing operation is carried out in a continuous flat belt furnace under a controlled nitrogen atmosphere. After that the parts are kept on the first-in, first-out (FIFO) lane by the assembly line.

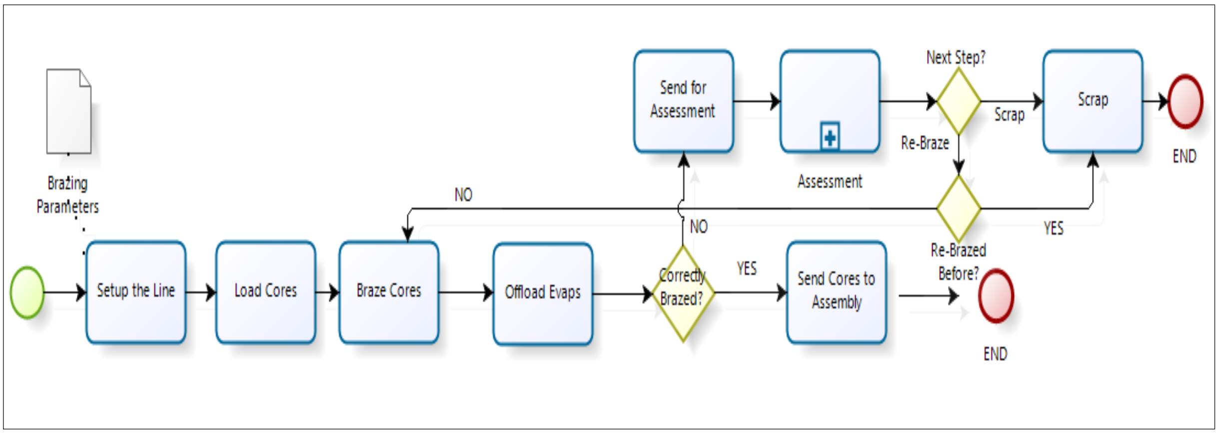


Figure 5.4: Sub-production Process: Brazing Process

(Source: Developed by author)

Figure 5.5 also shows the schematic for the brazing process whereby components that have an aluminium silicon cladding are joined permanently at a lower melting temperature.

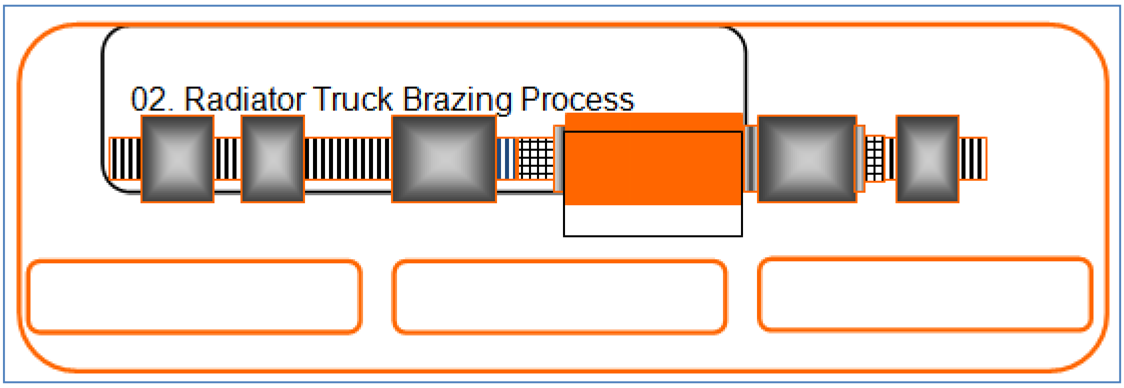


Figure 5.5: Brazing Process - Joining components with lower melting temperature

(Source: Developed by author)

The brazing operation is carried out on a continuous flat belt furnace under a controlled nitrogen atmosphere. The brazing furnace is loaded continuously and gaps of more than 1m on the conveyor belt must be filled with dummy heat exchangers in the manual fluxing zone in order to avoid temperature fluctuations inside the brazing furnace. Stabilization of the brazing furnace temperature at the beginning of production is also accomplished by loading a minimum 15 dummies. Additionally, after finishing with production, 10 dummies have to be loaded.

There are products that do not need the spray flux treatment as they use Silflux, which is flux that is already applied as a coating on the tubes of those products. These products include LTRs and some types of evaporators. For that reason, they are put on the conveyor just after the fluxing station. There has to be a waiting time of 15 minutes after brazing Silflux parts before the next spray flux part can be brazed and a 20 minutes waiting time for the next step. This is because Silflux and spray flux parts cause different levels of humidity in the furnace. In addition to that, LTRs are exceptional in terms of the necessary belt speed. In order to prevent corrosion of the product later in its lifecycle, the brazing process requires a very low belt speed.

Table 5.1: Current Brazing Profiles

Profile	Products	Belt Speed	Flux	Setup Time
Profile 1	CAC, Rads, Evaps, Cond	850 mm/min	Silflux and Spray Flux	25 min
Profile 2	Cond, Rad, CAC	1050 mm/min	Spray Flux	35 min
Profile 3	LTR	630 mm/min	Silflux	50 min

This leads to the following three brazing profiles as shown in Table 5.1. The different brazing profiles and Silflux and non-Silflux products are not the only constraints regarding the furnace. Most of the products need a product-specific brazing jig, which is only available at a limited number of units. As a consequence, core building cannot supply the furnace or the FIFO lanes in front of the furnace with unlimited numbers of products as they will run out of jigs. In that case, those products have to be brazed in order to release jigs. The furnace was running two shifts per day during the period under study, as its capacity did not require three shifts as at brazing and assembly. Yet the furnace still waited for material at times, which then required heat sinks in order to keep the furnace at a constant temperature level. Heat sinks are dummy cores which go through the furnace.

The furnace was running only two shifts per day and it was not shut down entirely during the third shift. The degreaser and the dryer were shut down so that they did not consume LPG unlike the preheat zone and the brazing zone, which still maintained a certain temperature level so that they still consumed electricity. The furnace was not switched off entirely to protect it from wearing off. If the furnace was shut down completely for one shift per day, the preheat zone and the brazing zone would be exposed to high changes in temperature and that would cause wastage predominantly in the welded joints due to thermal expansion. In addition to the temperature level the nitrogen level was also held on a standby level. To ramp up the furnace from “no shift standby” to “running” about one hour was required.

On weekends, the period where the furnace was not used was longer and the degreaser, the dryer and the preheat zone were shut down entirely, so that there was no consumption of LPG on the weekends. However, the brazing zone still ran at a certain temperature level in order not to expose it to higher changes in temperature. In addition, the nitrogen level stayed on standby. To ramp up from a weekend standby about seven hours were required so that in order to run the furnace on a Monday morning with the first shift at 6.00 am the furnace had to be switched on Sunday evening. In case of problems during the week, the furnace sometimes ran overtime on the weekend.

5.2.3 Sub-production Process Flow for Assembly

Figure 5.6 shows the sub-production process flow for assembly which happens just after brazing. The products were packed on post-braze FIFO lanes and then collected there for the next step, which was the assembly line. Products without manifolds passed light check before that. The assembly process consists of crimping machines and air leak testers as shown in Figure 5.7.

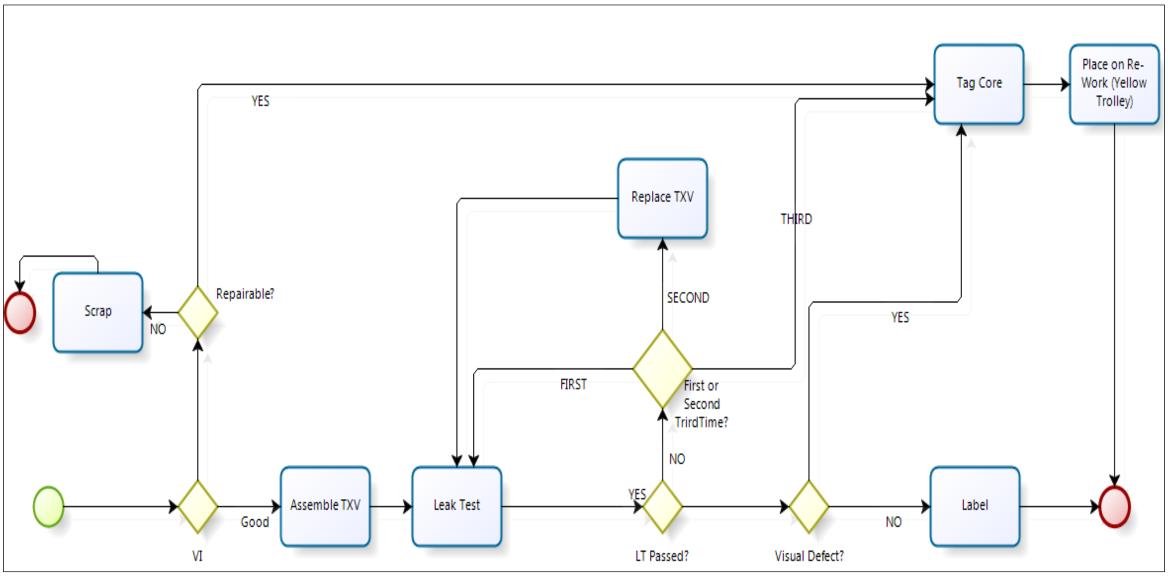


Figure 5.6: Sub-production Process Flow: Assembly

(Source: Developed by author)

In addition to that, the CAC OE line has a paint station as some CACs require coating and LTRs which do not require crimping just go through leak testing. Evaporators need more steps. The Evaporators pass the "oxal station" where they get chemical treatment. After that they go on the valve assembly station where a valve is assembled to the core. The next step is the leak testing, which is the last workstation, and then there is final inspection before the product is packed into the box.

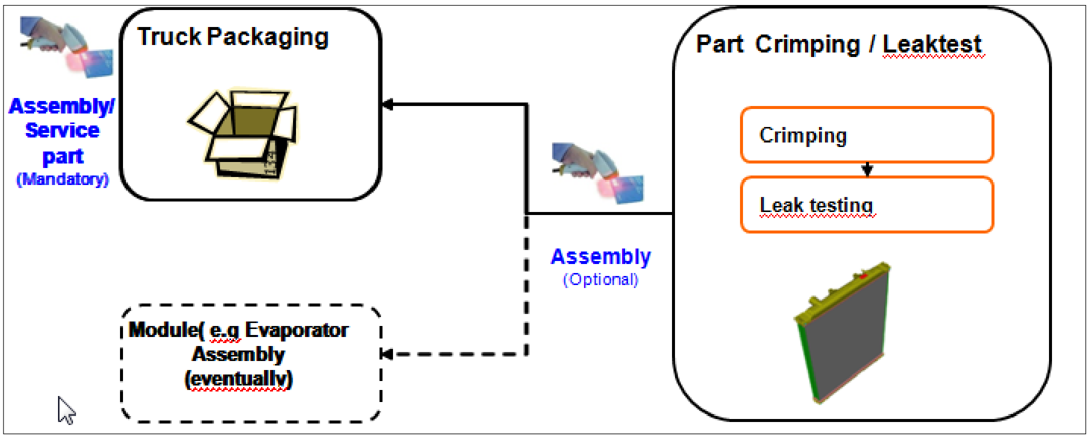


Figure 5.7: Assembly process - Crimping machines and air leak testers

(Source: Developed by author)

5.2.4 Sub-production Process Flow for OXAL

This process flow shows the sub-production line of the Oxal station which is the first step of the assembly line; only evaporators will pass the Oxal station where they get chemical treatment. The evaporators subsequently go to the valve assembly station where a valve is fitted to the core.

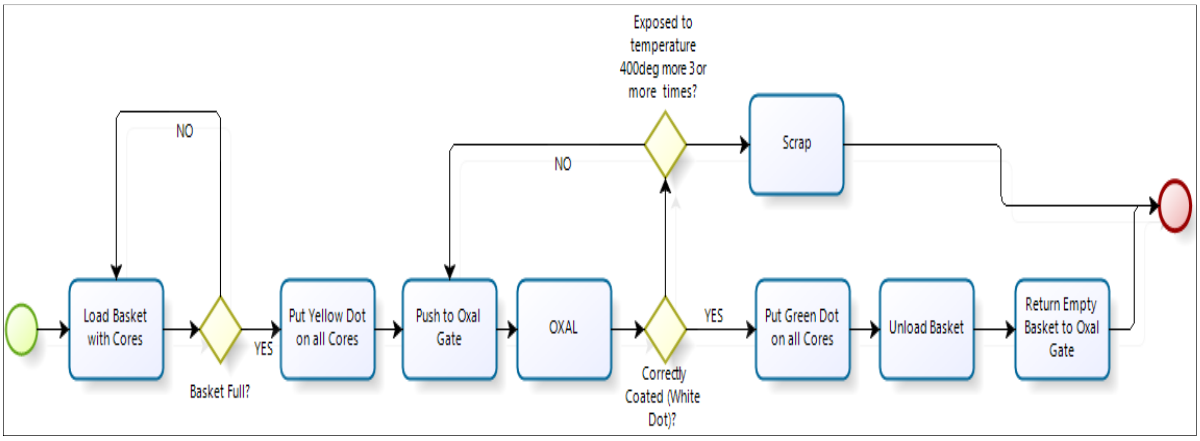


Figure 5.8: Sub-production Process Flow - Oxal

(Source: Developed by author)

Most of the previously described lines were designed to produce high volume parts. Very low volume aftermarket parts run on the three CAC LV lines. At those lines, one operator per line builds the cores manually. Those lines are very flexible since they consist of interchangeable units. There was one core builder table and one fin machine and both units were on wheels. Consequently, changeover times were very short because the only thing that had to be done was to put the right fin machine into place and to put the right core builder into place. There was no change of tools at the CB and no change of form rolls at the airway machine as the entire unit was moved in or out of the line. The cycle times were longer compared to the HV lines due to the manual processing. The CAC LV lines and the Condenser LV line were also entirely manual. The difference was that the core builder was not on wheels so there was a little less flexibility. The process of outlining the production processes revealed that there was a need to conduct a detailed process analysis to aid identify sources of waste.

5.3 Value Stream Mapping

The previous section outlined the detailed sub-production process flows that characterize the three fractals. This section addresses the second research objective, which was to conduct the value stream mapping for assessing the value- and non-value-adding activities in the manufacture of car heat exchanger components.

5.3.1 VSM Preparation

It is vital to plan or prepare for value stream mapping. Limits for this VSM are mainly the walls of the EC plant. Material supply and the finished goods warehouse are inserted in order to close the cycle because customer demand is most important. Appendix 3 shows an overall process flowchart giving an overview of the planning, core building, brazing and assembly processes. Appendix 4 shows an example of representative products demonstrating a typical definition of the product families.

Key factors for the core building and assembly sections are:

- Number of operators
- Part number of representative product
- The SAP cycle time
- Observed cycle time during plant walkthrough
- Throughput time
- Setup time
- Number of shifts

No observed cycle time is necessary for the heating process as the cycle time is determined by the belt speed of the conveyor. The persons responsible for the operations were interviewed in order to obtain necessary information about the planning and logistics.

5.3.2 Current state value stream map

A plant walkthrough was conducted at the case study company in order to accurately map the current state using the VSM symbols shown in Appendix 5 and Appendix 6. Figure 5.9 and Appendix 7 show the current state value stream map that was developed. Manufactured products were delivered to the customers once a week, excluding the radiators and the low temperature radiators (LTR) because these products were shipped on a daily basis.

