The applicability of selected lean manufacturing tools in a coal beneficiation plant

WH Kheswa
24738336

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Supervisor: Mr JA Jordaan

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ABSTRACT

The main objectives of this study were to investigate if lean manufacturing tools were applicable in a coal beneficiation plant and to apply these tools in an effort to optimise the plant processes. This study was conducted at XYZ coal beneficiation plant situated in the Mpumalanga province.

The volatility of mining commodity prices like coal prices poses a threat to the profitability of mining companies. Since mining companies have no control over the coal price; they need to keep their unit costs low to widen their profit margins. Lean manufacturing is one approach that could be utilised to improve productivity, eliminate waste and improve unit costs. A literature study was conducted to understand the Lean concepts, to analyse theory as well as to investigate similar studies on the topic. The theory was also analysed together with the practical processes to understand how theory can be applied to a coal beneficiation plant in practice.

The current state Value Stream Mapping (VSM) was drawn to uncover the type and amount of wastes and inefficiencies in the plant so as to identify opportunities for improvement. The study identified wastes of motion, inventory, inappropriate processing as well as other process inefficiencies. Subsequent to this, projects were initiated to optimise the processes. The projects were carried out through the application of such lean tools as Six Sigma, flexible plants, flexible processes, 5S’s of good housekeeping, standard work and quality at the source which all proved to yield positive results for XYZ plant.

The selected lean manufacturing tools were conclusively found to be applicable to the XYZ coal beneficiation plant; whilst some tools were not applied either because they were less applicable or have already been applied by the organisation. The study also presented opportunities for longer term projects which the organisation could pursue further for future optimisation as well as recommendations for the organisation and for future research.

KEY TERMS

Lean manufacturing, coal beneficiation
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>DMS</td>
<td>Dense Medium Separation</td>
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<td>DSM</td>
<td>Dutch State of Mines</td>
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<tr>
<td>EA</td>
<td>Equipment availability</td>
</tr>
<tr>
<td>EEP</td>
<td>Equipment efficiency performance</td>
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<tr>
<td>EQP</td>
<td>Equipment quality performance</td>
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<tr>
<td>ERP</td>
<td>Enterprise Resource Planning</td>
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<tr>
<td>GE</td>
<td>General Electric</td>
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<tr>
<td>JIT</td>
<td>Just in time</td>
</tr>
<tr>
<td>LOM</td>
<td>Life of Mine</td>
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<tr>
<td>OEE</td>
<td>Overall Equipment Effectiveness</td>
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<tr>
<td>PFD</td>
<td>Process Flow Diagram</td>
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<td>PSD</td>
<td>Particle Size Distribution</td>
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<td>RBCT</td>
<td>Richards Bay Coal Terminal</td>
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<tr>
<td>RCM</td>
<td>Reliability Centred Maintenance</td>
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<tr>
<td>RLT</td>
<td>Rapid Loading Terminal</td>
</tr>
<tr>
<td>ROM</td>
<td>Run-Of-Mine</td>
</tr>
<tr>
<td>SMED</td>
<td>Single Minute Exchange of Dies</td>
</tr>
<tr>
<td>TFR</td>
<td>Transnet Freight Rail</td>
</tr>
<tr>
<td>TPM</td>
<td>Total Preventive Maintenance</td>
</tr>
<tr>
<td>TQF</td>
<td>Tons and Quality Forecast</td>
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<td>VSM</td>
<td>Value Stream Mapping</td>
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GLOSSARY

Cycle time: The time it takes for a production section to complete its set of operations.

Kanban: A scheduling system whereby signals are used to notify the previous production step to produce only the required amount.

Takt time: The time required per unit of product to produce enough quantities to meet the customer demand.

OEE: Overall Equipment Efficiency based on quality, availability and effectiveness, calculated as; \( OEE = EA \times EEP \times EOP \);

Supermarket: a store where upstream continuous flow processes can withdraw stock as and when required.

Xeras: an activity based financial model designed for long term planning, financial budgeting and strategic decision making.

Xpac: a mine scheduling software used to model reserves, schedule production and evaluate best practice scenarios.
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CHAPTER 1: NATURE AND SCOPE OF THE STUDY

Background


The South African coal mining industry is no exception to the challenges facing other industries globally and locally. The South African coal mining industry is facing challenges with the mineable reserves depleting faster and this calls for a review in the way the mineral resources are being exploited / extracted from their ores. The coal export industry thus needs to improve efficiency of operations and reduce its costs of production in order to remain in business. According to Hartnady (2010:1) there has been a reduction of close to 18 billion tonnes (Gt) in South Africa’s coal reserves from 48 Gt to only 30Gt. Hartnady (2010:1) goes further to suggest that the South Africa (SA) year book 2007 / 2008 states that SA was ranked the 8th largest recoverable coal reserves owner in the world which is a step backward from the previous 6th place ranking in the work by the United States Department of Energy. South Africa may face further reduction of mineable coal reserves in a re-assessment (Hartnady, 2010:4). The coal export industry needs to find more efficient ways of extracting the most value from the ore using minimum resources.

The coal mining and export industry is also facing challenges with the actual price of thermal coal continuously falling below the budgeted price. Analysts predict that the coal prices will remain low for the most part of the year 2015; which makes it even more important for collieries to adopt lean manufacturing practices.

The structure of the SA coal industry

Coal production in SA is mainly concentrated in Witbank, Highveld and Ermelo regions of the Mpumalanga province, Sasolburg, Vereeniging and the Waterberg coalfields (Hartnady, 2010:3). The Mpumalanga (Witbank, Highveld and Ermelo) and the Sasolburg – Vereeniging
coalfields are located in close proximity to the major SA industries like Eskom, Sasol, Arcelor Mittal and are located favourably close to the Richards Bay coal line; whereas the Waterberg coalfields currently consist of one colliery (Grootegeluk) feeding the Matimba and Medupi Eskom power stations. The Waterberg coalfield has difficult geological structures and literature suggests that geological disturbances have progressively become worse. The lack of major industries and railway infrastructure in the Waterberg is a hindrance to the development of the area.

Hartnady (2010:4) attributes low grade coals and the lack of ground and surface water resources as the major stumbling block to the development in the Waterberg region. Hartnady (2010:4) continues to say that unfavourable geological conditions, hydro meteorological, technical and socioeconomic factors negate the existence of large mineable coal reserves in the Waterberg. This is not the case in the Mpumalanga coalfields as the geological conditions are more favourable, the coal is high grade for the export market; middling coal for major industries and there’s sound infrastructure to get the export coal to the Richards Bay Coal Terminal (RBCT). The above implies that even if the efficiency of operations were to be improved in the Waterberg coalfields, there wouldn’t be immediate additional demand for the local coal; since there’s only one major industry in the area and there would still be no infrastructure to rail the coal to RBCT. For this reason the study will be conducted in the Mpumalanga Province, Highveld coalfields; there’s an immediate need to improve efficiency of operations in the Mpumalanga coalfields so as to economically extract maximum value from the coal without premature depletion of the coal reserves.

Motivation of topic actuality
The coal mining industry forms part of the mining sector which makes a valuable contribution to the SA economy. It is important that the extraction of coal from the reserves is done economically so as to sustain the contribution to the economy. According to the Dassault Systemes’ Special Report on Mining Innovation (2013:6) today’s economic environment has completely changed the demand of commodities and its prices which makes it more challenging for mining companies to forecast future patterns / trends.

The falling coal prices versus increasing costs of mining / production pose a threat to coal exporting organisations who fail to adapt to the financially stressed coal market. The study will provide knowledge that the coal exporters need in order to be able to withstand the tough times facing the industry. Dr J Benndorf, resource engineering assistant professor in the Department
of Geosciences and Engineering at the TU Delft University in the Netherlands says that Mines must be set up such that it is easy to react to changes in demand and that some mining companies are turning to experts from other industries for assistance. (Special report on mining innovation, 2013:08)

The successful execution of this study will assist the organisation in its competitiveness and will better position the organisation to respond to market demands. The study will add to the knowledge base of the researcher. The other motivating factor is that the researcher is a practicing Metallurgist employed in a coal processing plant, she will have full access to the resources required for the study and would be able to make a positive contribution to her organisation through this study.

1.1 Problem Statement

Organisations today are faced with increasing challenges from global and industry competition such that manufacturers need to adopt new operations management strategies in order to improve their efficiencies and remain competitive (Nordin, Deros & Wahab, 2010:374 and Shah & Ward, 2003:129). Pieterse, Lourens, Louw, Murray and Van der Merwe (2010:11) suggest that just like the global world; South African organisations are faced with a certain collection of challenges; whether it’s supply, technological, skills shortage or labour issues; the advisable way is to analyse the situation and then determine what the appropriate response should be to achieve the desirable results with minimum resources.

Nordin, Deros and Wahab (2010:374) suggest that one of the greatest management tools to achieve that is lean manufacturing. According to Holweg (2007:420) lean manufacturing has become a widely accepted manufacturing tool worldwide and across industries. The main aim of a lean organisation is to produce the final products without waste (Nordin, Deros & Wahab, 2010:374). This view is shared by Shah and Ward (2003:129) when they suggested that the core of lean manufacturing is to produce customer products at the pace of customer demand with little or no waste; as well as Pieterse et al. (2010:2) who contend that the purpose of lean manufacturing is to satisfy the customer through faster, cheaper and better quality products through the relentless reduction of waste. Balle (2005:14), Doolen and Hacker (2005:56) and Ward and Shah (2003:131) argue that although many plants that have tried to implement lean manufacturing, a few of them have successfully done so. This view is supported by Nordin, Deros and Wahab (2010:374) who asserts that in reality many organisations are not able to
sufficiently transform themselves into lean organisations. Balle (2005:16) states that the few organisations that have successfully implemented lean manufacturing approached it as a system rather than just a toolbox; whilst Pieterse et al. (2010:11) support this argument by saying that the biggest danger in the implementation of lean manufacturing is that it is regarded as a set of tools rather than a system and Shah & Ward (2003:129) share the same view as they contend that lead production practices work synergistically as a system.

The coal beneficiation plant being studied currently has a lot of waste generated through the process, which the customers would not want to pay for; there's a lot of rework in the maintenance workshop and quality of the coal products produced fluctuates from the specifications. This necessitates that lean practices be investigated to eliminate the wastes generated. The purpose of this study is to investigate the applicability of lean manufacturing tools in a coal beneficiation plant, understand the factors that might inhibit successful implementation with the hope that the study will help the organisation to find ways to overcome hindrances and successfully implement an effective lean management system.

1.1.1 Objectives

Main Objectives

The beneficiation plant is supplied by the mine; when the plant generates waste the Mine must produce more Run of Mine (ROM) coal for the plant to be able to fulfil customer commitments. Eliminating waste produced from the plant will lower the volumes required from the Mine thus preventing premature depletion of the coal resources in the Mine. Pieterse et al. (2010:5) suggest that each organisation that wants to implement lean manufacturing must discover its own set of wastes first. Since lean production was pioneered in a batch production context; it is important to investigate the applicability of the tools and practices in a continuous high volume production process like the coal beneficiation plant.

The main objective of the study is:

- To investigate the applicability of lean manufacturing tools and techniques in a coal beneficiation plant.

Secondary Objectives

- To identify applicable lean optimisation techniques and tools through a literature study
To analyse these lean techniques and tools for applicability in the specific plant
To recommend improvements in the plant processes, using these tools and techniques.

1.1.1.1 Research design or method

The study was conducted in three phases. The first phase is a comprehensive literature study. The second phase is a practical study of the beneficiation process in the plant and a practical implementation of selected lean manufacturing tools on the process. The third phase is a comparative study of the results before and after the implementation of selected lean tools.

Literature review

A literature review was conducted to understand what has been learnt in the discipline of lean manufacturing and what still needs to be researched further. The literature review assisted the researcher in rationalising the need for this research study. The literature review also provided guidance in designing this study through learning how previous researchers went about conducting similar studies. Sources that were consulted include NWU library databases, scientific journals, accredited journals, internet sources and lean manufacturing and operations management text books. The databases that were used are Google scholar, Ebscohost, Science Direct, JSTOR, SAePublication, Web of Science and Sabinet references.

Empirical research

The empirical study consisted of a physical analysis of the beneficiation process before practical implementation of selected lean manufacturing tools and techniques.

Data analysis

Performance data were compared before and after the implementation of selected lean tools. To analyse the data basic statistical functions like correlations and regressions were employed.

1.1.1.2 Overview

The chapter layout are as follows:
Chapter 1: Nature and scope of study
The focus of the study is the subject of operations management. The study focused on improving efficiency of a coal beneficiation plant. The objectives of this chapter are to contextualise the study and introduce the basic components of the study. The purpose of this chapter is therefore to inform the reader regarding the contents of the study. This chapter covers the following subtopics:
- Problem statement
- Objectives of the study
- Scope of the study
- Research methodology
- Limitations of the study
- Layout of the study

Chapter 2: Overview of the organisation
The purpose of this chapter is to introduce the organisation, describe the beneficiation process and what caused the need for the study.

Chapter 3: Literature Review
The objective of this chapter is to provide information regarding what has been studied; the gaps that still need to be filled and to guide the researcher. This chapter defines the concept of lean manufacturing and lean practices and techniques.

Chapter 4: Empirical Study
The purpose of this chapter is to outline the research approach that the study followed and the reasoning behind it. It describes how data was collected and analysed. Findings and a discussion of the findings are also presented in this chapter.

Chapter 5: Research conclusions and recommendations
The purpose of this chapter is to draw conclusions and make recommendations regarding the topic. This chapter also links the findings back to the objectives, show limitations of the study and give recommendations for future research.
LITERATURE REVIEW

2.1 Introduction

Chapter 1 proposes that a study be carried out in a coal beneficiation plant to investigate whether lean manufacturing tools and principles could be applied in a coal washing plant. A coal washing plant forms part of the mining industry which has been pressured due to falling coal prices and subdued coal demand. This chapter discusses the applicable literature on lean manufacturing. The coal mining and exporting industry is facing challenges with the price of thermal coal continually on the decline; while the weakening Rand contributes to the situation as the costs of operations continue to increase. This necessitates that the coal exporting companies review the way they conduct business. As profit margins are squeezed, coal exporters need to find ways to reduce waste, improve efficiencies, do more with less and reduce costs in order to remain profitable in this pressured economic environment.

