Development of a continuous improvement framework for a small scale steelmaking company

by

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March 2018

Declaration

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………………………………. **…………………………..**

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Abstract

The South African steelmaking industry is currently sailing through a turbulent economic period characterised with commodity price instability and competition from European and Asian markets. This research study focuses on creating a production cost advantage for a local steelmaking organisation through the implementation of a continuous improvement (CI) framework. Implementing CI activities focuses on product value creation by systematic identification and elimination of process waste in the production process on a continuous basis.

Through a systematic literature review on the applications of lean manufacturing in South Africa, the research identified that there was limited application of continuous improvement techniques in steelmaking sector. The study further investigated the development of the South African steel industry and applications of Industrial Engineering (IE) principles to the industry. Findings of this review buttressed the absence of IE systematic research for steelmaking in South Africa.

To understand continuous improvement, the student used conceptual framework analysis (CFA), a non-deterministic research tool that provides a method to conceptualise a specific subject. The identified concepts of continuous improvement are: CI process management, organisational infrastructure and supportive framework, and CI techniques. These three concepts were used to construct a CI implementation framework for Unica Iron and Steel Company in Hammanskraal, Pretoria. The implementation framework consists of a cycle with six CI process management steps which include process audit, identification of areas of improvement, improve, optimise, sustain and review. The framework is based on the following CI techniques: **Lean Manufacturing**, **Toyota Production System**, **Six Sigma** and **Theory of Constraints**. To successfully implement CI activities the organisation should have proper channels of communication between line employees, supervisors and operational managers as organisational infrastructure and supportive framework aspects.

To assist in the validation of the CI implementation framework, Technomatix simulation software was used. From the results obtained through simulation, the first improvement cycle revealed 78% improvement in throughput per shift.

Opsomming

Die Suid-Afrikaanse staalvervaardigingsbedryf vaar tans deur 'n onstuimige ekonomiese tydperk wat gekenmerk word deur die prysstabiliteit en die mededingendheid van die Europese en Asiatiese markte. Hierdie navorsingstudie fokus op die skep van 'n produksiekostevoordeel vir 'n plaaslike staalproduksie organisasie deur die implementering van 'n deurlopende verbetering (DV) raamwerk. Die implementering van DV-aktiwiteite fokus op produkwaarde-skepping deur die stelselmatige identifisering en eliminering van prosesafval in die produksieproses op 'n deurlopende basis.

Die navorsing het deur middel van 'n sistematiese literatuuroorsig oor die toepassings van maer produksie in Suid-Afrika, bepaal dat beperkte toepassings in die staalvervaardigingsektor tans bestaan. Die studie het verder ondersoek ingestel na die ontwikkeling van die Suid-Afrikaanse staalindustrie en toepassings van bedryfsingenieurswese (BI) -beginsels vir die bedryf. Bevindinge van hierdie oorsig beklemtoon die afwesigheid van sistematiese navorsing in BI vir staalvervaardiging in Suid-Afrika.

Om deurlopende verbetering te verstaan, het die student konseptuele raamwerkanalise (KRA) gebruik, 'n nie-deterministiese navorsingsinstrument wat 'n metode bied om 'n spesifieke onderwerp te konseptualiseer. Die geïdentifiseerde konsepte van deurlopende verbetering is: DV prosesbestuur, organisatoriese infrastruktuur en ondersteunende raamwerk, en DV tegnieke. Hierdie drie begrippe is gebruik om 'n DV - implementeringsraamwerk vir Unica Iron and Steel Company in Hammanskraal, Pretoria, op te stel.

Die implementeringsraamwerk bestaan uit 'n siklus met ses DV prosesbestuurstappe wat proses-oudit insluit, identifisering van verbeteringsareas, verbeteringe, optimisering, en onderhoud. Die raamwerk is gebaseer op die volgende DV tegnieke: Lean Manufacturing, Toyota Produksie Sisteem, Ses Sigma en Theory of Constraints. Om die DV-aktiwiteite suksesvol te implementeer, moet die organisasie behoorlike kommunikasiekanale hê tussen lynwerknemers, toesighouers en operasionele bestuurders as organisatoriese infrastruktuur en ondersteunende raamwerk aspekte.

Die validering van die DV implementeringsraamwerk was gedoe deur Technomatix simulasie sagteware te gebruik. Uit die resultate van die simulasie was die bevinding dat die eerste verbeteringsiklus 'n verbetering van 78% in deursetverhoging per skof lewer.

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God Almighty

Glory and honour be to the God who made the heavens and the earth for successful completion of this research. May God increase in respect as I decrease forever and ever. Amen.