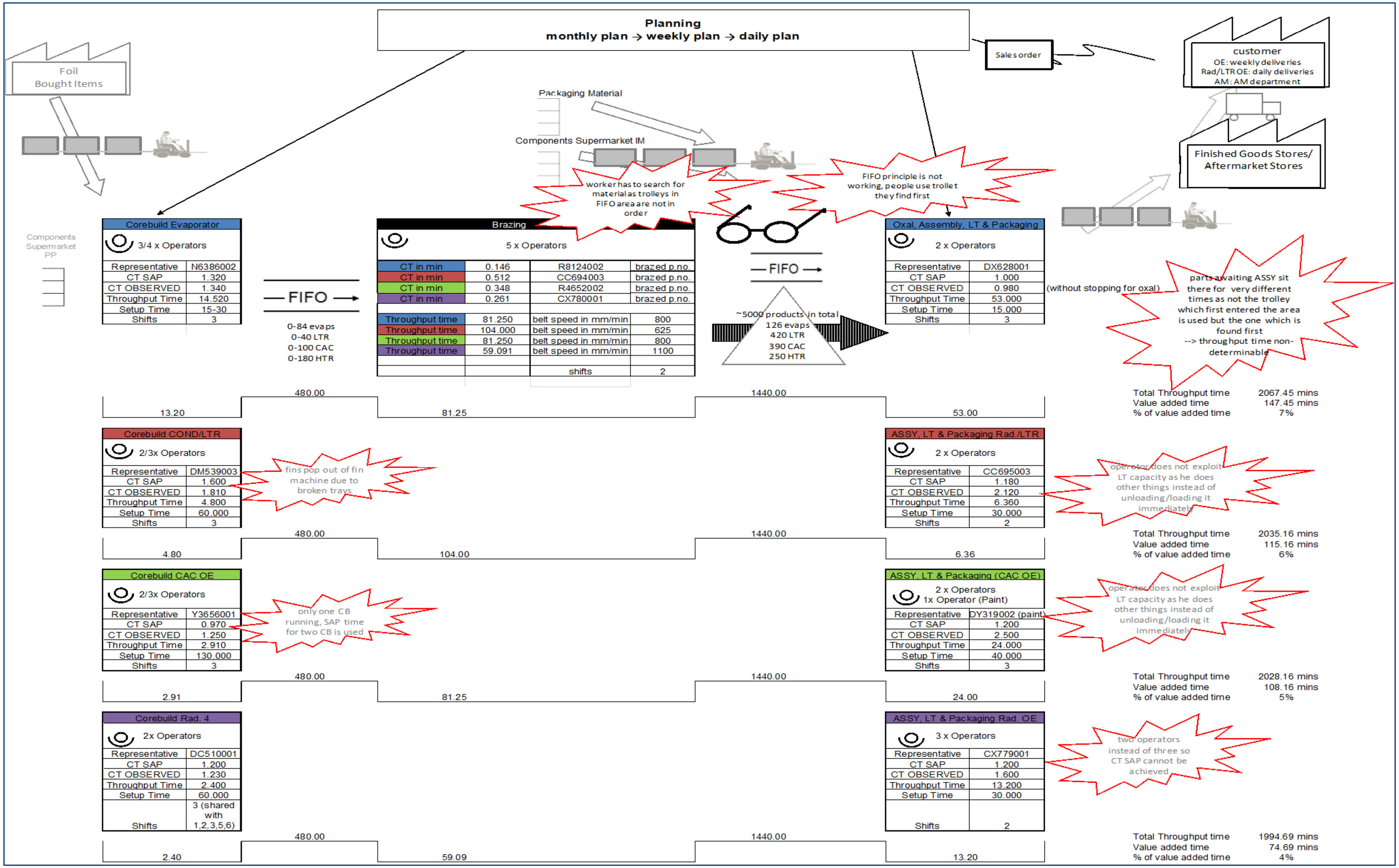


Figure 5.9: Current-state value stream map

Customer orders were sent to the planning department and a plan for core building was issued. This is indicated in the VSM with an arrow from planning to core building and a second plan was issued for the assembly line in which the sequence can vary from the core building sequence. A second arrow on the VSM goes from planning to the assembly line. Cores kept behind the furnace/ brazing line were counted daily and this information was used to issue a third plan for brazing. These three fractals do not work together when it comes to planning but all the parts start in core building then go to brazing and last step is assembly.

Oxal, Assembly, LT & Packaging	
2 x Operators	
Representative	DX628001
CT SAP	1.000
CT OBSERVED	0.980
Throughput Time	53.000
Setup Time	15.000
Shifts	3

Figure 5.10: Evaporator line cycle times

(Source: Developed by author)

The observation at the assembly line revealed that at three out of the four regarded lines, the operators could not achieve the SAP cycle time, though there was no occurrence of breakdowns or defective/ scrapped parts. The operators were able to produce fast enough than the evaporator line cycle time as shown in Figure 5:10.

The radiator assembly line had a shortage of manpower with only two operators working instead of three operators which would be the ideal situation. The CAC and Rad/LTR lines had no breakdown and no manning shortage but the leak testers were not fully utilised to their full capacity.

5.3.3 Kaizen flashes

The following Kaizen flashes were noted from the current state value stream map:

- The brazed parts waited for assembly process in the FIFO lanes at the assembly lines and in the post brazing FIFO lanes next to the furnace. The post brazing FIFO lanes were not used as FIFO lanes and new brazed parts were stored where the operators found some empty space. Therefore, in the value stream map the symbol for push material transfer and the triangle for inventory was indicated next to the FIFO lane and a Kaizen flash was inserted to underline this issue. The numbers of the parts that were selected for the VSM were counted at that point and it was found that there were about 5000 parts in total awaiting assembly.

- The furnace/brazing throughput and cycle times from SAP had no Kaizen flash as there was no problem observed. The inventory in the FIFO lanes upstream the furnace inlet was inserted as a range because the products were brazed during the observation.

- The core building fractal had some issues and some lines could not keep pace with SAP cycle time but the deviations were not as high as at the assembly line. The CAC core building line had one core builder instead of two possible core build machines and this led to higher cycle time and at the condenser/LTR line the observed cycle time was higher than the SAP time.. One reason was that the trays that were filled with airways from the fin machine were broken; fins popped out of the trays and the operator had to collect them and insert them manually.

- The leak testing process was found to be a bottleneck, since, instead of immediately unloading and loading the leak testers when they finished one product, the operators were performing other activities. For instance, at the CAC OE line, the operator would pack the products in the cardboard box for shipping and at the same time the operator of the crimping station stopped working as the FIFO lane in-between crimping and leak testing was full. After more than five minutes the crimping operator decided to unload the leak tester that had been waiting to be unloaded. Not using the “bottlenecked” machine (leak tester) all the time made it impossible to reach the SAP

- The percentage of the value-added time over the total throughput time is often a valuable key figure. The problem was that it was not possible to determine the time brazed cores would wait for assembly as the trolley with the brazed cores were a lot of in the waiting lanes. The operators took what they could access first in the FIFO lane, so they were not following the FIFO procedure.

5.3.4 Value- and Non-value-adding Activities

There are different ways of identifying value as well as non-value adding steps; process mapping or value stream mapping is one of the tools of Lean, which can be used to identify and eliminate waste. In the study conducted by Dal Forno *et al.* (2014), VSM is referred to as one of the important tools of lean approach and it is utilised to identify value-adding and non-value-adding (wasteful) activities in the system. When the VSM tool is not applied correctly, it can complicate the process of waste identification, lead to misunderstandings and assessment errors, and weaken the future improvements implementation. Process mapping highlights the different steps in the processes and underlines where the value is added.

Chaple and Narkhede (2017) defined value as the step where the expected outcomes for the customer are defined. The questions that were asked to define value include:

- Is this step changing the form or product's character?
- Does this step meet an exact customer specification?

If the answer was "yes", then more economic ways to perform this step were explored. This is where the classification of value- and non-value-adding activities was carried out. Methods time measurement (MTM) is one of the methods for optimization when using the lean approach, and can be used to identify value in the process (Karim and Arif-Uz-Zaman 2013).

The following definitions were used to classify the activities into three categories for the study:

- Value-Adding - changing the form or character of the product and other logistics activities that the customer is willing to pay for.
- Non-Value-Adding Essentials - waste that cannot be avoided yet can be eliminated through lean techniques.
- Non-Value Adding Waste – waste that can be avoided yet can be eliminated through lean techniques.

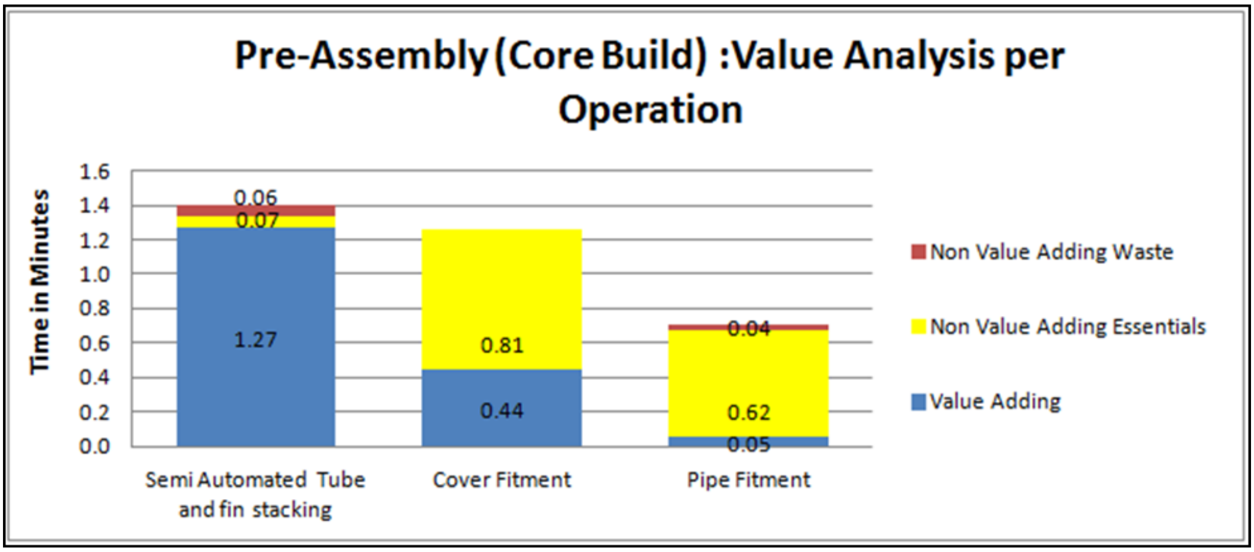


Figure 5.11: Core Build Value Analysis

Figure 5.11 shows the results of method time measurement (MTM) and displays value analysis per operation on the core build line of evaporators. The activities were classified as value-adding, non-value-adding waste and non-value-adding essentials. The results show that semi-automated tube and fin stacking had more value-adding activities while cover fitment and pipe fitment were dominated by non-value-adding essentials.

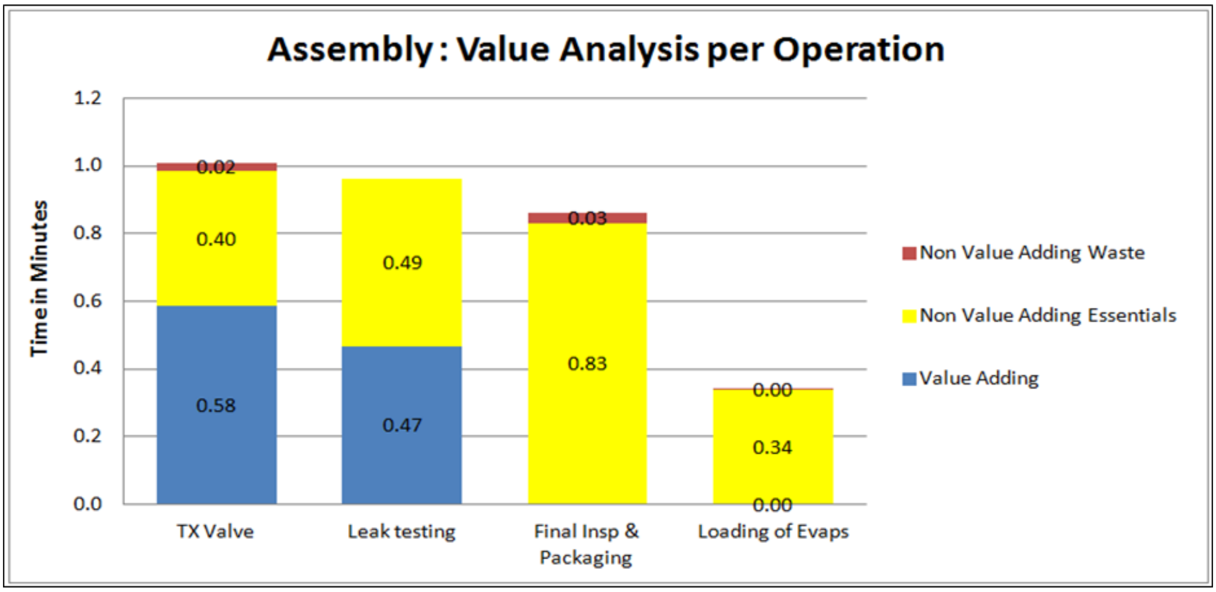


Figure 5.12: Assembly Value Analysis

Figure 5.12 displays value analysis per operation on the assembly line of evaporators. It presents the different elements on the Evap assembly lines and classifies the activities into value-adding, non-value-adding waste and non-value-adding essentials. The results show that expansion valve fitment had more value-adding activities while final inspection, packaging and loading of evaporators were dominated by non-value-adding essentials. It was concluded that assembly generally has more non-value-adding essentials compared to core building.

5.3.5 Idle Time for Furnace

As the furnace machine is a costly machine to run and has a high energy consumption, a detailed record of downtimes was kept. Table 5:2 shows the downtime in minutes for 2016 from January to June. The downtime due to non-availability of parts decreased from January to May but then increased slightly in May and June. Gu, Zhang and Li (2015) revealed that high maintenance costs can take up about 13% of the total operating cost, but it can be reduced by good planning. Nevertheless, the idle time at the furnace improved from March due to the ramp up of a new LTR model since the additional volume was then able to utilise the former excess capacity of the furnace.

Table 5.2: Extract from Furnace Downtime Report

Furnace Downtime (minutes) Due to Number of Cores					
Jan	Feb	Mar	Apr	May	Jun
2550	1170	260	0	120	190

(Source: Developed by author)

5.3.6 Work in Progress Awaiting Assembly

The other key issue derived from the Kaizen flushes was an inventory of brazed parts. Brazed parts going to the plant could be found in the FIFO lanes next to the furnace and at the production lines but also in other areas that were in fact supposed to be used for other issues. Figure 5:13 shows the cores in the FIFO lanes in the background and even more cores in the area next to them, and for that reason, the inventory was not easy to overview. The area marked in red was often used to store brazed parts.

Figure 5.13: Inventory around the furnace

A function in SAP was used to find out how many heated parts were awaiting assembly, and it would display all the part numbers with their quantities and value that were back-flushed after brazing. The challenge was that this function would include all products that were brazed until they get back-flushed again after assembly.

The products were counted manually at 7:00 in the morning for six weekdays in order to get a reasonable idea of the quantities. Since the furnace ran from 10:00 pm to 6:00 am and from 6:00 am to 2:00 pm and sometimes 4:00pm, it was possible to capture the average inventory in the morning. The manual counting was limited to the counting of different product types as CACs, radiators etc. Then the result of the manual count was compared to the results from SAP so that it could be concluded how many parts were already processed in the assembly lines and, on the other hand, the result of SAP was verified, since the back flushing could be erroneous.

As shown in Table 5.3, manual counting revealed that the average number of parts that were counted for one week was 4720 and that most of the parts were either radiators or CACs. An important fact about the manual count was that it was counted roughly and therefore was only used to assess the dimensions of the number of products preceding the furnace. The evaluation of the inventory using additional information from SAP done for CW 29 and CW30 models revealed that there were 6348 heated cores/parts on average, and the summarised data is presented Appendix 9.

Table 5.3: Summary of Manual Core Count

CAC	1081	1979	1684	1946	1488	1859	
Rad AM	1299	1795	1778	1993	1853	2026	
Rad OE	584	80	0	60	79	160	
LTR	372	372	0	0	450	741	
Cond	114	0	142	133	448	0	
Evap	300	600	1610	882	336	336	
SUM	3650	4826	5214	5014	4654	4962	4720

The quantity also included parts that were already in the processing at the assembly lines and assembled parts that were packed into boxes but not scanned. Nevertheless, since an average of about three lines was running at a time and the evaporator line was the only line that required a high WIP because of the Oxal process, that number of parts could only be a small percentage of the numbers extracted from SAP.