The graph below shows the declining price of thermal coal:

Figure 2 - 1: The price of thermal coal

Source: http://www.tradingeconomics.com/commodity/coal

Lean manufacturing has been widely known as one way of reducing waste and improving efficiency (Pavnaskar, Gershenson & Jambekar, (2003:3075). This study investigates the
applicability of selected lean tools in a coal beneficiation plant to help reduce waste. The tools that will be studied are Value Stream Mapping (VSM), Lean Six Sigma, 5S’s of housekeeping, Total Productive Maintenance (TPM), standard work, quality at the source, flexible processes and continuous improvement.

LEAN MANUFACTURING

Pieterse et al. (2010:2) describes lean manufacturing as a systematic method of designing or improving a process or value stream that eradicates waste, improves quality, satisfies customers, reduces costs, improves employee satisfaction and improves safety performance. Pieterse et al. (2010:2) go on to say that lean manufacturing is accomplished by achieving a smooth flow through relentless eradication of non-value added activities and this view is shared by Vinodh et al. (2010:889) where they contend that lean manufacturing is about elevating the awareness levels regarding the wastes at various levels of the production system and working to eliminate it. Das, Venkatadri and Pandey (2013:307) suggest that lean manufacturing aims to improve productivity and reduce waste.

Taiichi Ohno identified seven wastes that may be addressed through lean practices and these wastes are overproduction, waiting, transport, inappropriate processing, inventory, motion and defective goods. It is crucial that an organisation identifies and registers the wastes applicable to it and then adapt lean principles and tools to eliminate those wastes because not all seven wastes are applicable to any one organisation whilst some wastes may be excluded from the seven (Pieterse et al., 2010:5).

In their book, “Lean thinking”, Womack and Jones (1996) suggested that in order to implement basic lean tools, the process should involve identifying what the customer sees as good value, identifying the value stream, creating a flow of the value adding activities, designing, scheduling and producing exactly what the customer wants at the time they want it and finally simplifying the process and making it easy for improvements.

Bonavia and Marin (2006:507) define waste as anything that is above strict minimum required by way of equipment, materials, components, space or employee time in order to give added value to the goods produced. According to Pieterse et al. (2010:2) as well as Jacobs and Chase (2014:347), Ohno (1965) identified seven wastes that can be found in production processes and these wastes are: Overproduction, Defects, Waiting, Transport, Motion, Inventory and non-value
added processing. According to Doolen and Hacker (2005:55), Bergmiller and McCright (2009:2) and Pieterse et al. (2010:8), Womack & Jones defined five lean principles to eliminate waste in organisations. These principles are: specify value, identify the value stream, flow, pull and perfection.

Flott (2002:77-82) and Srinivasaraghavan (2006:1159-1168) assert that organisations who ignore the lean manufacturing strategy would not stand a chance in a highly competitive environment. I concur with this view, for example looking at the fluctuations in the price of thermal coal during the year 2014; only organisations that are cost competitive would remain profitable as the price of thermal coal continues to fall while the costs of raw materials continue to increase. Demeter and Matyusz (2011:2) say that all organisations have to invest in manufacturing management programs, methods and technologies so as to remain competitive.

Ward and Shah (2003:131) identified twenty two lean practices and categorised them into four lean bundles; namely Just in Time (JIT), Total Preventive Maintenance (TPM), Total Quality Management (TQM) and Human Resources Management (HRM). Panizzolo (1998:227) operationalized lean concepts for a lean organisation by categorising practices into six different areas, namely process and equipment, manufacturing planning and control, human resources, product design, supplier relationships and customer relationships; whereby the first four were classified into internal practices and the last two into external practices. The study by Panizzolo found that many organisations have difficulty in adopting lean tools when it comes to external relationships with suppliers and customers.

While Balle (2005:16), Pieterse et al. (2010:11) as well as Shah & Ward (2003:129) contend that applying a full set of lean principles and tools leads to successful lean manufacturing transformation; Nordin, Deros and Wahab (2010:375) cites Achanga, Shehab, Roy and Nelder (2006:460-471) are saying that successful lean management implementation is dependent on critical organisational factors like leadership and management, finance, skills and expertise and a supportive organisational culture. On the other hand Galbraith (1997) as cited by Ward and Shah (2003:131) argues that the successful implementation of lean manufacturing often depends on organisational characteristics and not all organisations can or should implement the same set of practices.

Various authors have defined well proven practices, tools and techniques (Pieterse et al., 2010; Rother & Shook (1998); www.strategosinc.com) to implement lean production of which some
may focus on the organisation as a whole as a unit of analysis; for example total productive maintenance whereas others like value stream mapping may focus only on the product value stream.

According to Womack, Jones and Roos (2007:52), lean is the elimination of waste. Lean manufacturing is about a relentless reduction of waste in a manufacturing process (Conroy, 2013:18). Conroy (2013:18) stated that the Lean Enterprise Research Centre (LERC) suggests that a typical manufacturing process has up to 60% of waste activities. Lean manufacturing is a production philosophy that originated from a Japanese automobile manufacturer, Toyota Motor Corporation; focused at removing waste or non-value adding activities thus reducing costs and improving productivity (Abdumalek & Rajgopal, 2006:1; Nordin, Deros & Wahab, 2010:374; Hines, Holweg & Rich, 2004:994; Doolen & Hacker, 2005:55; Shah & Ward, 2007:786; Detty, Yingling & Sottile, 2000:215; Jacobs & Chase, 2014:348 and Pieterse et al., 2010:7). In the environment of lean, value is defined as those activities which the customer is willing to pay for. Pettersen (2009:134) says that the purpose of lean manufacturing is waste elimination. Activities which the customer will not want to pay for if they knew they were occurring would be classified as waste. Waste elimination is therefore a very basic principle of lean manufacturing.

According to Melton (2005:665); Rich & Hines (1997:47); Pieterse et al. (2010:2) and Abdullah (2003:8), Taiichi Ohno identified seven wastes that can be found in any production process. These seven wastes are:

i. **Overproduction**: producing more than what’s needed in the next process.

ii. **Transportation**: the moving around of material in the workplace is another form of waste, for example the dumping of coal on the ground in a coal plants instead of just loading it into the conveyor belts.

iii. **Waiting**: the amount of time spent waiting; for example waiting for a job card, waiting for spares.

iv. **Inappropriate processing**: the way that processing of material might be such that it generates waste. Long unproductive meetings, rework, poor maintenance might be waste in the form of inappropriate processing.

v. **Inventory**: excess inventory is another form of waste.

vi. **Motion**: moving around between work stations constitutes waste. The flow of work must be continuous such that employees don’t spend time moving in between work stations.

vii. **Defective goods**: defects are those goods / products that do not meet the required quality specifications.
Apart from waste elimination; another philosophy central to the concept of lean manufacturing, is respect for people. According to Jacobs and Chase (2014:348), respect for people is key to lean manufacturing and Toyota has demonstrated this through assuring its permanent employees lifetime employment and by keeping level remuneration even during economic downturns. Respect for people could also imply giving employees meaningful work such that they make meaningful contributions in the organisation. In a lean organisation, employees are viewed as the most valued asset; they are encouraged to enhance productivity and are rewarded well for their contribution on the organisation’s profits (Jacobs & Chase (2014:348) and Yingling et al. (2000:17)

2.1.1 Lean Manufacturing Principles and Techniques

Lean manufacturing comprises of many different sets of tools and techniques that can be used to eliminate waste and improve / optimise a production process. The following lean manufacturing tools have been identified by various authors, including Pieterse et al. (2010:12) and these are: flexible resources, cellular layout, pull production, kanban production, quick set ups, uniform production levels, quality at the source, Just in Time (JIT), kaizen, supplier networks, standard work, Six Sigma, 5S’s of good housekeeping, Total Productive Maintenance (TPM) and Value Stream Mapping (VSM).

However according to Rodriguez, Santos, Tanco & Reich (2013:1640) applying all lean tools at once only leads to chaos and unsustainable efforts. Pieterse et al. (2010:7) say that most attempts of adopting lean manufacturing failed because the lean tools were not integrated as a complete system and because only a few people understood the underlying principles of lean manufacturing. Really implementing lean successfully therefore requires a major change management exercise.

Within the scope of this study, the investigation into the applicability of lean manufacturing tools and techniques in a coal beneficiation plant will only be limited to Value Stream Mapping (VSM), Lean Six Sigma, 5S’s of housekeeping, Total Productive Maintenance (TPM), standard work, quality at the source, flexible processes and continuous improvement.

2.1.1.1 Lean Six Sigma

Lean Six Sigma was originally developed by Motorola in 1985 when they were threatened by the Japanese competition in the electronics industry and they needed to reduce product defects (Schroeder et al. 2008:537; Pieterse et al. 2010:112; and Schroeder 2000:1). According to
Slater (1999), General Electric (GE) began its Six Sigma implementation in 1995. According to the BSI group, lean Six Sigma is a business approach that concentrates on eliminating waste and product variation from production, service or design processes (www.bsigroup.com). Lean Six Sigma is quality improvement approach of Total Quality Management in lean manufacturing (www.isixsigma.com).

“Lean Six Sigma is a quality program that, when all is said and done, improves your customer’s experience, lowers your costs, and builds better leaders.” (Jack Welch)

Schroeder et al. (2008:537) defines Six Sigma as a business process that enables organisations to better their bottom line by designing and monitoring their business activities in ways that minimise waste and resources as well as reduce quality defects while increasing customer satisfaction. Schroeder (2000:2) defines Six Sigma as an organized and systematic method for strategic process improvement and new product development that relies on statistical methods and the scientific method to make dramatic reductions in defect rates as defined by the customer. Six Sigma is an effective application of statistical techniques, delivered in an innovative manner that has achieved acceptance, use and results by the management and associates of many organizations (Edgeman, Wiklund & Klefsjoè, 2001:32).

According to Wang and Chen (2012:417) Six Sigma is a methodology that maximises shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, speed and invested capital. Six Sigma processes use a set of statistical tools to analyse and understand fluctuations in the process and focuses on reducing variation which will improve or enhance quality and solve process and business problems (Jacobs & Chase, 2014:301 and Klefsjoè, Wiklund and Edgeman, 2001:33).

Schroeder (2000:2) suggests that Six Sigma requires the commitment of top management leadership, must be customer driven, focuses on business and financial results, requires a structured approach, makes use of special metrics and uses improvement specialists. According to Chen and Wang (2012:419); Pieterse et al. (2010:113) and Jacobs & Chase (2014:302), one of the commonly used Six Sigma tools is the DMAIC methodology which is a cyclical / systematic method that focuses on finding process variations and process / quality defects; as well as understanding what the customer wants and realising it.

Jacobs & Chase (2014:302); Wang and Chen (2012:419) and Pieterse et al. (2010:113) describe the DMAIC methodology as follows:
Define (D): this step is about identifying customers, their requirements, characteristics customers consider being critical and a project suitable for Six Sigma based on what the business seeks to achieve; as well as customer needs and feedback.

Measure (M): the process factors that influence critical characteristics are identified and defects are measured.

Analyze (A): the data is analysed to understand what the causes of defects are.

Improve (I): Developing solutions to eliminate defects and measure the effects of implemented solutions to the process.

Control (C): controls are put in place to ensure that the key variables remain within limits.

**XYZ Plant Application**

*Six Sigma* will be applied in the cost and quality metrics to reduce variation and improve business results in these two key performance areas.

2.1.1.1.1 Total Productive Maintenance

According to Pieterse *et al.* (2010:38) total productive maintenance (TPM) is a concept that originated from Japan and was intended to maximise the effectiveness of machinery and equipment on the ground floor. Equipment availability is a very important aspect of a production process because loss of availability or unplanned downtimes costs the company millions of rand in standing times and it costs employees thousands of rand in production bonus losses.

With TPM every employee linked to a particular equipment takes responsibility for maintenance and equipment availability (Pieterse *et al.*, 2011:38; Das, Venkatadri & Pandey, 2013:309 and Yingling, Detty & Sottile, 2000:225). This means that not only maintenance operators but production operators take responsibility for the equipment since they operate it. With TPM, the equipment / machine operator is empowered to shut down the machine should there be any problem (Yingling, Detty & Sottile, 2000:225). According to Rameesh, Prasad and Srinivas (2008:45) and Pieterse *et al.* (2010:38), the goal of TPM is to improve the overall equipment efficiency. Pieterse *et al.* (2010:38) and Yingling, Detty and Sottile (2000:226) suggest that TPM eliminates unplanned downtimes, rework, production losses and start-up / set up losses.

Jeong and Phillips (2001:1404) argue that TPM is a labour intensive preventive maintenance system for maximising equipment effectiveness and which involves all departments in the organisation. Chan *et al.* (2005:72) says that total TPM encompasses three meanings, namely:
• Total effectiveness which indicates TPM’s pursuit of economic efficiency and profitability.
• Total maintenance system includes maintenance prevention, maintainability improvement and preventive maintenance.
• Total participation of all employees, meaning that maintenance is achieved through a team effort.