The pie chart in Figure 5:14 shows that the number of CACs made up almost half of the total quantity. This was followed by the group of radiators that came from the core building lines. In addition, the largest proportion of those was the OE radiators and compared to those numbers the percentages of evaporators and condensers, LTRs and radiators from the other core building lines were quite small.

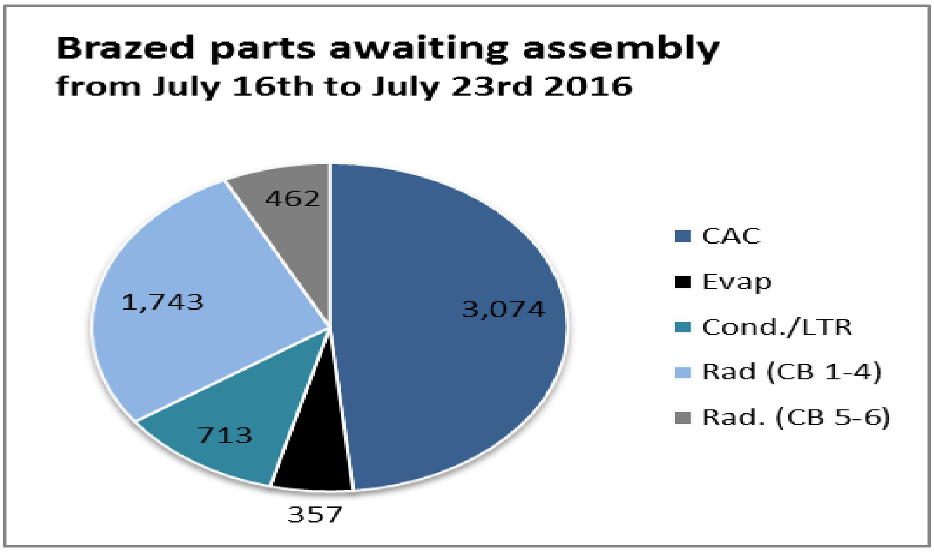


Figure 5.14: Summary of Inventory Level

Therefore, the majority of work in progress was processed on the CAC lines followed by parts that were supposed to go to the Rad.AM or the Rad.OE line. Overall, the average of the manual core count and the result of the SAP analysis was 5500 parts of work in progress between brazing and assembly. The remaining question was to establish how many parts would be optimal. The 5500 parts was more than two daily production quantities that is equivalent to monthly volumes, divided by 23 working days in the month. This was a pointer to excess inventory and, according to the planning process described in Chapter 3, parts that come out of the furnace were supposed to be assembled. This process required at least the same capacity at assembly as at core building. In order to assess whether assembly was capable of processing all the parts, which come from core building and brazing, a balancing chart was generated in the next subchapter. The ideal amount of work in progress has been determined as part of the economical evaluation of the proposals in Chapter 6.

5. 4 Line balancing analysis

Value stream mapping highlighted that there was a need to improve the process so as to reduce the work-process inventory. This section addresses the third research objective, which was to conduct a line balancing analysis for the production fractals. In order to conduct a line balancing analysis, it was crucial to appreciate the product mix and allocation to work centres as well as the variety of parts produced by the case study company.

5.4.1 Product Mix and Allocation to Work Centres

As indicated in the previous chapters, there were several products that ran on different lines and there were aftermarket products with very low volume and high volume parts that would go to Original Equipment Manufacturer (OEM) customers. According to Olhager (2013), in order to group products or components into flow groups, a product family matrix can be exploited when an organization is faced with a challenge of medium volume demand and a medium to high degree of product standardization. To get an overview of the different parts and volumes, a Pareto chart was prepared, followed by the allocation of the products to the lines.

5.4.2 Pareto Chart

In order to improve the process, it was crucial to conduct a Pareto analysis of the products that are produced at the case study company. The Pareto chart helps to evaluate which products make up the largest part of the total volume, as the EC plant produced low volume for aftermarket parts and high volume OE parts.

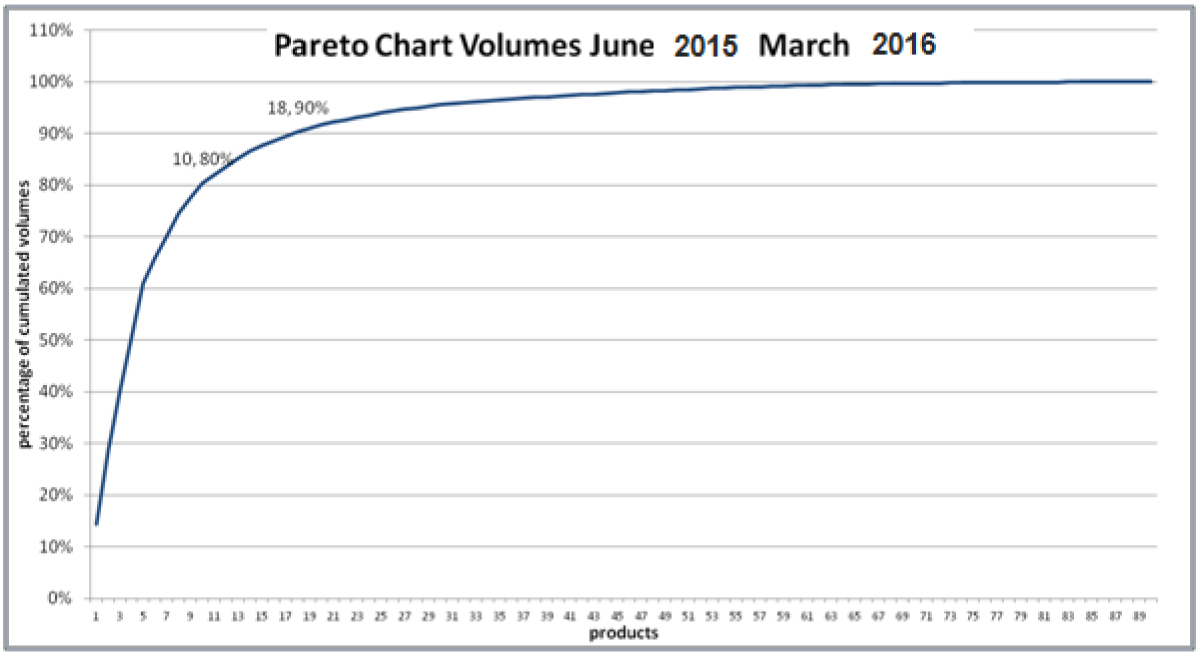


Figure 5.15: Pareto Chart for Engine Cooling Volumes

(Source: Developed by author)

The volumes for the Pareto chart were taken from the heating fractal part numbers as the same product might have different assembly part numbers. The chart shows that there were 90 different brazed products and ten of those made up 80% of the total volume and these were mainly CACs, Evaps, LTRs, one OE condenser model and the OE radiators. Raw data that was used to plot the graph shown in Figure 5.15 is shown in Appendix 8.

5.4.3 Product Allocation to Work Centres

The allocation of products to work centres is crucial for ensuring high utilization of machines and assuring greater throughput. As already indicated, the OE radiator assembly line processed high volume products. Figure 5.16 shows which products ran on which core building lines and were then brazed on a particular profile. It shows the core building lines feeding assembly lines without taking the brazing families into consideration. It summarises the relations for product families without considering the different brazing programs. The main data product and work station matrix (without part numbers for demonstrating the parts movement between workstations) is presented in Appendix 10. The routes of the high volume OE parts that could also be identified through the Pareto chart are displayed in blue, whereas the routes of low volume parts that are often only produced once a month or less are shown in grey.

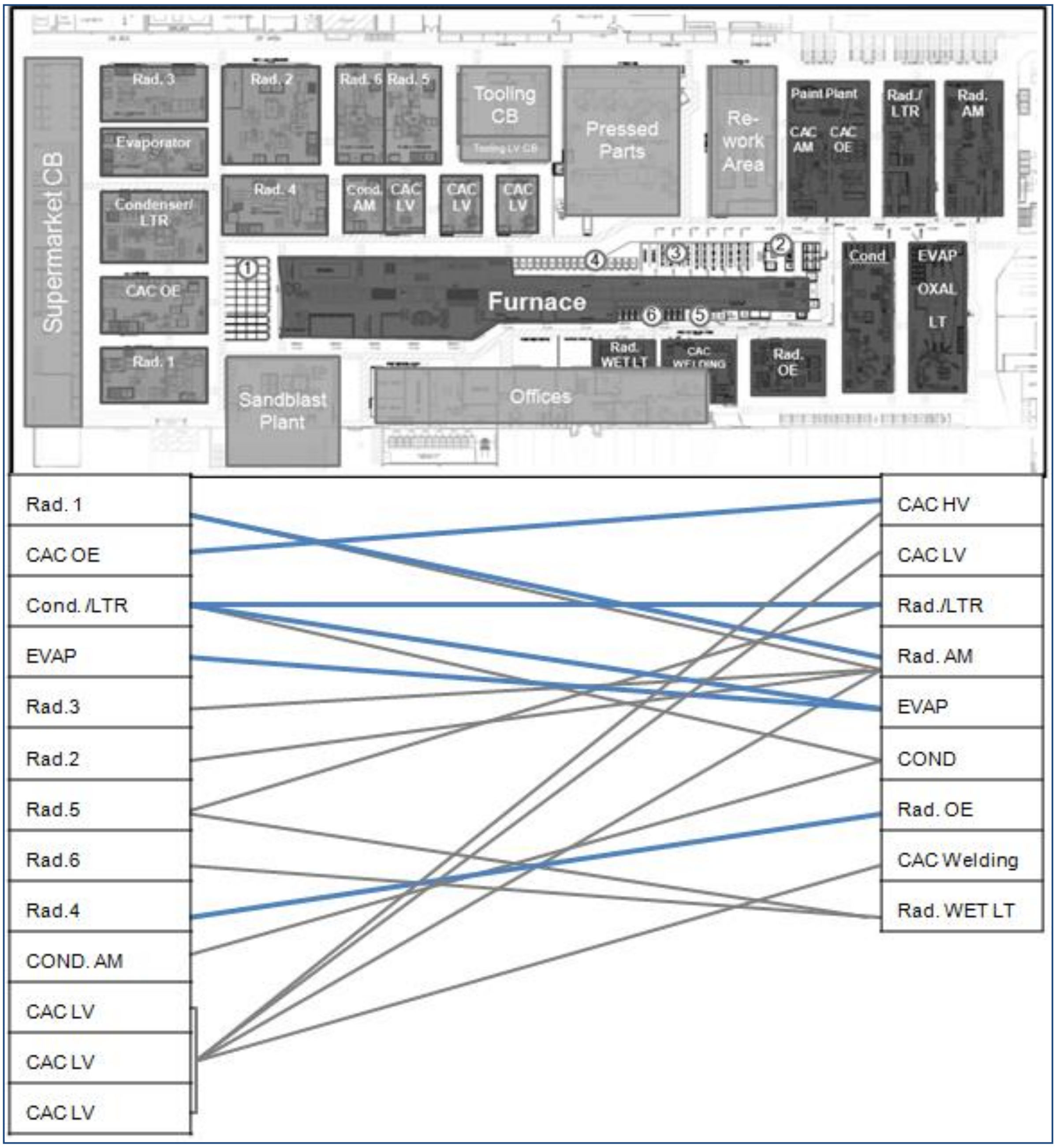


Figure 5.16: Core Building Lines Feeding Assembly Lines

(Source: Developed by author)

As displayed in Figure 5.16, the HV lines for the CAC, Rad.OE and the Rad.4 were dedicated to one product category and the assembly lines were only fed by a one-part building line if the very low volume cores that went from the LV Hand core builders to the CAC HV assembly line were disregarded. More complex was the situation for condensers, LTRs and evaporators. The Cond/LTR line produced high volume LTRs which went to the Rad./LTR assembly line and low volume condensers which went to the Cond. assembly line and one high volume condenser model that was leak tested at the evaporator line.

The evaporator pre-assembly line only fed the evaporator ASSY line. Figure 5.16 displays more grey links between core building and assembly but those routes are not described in detail as those parts were only produced once a month or less. In order to conclude whether there was an imbalance in the EC plant and to pinpoint idle fractals and high inventory level, a balancing chart was compiled.

5.4.4 Generation of Balancing Chart for Fractals

The Kaizen flashes from the VSM revealed that there were problems regarding line imbalance. The balancing chart helped to analyse the balance in between the three fractals in the EC plant. It is a complex scenario since the chart should not only show the situation of one manufacturing line but that of multiple lines feeding one furnace, and the same furnace feeding numerous lines. Firstly, the generation of the chart is depicted, then the chart is used to analyse the current situation for a month and also the future conditions after implementing proposals to improve the current situation. The chart hypothetically indicates the relations between the three fractals of core building, brazing and assembly; consequently it will have three bars. The bars consist of the net cycle time as well as additional times for defects, scrap, downtime and change-overs and their sum results in gross cycle time. In addition, the customer takt time is displayed in the chart to depict the gross cycle time in relation to customer demand.

5.4.4.1 Net Cycle Time

There were multiple lines with multiple products for core building (pre-assembly) and assembly and that led to varying cycle times. All these parts went through the furnace but due to varying product sizes, the parts were brazed while stacked on top of each other and the different brazing profile cycle times varied too. As a result the net cycle time of the balancing chart was calculated using the average cycle times of the products weighted by their volumes.

The cycle times per part number and work centre were recorded in SAP. The cycle times were derived from time studies using videos of the process and method time measurement (MTM) study based on the filmed material. This method was adopted because the operators had a tendency to slow down their work when they saw that a time study was being conducted since they perceived that time studies would result in an increase of their targets per hour. In addition to taking the weighted average of the cycle time for CB and ASSY, the result had to be divided by the number of lines that were active at the same time since there was not only one CB or ASSY line running at a time. Then the net cycle time bars for CB and ASSY would indicate the duration before one core or finished product would leave the fractal.

The number of lines running simultaneously was determined by the number of teams working in ASSY or CB. This result was an average output of the three fractals but showed an ideal situation and this is why additional time for defects, scrap, change-overs and other downtime was added because it would have had an impact on the output of the lines.

5.4.4.2 Additional Time for Scrap and Defects

Defects occurred during core building and the affected parts would be reworked immediately at the line by removing the damaged part. For example, a defective airway or a tube would be replaced with a new part. It was rare to find whole units that were scrapped just after core building. Parts that were not brazed properly were re-brazed. If parts at assembly did not pass leak-testing, they were sent to a separate rework area; the defective parts were reworked and were then sent back to the assembly line where they had to be leak-tested again. Therefore, defective parts at core building, brazing and assembly reduced the output of the fractal, which meant they increased the cycle time.

Parts that went for scrap had to be rebuilt, which meant a scrapped part from assembly had to be replaced and the parts had to go through the same process again, a new part from core building, get brazed and assembled. Therefore, scrap influenced the previous fractals as well because they were only detected in the assembly fractal. Cores rarely went for scrap after core building and brazing. Products that were scrapped were booked against CB, brazing and ASSY and additional time for scrap and defects and were just a percentage of defects and re-braze for the fractal plus the percentage of scrap, which was the same for all three fractals. Scrap, defect and re-braze rates were recorded per product or product group. The weighted average was calculated according to the volumes in order to get a more accurate representation. The weighted percentages for scrap and defects were then added onto the net cycle time.

5.4.4.3 Additional Time for Downtime

Downtime records were taken per line at assembly and core building and the percentage for the balancing chart was also calculated using the weighted average of the downtimes per line and the corresponding volumes. This was not necessary for the furnace as this was only one machine with one downtime percentage. As downtime refers to the available time, the time added was the downtime percentage multiplied by the customer takt time.

5.4.4.4 Additional Time for Changeovers

The additional time for downtime for core building (CB) and assembly (ASSY) was calculated as the quotient of the setup time and the lot size of the product. The weighted average of those times was then added onto the net cycle time for the furnace, and the percentage of downtime due to changeovers was used.

5.4.4.5 Customer Takt Time

Customer takt time for brazing is different from other fractals CB and ASSY customer takt time (CTT) because of the different shift patterns and the difference in the number of working hours. Takt time is the frequency at which a part or component must be produced to meet customers' demand (Sundar, Balaji and Kumar 2014).

The furnace was running two shifts without breaks. However, in the last hour before the furnace went to standby-mode it was not fed with cores anymore as it would take an hour until they reached the other end of the furnace. Therefore, 7.5 hours per shift multiplied by two shifts equals the available time per day for the furnace. Brazing ran two shifts, having a half an hour break per shift and ten minutes for a continuous improvement process meeting. Therefore, for CB and ASSY there was 7.33 hours multiplied by three shifts of available time per day. The available time per day was multiplied by the working days of the period under consideration divided by the volume of the period.

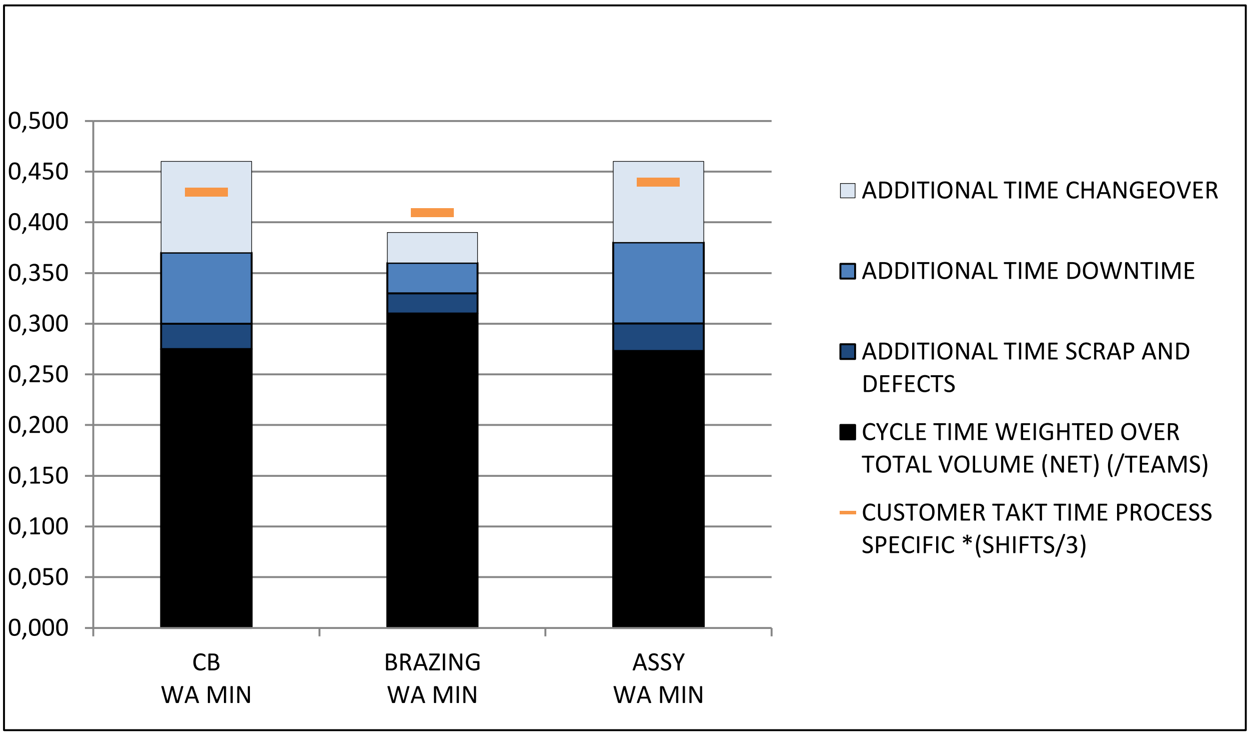
5.4.5 Plant balancing charts analysis

The balancing chart shown in Table 5.4 was then created using volumes, available labour and working days for July 2016 and all time units were recorded in minutes. The three bars represent the cycle times of core building, brazing and assembly, net cycle time and the additional times over and above it. The orange horizontal lines represent customer takt time for the fractal. The results showed that core building and assembly were unable to meet customer demand, as the gross cycle time was higher than CTT. This was because core building consisted of 13 lines but at the time only four of them were manned at a time.

The cycle time of core building depended on how many lines were running at the same time, which was dependent on the available labour. Therefore, the quotient of the cycle time and the CTT did not result in the loading of the 13 core building lines. The balancing chart for July also showed that the furnace was not fully loaded as there was a gap in-between CTT and the gross cycle time of brazing.After brazing, the products went to assembly, and in contrast to core building, the downtime for change-overs was relevant. The change-over times for assembly were generally shorter as in most cases just the leak testing jigs and crimp tools had to be exchanged but the operators helped with the changeover so that they could not work on another line in the meantime. The gross cycle time of assembly was slightly higher than the cycle time of core building. Consequently, assembly should have been able to process all the parts that were produced at core building and heated afterwards.

Table 5.4: Balancing Chart for July

BALANCE JULY		CB WA MIN	BRAZING WA MIN	ASSY WA MIN
CYCLE TIME WEIGHTED OVER TOTAL VOLUME (NET)		0.275	0.310	0.273
ADDITIONAL TIME SCRAP AND DEFECTS		0.025	0.020	0.027
ADDITIONAL TIME DOWNTIME		0.070	0.030	0.080
ADDITIONAL TIME CHANGEOVER		0.090	0.030	0.080
CYCLE TIME WEIGHTED OVER TOTAL VOLUME (GROSS)		0.400	0.351	0.410
CUSTOMER TAKT TIME PROCESS SPECIFIC *(SHIFTS/3)		0.430	0.410	0.440
CUSTOMER TAKT TIME FOR THREE SHIFTS	0.56			
working days in X months	100			
Shifts		3	2	3
teams (how many lines are active at the same time)		4	1	3.66



It was found that there were parts that had a very short cycle time for core building but needed more effort to be assembled so that they had to queue for assembly. It was also noted that there were multiple core building lines feeding one assembly line in some instances, and hence the assembly line would not be able to cope. The evaporator assembly line could only be fed by two HV core building lines when the evaporator line produced one special condenser and evaporators and condensers and evaporators were not the kind of product that made up the largest part of the cores awaiting assembly. Moreover, the comparison of the cycle times of assembly and core building revealed that the CT of CB was always higher or equal to the CT for assembly of the specific product. It was also imperative to investigate and find ways of reducing the downtime and changeover time as well as additional time for scrap and defects.

Table 5.5: Balancing Chart for August

BALANCE AUGUST		CB WA MIN	BRAZING WA MIN	ASSY WA MIN
CYCLE TIME WEIGHTED OVER TOTAL VOLUME (NET)		0.275	0.310	0.273
ADDITIONAL TIME SCRAP AND DEFECTS		0.013	0.020	0.010
ADDITIONAL TIME DOWNTIME		0.030	0.020	0.040
ADDITIONAL TIME CHANGEOVER		0.070	0.030	0.065
CYCLE TIME WEIGHTED OVER TOTAL VOLUME (GROSS)		0.400	0.351	0.410
CUSTOMER TAKT TIME PROCESS SPECIFIC *(SHIFTS/3)		0.400	0.390	0.410
CUSTOMER TAKT TIME FOR THREE SHIFTS	0.56			
working days in X months	100			
Shifts		3	2	3
teams (how many lines are active at the same time)		4	1	3.66

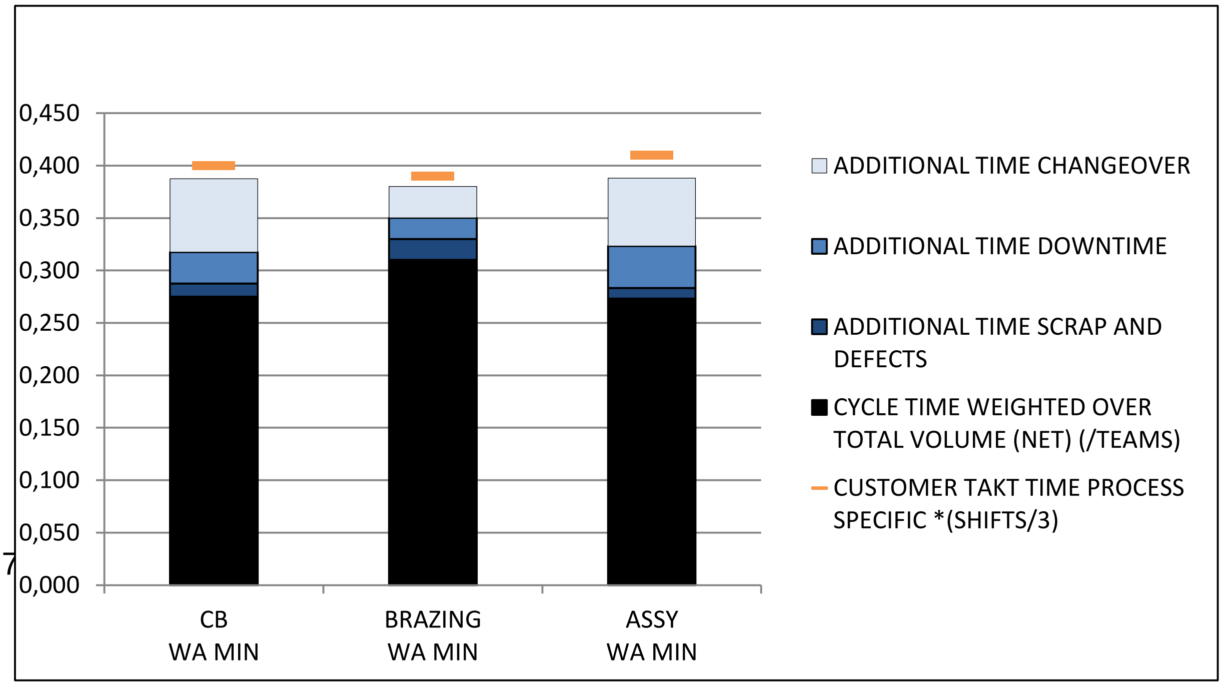


Table 5.5 shows a balancing chart for August after the interventions to reduce the downtime, changeover time as well as additional time for scrap and defects. It was also imperative to change the scheduling approach and adopt one that prioritised and spread the cores that had relatively short CT at assembly but needed slow brazing programmes. It was after the scheduling interventions that a balancing chart for the future was generated and Table 5.5 reveals that the fractals' imbalance had been reduced.

5.5 Discussion of results

Several Kaizen flashes were noted from the current state value stream map and these demonstrated that there was room for process improvement. The first balancing chart showed that there was some imbalance in the plant since there was a lot of inventory awaiting assembly. As the balancing chart is based on SAP times and includes scrap, defects and downtime, it was found that the core building and assembly fractals did not achieve its targets even if there was no documented downtime, defect or scrap.

This was due to the following reasons:

- The VSA exposed that there were two planning points in the EC plant instead of one. Those two plans sometimes differed; as a consequence, it was impossible to use the FIFO lanes at the end of the furnace machine because the furnace FIFO lanes often, products that were brazed after another product were assembled first.

- The VSA revealed that the operators did not run the lines properly so that they could not achieve their targets. The operators at assembly did not utilize the bottleneck workstations fulltime and therefore could not produce at the same pace as the SAP times. In addition, some lines were manned with less heads than was ideal and the balancing chart assumed that the lines ran with a maximum number of heads.

- The targets were too high which meant the cycle times in SAP times were too low. However, this was found to be very unlikely as the SAP times were the result of a methods time measurement (MTM) study done according to a video of the actual process. Moreover, the employees responsible for those time studies were trained.

- Alternatively, the lines ran with fewer operators than planned, which could happen because of absenteeism or when the plant had to run on short time due to low volumes.
- An improvement in line balance was achieved as visualised from the comparison of July and August balance chart. There was also an increase in volumes of parts that had a relatively short CT at assembly but needed a slow brazing programme, for instance, LTRs. Core building was now able to provide cores for brazing in time as the additional time for change-overs was actually reduced. Moreover, assembly should have been able to process what came out of the furnace as core building still had a higher cycle time than assembly.

5.6 Conclusion

The chapter was based on the future state but a future state VSM was not compiled as the issues that were discovered during the value stream analysis were mostly represented as Kaizen flashes. The future state is described in a written form as part of the development of the proposals for improvement in Chapter 6. With a view to prioritising product types according to demand, an overview of the different parts and volumes was prepared in a Pareto chart, followed by the allocation of the products to the lines. Balancing charts were then developed to indicate the relationship between the three fractals of core building, brazing and assembly and they consisted of net cycle time and additional times for defects, scrap, downtime and change-overs, and their sum resulted in gross cycle time, as well as customer takt time. It was established that the assembly lines did not produce at the rate of net cycle time even if there was no downtime or defect. Therefore, it was imperative to change the scheduling approach, and adopt one that prioritised and spread the cores that had relatively short CT at assembly but needed slow brazing programmes. This yielded an improved process that had better balance between the three fractals. The next chapter focuses on recommendations and a conclusion of the study.

CHAPTER 6 : RECOMMENDATIONS AND CONCLUSION

6.1 Introduction

The previous chapter highlighted production process flows, assessing value- and non-value-adding activities and value stream mapping, and line balancing analysis for the car heat exchanger parts company. Several Kaizen flashes were noted from the current state value stream map and these demonstrated that there was a need for line balancing and developing improvement initiatives to reduce work-in-process inventory. Continuous improvement is an initiative of improvement that decreases failure in the system and increases success. Continuous improvement can be governed by worker perception, team effort, adapting easy to change, engagement of management and motivation (Sundar, Balaji and Kumar 2014). Gonzalez, Rodrigo Valio Dominguez and Manoel Fernando (2016) also stated in their study that with continuous improvement of the different hierarchical levels of employees' involvement it becomes successful too and it is called kaizen. This chapter focuses on the recommendations for improvement and gives a conclusion of the research. Recommendations and a road map for continuous improvement are discussed in this chapter.

6.2 Recommendations

The following recommendations are aligned to the fourth objective, which is to develop a roadmap for reduction of waste in the manufacturer of car heat exchangers components. As highlighted in Chapter 3, sustainability of continuous improvement initiatives is vital and this can be achieved through skills and training, and follow-up actions, as well as assessment and monitoring of results, deviations, new actions, investments, costs and benefits.

6.2.1 Improvement Opportunities for Operators and the Removal of Second Planning Point

A major problem that the value stream analysis revealed was that the assembly lines often could not achieve their targets even if there were no defects or downtime. This was often due to operators not fully utilizing the capacity of the bottleneck workstations.

In order to improve this issue a workshop for the operators could help to raise their awareness of the existence of bottlenecks and the importance of utilizing them all the time. The workshop would consist of 2.5 hours of theory and during that time, it should be demonstrated that a chain is only as strong as the weakest link. Consequently, the operators should learn that it is impossible to achieve a target if the bottleneck stations are not fully utilised. In addition, team effort is crucial in cases where the operator at the bottleneck workstation has difficulties coping with the task.

After the theoretical part, the lessons learnt should be practised on the shop floor. The workshop should be spearheaded by a process technician. The benefits of the operator workshop include the fact that assembly would in future be able to process all the brazed material, and it would become possible to introduce dedicated FIFO lanes after brazing. Moreover, when the FIFO lanes were effectively utilised, there would be no need for a second planning point.

6.2.2 Improvement opportunities from Qualitative Evaluation of VSM

After a qualitative evaluation of the VSM indicated in the previous chapter, it was noted that there was an opportunity for continuous improvement in order for the case study company to remain competitive. It was crucial to ensure that the operators were trained. The training of operators and the removal of the second planning point would allow the reduction of work in progress thereby saving the cost of carrying inventory. Besides, lead times would be shorter and the FIFO lanes at the furnace would be clearer with the result that it would no longer be necessary to have to search for the right trolley for assembly. In addition to that, training would increase employee motivation.