Conroy (2013:18) defines eight pillars of TPM, namely:
• Autonomous maintenance: the operator is deemed responsible for maintenance. He or she cleans and lubricate the equipment. Cleaning includes marking all lubrication and adjustment points in the machine, correcting discovered problems, lubricating and restoring equipment to a new operating condition.
• Planned maintenance: scheduling maintenance based on reducing downtimes and failure rates.
• Quality maintenance: create error detection and prevention plans to eliminate defects.
• Early equipment management: improving design of new equipment with working knowledge.
• Training and education: filling the knowledge gap in the organisation.
• Health and safety: maintaining a safe working environment, ensuring that work is carried out safely, disposal of material and equipment is done in an environmentally friendly manner.
• Administration: applying TPM practices to administration functions.
• Focused improvement: improvement goals are set in terms of desired Effectiveness (OEE) value. Employees work proactively to identify and achieve Overall Equipment improvements in the operation. OEE indicates equipment efficiency based on quality, availability and effectiveness.

\[
OEE = EA \times EEP \times EQP;
\]

Whereby

\[
EA\text{ is the equipment availability}
\]

\[
EEP\text{ is the equipment efficiency performance; and}
\]

\[
EQP\text{ is equipment quality performance}
\]

2.1.1.2 The 5 S’s of housekeeping

Literature suggests that the 5S’s reveal the amount and the extent of waste in the workplace. Pieterse et al. (2010:35) say that the 5S’s stand for sort, straighten, sweep, schedule and
According to Abdullah (2003:11) and Pieterse et al. (2010:35) many authors view the 5S’s as the starting point to world class production. The 5S’s creates order in the workplace by exposing the extent of waste contained on the production areas so that it can be eliminated. The 5S’s are Japanese words which have been translated into these English words; sort (seiri), straighten (seiton), sweep (seiso), seiketsu (schedule) and shikutse (sustain),

- Sort is about removing from the workplace anything that is not needed for current work and adding those items that are needed but are not there.
- Straighten: creating order, arranging items such that they are easy to use.
- Sweep: cleaning the floors, equipment and ensuring that everything stays in a good clean state.
- Schedule: having a regular schedule to sort, straighten and sweep.
- Sustain: having the discipline by practicing and repeating the actions until they become a way of life throughout the entire organisation (Pieterse et al., 2010:35).

The coal plant is a spillage prone area therefore at the XYZ Coal Plant, 5S’s will be applied to improve and sustain the level of housekeeping with a possible indirect impact on TPM.

2.1.1.1.3 Value Stream Mapping (VSM)

Dal Forno, Pereira, Forcellini & Kipper (2014:779) describe VSM as a technique used for diagnosis, implementation and maintenance of a lean manufacturing approach, with its main function being to identify improvement opportunities and eliminate waste. Through VSM one can understand the current status of the process and identify opportunities to improve to the desired state.

A value stream is a collection of both value adding and non-value adding activities that are required to bring the product through main flows, starting from customer demand back to raw materials (Rother and Shook, 1999:13). Value stream mapping is a pencil and paper tool that assists us to visualise and understand the material and information flows as the product passes through the value stream (Rother and Shook, 1999:14).

The ultimate aim of the value stream mapping process is to improve flow, create pull and eliminate waste continuously (Van der Merwe, 2010:145). According to Rother and Shook (1999), VSM should be done by following a product’s production route from the customer to supplier; and visual representation of every material and information flows must be drawn.
Rother and Shook (1999:13) state that the value stream approach implies working on the big picture, not just individual parts; thus improving the whole and not just the optimisation of parts. According to Van der Merwe (2010:145), VSM provides a link between lean principles and lean tools. I concur with this view and it is shared by Abdumalek and Rajgopal (2007:225) who contends that most of the tools which have been developed by various researchers are coming short in connecting and visualising the flow throughout the organisation's entire supply chain whilst VSM tools provide this much needed link.

A three step structured approach as defined by Rother and Shook (1999) is used to improve the value stream. The first step in the Rother and Shook approach is to identify the product family from the customer perspective of the value stream and select one to target. The second step is to draw a current state of how things are currently done. This is done by physically walking the process starting from the shipping point to the raw materials receiving point; and recording material and information flows at each process. The third step according to Rother and Shook (1999) is to create a future state map of how the process should be like after addressing or elimination non value adding activities.

Lian and Landeghem (2002:2) define VSM as paper and pencil based technique that analyses the complete material and information flow from the delivery of raw materials up to the sale of products; as well as the time used and the percentage of time that adds value to the customer. It is through conducting a value chain analysis that a company can establish its customer demand and provide value adding activities in order to satisfy its customer requirements.

Literature defines a value chain as a set of both value adding and non-value adding activities required to move a product through a production flow. The ultimate aim of the value stream mapping process is to improve flow, create pull and eliminate waste continuously (Van der Merwe, 2010:145). According to Rother and Shook (1999) VSM should be done by following a product's production route from the customer to supplier; and visual representation of every material and information flows must be drawn.

According to Tanco, Santos, Rodriguez, and Reich (2013:1641) a value chain is composed of three different kinds of flow, mainly:

i. Flow of information: supporting and directing the flow through the operations from the processing of materials.

ii. Flow of materials: from the receiving of raw materials to the final product delivery.
iii. Flow of people and processes: these support the flow of information and materials.
The VSM maps all the three flows as it focuses on the entire value stream to reveal waste in the system so that the whole value chain can be optimised.
Braglia et al. (2011:3930) identified the following advantages offered by VSM:
- VSM forms the basis for lean manufacturing implementation.
- VSM relates the internal manufacturing process to the whole supply chain.
- VSM displays both the product and information flows.
- VSM links product planning and demand forecast to production scheduling and flow shop control.

Lian and Landeghem (2002:2) and Braglia et al. (2011:3931) are of the view that VSM has the following main drawbacks:
- VSM is a paper and pencil based technique and hence the accuracy level is limited and the number of versions that can be handled is low.
- In a real work situation, many organisations are of a high variety – low volume type which means that many value streams are composed of hundreds of industrial parts and products.
- Many people in the workplace fail to see how a VSM translates into reality.
According to McDonald (2010:215) and Braglia et al. (2011:3931), Rother and Shook (1999) have developed widely accepted key guiding questions that must be answered in order to map the future state. According to Rother and Shook (1999:66), these questions are:
1. What is the takt time?
2. Will production be to a finished goods supermarket or directly to shipping?
3. Where can continuous flow processing be used?
4. Where will the organisation need to use supermarket pull systems?
5. At what single point in the production chain will production scheduling be used?
6. How will the production mix be levelled at the pacemaker process?
7. What process improvements will be necessary?
8. A future state map is then created based on the outcomes or answers of the seven key questions. Once that desired state has been created, an implementation plan must be developed in order to achieve the future state.

When these eight questions have been answered, the desired future state is then mapped. Once the future state is mapped; an implementation plan must be developed with measurable goals in order to reach the desired state.
2.1.1.4 Standard work

Standardisation of work is another tool for eliminating waste because it ensures that every employee understands how the work should be done thus eliminating errors and defects. Pieterse et al. (2010:15) suggest that people doing the actual work must compile the standard work procedure instead of industrial engineers. This ensures employee involvement and cultivates a sense of pride and ownership. The employee would be able to grow through this tool. This implies that for the beneficiation plant, the manual hand relative density sampling must be conducted in a standard way irrespective of the process operator doing the test.

2.1.1.5 Quality at the source

Quality at the source is about ensuring that quality problems are addressed the moment they occur such that there are no defects. It is important that the plant produce the required quality out of the resources at its disposal. This pertains to the quality of repair work, fabrications in the maintenance workshops and the quality of the coal products.

2.1.1.6 Capacity flexibility

According to Pieterse et al. (2010:12), flexible resources mean multi-skilled employees and flexible machines. This means that workers must be able to operate different machines. For machines to be flexible machines, they should be easily adjustable and movable around. Flexible resources in a beneficiation plant would mean that operators and artisans working in a coal handling plant should be as equally competent to work in a wash plant.

2.1.1.7 Continuous improvement

According to Abdullah (2003:24), continuous improvement is a systematic approach to gradual continual improvement and can occur in many forms such as reduction of inventory and defects. In my professional experience, a number of coal beneficiation plants have tried without success to implement continuous improvement and therefore this study will focus on defining success criteria for this tool.
2.1.1.1.8 Just in Time (JIT)

According to Abdullah (2003:14) just-in-time (JIT) production is a lean manufacturing practice that aims to eliminate waste by producing the right product at the right time and it eliminates wastes such as work in process, defects and poor scheduling. With JIT, production is driven / pulled by customer demand, as compared to a push system. A kanban (signalling card) is used to signal the quantities required in a succeeding production step. This practice needs to be investigated in a beneficiation plant to ascertain whether coal shipments at Richards Bay Coal Terminal (RBCT) cannot be utilised to order the amount of trains railed from the plant to RBCT.

2.1.1.1.9 Cellular Manufacturing

With cellular layouts, different machines are grouped together in a U shape resembling an assembly line to carry out work on a family of similar products. Work is then moved in a line, passed from equipment to equipment with little or no waiting time (Abdullah, 2003:23; Pieterse et al., 2010:12 and Jacobs & Chase, 2014:351). According to Jacobs & Chase (2014:351), manufacturing cell or group technology cells as it’s referred to by some authors eliminates motion, waiting, reduce inventory and the number of workers required. With the coal beneficiation process being a continuous process rather than a batch process, it’s interestingly important to evaluate if there are sections within the value chain that can be adapted to group technology cells.

2.1.1.1.10 Summary

Theory suggests that there are quantifiable benefits that could be reaped from the use of lean tools. Theory will contribute towards the understanding during the field application of these tools at XYZ coal beneficiation plant. The next chapter explains the processes involved in a coal beneficiation plant and possible areas where lean manufacturing tools and techniques could be tested in practice.
CHAPTER 3: OVERVIEW OF THE XYZ COAL PLANT

3.1 Introduction

With the knowledge gained by the researcher through the literature survey conducted in chapter 2, this chapter briefly explains the process overview, challenges involved and how these challenges could be addressed through the integration of lean theory and practice. The VSM approach will be followed at XYZ coal plant to expose and eliminate the waste in the coal handling, beneficiation and despatching flows.

3.2 Background of the organisation

XYZ plant is one third of the XYZ business value chain; which is composed of the XYZ Mine, the XYZ Plant and XYZ Marketing. All these three units function together to make the business a success. The function of the Mine is to produce or mine coal from underground; whilst the plant’s role is to beneficiate the coal into different value streams and finally the marketing department markets and sells the coal to various markets. For the purposes of the study, the scope will be limited to XYZ Plant only.

XYZ coal plant is a metallurgical coal exporting plant that began its operations in 1996. The plant is located in the Highveld Region of the Mpumalanga Province. The plant produces about 7 Million tonnes of saleable coal annually. About 4 Million tons of saleable coal is exported overseas and the 3 Million tons is sold to the local market. The fluctuating coal price poses threats to XYZ. Coal mining companies don’t have control over the coal price and the industry has seen a downward decline in the price since 2011. This necessitates that XYZ increases its profit margins by lowering its unit costs so that the company could still remain profitable in the pressured coal market. This study will investigate the applicability of lean manufacturing tools in the XYZ’s coal handling and beneficiation processes with the aim of cutting down on waste and improving efficiency; which will potentially result into cost saving.

3.2.1.1 The coal handling process

XYZ plant receives Run of Mine (ROM) coal from the mine. The ROM is screened and crushed to a nominal top size of 40.00mm for beneficiation. The purpose of screening and crushing the coal is to reduce the coal to sizes suitable for beneficiation without generating excessive fines in the process. The sized ROM coal is then stockpiled in the plant feed stockpiles for blending and
homogenising purposes. The blended raw coal is then reclaimed via a ROM reclamer into the beneficiation plant where separation of clean coal from waste occurs.

The feed into the plant is first pre-screened at 1.00mm to remove fine coal that is not suitable for dense medium separation. The beneficiation plant is a high gravity dense medium separation plant utilising Dutch State of Mines (DSM) cyclones. The pre-screened feed gravitates into the mixing boxes where it is mixed with magnetite pumped from the magnetite make up sumps. The coal and magnetite mixture is then fed into the cyclones where separation takes place. The lighter particles (clean coal) floats and goes into the drain and rinse screens where magnetite is drained from the coal and excess magnetite is washed off through spray waters. After drainage the product is sent to the product stockpiling yard for reclamation into the trains. Trains are loaded via a rapid train loading terminal (RLT) and railed to Richards Bay Coal Terminal where shipments to various overseas customers take place.

3.2.1.2 The beneficiation process

Coal handling and coal flow

Coal handling operations begin when coal is conveyed from the Mine bunkers into the crushing and screening plant. At least 97% of coal exiting the crushing stream must be less than 38.00mm in particle size whereas the finer material (-6.00mm) must not exceed 30%. From the crushing and screening plant, the coal is stockpiled on the ROM stockpiles for blending. The purpose of stockpiling is to homogenise the coal for stable quality control in the beneficiation plant.

From the ROM stockpiles the coal is reclaimed to the primary bins at the beneficiation plant. The purpose of the primary bins is to maintain a stable feed to plant. The ROM is fed to the plant via inclined conveyors. The feed is screened first to remove ultra-fine coal particles that do not need dense medium separation. Magnetite is a medium for separation used at the plant. As the screened feed flows into the mixing boxes, magnetite suspension is pumped into the head boxes and gravitates into the mixing boxes. The purpose of the head boxes is to ensure sufficient head / pressure to the mixing boxes. The purpose of the mixing boxes is to ensure correct medium to ore ratio and proper mixing of the coal and magnetite.

The mixture gravitates into the cyclones where separation of clean coal from dirty coal takes place. The clean coal (export product) is sent to the stockpiles for water drainage, the middling coal is sent to the domestic market stockpiles and the magnetite is recovered for reuse in the
Density control and monitoring is a critical factor for efficiency in the beneficiation process.

The ultrafine coal resulting from the screening of the feed is sent to the fines cyclones where separation of fines from slimes takes place. The medium for separation here is water. The heavier density fine coal is sent to the domestic market stockpiles whereas the super fines are sent to the water recovery circuit. The water recovery circuit has two conventional thickeners whereby a flocculent is dosed for thickening the super fines into sludge. The thickened sludge is pumped into the slimes dams and the water is recovered back into the beneficiation process for reuse.

3.2.1.2.1 Thickening

Thickening in the beneficiation plant is the process of separating water from ultra-fine coal through thickening of the fine coal particles by means of a flocculation agent. The flocculent solution is prepared at the required strength / concentration in the flocculent plant by mixing a polymer with water. The concentrated solution is then dosed to the thickeners. The main purpose of the flocculent is to speed up the agglomeration process of the ultra-fines into lumps which then settle to the bottom of the thickeners as sludge. Upon separation the water overflows into a clarified water tank and is then pumped back into the beneficiation process. The quality of the polymer / flocculent and the strength of the solution are important aspects to consider for the efficiency of the water clarification process.