Training costs are incurred during a workshop since the operators do not work and facilitators need to be remunerated as well. Nevertheless, once the training is done, the issue should be followed up in Continuous improvement program (CIP) meetings that are held after every shift in the organisation.

6.2.3 Improvement opportunities from Economical Evaluation of VSM

An economic evaluation was utilised to pinpoint the best plan of action, based on the data that the researcher collected. After an economic evaluation of the VSM, it was noted that there was an opportunity for continuous improvement. Compared to the current situation, the workshop and the elimination of the second planning point would help to reduce the level of inventory and the cost of carrying inventory.

As described by Soliman (2017), the costs of carrying inventory include the cost for the physical space occupied, the cost of lost opportunity because of the capital lockup, handling costs and the cost of deterioration and obsolescence. In order to compare the annual cost of carrying inventory in the EC plant with and without the implementation of the proposal, the focus lies on the cost of space and tied up capital. This is because there is one worker per shift who is responsible for the internal material handling. The fact that less inventory and sticking to the FIFO principle requires less work for the IMH worker due to less searching for material has not been considered in this evaluation. Deterioration is also not taken into account because products are made to order and even if the products spend more time waiting for brazing, there is no chance that they will not be taken by the customer.

The assessment revealed that the brazed parts occupied about 183 square meters in the plant. This space inculded the area of the post brazing FIFO lanes next to the furnace and the FIFO lanes at the assembly lines. Furthermore, the area between the post braze FIFO lanes and the steps of the control panel of the furnace were included as CACs and radiators were stored there as well. Moreover, the space for two more LTR/condenser trolleys was added since it was a temporary storage area for LTR/Rad. Line during the manual core count.

Brazed cores were identified in different areas during the course of the manual core count, but most of the time the previously mentioned area was covered with cores and therefore it was not taken into account. Operational costs of R96 782 per year were incurred for rent, insurance and overheads. Assuming that there were 5 500 brazed parts on average, which was the average quantity of the manual count and the observation using SAP, and an average value of R246 per part, this would result in R94 710 of opportunity costs. A rate of input interest of seven percent per year was assumed, and that rate was used for the calculations.

The inventory level would decrease after the workshop and the removal of the second planning point, and on average there would be one sixth of the daily production quantity of core building. This would be because the daily production quantity was produced for core building during three shifts. The furnace would be able to braze this quantity in two shifts whereas assembly could process the same quantity in three shifts.

Using the gross cycle time minus the additional time for change-overs of the balancing chart for the period from August to December, this would result in an average daily production quantity of 2587 parts. One sixth of this quantity times the average value of a brazed core of R246 would result in the average value of R106 069. This would result in opportunity costs for the tied up capital of R7 422 per year.

Concerning the space, it should be possible to use the provided post-brazing FIFO lanes and the assembly FIFO lanes so that the extra space that is currently occupied by cores would no longer be required. This is because they were designed to cater for the brazed parts if the production ran according to the process description (see appendix 6 for the process flow chart). To conclude, this proposal could save R107 650 of costs for carrying inventory per year and Appendix 11 shows the calculation of inventory costs. Appendix 12 shows the revised space required for poast Braze FIFO lanes. As a consequence, the required space would reduce to 129 meters square, which would result in annual costs of R68 006 for the space.

The workshop for the operators would also incur costs. An estimate of costs from the Training and Development department quoted R8410 for the preparation and three rollouts of the training as there would be three shifts of operators. Appendix 13 shows the cost estimate for the workshop. However, there would still be a saving of R99 000 per year, presuming that a workshop was performed once a year.

6.2.4 Improvement opportunities from shift models

As the furnace was running two shifts and assembly and core building was running three shifts there was always WIP building up in front of the furnace when it was not running and on the other side the inventory level was increasing behind the furnace when it was running and decreasing when it was not running (Chen and Xu 2015). Because core building was producing the daily production quantity during three shifts and the furnace was brazing that same quantity within two shifts, the average number of parts awaiting brazing should have been one sixth of the daily production quantity.

Moreover, one sixth of the daily production was awaiting brazing at the other end of the furnace on average, as assembly consumed in three shifts the number of parts that the furnace brazed during two shifts. In order to reduce this level of inventory it would be an option to run core building and assembly on a two-shift model as well.

If all three fractals were running in two shifts, the inventory level could be reduced even more. In addition, lead times would decrease, provided that all cores were brazed and assembled on the same day. Besides, running the EC plant on two-day shifts would save the night shift allowance for the operators. However, there would also be a high investment required for more core building tools or even additional core building lines and more leak testing jigs for assembly. This is why the products of the lines that are currently running for three shifts must be produced on other lines. This means that there would be even more core building lines than at the moment and all of them would stand idle at night. As a result, there would be less capacity utilisation, which would also be reflected in higher machine hour rates. Additionally, there would be more space and less maintenance.

In addition, a two-shift model for the whole EC plant would not reduce the inventory to zero. If the furnace started brazing when the core-building shift began, there would not be enough cores to braze for two reasons: firstly, the products from core building go to the FIFO lanes in front of the furnace on trolleys with at least 36, which is the smallest pan size, products on one trolley. Therefore, as long as no core building line has filled a trolley, the furnace does not have parts to braze. The quantities designated to a trolley could be reduced, but even more important would be that the core building lines produce different products that need different brazing profiles and require either Silflux or spray flux and they therefore cannot be brazed together. Moreover, one core building line cannot feed the furnace at the rate that it is able to braze. Therefore, there has to be some inventory before the furnace ramps up which again causes imbalance.

Furthermore, the volumes of the EC plant are likely to increase so that the furnace would probably have to run three shifts. Consequently, high investment in more lines to be able to build cores and assemble in two shifts would not be a forward-looking decision.

As the volumes are likely to increase so that the furnace has to run three shifts again, it does not make sense to invest money in new tools and lines just to be able to do core building and assembly in two shifts. In addition, the investment would not be justifiable from an economic point of view. Compared to the saving due to reduction of inventory, the investment is too high.

This is because the maximum saving that would be possible through the adjustment of the shift model are only part of the costs of carrying inventory in the plant. This would make R68 006 for the space and R7421 for the tied up capital for the post brazing area and R32 524 for the space and R6064 (as unbrazed parts have less value) for the cost of carrying inventory in the pre-brazing area. In total this would be R114 017, which could be reduced partially.

Appendix 14 shows the annual energy costs for the third brazing shift. There would be too much capital investment required as the products from the lines that are running three shifts would have to be processed on other or even on additional new lines. For the investment to be able to run only on one part on another line, the cost would be R1.35 million as new tooling would be required.

All in all, the adjustment of the shift models for the three fractals would not result in savings and does not have other strategical advantages. To conclude, it would not make sense to implement this proposal. Instead of increasing the capacity for core building and assembly, there is an option of investigating the possibility of a slower brazing profile so that the furnace would be running three shifts as well. To run all three fractals for three shifts could reduce the level of inventory that is on both sides of the furnace due to the different shift models.

In addition, one slow-brazing profile would reduce the downtime of the furnace due to profile changes and at the same time, it would remove the constraint of the different brazing families. However, the constraint of the different brazing fluxes that cannot be brazed together would remain. Moreover, there is the possibility that the furnace would consume less energy per hour when running, as the parts now spend more time in the furnace so that the temperature level can be kept lower than at the current profiles. But this is not necessarily the case as heat sinks would be necessary for some parts while others need the high temperature; so in order to be able to make a conclusive deduction, brazing trials would be necessary. The furnace would also run longer hours (three shifts instead of two) so that it might consume less energy per hour but then run more hours so that the total energy consumption would be more likely to increase. In addition, one more shift of operators for the furnace and a supervisor would be necessary.

Besides, the acquisition of more brazing jigs would also be necessary. Some products would have to go through the furnace double and triple stacked or need a jig as a heat sink on top of them so that they do not burn. Additional jigs would also require a storage area, which was currently not available in the EC plant. There is also a need to investigate whether a slower brazing profile is feasible in the long-term since the introduction of new products with a lower profile could require another brazing profile. Moreover, in the event that product demand increases, the furnace would have to run for three shifts with the current three profiles and with one slower brazing profile. Running costs for the extra shift of six furnace operators and a supervisor for the furnace would be about R610 580 per year, which is a lot more than the potential saving of the costs of carrying inventory in the EC plant of about R114 017 per year. The annual labour costs for a supervisor for the furnace would be R159 332, while the annual labour costs for the operator of the furnace would be R75 208.

In addition, there would be the energy consumption of the furnace, which would amount to additional costs of R826 000 per annum, assuming that the energy consumption of the new brazing profile would be the same as the current energy consumption (see Appendix 14 for the calculation of energy costs). Moreover, there would be the investment in new jigs, which would amount to about R2000 per jig and the cost of the brazing trials and the development of the new brazing profile. The comparison of the potential savings and the estimated additional running costs for the third shift already show that the implementation of one new brazing profile would not result in savings.

6.3 Roadmap for reduction of waste

Three proposals to improve the situation in the EC plant were developed and the first proposal aims at fixing the problems that were discovered during the analysis. This proposal includes a workshop for the operators at assembly, which should enable them to meet their targets for the hourly production quantities. In addition, it would then be possible to again use the post brazing FIFO lanes as dedicated FIFO lanes and the second planning point would no longer be necessary.

The introduction of this proposal is highly recommended as it generates a saving due to the reduction of inventory and does not have disadvantages, except for the fact that the high inventory level currently works as a huge safety buffer. Since after the implementation of this proposal an imbalance due to the different shift models of the three fractals would remain, two further proposals have been developed.

The first way of adjusting the shift models is a two-shift model for the entire plant. In order to achieve this, high investment would be required and it would not pay off, as the potential saving of inventory costs are small. Moreover, this may only be a short-term improvement, as the furnace would have to run three shifts if demand increased.

The other option to adjust the shift models would be to create a slower brazing profile, so that the furnace runs three shifts, as executed for CB and assembly. However, the economic evaluation revealed that this option would not generate savings. Moreover, this would not be strategic if product demand were to increase in the future.

Nevertheless, even if the adjustment of the shift models does not make good economic sense, the implementation of the first proposal allows good cost savings. Table 5.7 summarizes the arguments that speak for and against the proposals and gives an idea about the costs and savings.

The balancing chart was adopted as a template so that new parts and volumes as well as changes in shift patterns or in terms of the scrap, defect or downtime rates could be inserted easily. Appendix 15 shows the description of the template. This template was then handed over to the Industrial Engineering department so that the balance in the plant could be monitored. In addition, in case of an imbalance, corrective measures could be developed and this part addresses objective three, which is the line balancing analysis for the production fractals.

Table 6.1: Summary of Proposals

Summary of Proposals				
	Status Quo	Training + One Planning point	Two Shifts	Three Shifts
basis for comparison of savings and costs				
cost of carrying inventory for post braze WIP	ZAR 191 492 per year (space and opportunity costs)	ZAR 75 428 per year (space and opportunity costs)	probably less than ZAR 75 428 per year	probably less than ZAR 75 428 per year
cost of carrying inventory for pre braze WIP	ZAR 38 589 per year (space and opportunity costs)	ZAR 38 589 per year (space and opportunity costs)	probably less than ZAR 38 589 per year	probably less than ZAR 38 589 per year
other costs and required investments	-	• Workshop (once a year) ZAR 8 410	• tools and LT jigs: more than ZAR 1.350 million •space for additional machines	• labour ZAR 610 580 per year • energy ZAR 826 000 per year • brazing jigs, • brazing trials, research
savings	-	ZAR 107 654 per year	• no saving because of high investment for tools etc.	• no saving because of costs for energy and labour and the investment in brazing jigs
(+)	-	• reduction of inventory • no more searching for brazed material • reduction of lead times	• further reduction of inventory •further reduction of lead times for most parts	• removal of constraint of brazing families • further reduction of inventory
(-)	• chaotic, products are hard to find in piles of material	• imbalance of the 3-2-3 shift model	• **high investment in tools/ LT jigs or entire lines** • expensive HV CB and ASSY lines are only utilized for two shifts • **not future oriented as furnace must probably run three shifts next year**	• **feasibility** • high investment • higher costs for energy and labour • **furnace runs out of capacity when volumes increase as expected**

6.4 Conclusion

The first objective of this research was to outline the production flow for the manufacture of automotive heat exchanger parts. An overview of the production flows was provided and it was crucial for the subsequent analysis of value and non-value adding activities. The second objective of this research was to conduct value stream mapping to assess the value- and non-value adding activities in the manufacture of automotive heat exchangers components. Kaizen flashes were highlighted on the

VSM and a value analysis was conducted for core building and assembly, as well as assessment idle time for the brazing furnace.

The third objective of this research was to conduct a line balancing analysis for the three production fractals. It was established that the assembly lines did not produce at the rate of net cycle time even if there was no downtime or defect. Therefore, it was imperative to change the scheduling approach and adopt one that prioritised and spread the cores that had relatively short CT at assembly but needed slow brazing programmes, and also reduce downtime, changeover time as well as additional time for scrap and defects. The third objective was achieved and a future-state balance chart revealed that the fractals' imbalance had been reduced.

The fourth objective of this research was to develop a roadmap for reduction of waste in the manufacture of car heat exchangers components. A roadmap was developed for improving the manufacture of automotive heat exchangers through value stream mapping. Removing the second planning point in the EC plant and the training of the operators will allow for the reduction of inventory and this has many advantages such as less costs of carrying inventory, more clarity in the plant and the reduction of lead times.

Since there were several products with different brazing profiles running on different lines, further research could be conducted to develop an optimal scheduling algorithm for allocation of products to work centres to ensure high utilization of work centres and reduce work-in-process inventory.

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APPENDICES

Appendix 1: Ethics Clearance Certificate

Certificate of Completion

The National Institutes of Health (NIH) Office of Extramural Research certifies that **Kate Lusiba** successfully completed the NIH Web-based training course "Protecting Human Research Participants".