The thickened sludge is pumped into the slimes settling dam where further settling takes place, the water is pumped back to the plant and the slimes are retained in the dams.
Process Flow Diagrams

Figure 3 - 1: Crushing and screening process flow diagram

**Simplified PFD - Crusher and feedbin arrangement**

ROM
Primary Screen
Double Roll Crusher
+ 75 mm
- 38 mm

Secondary Screen
Double Roll Crusher
+ 38 mm
90.5% - 38 mm
- 38 mm

Stacker + Reclaimer
Feed Bins
+65 mm
Protection Screen
- 0.8 mm
- 38 mm

To fines circuit
To sec. plant
To prim. plant
To fines circuit

Figure 3 - 2: Fine coal beneficiation and thickening

**SIMPLIFIED PROCESS FLOW DIAGRAM**

Crushed ROM
- 38 mm

Process water

Desliming screen

0.63 mm

- 0.15 + 0 mm

- 0.63 + 0.15 mm

x 2 Thickeners

126 t/h

33% ash

Spirals x 54

13.5% ash

Coal to RBCT

1500 t/h

38 > 0.63 mm

Magnetite Medium @ 1.4 t/m³

x 18 Prim. DMS Cyclones

12 Sec. DMS Cyclones

55% ash

Medium @ 1.9 t/m³

37 t/h

78 t/h

> 73% ash

36% ash

Discard Rocks to dump

Middlings
Figure 3 - 3: Dense medium plant

Simplified Process Flow Diagram

Clean Coal to Product Stockpile
Middlings coal
Rocks to Discard dump

ROM
Primary Screen

Double Roll Crusher
Secondary Screen

65% -38mm

ROM S-Pile
Shaker + Reclaimer

Red Bine

+65mm

Protection Screen
De-slimging Screen
De-slimging Cyclones
De-slimging Screens
Spirals
De-watering Screens

+0.8mm

Fines Discard

+65mm

Middlings coal

Middlings by-pass

+0.8mm

-0.8mm

Prim. Reject D&R Screen

Sec. DMS Cyclone

Prim. Mag. Sep

Sec. Mag. Sep

Middlings D&R Screen

Medium

Middlings to Slurry Pond

Slimes to Slurry Pond

Filter cake to s/pile

Filter plant

Return water to process

Prep plant

Return water to process

Return water to process

Stacker + Reclaimer

To RBCT
3.2.2 Challenges

The challenge at the screening plant is poor liberation / inconsistencies in the crushing of coal resulting from factors such as worn crusher segments, worn screen panels, reduced efficiency, poor configuration, blockages and overloading of the plant. When this happens it results into oversize or out of specification coal which doesn’t meet the requirements for beneficiation thus yielding less product and loss of income for the business unit. Lean manufacturing principles and techniques will be tested in this section for waste elimination and efficiency improvement.

The challenge in the stockpiling operations is the different blend ratios by each operator. The stockpiling activities will be studied to investigate the causes of poor blends leading to higher variations in product qualities and inefficiencies.

The challenges in the dense medium separation process at the beneficiation plant are:

- The lower process stability observed in the secondary plant.
- The high panel maintenance costs / high panel consumption
- The above target magnetite consumption
- The increasing costs of flocculation and water treatment

The applicability of lean manufacturing principles and techniques will be investigated in the desliming process, the medium density preparation and the mixing boxes areas to minimise any waste that might be present and improve efficiency.

Within the beneficiation process there are various forms of wastes that need to be studied and understood eliminated and hence this study will assist with the process.

3.2.2.1 Summary

The process has been briefly explained and there seems to be challenges that the organisation needs to address. The next chapter will analyse the current state, look at opportunities for improvement and pursue the identified opportunities through the application of lean tools and principles.
CHAPTER 4: EMPIRICAL STUDY

INTRODUCTION

The purpose of this chapter is to present an analysis of the study conducted in the coal washing plant. With the theoretical background of lean manufacturing tools and techniques; as well as the understanding of the beneficiation process, lean tools were tested in practice in the plant. This chapter presents findings of the applicable tools.

The applicable lean principles that were selected for use in the study are Lean Six Sigma, 5S’s of good housekeeping, quality at the source, TPM, capacity flexibility, standard work and Value Stream Mapping (VSM). Tools that were not used in this study include cellular manufacturing, Just -in -Time, and continuous improvement. Cellular manufacturing, small production and Just-in-Time (JIT) production tools were not used in the study because they were less applicable to a continuous coal beneficiation process. Small production tool was less applicable to a high volume bulk material plant like XYZ coal beneficiation plant. The continuous improvement tool was not used in this study because the organisation has already established the applicability in its mining operations and is already applying this tool. The structure of the chapter is as follows:

Figure 4 - 1: Chapter 4 structure

Included in this study
Not included in this study

Future optimisation exercises

Lean principles from literature study

Current state
VSM (identify opportunities and techniques)

Future state
VSM (quantify benefits)

Lean Six Sigma

Standard Work

Quality at the source

SS's of good housekeeping

Flexible resources

JIT manufacturing

Continuous Improvement

Small lot production

Continuous optimisation exercises

Excess fine coal processing

Flocculant make up unit

Spillage elimination

Higher processing units

Included in this study

Not included in this study

Flexible resources

Quality at the source
4.1 Data Collection

The research design used in this study can be described as experimental research by means of field studies in a coal washing plant.

The primary objective of this study was to investigate the applicability of lean manufacturing tools and techniques in a coal beneficiation plant. XYZ plant needed to first discover its wastes so that these wastes could be eliminated; whereby VSM was used to identify waste and thereafter opportunities for improvement identified. Secondary as well, the study aimed to introduce plant operators to the selected lean manufacturing and discuss the potential applications to the plant. The coal washing process was evaluated according to the relevant theory in chapter 2 and the selected lean tools applicable in a coal washing plant were applied. This research methodology is therefore applicable to the type of study being done in this case. According to Welman et al. (2005:86); field studies are carried out in a real environment like the plant where the production actually occurs.

Data was collected through physical inspections to uncover wastes, mapping out the current state, through quality analysis as well as financial data (costs) which was collected from the company’s Enterprise Resource Planning (ERP) system. Value stream mapping was used to analyse the current processing state; opportunities were discovered and improvements were measured after the application of lean principles.

4.1.1 Value Stream Mapping

The current state VSM for XYZ Plant is shown in Figure 4-1. The approach recommended by Rother and Shook (1999) was followed in the collection of data for the current state map. The collection of data started at shipping and moved backwards to the supply of ROM coal where the process starts. Information such as inventory levels before each process, cycle times and number of workers were recorded and this information is shown on the current state VSM. The line below the current state map depicts the lead time and the processing time. The total production lead time observed in the current VSM state is 32.77 days whilst the processing time is 991.44 seconds. The inventory waiting time was calculated by dividing the inventory before each process by the daily customer demand. The cycle time was determined by adding the processing time at each processing step. The throwing out of product at the emergency stockpiles takes the longest time and increases both the lead and processing times. Therefore this process must be addressed.
a) Production Planning

The XYZ plant has a business planning department headed by the Business Manager. The production planning department has production planners and planning managers who utilise Xeras and Xpac planning models to schedule production. The organisation uses monthly tons and quality forecast (TQF) meetings where production schedules, budgets and plans are discussed, agreed upon and reconciliations are analysed. The TQF workgroup meetings include Production Planning Managers, Operations Managers and Marketing Managers.

Marketing managers get the requirements from customers in the form of monthly and biweekly updated shipping schedules and then discuss the requirements with plant production planning managers in order to schedule production according to customer requirements. Marketing also orders trains from TFR according to the product stockpile levels at the plant. There are also weekly TQF and production meetings between the Production planning department, operations and engineering departments to discuss the production requirements and align these with maintenance plans. There are daily production reports prepared by the production planning department; and in addition daily discussions between the Mine planners, Plant production planners, Marketing and TFR take place. Marketing sends the biweekly railing demand to TFR and TFR in turn sends the confirmed railing schedule and the daily reports detailing estimated times of arrival.

b) Production System at XYZ Plant

The current production system at XYZ Plant is of a push nature in that production occurs according to the export sales forecast as well as mining being a volume driven industry. The plant then pushes approximately the equivalent quantities of ROM feed tons monthly through the plant in order to get to the required saleable tons. One of the factors causing this is that the plant is measured on the Rand per feed ton basis for its monthly financial performance. However the push system is costly to the plant because the export sales are not spread evenly through the year, shipping varies widely between months. This results into a lot of product double handling because product stocks would then run high resulting into more tonnes thrown out into the emergency stockpiles and reloaded with the pay loaders instead of being loaded directly into trains. Cost analysis indicates that the plant incurred about R8M in the last financial year in double handling costs and this could be reduced through a pull production system.
4.1.1.1 Value Stream Mapping: Current State

Figure 4 - 2: VSM Current State

4.1.1.1.1 Analysis of the current state

4.1.1.1.2 ROM pulling

The current state revealed unnecessary mine stoppages resulting from the delays in pulling the coal from the Mine. The philosophy for pulling coal was such that coal from the different Mines would be stockpiled separately meaning that the operators could draw coal from one Mine at a time. This resulted in as much as four change overs per day from one Mine to the other resulting in lost time. The Control Room Operators had to clear the conveyor belts before stopping which takes about 45 minutes each time a conveyor belt must be stopped. The field operators had to move the stacker from one stockpile to the next; resulting in a 25 minute downtime each time a stacker is moved.

While the plant operators changed settings and stackers; the mines continue to produce until the bunker levels get full. Once the bunker levels are filled, the mine waits for the plant to create
capacities in the bunkers. The start-up process would take an additional 75 minutes. This process resulted into about 96 hours of Mine stoppages which equates to a loss of 144 000 production tonnages.

The reasoning behind the separate stockpiling was that the coal qualities varied considerably between the two Mines which led to a belief that combining the coal was the cause of quality problems in the beneficiation plant. The actual cause of quality deviations was never investigated prior to this study. Mapping the current state thus presented opportunities to investigate the actual cause of quality deviations and to review the operating philosophy in order to reduce Mine stoppages.

4.1.1.1.3ROM screening and crushing

The unit operations in the primary beneficiation plant are designed for <38.00mm coal particle size and for 65mm coal particles in the secondary beneficiation plant. The primary plant is not suitable to beneficiate >38mm material and such particle sizes would result into efficiency losses. The primary function of the ROM screening and crushing plant is to sort and reduce the size of ROM coal from >150.00mm; as mined to <38.00mm particles suitable for beneficiation. The process is designed to withstand not more than 3% of the plus 38.00mm material and therefore at least 97% ROM leaving the crushing and screening plant must be less than 38.00mm in particle size.

The crushing and screening plant is consisted of two streams, A & B; which are fed equally and are identical in operation. As coal is drawn from the Mine bunkers it is first fed into the primary screens to remove coal particles less than 38.00mm. The larger particles overflow into the primary crushers for size reduction. Secondary screening and crushing is also performed after the primary process to correctly sort and size coal that wasn’t sized in the primary process. The <38.00mm coal is then stockpiled in the plant feed stockpiles ready for beneficiation.

During the VSM of the crushing and screening process it was observed that the crushed material was not consistent in size and the distribution was unequal between the two streams. This necessitated a detailed investigation into the process. The screen deck and the crusher segments were inspected for wear and defects. There were no abnormalities found on the screen decks; however uneven wear was observed on the crusher segments which resulted from uneven feed distribution. Further investigation revealed that crusher segments were changed every five weeks instead of two monthly. Sampling an analysis of the different streams in the crushing and screening plant also confirmed that the material was not consistent in size.
distribution; which also explains the uneven wear profile. The current state VSM of the crushing and screening plant exposed opportunities to homogenise the particle size distribution, improve the wear profile of the crushers and the life span of the crushers.

4.1.1.4 Beneficiation process monitoring

The beneficiation process begins with the reclaiming of crushed coal from the plant feed stockpiles into the plant. As coal is fed, magnetite is pumped from the make-up tanks into the mixing tanks where the mixing of the coal and medium occurs. The beneficiation process is a continuous automated process; characterised by the flow of materials (coal, water and magnetite) and hence it is not a labour intensive process. The plant operators monitor the process parameters and do adjustments accordingly when the plant is running. When the plant is down for maintenance, the plant operators conduct process maintenance. The beneficiation process VSM was conducted both while the plant was in operation and when it was down for maintenance.

During the process it was observed that the process operators were required to take density measurements for both the primary and secondary plants although there was no density measuring equipment in the secondary plant. The primary plant was observed to be more stable than the secondary plant. The density monitoring equipment was located in the primary plant and operators were required to walk two floors up and down to conduct the same task at the secondary plant because there was no equipment located in the secondary plant. This created some slower response times to the secondary plant due to the time it took to go to the primary plant to get the equipment and then back to the primary plant to return the equipment. There were reports of lost density scales due to the scales being moved around between the two plants. There were also errors resulting from the multiple calibrations of the scale by various operators each time the scale was moved and also due to the different specific gravities of the two plants.

4.1.1.5 Screen panel maintenance

The current state mapping revealed waste of panels’ inventory at the beneficiation plant. Panels are mounted on the screen decks for the purposes of sizing and drainage. Panel maintenance is the responsibility of the production personnel. The operators would walk through the screens at the plant; visually inspect the decks to see if there are any worn panels that needed to be changed. After that they’d request their supervisors to order the panels. The outcome of the deck inspections would differ for every operator; resulting in the ordering of excessive or
sometimes less than required panels. This has led to supervisors ordering more than the required amount of panels to prevent multiple orders and waiting longer for the panels. The unused panels are most often not taken back to the panel storage yard for proper stock keeping. This has created three problems:

- A housekeeping problem as there’d be stocks of panels in areas of the plant where there shouldn’t be.
- An inventory management problem, as the ordering process is automated for the supplier to deliver a new batch once the stock at the warehouse reaches 50 panels; which occurred more frequently with the current maintenance system.
- A waste problem; with costs escalating excessively as some panels are not being used as indicated by a 30% increase in panel costs in 2014.

The visual inspections have always yielded different results for each operator. This has resulted into some panels being replaced prematurely and some ran to failure leading to plant downtimes and production losses.