Date of completion: 05/28/2015

Certification Number: 1770639

Appendix 2: Turnitin Report

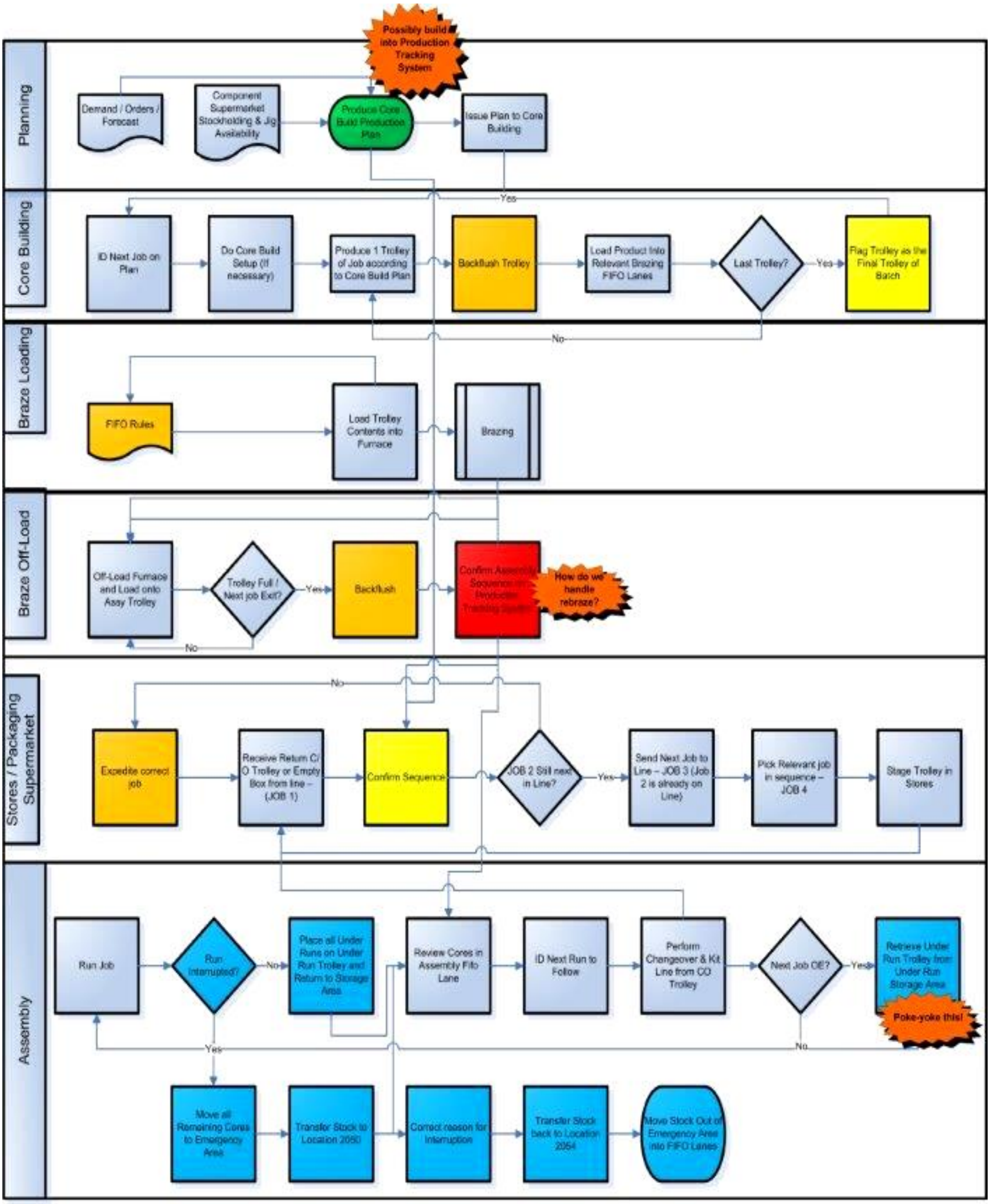
ORIGINALITY REPORT

6%	5%	3%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.artec-pneumatic.com Internet Source	1%
2	Gossauer, E., Gropp, Th., Moosmann, C. and Wagner, A.. "Workplace Occupant Satisfaction - a Study in Sixteen German Office Buildings",	1%

Appendix 3: Planning Process



Appendix 4: Definition of the Product Families

Value Stream Design

Define a Product Family

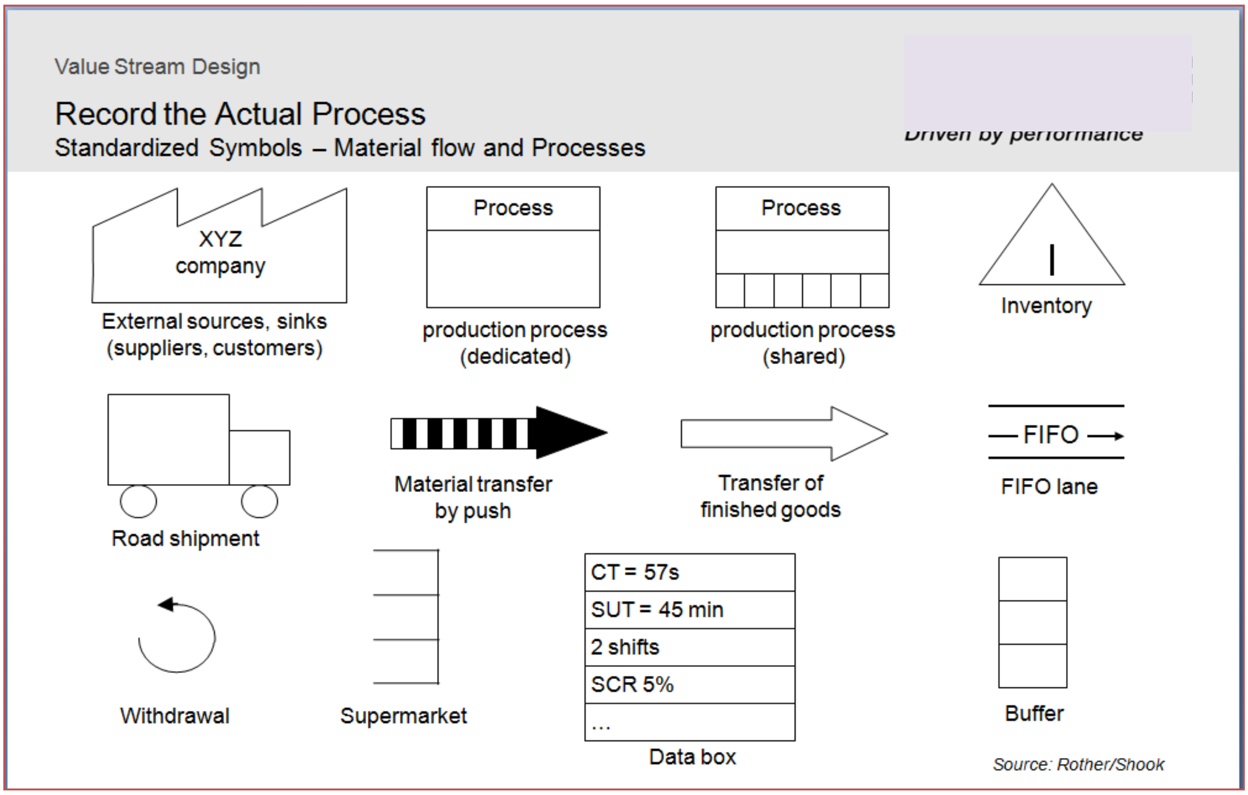
Example Engine Cooling

	Core builder 1	Core builder 2	Furnace	Backend 1	Backend 2	Module Assembly 1	Module Assembly 2
Cooling Module Type A	X		X	X		X	
Cooling Module Type B		X	X	X		X	
Cooling Module Type C	X		X	X		X	
Cooling Module Type X		X	X		X		X
Cooling Module Type Y		X	X		X		X

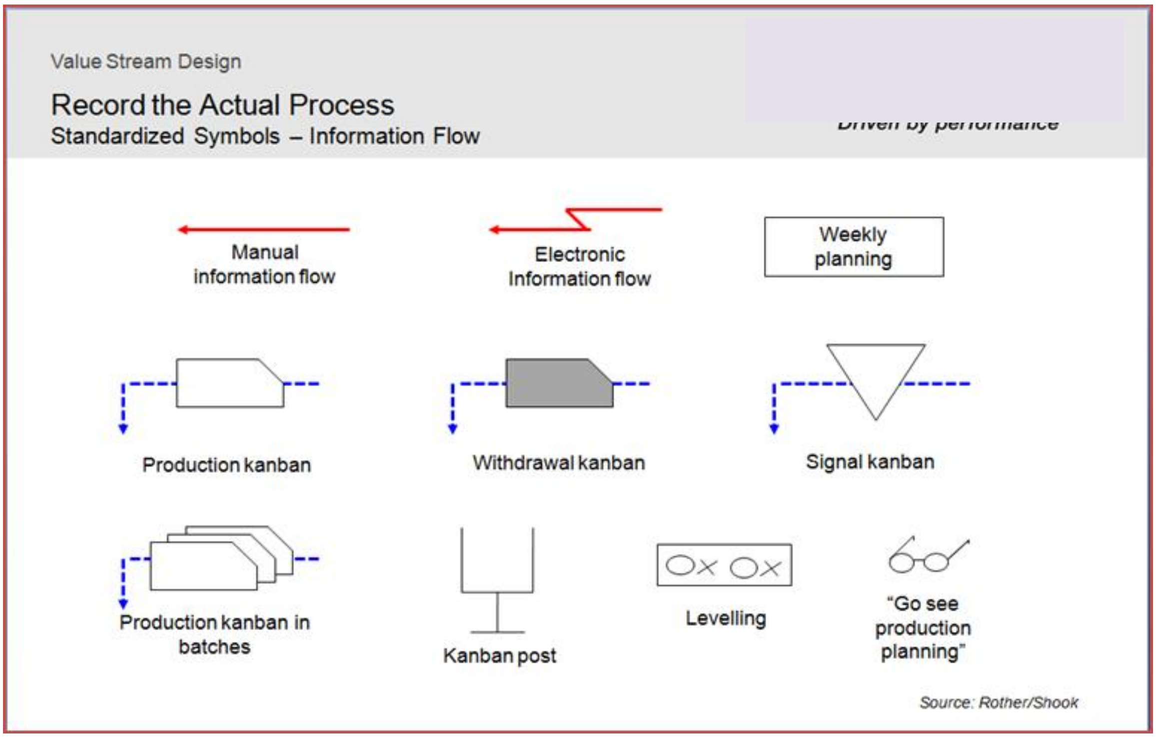
Important things to know:

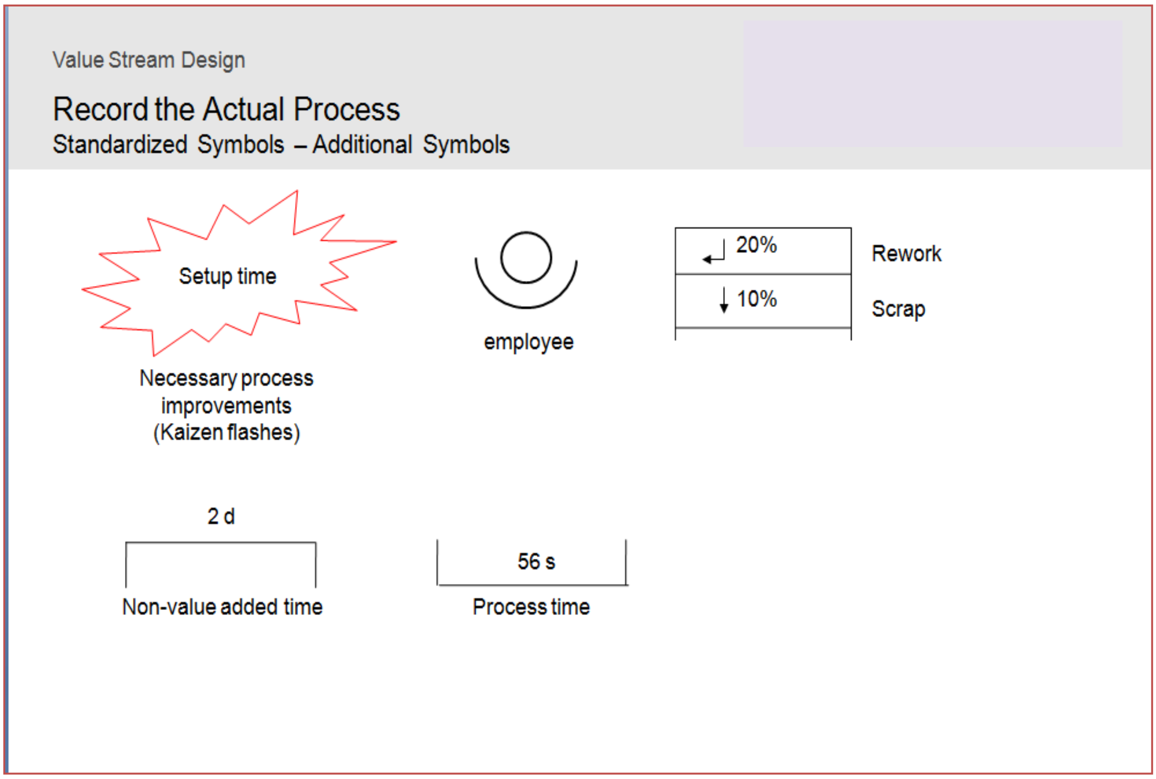
- Start from the nearest end to customer
- Go upstream
- Consider the additional products running on the processes of the product family

Appendix 5: VSM Symbols

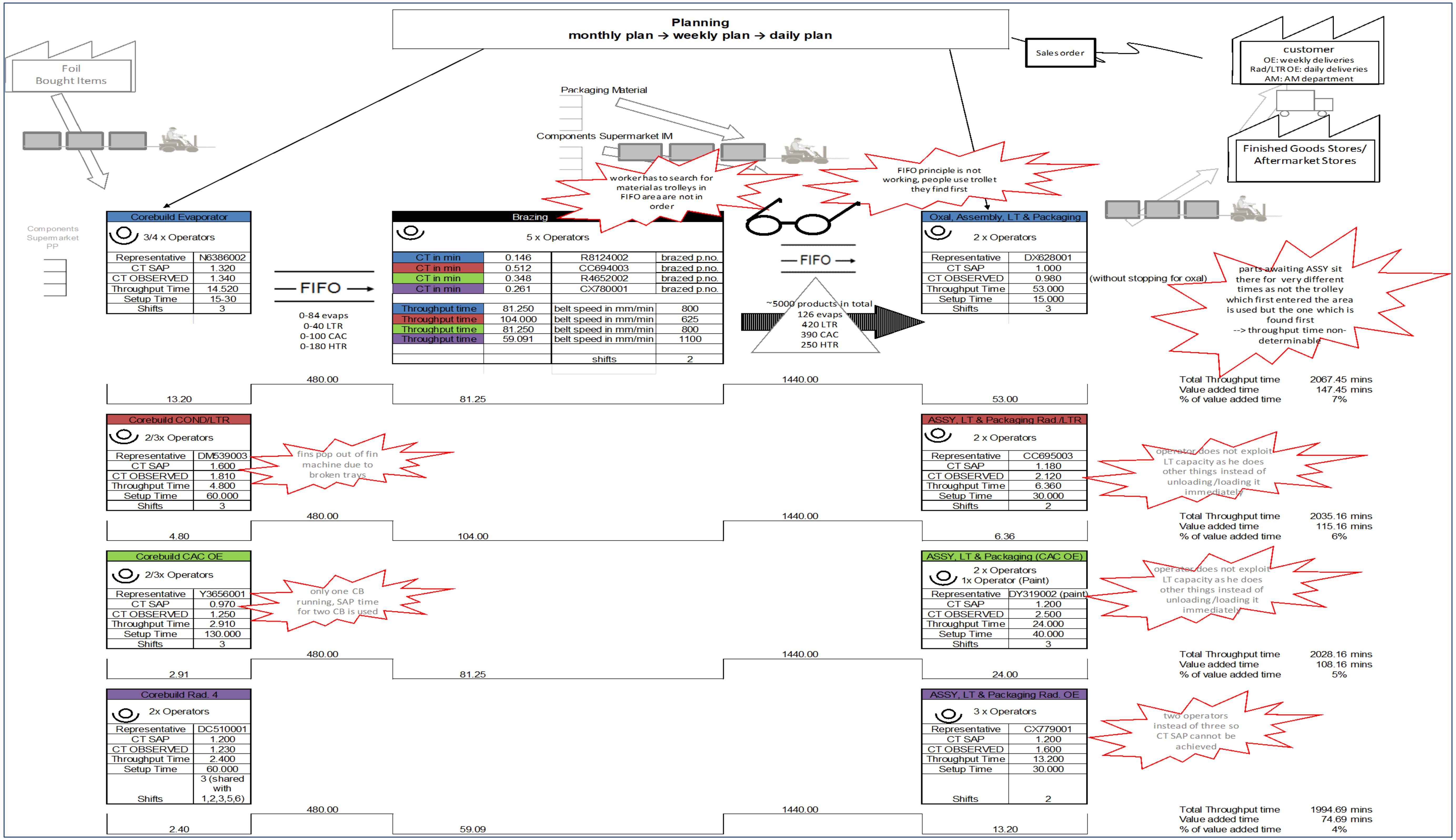


Appendix 6: VSM Symbols





Appendix 7: Value Stream Map of EC Plant



Appendix 8: Data for Pareto Chart

	Part No.		Name	VOLUME	cumulated volume	percentage
	Brazing	Core Build				
1	R35[redacted]	Y25[redacted]	COOLER - CHARGE-AIR CPL	55674	55674	14%
2	CC5[redacted]	DM[redacted]	LOW-TEMPERATURE RADIAT.ENT	55135	110809	29%
3	Y34[redacted]	Z58[redacted]	COOLER- CHARGE-AIR/AIR	45680	156489	40%
4	CX6[redacted]	DC[redacted]	COOLANT/AIR COOLER	40540	197029	51%
5	R70[redacted]	N5[redacted]	EVAPORATOR ENT	38958	235987	61%
6	CX6[redacted]	DC[redacted]	COOLANT/AIR COOLER	18540	254527	66%
7	L92[redacted]	Y26[redacted]	COOLANT/CHARGE AIR COOLER	16936	271463	70%
8	C83[redacted]	DU[redacted]	CONDENSER	16717	288180	75%
9	Y83[redacted]	Y83[redacted]	EVAPORATOR CPL	12096	300276	78%
10	COF[redacted]	Y28[redacted]	RADIATOR	10664	310940	80%
11	COF[redacted]	Y28[redacted]	RADIATOR	6310	317250	82%
12	CN[redacted]	CN[redacted]	EVAPORATOR CPL	6144	323394	84%
13	X40[redacted]	Y71[redacted]	COOLER- CHARGE-AIR	5771	329165	85%
14	COF[redacted]	Y25[redacted]	RADIATOR	5523	334688	87%
15	CC7[redacted]	DM[redacted]	LOW-TEMPERATURE RADIAT.ENT	4080	338768	88%
16	COF[redacted]	Y28[redacted]	RADIATOR	4070	342838	89%
17	COF[redacted]	Y28[redacted]	RADIATOR	3343	346181	90%
18	T43[redacted]	Y31[redacted]	RADIATOR ASSY	3223	349404	90%
19	COF[redacted]	Y31[redacted]	RADIATOR	2810	352214	91%
20	P30[redacted]	Y25[redacted]	COOLANT/CHARGE AIR COOLER	2322	354536	92%
21	COF[redacted]	Y26[redacted]	RADIATOR	2091	356627	92%
22	X74[redacted]	EZ[redacted]	CORE	1860	358487	93%
23	286[redacted]	Y26[redacted]	RADIATOR	1800	360287	93%
24	CH4[redacted]	CR[redacted]	COOLER- CHARGE-AIR/AIR	1677	361964	94%
25	CP7[redacted]	CT[redacted]	COOLER- CHARGE-AIR	1609	363573	94%
26	COF[redacted]	Y26[redacted]	RADIATOR	1371	364944	94%
27	ACC[redacted]	Y26[redacted]	CONDENSER	1282	366226	95%
28	COF[redacted]	Y26[redacted]	RADIATOR	1250	367476	95%
29	001[redacted]	Y25[redacted]	RADIATOR	1105	368581	95%
30	COF[redacted]	Y28[redacted]	RADIATOR	980	369561	96%
31	T44[redacted]	Y32[redacted]	RADIATOR ASSY	797	370358	96%
32	G29[redacted]	Y26[redacted]	COOLER- CHARGE-AIR/AIR	789	371147	96%
33	826[redacted]	Y27[redacted]	RADIATOR	709	371856	96%
34	045[redacted]	Y25[redacted]	RADIATOR	700	372556	96%
35	ACC[redacted]	Y25[redacted]	CONDENSER	700	373256	97%
36	T43[redacted]	Y31[redacted]	RADIATOR ASSY	620	373876	97%
37	COF[redacted]B	Y31[redacted]	RADIATOR	610	374486	97%
38	689[redacted]	Y27[redacted]	RADIATOR	572	375058	97%
39	655[redacted]	Y26[redacted]	RADIATOR	564	375622	97%
40	CP0[redacted]	CW[redacted]	COOLER- CHARGE-AIR ENT	537	376159	97%
41	214[redacted]	Y25[redacted]	CORE ASSY	536	376695	97%
42	ACC[redacted]	Y25[redacted]	CONDENSER	520	377215	98%
43	COF[redacted]	Y27[redacted]	RADIATOR	500	377715	98%

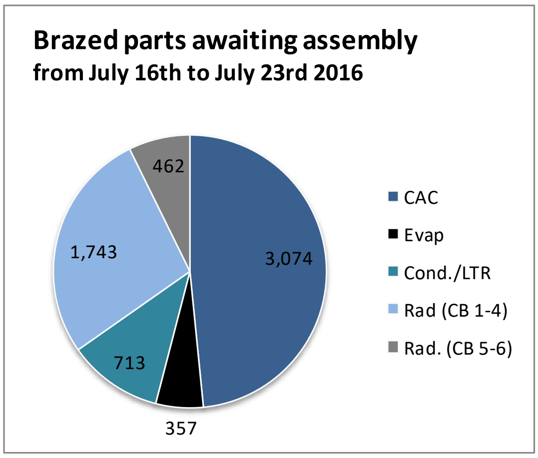
44	[redacted]	[redacted]	RADIATOR	500	378215	98%
45	[redacted]	[redacted]	RADIATOR	500	378715	98%
46	[redacted]	[redacted]	CORE ASSY	449	379164	98%
47	[redacted]	[redacted]	RADIATOR ASSY	424	379588	98%
48	[redacted]	[redacted]	RADIATOR	400	379988	98%
49	[redacted]	[redacted]	RADIATOR	400	380388	98%
50	[redacted]	[redacted]	RADIATOR	397	380785	98%
51	[redacted]	[redacted]	COOLER- CHARGE-AIR/AIR	384	381169	99%
52	[redacted]	[redacted]	CONDENSER	380	381549	99%
53	[redacted]	[redacted]	COOLER- CHARGE-AIR/AIR	380	381929	99%
54	[redacted]	[redacted]	RADIATOR	360	382289	99%
55	[redacted]	[redacted]	RADIATOR	300	382589	99%
56	[redacted]	[redacted]	RADIATOR	300	382889	99%
57	[redacted]	[redacted]	RADIATOR	300	383189	99%
58	[redacted]	[redacted]	RADIATOR	300	383489	99%
59	[redacted]	[redacted]	COOLANT/CHARGE AIR COOLER	253	383742	99%
60	[redacted]	[redacted]	RADIATOR	240	383982	99%
61	[redacted]	[redacted]	COOLER- CHARGE-AIR/AIR	240	384222	99%
62	[redacted]	[redacted]	RADIATOR	220	384442	99%
63	[redacted]	[redacted]	RADIATOR	200	384642	99%
64	[redacted]	[redacted]	RADIATOR	200	384842	100%
65	[redacted]	[redacted]	RADIATOR	198	385040	100%
66	[redacted]	[redacted]	RADIATOR	168	385208	100%
67	[redacted]	[redacted]	COOLANT/AIR COOLER	149	385357	100%
68	[redacted]	[redacted]	COOLER- CHARGE-AIR/AIR	143	385500	100%
69	[redacted]	[redacted]	RADIATOR	100	385600	100%
70	[redacted]	[redacted]	RADIATOR	100	385700	100%
71	[redacted]	[redacted]	RADIATOR	100	385800	100%
72	[redacted]	[redacted]	RADIATOR	100	385900	100%
73	[redacted]	[redacted]	RADIATOR	100	386000	100%
74	[redacted]	[redacted]	RADIATOR	100	386100	100%
75	[redacted]	[redacted]	COOLANT/CHARGE AIR COOLER	100	386200	100%
76	[redacted]	[redacted]	COOLANT/CHARGE AIR COOLER	96	386296	100%
77	[redacted]	[redacted]	RADIATOR	80	386376	100%
78	[redacted]	[redacted]	RADIATOR	79	386455	100%
79	[redacted]	[redacted]	RADIATOR	57	386512	100%
80	[redacted]	[redacted]	RADIATOR	50	386562	100%
81	[redacted]	[redacted]	RADIATOR	50	386612	100%
82	[redacted]	[redacted]	RADIATOR	45	386657	100%
83	[redacted]	[redacted]	RADIATOR ASSY	39	386696	100%
84	[redacted]	[redacted]	COOLER- CHARGE-AIR ENT	23	386719	100%
85	[redacted]	[redacted]	RADIATOR	20	386739	100%
86	[redacted]	[redacted]	RADIATOR ASSY	5	386744	100%
87	[redacted]	[redacted]	RADIATOR	4	386748	100%
88	[redacted]	[redacted]	RADIATOR	3	386751	100%
89	[redacted]	[redacted]	CONDENSER CPL	3	386754	100%
90	[redacted]	[redacted]	RADIATOR	1	386755	100%

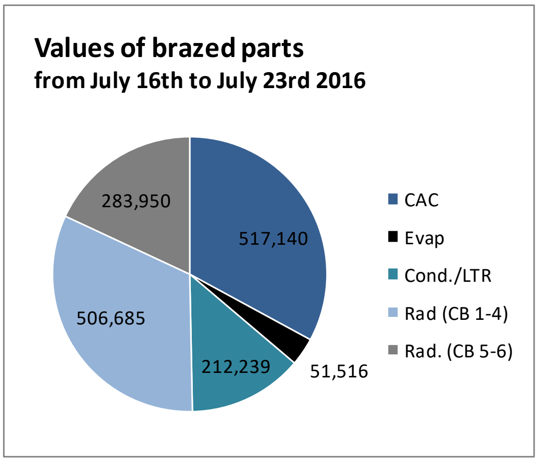
Appendix 9: Summary of MB52

MB53 INVENTORY SUMMARY						
Total Numbers						
Date	16.07.2016	17.07.2016	21.07.2016	22.07.2016	23.07.2016	AVERAGE
Total Quantity (pcs.)	7,487	6,738	6,168	6,181	5,166	6,348
Total Value (ZAR)	1,828,164	1,713,303	1,472,016	1,494,312	1,349,851	1,571,529

Product Types

MRP Controller	Product	Average Qty	Average Value (ZAR)
ECC	CAC	3,074	517,140
BCE	Evap	357	51,516
BCC	Cond./LTR	713	212,239
ECR	Rad (CB 1-4)	1,743	506,685
BCW	Rad. (CB 5-6)	462	283,950





Appendix 10: Product and Work Station Matrix (without part numbers)

NAME	CORE BUILDING													BRAZING						ASSEMBLY																VOLUME
	Rad. 1	CACOE	Condenser/LTR	EVAP	Rad. 3	Rad. 2	Rad. 5	Rad. 6	Rad. 4	Cond. AM		CAC LV		625 mm/min (3)	obsolete		800 mm/min (1)		1100 mm/min (2)	CAC OE	CAC AM		CAC OE	Rad./LTR		Rad. AM		Evap			Cond		Rad. OE	CACWelding	Rad. WET LT	10 months
RADIATOR							X												X					X												1105
RADIATOR							X												X					X												700
RADIATOR							X												X																	100
CORE ASSY								X											X																X	536
CORE ASSY							X	X											X																X	449
RADIATOR								X											X																X	300
RADIATOR							X												X																	1
RADIATOR								X											X																	1800
RADIATOR							X												X																	50
RADIATOR							X												X																	57
RADIATOR							X												X																	564
RADIATOR								X											X					X												400
RADIATOR							X												X					X												3
RADIATOR							X												X					X												4
RADIATOR							X												X																	300
RADIATOR							X												X																	100
RADIATOR							X												X																	572
RADIATOR							X												X																X	100
RADIATOR							X												X					X												709
CONDENSER			X							X								X												X	X					1282
CONDENSER										X									X											X	X	X				700
CONDENSER			X							X								X												X	X					380
CONDENSER			X							X									X											X	X					520
CONDENSER			X														X												X							16717
LOW-TEMPERATURE RADIAT.ENT			X											X										X												55135
LOW-TEMPERATURE RADIAT.ENT			X											X										X												4080
COOLER-CHARGE-AIR/AIR												X							X		X															1677
EVAPORATOR CPL				X												X												X								6144
RADIATOR						X													X						X	X										5523
RADIATOR						X													X						X											168
RADIATOR						X													X						X	X										198
RADIATOR						X													X						X											1250
RADIATOR						X													X						X	X										1371
RADIATOR					X														X						X											20
RADIATOR						X													X						X	X										45
RADIATOR	X																		X						X											240
RADIATOR						X													X							X										2091
RADIATOR					X														X							X										220
RADIATOR	X																		X						X											100
RADIATOR						X													X						X											400
RADIATOR					X														X							X										500
RADIATOR					X														X						X	X										980
RADIATOR	X																		X						X	X										360
RADIATOR	X																		X						X	X										3343
RADIATOR	X																		X						X	X										10664
RADIATOR					X														X						X	X										80
RADIATOR					X														X						X	X										2810
RADIATOR					X														X						X	X										397
RADIATOR	X																		X						X	X										79
RADIATOR	X																		X						X	X										100
RADIATOR						X													X						X											300
RADIATOR	X																		X						X	X										500
RADIATOR	X																		X						X	X										100
RADIATOR					X														X						X											4070
RADIATOR	X					X													X						X											6310
RADIATOR						X													X						X	X										200
RADIATOR					X														X						X	X										610
RADIATOR					X														X						X	X										50
RADIATOR					X														X						X	X										500
RADIATOR						X													X						X	X										300

NAME	CORE BUILDING													BRAZING						ASSEMBLY																VOLUME 10 months
	Rad. 1	CAC OE	Condenser/LTR	EVAP	Rad. 3	Rad. 2	Rad. 5	Rad. 6	Rad. 4	Cond. AM	CAC LV			625 mm/min (3)	obsolete	800 mm/min (1)			1100 mm/min (2)	CAC OE	CAC AM		CAC OE	Rad./LTR	Rad. AM			Evap		Cond			Rad. OE	CAC Welding	Rad. WET LT	
COOLER- CHARGE-AIR ENT											X				X					X																537
COOLER- CHARGE-AIR											X							X		X																1609
COOLANT/AIR COOLER									X										X														X			18540
COOLANT/AIR COOLER									X										X														X			40540
COOLER- CHARGE-AIR/AIR											X							X																X		240
COOLANT/CHARGE AIR COOLER											X							X			X															253
COOLANT/CHARGE AIR COOLER											X							X			X															100
COOLANT/CHARGE AIR COOLER		X																X		X																96
COOLER- CHARGE-AIR ENT		X																X		X																23
RADIATOR ASSY									X										X														X			39
COOLER- CHARGE-AIR/AIR		X																X		X																789
RADIATOR							X												X						X											200
COOLER- CHARGE-AIR/AIR		X																X		X																384
COOLANT/CHARGE AIR COOLER		X																X		X																16936
RADIATOR ASSY									X										X														X			5
COOLANT/CHARGE AIR COOLER		X																	X	X																2322
COOLER - CHARGE-AIR CPL		X																X		X			X													55674
EVAPORATOR ENT				X												X												X								38958
COOLER- CHARGE-AIR/AIR		X																X		X																380
RADIATOR ASSY	X																		X						X	X										620
RADIATOR ASSY	X																		X						X	X										3223
RADIATOR ASSY	X																		X						X	X										424
RADIATOR ASSY	X																		X						X	X										797
CONDENSER CPL										X				X																X	X					3
COOLER- CHARGE-AIR/AIR																		X			X															143
COOLANT/AIR COOLER													X						X						X											149
COOLER- CHARGE-AIR		X																X		X																5771
CORE											X								X			X														1860
COOLER- CHARGE-AIR/AIR		X																X		X																45680
EVAPORATOR CPL				X												X												X								12096

Appendix 11: Inventory Carrying Costs Before and After Implementation of Proposal 1

	CURRENT	AFTER WORKSHOP/ ONE PLANNING POINT
average qty awaiting assembly	5500	431
average value per unit (ZAR)	246	246
imputed interest	7%	7%
opportunity cost of capital per year (ZAR)	94 710.00	7 421.82
required space (sqm)	183.30	128.80
cost per squaremeter per year (ZAR)	528.00	528.00
cost for space (ZAR)	96 782.40	68 006.40
cost for carrying inventory post braze	191 492.40	75 428.22
average qty awaiting brazing	431	431
average value per unit (ZAR)	201.00	201.00
imputed interest	7%	7%
opportunity cost of capital per year (ZAR)	6 064.17	6 064.17
required space (sqm)	61.60	61.60
cost per squaremeter per year (ZAR)	528.00	528.00
cost for space (ZAR)	32 524.80	32 524.80
cost for carrying inventory pre braze	38 588.97	38 588.97
annnual cost for carrying inventory pre and post braze	**191 492.40**	**75 428.22**