4.1.1.1.6 Water recovery

Water recovery begins with the thickening of effluent from the beneficiation process. The effluent is a mixture of ultra-fine coal particles and waste water resulting from the drained products. A flocculent is dosed into the thickener feed to agglomerate the ultra-fines. The ultra-fine coal then forms a thick sludge and settles into the bottom of the thickener. The settled slurry is then pumped into the slurry ponds while the clear water overflows into the process water handling systems. Water run offs from the washing plant and stockpile areas is channelled via a system of silt traps and trenches into the process make up dam for reuse in the beneficiation plant. The recovered water is treated for scaling and corrosion before use through a chemical dosing program.

The current VSM of the water recovery circuit revealed that the slurry settling rate was slower than it should be as indicated by the black water (instead of clear water) overflow. This necessitated that the flocculent dosage into the thickener feed be increased from 15 grams per ton to 25 grams per ton which increased the flocculent costs and caused other problems in the process. The flocculent make up concentration / strength was also increased from 0.05% to 0.1%. The increased flocculent strength from 0.05% to 0.1% and dosage from 15 to 25 grams per ton more than doubled the flocculent consumption from 3 grams per ton to 6.5 grams per ton. This resulted in a 63% increase in flocculent costs from R0.20 per ton to R0.33 per ton.
The black water overflow means that there were ultra-fine particles in the water flowing back to the process which created other process problems like blockages in the water spray pipelines on the drain and rinse screens due to the presence of fines. The blockages resulted in poor magnetite removal from the drain and rinse screens whereby the magnetic losses in the products increased from 0.5% to at least 2%. The poor process water quality also negatively affected the efficiency of the magnetic separators whereby the efficiency dropped from the industry standard of 95% to 85% due to the magnetic drum overloaded by the fines that were not recovered in the thickening process. The excessive magnetite losses in the plant resulted into a 80% increase in magnetite consumption and about 80% increase in magnetite costs. According to the coal processing handbook for plant operators and the coal beneficiation industry norm; the allowable magnetic losses in a cyclone type dense medium coal washing plant should only be 0.5%; meaning that 99.5% should be recovered.

As a result of the VSM, further investigations to optimise the thickening process needed to be explored.

4.1.1.1.7 Process water treatment

The process water recovered from the thickening process and from the plant run offs is reused in the plant for beneficiation. This water consists of high salt content which could cause scaling and corrosion of pipelines and process equipment. The water is then treated for corrosion and scaling via a chemical dosing plant employing a combination of a two chemical dosing program. High rates of corrosion will cause premature failure of equipment and could shorten the life of plant if not treated.

The chemical dosing plant was owned by a certain supplier called Supplier X on condition that only chemicals from Supplier X will be dosed on this plant. As a result a set of two chemicals only from Supplier X have been used since the plant's inception. The dosage has been 45ppm and 145ppm per day for the corrosion and anti-scalant respectively for almost the past 2 decades. The monthly report detailing the dosage and the chemicals to be ordered has been supplied by Supplier X from the beginning. During the mapping of the current state; white deposits around the structures and equipment in the plant were observed.

The assumption was that it could be residue from the chemical dosage process; however similar deposits were observed before the chemical dosing plant. Samples of these deposits were taken to Supplier Y for analysis and the results indicated high salt deposits that the dosing plant was supposed to treat in the cycled process water. Water samples were taken before and after
the dosing plant to compare the water chemistry. These samples were sent to three independent water laboratories for full water analysis. The results indicated that there was no difference in the water chemistry before and after treatment and yet the reports from the Supplier X indicated an improvement in the water chemistry after treatment.

Furthermore cost analysis for chemicals spent on Supplier X was conducted and found to be increasing by 50% annually; leading into costs escalating way above the budgeted costs. Discussions were held with Supplier X regarding the water treatment results and the excessive costs; to which Supplier X proposed different chemicals at a much higher costs. Negotiations were held into with Supplier X regarding a cost optimal yet effective dosing program to which Supplier X was not keen to meet the requirements of the plant. The plant then requested to test different chemicals from different suppliers; to which Supplier X refused to have other products dosed into their plant. The plant then had to test the water chemistry on a larger laboratory scale to find a suitable water treatment solution. The plant is in the process of overhauling the equipment and structure through a sandblasting and painting corrosion protection program resulting in a R15 Million expenditure; which could have been minimised through the years by an effective water treatment program. It is clear that the plant cannot continue with Supplier X, cost effective changes that will improve the water chemistry must be made in the water treatment program.

A detailed comparison of the chemical costs and the consumption also showed a discrepancy; according to the costs incurred the consumption should have doubled. An investigation into this discrepancy indicated that some chemicals were not delivered to the warehouse but were claimed as delivered directly into the plant without any proof of acceptance from a plant representative.

4.1.1.2 Application of lean tools / techniques

The application of lean tools will be explained in this section. Some lean tools needed to be applied prior to the application of the other for example in the ROM pulling process whereby Six Sigma needed to be applied first to understand the quality of the coal before building flexibility into the process. The following lean tools were applied to the respective processes:

- Flexible processes / SMED and Six Sigma: ROM Pulling and process water treatment
- Six Sigma: ROM screening and crushing
- Seven wastes and 5S’s of good housekeeping: Beneficiation processes
- Standard work: panel maintenance
Quality at the source: Thickening process

The application of Six Sigma technique in the different processes will be dealt with first.

4.1.1.2.1 Lean technique 1: Six Sigma

The DMAIC methodology of Six Sigma was used to investigate the variations in each of the processes as detailed below.

ROM Qualities

According to the plant operators, the high variation in the ROM qualities was the reason behind the separate pulling of ROM. The qualities were never investigated and hence the DMAIC methodology was used to understand the ROM quality variance before making changes to the pulling process.

Define: The ROM customer is the plant. The plant requires at least 33 000 tons of ROM per day at an ash percentage of 30%; fines percentage of 28% and saleable yield of 73% (48% export and 25% domestic). The most important characteristic of the ROM coal is the washability characteristics and hence a saleable yield of 73%.

Measure: The ash percentage and the washability characteristics of the ROM from each Mine were measured via sampling and analysis before processing. Samples from the two mines were combined and the washing process was simulated in the laboratory. Furthermore a batch of coal from the two Mines was processed as a blend in the beneficiation plant to collect data for analysis. Geological data was also collected from the scheduling model and simulated via a washability model to compute expected yields. The data is presented below:
Figure 4 - 3: Gross CV’s obtained for Mine A and B

Figure 4 - 4: Product yields obtained for Mine A and B

The product yields graph above indicates a decrease in the product yields; this is because of the section deployment in the low yield reserves. However it is important to note that the actual yields were optimised and exceeded the budgeted yields.

Analyse: The results indicate a big variation in the washability characteristics of the coal. Whilst coal from Mine A is good quality coal that should be beneficiated at high relative densities and
doesn’t need much variation in the operating relative density; coal from Mine B is poor quality coal which should be beneficiated at very low densities and there’s much more fluctuations in the coal qualities that needs frequent process adjustments. When the coals were washed together, it would be at a density lower than the operating density of Mine A and higher than the operating density for Mine B.

This resulted in efficiency losses, saleable yield losses which could have been millions of revenue earned; as well as quality losses as it became very challenging to achieve both export and domestic customer specifications. This explains why the coal from the two Mines was processed separately from the plant’s point of view. However this philosophy was impacting negatively to the productivity of the two Mines due to frequent disruptions and production stoppages by the plant.

**Improve:** Further testing of the coal at different blend ratios was conducted to determine the best blend ratio that will homogenise the quality of the ROM feed to plant and provide for stable quality control thus improving the process without detriment to the Mines. A simulation program was used to compute the expected yield at the required customer qualities from the data consisting 167 and 285 washability data sets from Mine A and Mine B respectively. The two coals were simulated when processed separately as well as when processed as a blend in the ratios of 25/75, 50/50 and 75/25. Table 4-1 – Table 4.7 shows the results of each Mine as well as the results of the different blends.

The results of each blend yielded better results than the individually processed ROM. The 50/50 blend which showed the best results during the simulation was tested in the plant and performed just as well as it did in the simulation. From this the ROM pulling philosophy was reviewed such that the coal is blended together when pulling in order to improve product recovery and reduce Mine stoppages.

**Yield and product qualities at different blend ratios**

Table 4 - 1: Yield and product quality – Mine A and Mine B coal

<table>
<thead>
<tr>
<th>Raw coal</th>
<th>Yield %</th>
<th>CV</th>
<th>Moist</th>
<th>Ash</th>
<th>VM</th>
<th>F/C</th>
<th>TS</th>
<th>d50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>59.24</td>
<td>26.50</td>
<td>4.22</td>
<td>13.48</td>
<td>30.18</td>
<td>52.12</td>
<td>0.93</td>
<td>1.624</td>
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<tr>
<td>Mine B</td>
<td>37.74</td>
<td>26.50</td>
<td>4.86</td>
<td>11.63</td>
<td>27.38</td>
<td>56.13</td>
<td>0.55</td>
<td>1.488</td>
</tr>
</tbody>
</table>
Table 4 - 2: Yield and product quality – 75% Mine A and 25% Mine B coal processed separately

<table>
<thead>
<tr>
<th>Raw coal</th>
<th>Ratio</th>
<th>Yield*</th>
<th>Product tons</th>
<th>CV</th>
<th>Moist</th>
<th>Ash</th>
<th>VM</th>
<th>F/C</th>
<th>TS</th>
<th>d50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>75</td>
<td>67.32</td>
<td>44.43</td>
<td>26.50</td>
<td>4.22</td>
<td>13.48</td>
<td>30.18</td>
<td>52.12</td>
<td>0.93</td>
<td>1.62</td>
</tr>
<tr>
<td>Mine B</td>
<td>25</td>
<td>42.89</td>
<td>9.44</td>
<td>26.50</td>
<td>4.86</td>
<td>11.63</td>
<td>27.38</td>
<td>56.13</td>
<td>0.55</td>
<td>1.49</td>
</tr>
<tr>
<td>Combined</td>
<td>100</td>
<td>53.87</td>
<td>26.50</td>
<td>4.33</td>
<td>13.16</td>
<td>29.69</td>
<td>52.82</td>
<td>0.86</td>
<td>1.60</td>
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Table 4 - 3: Yield and product quality – 75% Mine A and 25% Mine B coal processed together

<table>
<thead>
<tr>
<th>Raw coal</th>
<th>Ratio</th>
<th>Yield*</th>
<th>Product tons</th>
<th>CV</th>
<th>Moist</th>
<th>Ash</th>
<th>VM</th>
<th>F/C</th>
<th>TS</th>
<th>d50</th>
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<tbody>
<tr>
<td>Mine A &amp; B</td>
<td>75/25</td>
<td>64.21</td>
<td>56.51</td>
<td>26.50</td>
<td>4.39</td>
<td>12.95</td>
<td>29.35</td>
<td>53.31</td>
<td>0.81</td>
<td>1.581</td>
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Table 4 - 4: Yield and product quality – 50% Mine A and 50% Mine B coal processed separately

<table>
<thead>
<tr>
<th>Raw coal</th>
<th>Ratio</th>
<th>Yield*</th>
<th>Product tons</th>
<th>CV</th>
<th>Moist</th>
<th>Ash</th>
<th>VM</th>
<th>F/C</th>
<th>TS</th>
<th>d50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>50</td>
<td>67.32</td>
<td>29.62</td>
<td>26.50</td>
<td>4.22</td>
<td>13.48</td>
<td>30.18</td>
<td>52.12</td>
<td>0.93</td>
<td>1.62</td>
</tr>
<tr>
<td>Mine B</td>
<td>50</td>
<td>42.89</td>
<td>18.87</td>
<td>26.50</td>
<td>4.86</td>
<td>11.63</td>
<td>27.38</td>
<td>56.13</td>
<td>0.55</td>
<td>1.49</td>
</tr>
<tr>
<td>Combined</td>
<td>50/50</td>
<td>48.49</td>
<td>26.50</td>
<td>4.47</td>
<td>12.76</td>
<td>29.09</td>
<td>53.68</td>
<td>0.78</td>
<td>1.57</td>
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Table 4 - 5: Yield and product quality – 50% Mine A and 50% Mine B coal processed together

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<thead>
<tr>
<th>Raw coal</th>
<th>Ratio</th>
<th>Yield*</th>
<th>Product tons</th>
<th>CV</th>
<th>Moist</th>
<th>Ash</th>
<th>VM</th>
<th>F/C</th>
<th>TS</th>
<th>d50</th>
</tr>
</thead>
<tbody>
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<td>12.50</td>
<td>28.63</td>
<td>54.32</td>
<td>0.71</td>
<td>1.547</td>
</tr>
</tbody>
</table>

Table 4 - 6: Yield and product quality – 25% Mine A and 75% Mine B coal processed separately

<table>
<thead>
<tr>
<th>Raw coal</th>
<th>Ratio</th>
<th>Yield*</th>
<th>Product tons</th>
<th>CV</th>
<th>Moist</th>
<th>Ash</th>
<th>VM</th>
<th>F/C</th>
<th>TS</th>
<th>d50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>25</td>
<td>67.32</td>
<td>14.81</td>
<td>26.50</td>
<td>4.22</td>
<td>13.48</td>
<td>30.18</td>
<td>52.12</td>
<td>0.93</td>
<td>1.62</td>
</tr>
<tr>
<td>Mine B</td>
<td>75</td>
<td>42.89</td>
<td>28.31</td>
<td>26.50</td>
<td>4.86</td>
<td>11.63</td>
<td>27.38</td>
<td>56.13</td>
<td>0.55</td>
<td>1.49</td>
</tr>
<tr>
<td>Combined</td>
<td>100</td>
<td>43.12</td>
<td>26.50</td>
<td>4.64</td>
<td>12.27</td>
<td>28.34</td>
<td>54.75</td>
<td>0.68</td>
<td>1.53</td>
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</tr>
</tbody>
</table>

Table 4 - 7: Yield and product quality – 25% Mine A and 75% Mine B coal processed together

<table>
<thead>
<tr>
<th>Raw coal</th>
<th>%</th>
<th>Yield*</th>
<th>Product tons</th>
<th>CV</th>
<th>Moist</th>
<th>Ash</th>
<th>VM</th>
<th>F/C</th>
<th>TS</th>
<th>d50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A &amp; B</td>
<td>25/75</td>
<td>52.58</td>
<td>46.27</td>
<td>26.50</td>
<td>4.70</td>
<td>12.07</td>
<td>27.97</td>
<td>55.25</td>
<td>0.63</td>
<td>1.518</td>
</tr>
</tbody>
</table>
**Control:** Controls have been put in place to ensure adherence to the new ROM pulling philosophy. These controls include an automated coal demand in the control room to ensure that the Mines are synchronised such that an equal tonnage of 1000 tons per hour per mine is conveyed to the plant at all times.

**ROM crushing and screening**

The DMAIC methodology was used to understand the inconsistency in the crushed ROM coal.

**Define:** The customer of the crushing and screening plant is the beneficiation process and ultimately the export and domestic customers. The primary beneficiation plant requires that 97% of the material be <38mm in particle size whilst customers require that <6.3mm does not exceed 34% and allows for 0% >50mm.

**Measure:** The performance of the crushing and screening plant was measured through the ROM particle size distribution (PSD). The key internal processes that affect the PSD are screening, screen deck apertures, open area for screening, feed distribution, loading of the screens, quality and condition of the crusher segments, characteristics of the coal itself as well as the crusher segments gap settings. ROM samples were taken two hourly via an automatic sampler for particle size distribution (PSD) analysis whilst the products were analysed for the <6.3mm as well as >50mm material as they exit the plant as well as en route to the customers. The results of these analyses are shown below:
Analyse: Analysis included data analysis as well as physical analysis of the sizing equipment. Data analysis indicated inconsistencies in the sized material as observed over time. The graphs show the inconsistency of the size distribution and that the targets were consistently not achieved.

Field analysis included the loading of the plant, condition of the screens and crushers. Overloading of the process was eliminated because operating trends indicated the equipment was operated within the design capacities. The crusher segments were taken to a physical
metallurgy laboratory for testing. The results indicated that the chemical composition met the required Manganese specifications of 11.5 to 14.5% weight by weight. The streams were also inspected for distribution and it was discovered that the coal particles were skew loaded to the right hand side of the screens and the wear was predominantly on the same side of the segments. Root cause investigations revealed that the feeder plate that should divide the coal equally between the two streams was no longer fixed to its position and has shifted to the left which restricted the flow of coal to the left hand side of the screens. Figure 4-7 shows the uneven wear on the crusher segments before the improvement.

**Figure 4 - 7: Crusher segments wear profile before the improvement**

![Crusher segments wear profile before improvement](image)

**Improve:** The feeders and dividers were then reinstalled and fixed to the correct position for even distribution of coal into the streams. Since the installation, the wear profile on the cusher segments has improved as can be seen on Figure 4-8. This has improved the life of crusher segments from five weeks to eleven weeks with an accompanying 50% cost of sizing decreasing from R62 per ton to R31 per ton of crusher feed. The crusher plant output particle size distribution also improved due to the improved wear profile. Figure 4-8 shows the improved PSD profile.
Figure 4 - 8: Improvement in the crusher segments wear profile

**Control:** The job cards and task lists were also created for weekly inspections of the feeder plates. The reliability centred maintenance (RCM) now also includes the routine maintenance of the feeders.

To conclude; there's evidence of an even wear profile in the crusher segments after the optimisation as opposed to the uneven wear profile before the improvement was made.

4.1.1.2.2 Lean technique 2: Flexible processes / SMED

The flexible processes tool was used in the ROM pulling as well as in the water treatment process to eliminate the inflexibility and the accompanying complexities resulting from the lack of flexibility.

4.1.1.2.3 Application of flexible processes to ROM pulling

Through the application of the DMAIC methodology of the Six Sigma technique, it was discovered that the coal from the two mines could be homogenised for stable beneficiation process control and optimal product qualities. Therefore it meant that the separate pulling of coal philosophy which brought about mine stoppages and inflexibility to the process was no longer applicable to the plant.

This necessitated the application of the flexible processes technique to the pulling of ROM coal from the Mines. To reduce the operational stoppages that resulted in the Mine stoppages, the ROM coal pulling philosophy had to be reviewed. The revision had to take into consideration bunker capacities at each Mine as well as the takt time and processing times for each Mine. The
ROM coal qualities and their behaviour in the beneficiation plant had to be taken into consideration as well. The takt and processing time observations indicated that it took about 45 minutes and 75 minutes for ROM coal to get to the plant from Mine A and Mine B respectively. Testing of ROM coal at different blend ratio for the two Mines were conducted to find the best suitable blending ratio for the plant. Looking at the optimal homogenising ratio and the time taken to get the coal into the plant; a new ROM operating procedure was drafted and approved for pulling of coal into the plant.

The philosophy is such that coal is blended on the belts and the belts are always loaded thus maximising operating times and reducing the change over time to zero minutes. The blending of coal on the belts also meant that there would be no stoppages to change stockpile areas; instead there would be constant of flow of coal on the conveyors. Because the coal is pulled simultaneously from both Mines, the Mine bunkers are emptied faster resulting in additional maintenance window for the maintenance teams to conduct inspections and maintenance. The procedure is attached as Annexure II. Since the implementation of the procedure, mine stoppages has dropped from 2708 downtime minutes in 2014 to 217 downtime minutes in 2015; which is a 96% reduction in mine stoppages. Figure 4-9 shows the Mine stoppages before and after the change in the pulling philosophy.

**Figure 4 - 9: Mine stoppages due to XYZ plant**

<table>
<thead>
<tr>
<th></th>
<th>11/12</th>
<th>12/13</th>
<th>13/14</th>
<th>14/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine A</td>
<td>878</td>
<td>2210</td>
<td>1079</td>
<td>157</td>
</tr>
<tr>
<td>Mine B</td>
<td>0</td>
<td>0</td>
<td>275</td>
<td>60</td>
</tr>
<tr>
<td>Total Mine Stoppage</td>
<td>878</td>
<td>4600</td>
<td>2708</td>
<td>217</td>
</tr>
</tbody>
</table>
4.1.1.2.4 Application of flexible processes to process water treatment

Since the process water treatment agreement with the service provider didn’t allow for use of alternative suppliers’ products in the plant, an investigation into a new treatment program that will allow for testing and use of other suppliers was launched.

The plant could not afford to continue with the use of corrosive water as it costs the plant millions of rand in corrosion protection costs. Process water samples were sent to different water treatment service providers to test the water, treat it and evaluate if there were any improvement in the water chemistry. The laboratory test work indicated that the chemistry improved and a treatment program needed to be designed for the test work on a plant scale. Because the agreement with the current service provider was such that chemicals from alternative suppliers could not be tested; thousands of litres of water samples were sent to an independent supplier for pilot testing and the treatment program modified to XYZ’s treatment requirements.

When pilot tests were successful, a water treatment for XYZ was designed and purchased; whereby XYZ could source any chemicals of their choice from any supplier without limitations to a specific supplier. The business case done for the change is attached in the appendix. The old plant was decommissioned and taken by the owner. The new treatment plant for XYZ was successfully commissioned with a suitable treatment program for XYZ. The new plant allows XYZ flexibility in sourcing chemicals from any supplier. The results indicate an improvement in water chemistry. Table 4-2 summarises the improvement in the water chemistry; while figure 4-10 shows the cost improvement.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Increase from 7.87 to 8.23</td>
</tr>
<tr>
<td>Cond</td>
<td>Decrease from 8600 to 8600 mg/l</td>
</tr>
<tr>
<td>P-Alkalinity</td>
<td>Zero</td>
</tr>
<tr>
<td>M-Alkalinity</td>
<td>Constant at 240 mg/l</td>
</tr>
<tr>
<td>Total Hardness</td>
<td>Constant at 874 mg/l</td>
</tr>
<tr>
<td>Ca Hardness</td>
<td>Constant at 110 mg/l</td>
</tr>
<tr>
<td>Mg Hardness</td>
<td>Reduction from 780 to 764 mg/l</td>
</tr>
<tr>
<td>SiO2 (Silicates)</td>
<td>Increase from 1.3 to 1.4</td>
</tr>
<tr>
<td>Cl</td>
<td>Reduction from 625 to 620 mg/l</td>
</tr>
<tr>
<td>SO4 (Sulphates)</td>
<td>Reduction 4500 to 3300 mg/l</td>
</tr>
<tr>
<td>Mn (Manganese)</td>
<td>Reduction from 0.3 to 0.1 mg/l</td>
</tr>
<tr>
<td>Fe (Iron)</td>
<td>Increase from 0.7 to 0.9 mg/l</td>
</tr>
<tr>
<td>Cu (Copper)</td>
<td>Reduction 2.54 to 2.41 mg/l</td>
</tr>
<tr>
<td>Zn (Zinc)</td>
<td>Reduction 0.47 to 0.14 mg/l</td>
</tr>
</tbody>
</table>
This had a resultant 44% reduction in water treatment costs from R0.25 per ton to R0.14 per ton of feed to plant. The chemical delivery procedure (Annexure II) was also reviewed such that a plant representative signs for the chemicals and the delivery note be taken to the warehouse otherwise no payment will be made if there was no acceptance of chemicals by a plant foreman / his representative.

Figure 4 - 10: Improvement in water treatment costs

<table>
<thead>
<tr>
<th>Water Treatment Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
</tr>
<tr>
<td>Oct-14</td>
</tr>
<tr>
<td>Nov-14</td>
</tr>
<tr>
<td>Dec-14</td>
</tr>
<tr>
<td>Jan-15</td>
</tr>
<tr>
<td>Feb-15</td>
</tr>
<tr>
<td>Mar-15</td>
</tr>
</tbody>
</table>

4.1.1.2.5 Lean technique 3: Standardised work

The standard work technique was used to address the different outcomes from the inspection of panels and the decision to replace panels. The inspections had to be standardised by way of adding task lists in order for each operator to look for the same irregularities. Furthermore an engineering solution was investigated. An inspection task list was created to standardise the inspections which ensured that all operators are aligned with the requirements. A panel wear monitoring program was also installed in order to assist with the inspections. The program shows the wear profile of panels on each screen deck, a foreman can track how long the panels have been in operation and can then estimate the life of panels on each screen and the future consumption. The operators would then verify the wear detected by the system when they change the panels. The system has assisted the plant foremen to order the amount of panels
beforehand, take them to the respective screens whereby the operators would just get to each screen to verify and change the panels indicated by the software. This has had the following benefits:

- Reduction of inspections duration from 2 hours to 15 minutes per screen.
- Reduction of downtimes relating to panel failure from 1792 downtime minutes in 2014 to 293 downtime minutes in 2015.
- Reduction in waste of panel inventory as realised by a 20% cost savings in panel costs.

**Figure 4 - 11: Improvement in screen panel process downtimes**

![Unplanned panel downtime minutes](chart)

4.1.1.2.6 Lean technique 3: quality at the source

The black water overflow that was observed during the current state VSM means that there were fine coal particles that should have been thickened out as sludge. The presence of fine coal particles might be due to process inefficiencies, equipment failure or the flocculent itself. Investigations ruled out any process inefficiencies or equipment failures. The flocculent in use was then tested on a laboratory scale with a range of other different flocculants containing similar polymer molecular weights to ascertain its performance and to determine if it is the most suitable reagent for the plant. At least three flocculants performed better than the plant’s
flocculent in the laboratory test work. The poor quality of the flocculent in use was then determined to be the cause of the poor water recovery.

Costs comparisons were conducted on the three flocculants and were all found to be at least 30% to 50% lower than the cost price of the plant’s flocculent. A plant trial run was then conducted for a period of three months with each flocculent allowed for plant dosage for a period of three months. One flocculent performed exceptionally well in terms of the settling rates and overflow water clarity; which was then selected and is currently used as the only plant flocculent. This has resulted into flocculent cost reduction from R0.33 per ton to R0.12 per ton.

The improved water clarity has had some other spin offs such as less downtimes in spray water valve blockages. The high clarity water has also improved the magnetite recovery from the washed products. Because the spray water valve blockages has more than halved the recovery rate has improved from 85% to 99% and this is also evident in the drop of the plant magnetite consumption from 2kg per ton to 1kg per ton of feed to plant.

**Figure 4 - 12: Improvement in flocculent costs**
4.1.1.2.7 Lean technique 4: Seven wastes (beneficiation process)

Wastes uncovered at the beneficiation plant include waste of motion, transportation, inventory, inappropriate processing and waiting.

Process operators had to walk from one plant to the other just to get the relative density measuring equipment to monitor the process and then return the equipment back after they had finished the monitoring. The control room operators had to wait 30 minutes longer to make process adjustments due to this moving between plants; which resulted in lower organic efficiency caused by inappropriate processing in the secondary plant. The density measurement scale was purchased for the secondary plant in order to eliminate waste of motion which automatically reduced unnecessary waiting time thus improving efficiency.

The inconsistencies resulting from different panel inspection outcomes had resulted into wastes of transportation and inventory due to excessive panels being handled and transported into the plant unnecessarily. These wastes have been eliminated through the technique of standard work.
4.1.1.2.8 Lean technique 5: 5S’s of good housekeeping

While mapping the current state general poor housekeeping conditions were observed at the different sections of the plant. As an intervention the 5S’s concept was introduced to the teams to explain to them what it is all about and what the teams would themselves benefit from a clean workplace. Housekeeping was introduced as a metric to each section whereby the teams that reach at least 80% are rewarded with points monthly on a linear scale; whereby the best performing section gets the maximum points. Housekeeping inspection lists were designed for each section and implemented as an audit tool which each section is measured. Weekly housekeeping audits have been scheduled in order to encourage teams to sustain good housekeeping. The worst performing section is obliged to present to the plant’s management as to why they have not attained at least 80% and what actions have they put in place to ensure compliance with the expectations.

Although the organisation already uses a reliability centred maintenance (RCM) approach, the use of 5S’s of good housekeeping has led into the integration of TPM into the RCM system. Since teams are held accountable for the state of housekeeping in their sections, supervisors went further to assign equipment responsibilities to every artisan and operator working on that equipment. Apart from only conducting scheduled maintenance and or operating equipment, employees now clean the equipment and make sure it’s in a good condition. As part of training Tuesdays, employees are trained and educated in areas where there are still gaps and the importance of asset care and maintenance is emphasised.