Appendix 12: Required Space for Post Braze FIFO lanes

Required Space For Post Braze Fifo Lanes

Assembly line	Min. qty on trolley	Cycle time CB	Produced qty in one CB shift	required FIFO lane bays	provided FIFO bays at line	provided post braze bays	Cycle time brazing	Time to Braze Qty (hours)	CB No.	Brazed No.	Assy Part No.
CAC OE	30	1.50	293.20	10	9	6	0.28	1.37	[redacted]	[redacted]	[redacted]
CAC AM	30	4.00	109.95	4	4	6	0.18	0.33	[redacted]	[redacted]	[redacted]
Rad.	42	2.56	171.93	5	8	6	0.42	1.21	[redacted]	[redacted]	[redacted]
LTR	45	1.60	274.88	7	2	6*	0.51	2.35	[redacted]	[redacted]	[redacted]
Rad. AM	87	1.98	222.57	3	6	6	0.47	1.73	[redacted]	[redacted]	[redacted]
Evap	42	1.71	257.19	7	7	-	0.15	0.62	[redacted]	[redacted]	[redacted]
Cond.	45	1.62	271.48	6	6	-	0.26	1.16	[redacted]	[redacted]	[redacted]
Rad. OE	50	1.20	366.50	8	6	6	0.26	1.59	[redacted]	[redacted]	[redacted]

*bays at condenser line

Ideally, the furnace runs every brazing profile once a shift in order to reduce downtime at the furnace.
Often, there have to be more model changes.
Nevertheless, the maximum quantity of one CB product that can be brazed is the quantity of one shift of CB.
So this is the maximum quantity that can fill up the assembly FIFO lanes very quickly (within from 0.33 hours up to 1.73 hours)

Appendix 13: Cost Estimate for Workshop

BOTTLE NECK WORKSHOP COST				
Cost per hour of Process Technician	**No. Hours**	**Cost**		
R 126				
1) Training Material Preparation				
Presentation	5	R 630		
Assessment Guide	2	R 252		
2) Workshop Duration in Hours				
Workshop (Classroom based)	2.5	R 315		
Practical (In plant)	2	R 252		
Tea/Lunch break	1	R 126		
Knowledge Assessment	0.5	R 63		
Practical Assessment per 7 Employees	0.7	R 88		
Total Hours = 6.1				
3) Roll-Out				
X3 Sessions of Workshop	7.5	R 945		
X3 Sessions of Practical Assessment	6	R 756		
Roll out of 3 sessions and Preparation	**20.5**	**R 3 427**		
Training Cost per Job	**Per Hour**	**Duration**	**Number**	**Total**
OE Assembly Operator	40.84	6.1	20	**R 4 982**
SUM COST OF OPERATORS AND PROCESS TECHNICIAN				**R 8 410**

Appendix 14: Annual Energy Costs for Third Brazing Shift

	hours	LPG in kg/hour	cost per kg	electricity in kWh	cost per kWh	total costs	total costs per option
weekly standby	7	7.2	13.6136	60	0.04077	703.24884	1 153.41
	1	32.6	13.6136	156	0.04077	450.16348	
1 shift running	8	43.8	13.6136	169	0.04077	4825.3265	4 825.33

costs in ZAR

2 shifts running, one shift weekly standby	
annual energy costs for the standby shift	259 517.77
3 shifts running	
annual energy costs for the third running shift	1 085 698.46

- LPG is 13,6136 ZAR/kg
  or 7,56 ZAR/l
- Electricity is 6.077 ct/kWh

Normal operating conditions (per hour)

LPG: 43.8 kg

electricity: 169 kW

Weekly standby (per hour)

LPG: 7.2 kg

electricity: 60 kW

Ramp up (per hour)

LPG: 32.6 kg

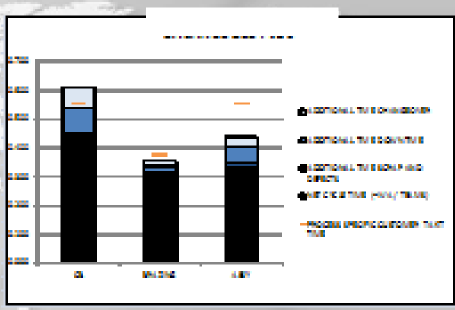
electricity: 156 kW

Appendix 15: Description of Balancing Chart Template

Macro Line Balancing Chart

CONTENTS

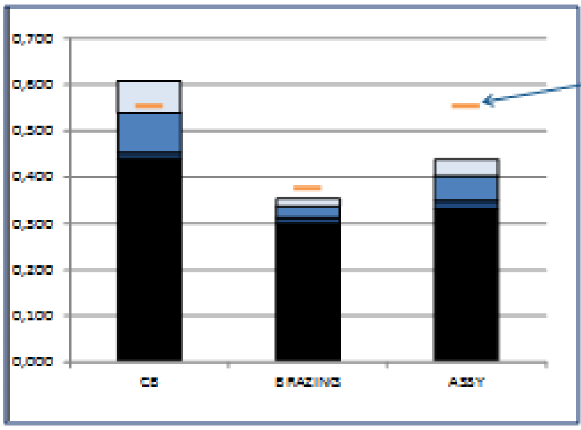
- What does the chart tell you?
- Calculation of the Chart (3)
- Where to insert data? (3)



Macro Line Balancing Chart

What does the chart tell you?

- Every how many minutes does CB produce one core?
- Every how many minutes consumes the furnace a product?
- Every how many minutes does assembly process one part?

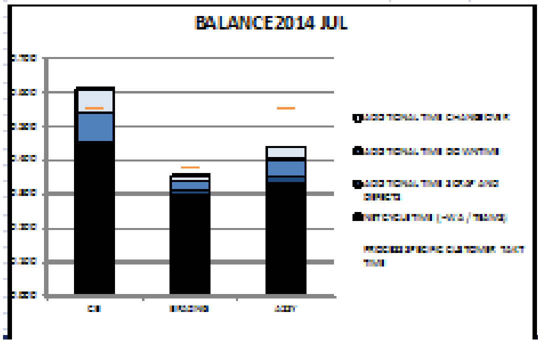


Every how many minutes do we have to produce a part in order to meet customer demand?

Macro Line Balancing Chart

Calculation – Net Cycle Time (1/3)

		CB	BRAZING	ASSY
NET CYCLETIME (=WA / TEAMS)		0.442	0.299	0.330
ADDITIONAL TIME SCRAP AND DEFECTS		0.011	0.014	0.020
ADDITIONAL TIME DOWNTIME		0.087	0.024	0.052
ADDITIONAL TIME CHANGEOVER		0.069	0.016	0.036
GROSS CYCLE TIME (=NET CT+ ADDITIONAL TIME)		0.608	0.353	0.439
PROCESS SPECIFIC CUSTOMER TAKTTIME		0.553	0.377	0.553
total demand for period	54 919			
working days in period	23			
operating hours per shift		7.33	7.5	7.33
shifts		3	2	3
teams (How many lines are active at the same time?)		4	1	3.66

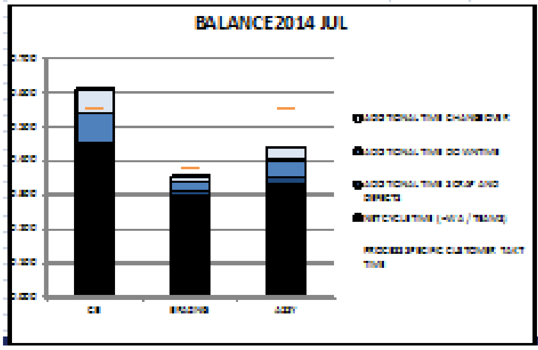


- The basis is the net cycle time, which is the SAP cycle time of the products weighted by their volumes for the regarded period of time
- For core building and assembly, this time has to be divided by the number of lines that run simultaneously (teams)

Macro Line Balancing Chart

Calculation – Gross Cycle Time (2/3)

		CB	BRAZING	ASSY
NET CYCLETIME (=WA / TEAMS)		0.442	0.299	0.330
ADDITIONAL TIME SCRAP AND DEFECTS		0.011	0.014	0.020
ADDITIONAL TIME DOWNTIME		0.087	0.024	0.052
ADDITIONAL TIME CHANGEOVER		0.069	0.016	0.036
GROSS CYCLE TIME (=NET CT+ ADDITIONAL TIME)		0.608	0.353	0.439
PROCESS SPECIFIC CUSTOMER TAKTTIME		0.553	0.377	0.553
total demand for period	54 919			
working days in period	23			
operating hours per shift		7.33	7.5	7.33
shifts		3	2	3
teams (How many lines are active at the same time?)		4	1	3.66



- The Net Cycle Time shows the situation in an ideal plant
- To calculate the Gross Cycle Time, additional times are added for scrap & defects, downtime and changeovers are added:

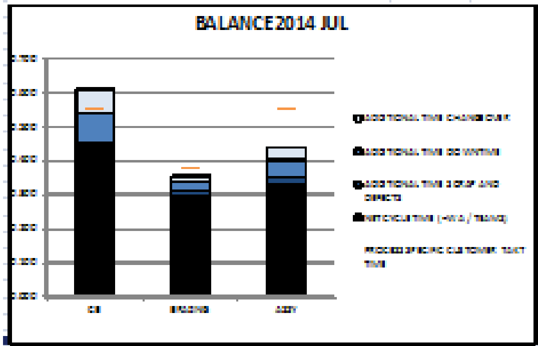
weighted by the volume

- Additional Time Scrap & Defects
  = (scrap rate+ defect rate)* net cycle time
  Scrap % per product group (Jan-Jul)
  Defect % per p. no (Jan – Jul)
  Rebraze % per product group (Jan – Jul)
- Additional Time Downtime
  = downtime percentage*customer takt time
  Downtime % per line (Jan – Jul)
- Additional Time Changeovers
  = setup time/CLS

Macro Line Balancing Chart

Calculation – Customer Takt Time (3/3)

		CB	BRAZING	ASSY
NET CYCLE TIME (=WA / TEAMS)		0.442	0.299	0.330
ADDITIONAL TIME SCRAP AND DEFECTS		0.011	0.014	0.020
ADDITIONAL TIME DOWNTIME		0.087	0.024	0.052
ADDITIONAL TIME CHANGEOVER		0.069	0.016	0.036
GROSS CYCLE TIME (=NET CT + ADDITIONAL TIME)		0.608	0.353	0.439
PROCESS SPECIFIC CUSTOMER TAKT TIME		0.553	0.377	0.553
total demand for period	54 919			
working days in period	23			
operating hours per shift		7.33	7.5	7.33
shifts		3	2	3
teams (How many lines are active at the same time?)		4	1	3.66



- In order to see, if the fractals are able to meet customer demand, customer takt time is added
- This is the available time of the fractal divided by the available time at the fractal
- Example core building:

$$\frac{7.33\ hours * 60\ minutes * 3\ shifts * 23 working\ days}{54\,919\ parts} = 0.553\ minutes/part$$

Macro Line Balancing Chart

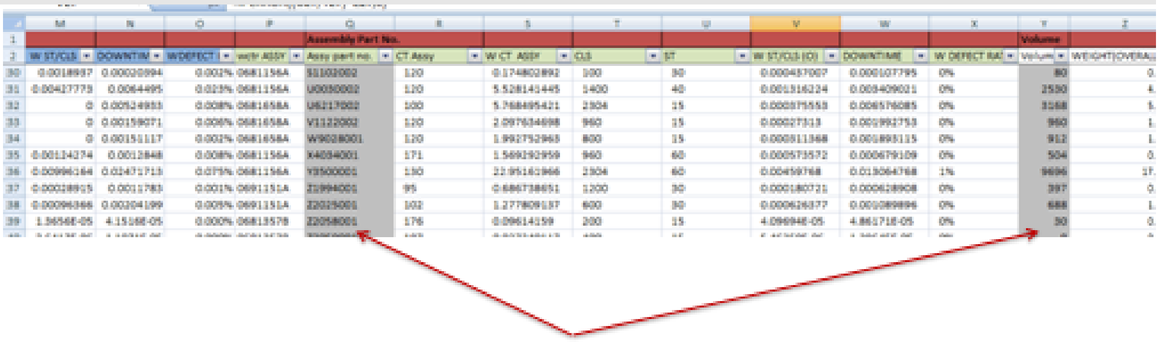
Where to insert Data – Chart

		CB	BRAZING	ASSY
NET CYCLE TIME (=WA / TEAMS)		0.442	0.299	0.330
ADDITIONAL TIME SCRAP AND DEFECTS		0.011	0.014	0.020
ADDITIONAL TIME DOWNTIME		0.087	0.024	0.052
ADDITIONAL TIME CHANGEOVER		0.069	0.016	0.036
GROSS CYCLE TIME (=NET CT + ADDITIONAL TIME)		0.608	0.353	0.439
PROCESS SPECIFIC CUSTOMER TAKT TIME		0.553	0.377	0.553
total demand for period	54 919			
working days in period	23			
operating hours per shift		7.33	7.5	7.33
shifts		3	2	3
teams (How many lines are active at the same time?)		4	1	3.66

- Grey boxes in the chart require data to be inserted
- On the chart sheet the available time and the number of teams need s to be inserted

Macro Line Balancing Chart

Where to insert Data – Data sheet



	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1					Assembly Part No.								Volume	
2	W ST/CLS	DOWNTIM	WDEFECT	wo/tr ASSY	Assy part no.	CT Assy	W CT ASSY	CLS	ST	W ST/CLS (O)	DOWNTIME	W DEFECT RA	Volum	WEIGHT(OVERAL
30	0.0018937	0.00020994	0.002%	0681156A	S1102002	120	0.174802892	100	30	0.000457007	0.000107795	0%	80	0.
31	0.00427773	0.0064495	0.023%	0681156A	U0050002	120	5.528141445	1400	40	0.001316224	0.003409021	0%	2530	4.
32	0	0.00524933	0.008%	0681658A	U6217002	100	5.768495421	2304	15	0.000375553	0.006576085	0%	3168	5.
33	0	0.00159071	0.006%	0681658A	V1122002	120	2.097634698	960	15	0.00027313	0.001992753	0%	960	1.
34	0	0.00151117	0.002%	0681658A	W9028001	120	1.992752963	800	15	0.000311368	0.001893115	0%	912	1.
35	0.00124274	0.0012848	0.008%	0681156A	X4034001	171	1.569292959	960	60	0.000573572	0.000679109	0%	504	0.
36	0.00996164	0.02471713	0.075%	0681156A	Y3500001	130	22.95161966	2304	60	0.00459768	0.013064768	1%	9696	17.
37	0.00028915	0.0011783	0.001%	0691151A	Z1994001	95	0.686738651	1200	30	0.000180721	0.000628908	0%	397	0.
38	0.00096366	0.00204199	0.005%	0691151A	Z2025001	102	1.277809137	600	30	0.000626377	0.001089896	0%	688	1.
39	1.3656E-05	4.1516E-05	0.000%	0681357B	Z2058001	176	0.09614159	200	15	4.09694E-05	4.86171E-05	0%	30	0.

- In order to calculate the weighted averages and the customer takt time, the chart requires the assembly part numbers and the corresponding volumes
- The data has to be inserted in the grey columns, the white columns will change automatically

Macro Line Balancing Chart

Where to insert Data – new model introductions

- If there are new model introductions or changes in the percentages of downtime, defects, rebrazes or scrap, the sheets that contain the background data have to be updated
- In order to do so, the data in the grey boxes in the sheets marked below can be overwritten

Appendix 16: Editing Confirmation Letter

24 June 2019

To whom it may concern

Dissertation prepared by Ms Kate Lusiba

This letter confirms that I have edited the Dissertation entitled **A Roadmap for Improving the Manufacture of Automotive Heat Exchangers through Value Stream Mapping** for linguistic and grammatical correctness.

I am a qualified editor and proof reader.

Michael Vermeer
Editor/ Proofreader

082 093 4347

mike.vermeer3@gmail.com