Housekeeping points shown in the table below were measured before and after the intervention to track progress or lack thereof.

**Table 4 - 9: Improvement in the housekeeping results**

<table>
<thead>
<tr>
<th>Date</th>
<th>Engineering Structural</th>
<th>Engineering Workshop</th>
<th>Crushing and Screening plant</th>
<th>ROM pulling</th>
<th>Product handling</th>
<th>Laboratory</th>
<th>Beneficiation plant</th>
<th>Mine Residue Dump</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/12/2014</td>
<td>53%</td>
<td>44%</td>
<td>62%</td>
<td>56%</td>
<td>57%</td>
<td>79%</td>
<td>83%</td>
<td>81%</td>
</tr>
<tr>
<td>01/01/2015</td>
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<td>82.00%</td>
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<td>81.00%</td>
<td>88.00%</td>
<td>85.00%</td>
<td>94%</td>
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<tr>
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<td>93.00%</td>
<td>89.00%</td>
<td>90.00%</td>
<td>100.00%</td>
<td>91.00%</td>
<td>96%</td>
</tr>
<tr>
<td>01/03/2015</td>
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<td>87.00%</td>
<td>96.00%</td>
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<td>99.00%</td>
<td>94.00%</td>
<td>99%</td>
</tr>
<tr>
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<td>94.00%</td>
<td>94.00%</td>
<td>88.00%</td>
<td>88%</td>
<td>100%</td>
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<tr>
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<tr>
<td>01/06/2015</td>
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<td>96.00%</td>
<td>88.00%</td>
<td>99%</td>
</tr>
<tr>
<td>01/07/2015</td>
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<td>92.00%</td>
<td>96.00%</td>
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<td>87.00%</td>
<td>95.00%</td>
<td>86.00%</td>
<td>100%</td>
</tr>
<tr>
<td>01/08/2015</td>
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<td>93.00%</td>
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<td>91.00%</td>
<td>90.00%</td>
<td>82.00%</td>
<td>92%</td>
</tr>
<tr>
<td>01/09/2015</td>
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<td>94.00%</td>
<td>93.00%</td>
<td>89.00%</td>
<td>91.00%</td>
<td>93.00%</td>
<td>92.00%</td>
<td>98%</td>
</tr>
</tbody>
</table>
4.1.2 Mapping the future state

Areas of improvement started showing up while developing the current state value stream mapping. While looking at the current state for XYZ Plant, it is evident that:

- There is a difference between the lead time of 32.77 days and the value added time of 991.44 seconds.
- There’s an excessive 2706 minutes of Mine Stoppages caused by the operating philosophy in the pulling of coal.
- There has been a discrepancy of 4% in the product yield as a result of the ROM operating philosophy.
- There’s a shortening of crusher segments’ life from two months to five weeks.
- A 15 minute delay in the density monitoring process.
- There has been unplanned downtime of 1792 minutes due to panel failures.
- An 11% increase in panel costs.
- A 63% increase in flocculent costs.
- An 80% increase in magnetite and in magnetite costs.
- A 50% increase in chemical costs.

The key guiding questions as defined by Rother and Shook (1999) will be used to map the ideal future state.

4.1.2.1 ROM Pulling

Before the future state could be mapped; 8 questions should be answered? These are:

4.1.2.1.1What is the takt time?

Pieterse et al. (2010:149) as well as Seth and Gupta (2014:51) defines takt time as the time available to produce one unit based on what the customer requires. It is calculated by dividing the production time per day by the daily demand. XYZ a three shift system, each running eight hours a day and the sales requirement is 9315 tons per day. This means that:

\[
Takt\ time = \frac{\text{Available Time}}{\text{Customer Demand}}
\]

\[
Takt\ time = \frac{86400\ \text{seconds}}{9315\ \text{tons}}
\]
Takt time = 9.275

This means that in order for XYZ Plant to meet its customer volume requirements, the plant must produce a ton of coal every second.

4.1.2.1.2 Will production be to a finished goods supermarket or directly to shipping?

Van der Merwe (2010:149) describes a supermarket as a storage or buffer where upstream continuous flow processes can withdraw stock when required. Production at XYZ will be to a finished goods supermarket. The Mine will produce to a finished goods supermarket because of the different operating times between the Mine and the plant. Producing to a finished goods supermarket will also improve plant quality control and plant organic efficiency resulting from the blending and homogenising of coal in the plant feed stockpiles. The beneficiation plant itself will also produce to a finished goods supermarket and not directly to shipping. There are many factors affecting the delivery of export coal to the Richards Bay Coal Terminal which may cause delays thus risking on time delivery to the customers. Among these factors are:

- While XYZ Plant can only rail a maximum of 17 000 tons per day; shipments come in barges of >75 000 tonnes meaning that with producing directly to shipping, a shipment will now take a minimum of 8 days to load instead of the current loading time of 48 hours. It also takes about 22 hours for a train to transport coal from XYZ Plant to RBCT.
- XYZ Plant also has at least more than 6 major export customers and sometimes these customers send their shipments within the same period. With the goods supermarket, various ships are loaded concurrently within the specified loading times whilst this will be impossible when producing directly to shipping.
- XYZ customers sometimes require a blend of the export product thus loading different portions of XYZ and other exporters in the same shipping vessel which is executed efficiently with the finished goods supermarket set up.
- The Transnet Freight Rail (TFR) performance affects XYZ Plant despatches negatively in that any breakdown on the coal line will be a risk to XYZ Plant.
- Allocation of trains in the coal line industry – XYZ Plant shares the same railway line with at least 10 other commodity exporters and the allocation of trains is done according to the industry performance on this line.
- RBCT performance – any breakdowns at the RBCT loading equipment affects the receiving of trains thus resulting into the delay of shipments.
4.1.2.1.3 Where will XYZ need to use pull system supermarkets inside the value stream?

XYZ will need to use a pull system at the screen panel workshop, flocculation station water treatment plant and at the end of the plant product stockpiles during the train loading phase and the shipment loading stage. McDonald et al. (2002:222) define a pull system as an interface between process steps in a production process. Four supermarkets can be defined for XYZ.

The first supermarket will be designed for the delivery of screen panels to the plant workshop and warehouse. Once maintenance has been done, a Kanban will be released to production foremen to order more panels to replenish the workshop stock. As the panels are withdrawn from the warehouse, a Kanban will be released for a buyer to order panels from the supplier in order to keep the minimum required stock.

The second supermarket will apply to the flocculent and water treatment chemicals. Once the batches have been consumed, a Kanban will be released for the buyers to order stock from the suppliers.

The third supermarket will be designed for the delivery of export coal to customers. Once a batch has been loaded / shipped for the customer a production Kanban will be released to operations in order to replenish the certain stockpile from which a ship was loaded.

The fourth supermarket will be designed for the XYZ live product stockpiles onsite. Once a train has been loaded from the live product stockpile, a production Kanban will be released to production to replenish the rapid train loading terminal for the next train.

4.1.2.1.4 Where can continuous flow processing be used?

The beneficiation process at XYZ is a continuous process from the ROM feed to plant until the product stockpiling end. At the end of stockpiling the process becomes a batch process whereby trains are loaded and despatched according to the TFR train schedule. The introduction of supermarkets will compel the stockpiling end to pace each process to the speed of the bottleneck.
4.1.2.1.5 At what single point in the production chain will production be scheduled?

Rother and Shook (1999) suggest that to control production, only one point in the value stream need to be scheduled for production and this point is known as the pacemaker process. It sets the production pace for all upstream processes and links the downstream and upstream processes together. Typically the pacemaker is a continuous flow process, farthest downstream in the value stream such that there should be no supermarket other than finished goods downstream of it (Rother and Shook, 1999). For XYZ the pacemaker process will be the beneficiation process since it is a continuous process running at a capped rate, cannot exceed the design capacity and links the ROM production (upstream process) and product stockpiling (downstream) processes together. This single point will regulate the entire export production value stream.

4.1.2.1.6 How will the production mix be levelled at the pacemaker process?

The XYZ coal beneficiation process is such that a single feed tonne of ROM into the plant is separated into the different products. There are no change overs or set ups for the different products. As the coal is mixed with the medium the different products will be separated according to the density differences.

Levelling product mix implies distributing the production of different products evenly over a time period (Rother and Shook, 1999). To distribute production evenly, XYZ will need to schedule export coal production evenly each month in order to be able to respond to customer requirements within shorter lead times at the same time keep to its minimum stock requirements. Production frequency and the quantities of XYZ products will be calculated based on the plant capacity analysis. The DRA solver and Xpac Scheduling models will be used to schedule production. The guiding principles in the approach proposed by Rother and Shook (1999) will also be followed.

4.1.2.1.7 What increment of work will be consistently released from the pacemaker process?

Literature suggests that as a guideline, small increments of work must be released and withdrawn (pitch) at the pacemaker process. Abdulmalek and Rajgopal (2007:230) define the pitch as the material transfer interval at the pacemaker process. The pitch is calculated by multiplying the takt time by the finished goods transfer at the pacemaker process. For XYZ takt time is 9.275 seconds, the transfer batch is 625 tonnes, the pitch is therefore 1.08 hours. Therefore XYZ will release work instructions and withdraw finished goods according to this
pitch. Because the beneficiation process at XYZ is a complex continuous automated process without any physical change overs, applying the pitch to the process means that the ROM reclaimer will have to feed 1500 tonnes every 1.08 hours into the plant. The Control Room Operator must monitor the process on the SCADA and check that the ROM feed to plant increases by 1500 tonnes per hour whilst the product tons is produced at 625 tonnes per hour every 1.08 hours.

4.1.2.1.8What process improvement will be necessary to achieve the future state?

In order for XYZ to achieve its desired state, improvement actions must occur. The fruits of the VSM technique cannot be realised without applying lean tools for process improvements. As with any other process improvements there might be room for improvement in the beneficiation process but the process currently is adequate in supporting the 13 857 tonne per day export coal production.

The important improvement area to consider is the current double handling of product between the live and emergency stockpiles. The introduction of a supermarket pull system in the plant product stockpiles will give the following benefits for XYZ:

- Overproduction will be eliminated
- Minimise unnecessary throw outs of coal into the emergency stockpile.
- Eliminate the risks of spontaneous combustion resulting from excessive storage periods.
- Reduce product handling costs.
- Eliminate the deterioration of coal qualities with regards to the volatile matter and calorific value.
- Eliminate the segregation of coal particles thus generating fines which cause other coal dust explosion risks.
- Enhance relationships between TFR and XYZ due to the reduced train turnaround times because the train will no longer have to wait for stock that is being moved from the emergency stockpile.

The following improvements will be necessary in order to achieve the desired future state:

- Reduce mine stoppages by at least 50%
- Improve panel maintenance time
- Reduce flocculent costs
- Improve process water quality after treatment
- Improve the life of crusher segments from five weeks to eight weeks
With regards to the levelling / scheduling of production, questions regarding the production system could not be addressed through the value stream map alone, additional tools are required to provide the necessary information regarding the dynamics and capability of the XYZ beneficiation process. The information required to answer some of the questions can be obtained by process simulation using tools such as the XYZ TQF scheduling tool and the ash balance model.

4.1.3 Production Scheduling

The TQF and the ash balance models were used to calculate and predict exactly how much ROM will be needed to produce the committed annual sales and what efficiency rates should be achieved. With this information, the number of trains ordered from TFR was then aligned to match the shipping / sales requirements and the production volumes. This resulted in a coal handling cost reduction from R6/ton to R4.8/ton. The ash balance models are attached in appendix 3.
Value Stream Mapping

Process: XYZ Coal Beneficiation
Date: 26 May 2015

Production Planning
Weekly Schedule
Marketing
Monthly Forecast

Weekly Schedule
Production
Planning

Daily Plans

Twistdraai Mine
Weekly plan

ROM screening & crushing

ROM FTP

Beneficiation

Live product Stockpile

Rapid train loading

RBCT stockpile

Ship loading

BiWeekly Orders
Monthly Forecast
Monthly TQF

60 000 t
36 000 t
15 000 t
30 000 t
8 350 t
15 000 t

1.6 days 2.5 days 1.78 days 3.59 days 1 day 15 days

2.6s 2.4s 2.4s 5.14s 59s 2s

C/T : 2.4s
Avail: 99%
OEE/Util : 99.82%

C/O : N/A

C/T : 5.14s
Avail: 99%
OEE/Util : 99.82%

C/T : 59s
Avail: 90%
OEE/Util : 86%

C/T : 2s

C/T : 3.5s

Production Lead time: 25.47 days
Production Cycle Time: 77.09s
4.1.4 Subsequent projects

Projects that resulted from this study are:

- The crusher segment optimisation project: aimed at extending the life of crusher segments to 11 weeks or at least 2,000,000 crushed ROM tons.
- The water treatment project: aimed at reducing water treatment cost and extending the treatment to other streams like service and fire water.
- Yield optimisation project: aimed at continuous evaluation of the coal washability characteristics and continuous adjustment of the gross coal qualities to achieve the net as received qualities with minimal ROM feed to plant.
- Flocculent testing project: this entails continuous evaluation of different flocculants to always ensure the selection and use of the best quality flocculent at economical cost.

4.1.5 Principles not used in optimisation exercise

The following principles were not used in optimisation exercise:

- Cellular manufacturing: cellular layout is less applicable to a coal washing plant as this plant is made up of unit operations each essential to the processing of bulk materials.
- Just in Time (JIT) production: this tool is less applicable to XYZ because extracting as much coal as possible is key to XYZ in this low coal price environment. Although the demand is known, placing more coal than demanded in the market will impact XYZ positively.
- Continuous improvement: the organisation has already implemented a continuous improvement system which they are working hard to make it part of the organisation’s culture so any improvements suggested will already be based on the culture of continuous improvement.
- Small lot production: this tool is less applicable to a coal washing plant as the plant processes bulk materials and the higher the volumes produced the lower the unit costs of the plant. The plant is characterised by economies of scale.
- Supplier networks: the organisation has good supplier networks and has already a long running supplier development department that is focused and developing small suppliers and strengthening its relations with its supplier.
4.1.5.1 Future optimisation exercises

Flexible plants: this will address the deteriorating coal qualities and allow for flexibility as compared to the current capacity.

TPM: this will address the production and engineering departments that each is focused on their business. The organisation will need to look at aligning the structure such that it encourages team approach to reduce breakdowns and improve productivity.

4.1.5.2 Second wave lean projects (outside of this project’s scope)

The following projects came about as a result of this study. These projects are however outside the scope of this study and the company needs to launch detailed investigations to find suitable optimisation solutions. They will all require capital funding to execute.

- Excess fine coal processing: the ultra-fines pumped out of the thickeners into the fine coal dumps have a heat value appropriate for power generation. The challenge is the handling of those fines at the moment. It should be investigated how those fines could be processed for ease and cost effective handling such that they can generate income. This project will require pilot testing in different fine coal processing plants, licensing, risk assessments, environmental impact studies and huge capital funds and therefore it is outside of the scope of this study.

- Installation of a flocculent make up unit: this is as a result of the current make down unit whereby flocculent still need to be manually diluted by operators at the feeding point. A flocculent make down unit whereby the flocculent solution is already diluted to the correct solution strength when it leaves the plant will further reduce flocculent consumption in the plant. This project is outside of the scope of this study and will require capital funds.

- Spillage elimination: the spillages observed through the current VSM could not be entirely addressed through housekeeping in isolation. A permanent solution to eliminate spillages is necessary and it will require modifications and upsizing of chutes and other plant equipment.

- Higher capacity coal processing cyclones: as the mines are moving into poor coal reserves, the plant will need bigger capacity to process large volumes of ROM coal in order to get the equivalent products that they are getting now. This project will require pilot testing in bigger pilot test plants. The bigger size vessels will need to be investigated for higher capacity and this will be a capital intensive project that is outside
of the scope of this project and cannot be dealt with now in this low coal price environment.

- Organisational design: this will entail integrating the production and engineering crews towards a TPM approach.

4.2 Summary

In summary it is evident that the lean tools applied helped in elimination of waste and efficiency improvements at XYZ plant. Table 4-3 below summarizes the results.

Table 4-10: Summary of improvement results

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Results Before improvement</th>
<th>After improvement</th>
<th>Tools used</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROM blending</td>
<td>42.86%</td>
<td>48%</td>
<td>Six Sigma</td>
<td>9.50%</td>
</tr>
<tr>
<td>Reduce mine stoppages (udm)</td>
<td>2706 udm</td>
<td>217 udm</td>
<td>Flexible processes</td>
<td>92%</td>
</tr>
<tr>
<td>Reduce water treatment costs</td>
<td>R0.25/ton</td>
<td>R0.14/ton</td>
<td>Flexible processes</td>
<td>44%</td>
</tr>
<tr>
<td>Reduce panel downtimes (udm)</td>
<td>1792</td>
<td>293</td>
<td>Standard work</td>
<td>84%</td>
</tr>
<tr>
<td>Reduce panel costs</td>
<td>R0.36/ton</td>
<td>R0.30/ton</td>
<td>Standard work</td>
<td>18%</td>
</tr>
<tr>
<td>Reduce flocculent costs</td>
<td>R0.33/ton</td>
<td>R0.12/ton</td>
<td>Quality at the source</td>
<td>64%</td>
</tr>
<tr>
<td>Improve organic efficiency</td>
<td>95%</td>
<td>99.5%</td>
<td>Seven wastes</td>
<td>4.5%</td>
</tr>
<tr>
<td>Improve housekeeping</td>
<td>Min 44%</td>
<td>Max 100%</td>
<td>5S’s of good</td>
<td>&gt;50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>housekeeping</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>TPM</td>
<td></td>
</tr>
<tr>
<td>Reduce coal handling cost</td>
<td>R6/ton</td>
<td>R4.8/ton</td>
<td>Capacity scheduling</td>
<td>20%</td>
</tr>
</tbody>
</table>
CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The main objective of the study was to investigate if the lean tools and techniques were applicable in a coal washing plant. This was done based on the lean manufacturing literature; each tool tried practically for applicability in the plant.

During the field studies it was clear that there were definitely opportunities for optimisation and some tools were more applicable than others. The applicable tools were selected and applied; with the benefits becoming more evident. The applicable tools gave rise to optimisation projects which some could be executed immediately while others fell outside of the scope of this study due to the lengthy time required for further investigations and the resources required for successful execution.

5.1.1 Conclusions

In conclusion selected lean tools are applicable to a coal washing plant; each plant needs to first uncover its wastes and identify opportunities for improvement. The following lean tools were found to be applicable in a coal washing plant:

- Six Sigma
- 5S's of good housekeeping
- Seven wastes
- Flexible processes
- Standard work; and
- Quality at the source

Through the application of Six Sigma, XYZ was able to build homogeneous blends of their different coals such that they recover maximum product from minimal ROM feed to plant. If this is sustained, it could contribute towards economisation of mineable coal reserves by prolonging the life of the current Mines. Because of the blending opportunities; the operations became flexible.

The application of the flexible processes tool brought about the improvement in runtime thus reducing Mine disruptions or production stoppages by 96%. By applying the standard work technique at XYZ coal the panel inspection duration reduced from 2 hours to 15 minutes per
screen, downtimes relating to panel failure reduced from 1792 downtime minutes in 2014 to 293
downtime minutes in 2015 and the panel costs dropped by 20%.

Due to the quality at the source tools applied at the thickening process; the flocculent costs
reduced by 75% whilst the magnetite recovery improved from 85% to 99% as a spin off.

Through the application of seven wastes, the wastes uncovered at the beneficiation plant were
eliminated resulting into organic efficiency improvement.

The 5S’s application helped to improve the housekeeping in the plant, brought order and
improve the readiness for the plant’s Safety Health and Environment (SHE) audits; while
improving employees’ morale through rewards and recognition for good housekeeping.

5.1.1.1 Recommendations

It is recommended that XYZ Plant embed the applicable tools in the way the plant operates and
continuously seek ways to improve.

It is recommended that XYZ coal beneficiation plant incorporates lean manufacturing targets in
their annual “game plan”.

It is recommended that XYZ coal beneficiation plant measures the extent of leanness and
quantify the benefits annually.

It is also recommended that XYZ plant pursues further optimisation through the second wave of
lean projects that were outside the scope of this study.

The recommendations to the industry are to make allowance for testing of lean tools in their
plants and make lean manufacturing part of their businesses. Positive reception and use of
such tools will build resilience in the volatile commodity sector.

5.1.1.2 Achievement of the study’s objectives

The main objective of the study was to investigate if the lean tools and techniques were
applicable in a coal washing plant. The investigation conducted established that selected tools
are applicable in a coal beneficiation plant and those applicable were implemented / utilised.

The secondary objectives were:

- To identify applicable lean optimisation techniques and tools through a literature study
- To analyse these lean techniques and tools for applicability in the specific plant
• To recommend improvements in the plant processes, using these tools and techniques. The applicable lean optimisation tools and techniques were successfully identified through literature study and there were analysed specifically at the XYZ coal beneficiation plant. These led to the recommendation of various improvements of which some were initiated successfully while others require long term implementation. Therefore the objectives of the study were achieved.

5.1.1.3 Recommendations for future research

It is suggested that further research be conducted to measure the leanness of coal beneficiation plants.

It is recommended that feed to plant be blended in the stockpiling yards before the coal is fed into the beneficiation plant.

It is recommended that all causes of quality deviations be properly investigated before changing processes or procedures in the plant.

Is also recommended that further research focuses on the prolonging of Life of Mine (LOM) through application of lean tools in the Mines.

Lastly it is recommended that a study be conducted to determine key success factors for lean application in a mine; given the demographics of the mine workers with respect to skills.

The main objectives of the study are:

• To investigate the applicability of lean manufacturing tools and techniques in a coal beneficiation plant.
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ANNEXURES

Annexure A: ROM Operational guidelines
XYZ coal beneficiation plant
Operational Guidelines for ROM Pulling
To: All plant Foremen and Control Room Operators
Date: 01 December 2014

A: Purpose
This document serves as an operational guideline to ensure that deviations are attended promptly in order to maintain consistent pulling of coal into the plant and avoid unnecessary stoppages.

B: Pulling of coal
The bunkers must be pulled in sequence as per supply chain demand. The daily budgeted production from X and Y shaft is 18000 tons and 15000 tons respectively. The targeted daily ROM pulling duration for these shafts is 11 hours and 7 hours respectively.

C: Mine bunker operation
   • X and Y shaft bunkers must not be left unattended at a level of 60% or above.
   • Coal demand at X mine must be set at 1600 tons per hour.
   • CV000 must consistently run at 1400 tons per hour.
   • Y mine must be operated at 1000 tons per hour as an addition to the tons from X mine.
   • At the end of the production period, bunkers will be drawn empty unless there’s a plan to leave them full as a result of operational decisions, for instance a planned ROM reclaimer change over.

D: CV00X operation
The design capacity for the CV00X is 2600 tons per hour. CV00X must be operated at a minimum of 2000 tons per hour at all times by operating mine bunkers such that the flow of coal from the various shafts is synchronised.

E: Breakdown reporting
If there’s operational breakdowns resulting in CV00X running below 2000 tons per hour for an hour:
- The Control Room Operator must immediately inform the Chief Foremen at Coal Handling.
- If the problem cannot be solved within 2 hours, the Engineer and Operations Manager must be informed.

NB: After hours; the Foreman on Standby and the Manager on Standby in conjunction with the responsible Mine standby personnel will fulfil the above roles.

**Bunker operation during a breakdown**

The Control Room Operator must keep track of the bunker levels during a breakdown period. The focus must be to avoid Mine stoppages.

At 50% the Control Room Operator must arrange Front End Loaders
- Know how many sections are producing
- Align the positioning of the front end loaders with the number of sections producing at each shaft.
- Communicate the throw out plan with the Mine Control Room Operator.

At 70% start throwing out
- Notify Chief Foreman or manager on standby after hours
- Throw out until the bunker level goes below 50%
- Follow up on the breakdown progress
- Should the breakdown be resolved before the bunker levels reach 70%, revert back to the pulling of coal, otherwise resume throwing out.

**Signed** XXXXXXX

XYZ Coal Beneficiation Plant
Plant Manager
Annexure B: Water treatment chemicals delivery procedure
XYZ coal beneficiation plant
Delivery procedure for water treatment chemicals
To: All plant Foremen; Service Provider X and Warehouse Controllers
Date: 01 November 2014

Following a discrepancy in the amount of chemicals invoiced and utilized; the following procedure shall apply to all water treatment chemicals delivered at the dams.

The supplier must sign in at the Security reception and then report to the control room for delivery.

The Foreman on shift must accompany the supplier to offload the chemicals at the chemical dosing plant.

After offloading; the Foreman must sign the delivery note (proof of delivery) and hand it back to the Supplier.

The supplier must then take the signed delivery note to the warehouse receiving department whereby the chemicals will be booked in as good received.

The delivery note and invoice will be attached in the system for service entries.

This is to ensure that goods paid for are received and all received goods are paid for.

Signed XXXXXXX
XYZ Coal Beneficiation Plant
Plant Manager
Annexure C: Ash balance model

XYZ coal beneficiation plant
Annexure D: Motivation for capital for the process water treatment plant

XYZ Coal Plant

05 September 2014
The General Manager

XYZ COAL BENEFICIATION PLANT: PROCUREMENT OF DOSING EQUIPMENT FOR PROCESS WATER TREATMENT CHEMICALS

Purpose
The General Manager, XYZ coal beneficiation plant is REQUESTED to APPROVE an amount of R89 900 to purchase dosing equipment for process water chemicals for the Operations Department at XYZ coal beneficiation plant.

Background
Dosing equipment is utilized to dose water chemicals (corrosion inhibitors) in corrosive process water to reduce the corrosion rate of the steel water pipes and metallic structures at XYZ coal plant; thus this process is essential for mitigating abrupt metallic structural failure and also prolongs the life of the steel water pipes. XYZ coal plant currently employs Supplier X’s dosing equipment at zero cost on condition that water chemicals are procured only from Supplier X. However this condition limits XYZ coal plant to procure water chemicals from other merchants. A merchant that supplies similar water chemicals at a lower cost as compared to Supplier X was identified and thus this prompted the Operations Department to procure their own dosing equipment.

Proposed solution
Procure the following dosing equipment from Supplier Y at a once off cost of R89 900.

<table>
<thead>
<tr>
<th>Item</th>
<th>Order Quantity</th>
<th>Unit Price</th>
<th>Sub Total (R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prominent pump</td>
<td>2</td>
<td>R 23 000.00</td>
<td>R 46 000.00</td>
</tr>
<tr>
<td>2500lt heavy tank</td>
<td>2</td>
<td>R 4 950.00</td>
<td>R 9 900.00</td>
</tr>
<tr>
<td>Industrial agitator and support frame</td>
<td>1</td>
<td>R 34 000.00</td>
<td>R 34 000.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>R89 900.00</strong></td>
</tr>
</tbody>
</table>

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Deliverables
The equipment must be procured and commissioned in order to continue with the proactive behaviour of mitigating the unexpected metallic structural failure and to protract the life of the steel water pipes by reducing the corrosive behaviour of the process water at XYZ coal beneficiation plant.

Project execution
The installation will be done by Supplier Y personnel and there will be no additional costs charged for labour/execution. XYZ plant personnel will however offer support throughout the commissioning process and also maintaining the operation of the equipment.

Financial Motivation
- The graphs show that Supplier Y provides a similar water chemical at a lower cost as compared to Supplier X.
- Purchasing Supplier Y’s water chemical will yield a cost saving of R72 000 per month.
- The project will be financed from the capital budget of the Financial Year 2015.
Request

The General Manager is REQUESTED to APPROVE an amount of R 89 900 to purchase dosing equipment for process water treatment chemicals for the Operations Department at XYZ coal beneficiation plant.

Requested by:
Candidate Metallurgical Engineer
XYZ coal beneficiation plant

Recommended by:
Plant Manager
XYZ coal beneficiation plant

Approved by:
General Manager
XYZ coal beneficiation plant