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Unica Iron and Steel Private Limited

Many thanks to Unica for assistance during the field work exercise.

Family

Special thanks to my parents and Dondofema family (vana-Chitova) for the prayers, guidance and support since I embarked this journey. To my wife Isabellah and siblings, thank you all for your support and patience. I am blessed to have you all.

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Glossary

Acronyms and Abbreviations

Amcor	African Metals Corporation
CFA	Conceptual Framework Analysis
CI	Continuous Improvement
CISCO	Cape Town Iron and Steel Works
CSBR	Cost Saving and Business Restructuring
DAS	Development Appraisal System
DMAIC	Design, Measure, Analyse, Improve, Control
HSVC	Highveld Steel and Vanadium Corporation
IE	Industrial Engineering
IQMS	Integrated Quality Management Systems
Iscor	South African Iron and Steel Industrial Corporation
JIT	Just In Time Production
LM	Lean Manufacturing
PCM	Performance Centred Maintenance
PDCA	Plan, Do, Check, Act
SAIIE	Southern Africa Institute of Industrial Engineering
SAJIE	South African Journal of Industrial Engineering
SPC	Statistical Process Control
SS	Six Sigma
TOC	Theory of Constraints
TPS	Toyota Production System
TQM	Total Quality Management
Unica	Unica Iron and Steel Private Limited
WSE	Whole School Evaluation

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1 INTRODUCTORY CHAPTER

1.1 Chapter Introduction

Mini-mill steelmaking is a secondary steelmaking route in which scrap metal is used as the raw material to produce different steel products as shown in Figure 1. 1. Mini-mill steelmaking has two main processes, continuous casting and rolling. The continuous casting process is whereby molten steel is solidified into slabs, billets and blooms. The casting process starts by off-loading molten steel from electric furnace into a ladle pot. The molten metal will then be transferred to continuous caster machine. At the casting machine, molten metal will be decanted into a tundish which will supply molten metal to the mould at a regulated rate. The tundish contains nozzles at the bottom section which distributes flow evenly into the mould and maintains a stable stream pattern.

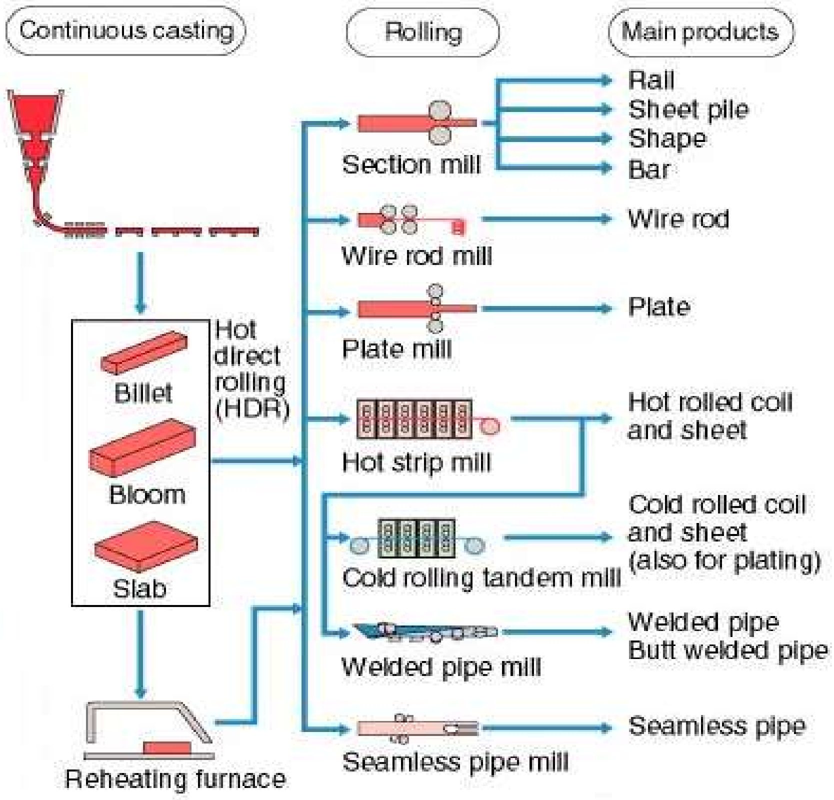


Figure 1. 1: Mini mill steelmaking (Ishii et al. 2006)

Rolling is a manufacturing process of shaping metals through application of compressive stresses resulting in plastic deformation of the metal into the intended geometry (Groover

2010). There are two types of rolling operations, the hot rolling operation and the cold rolling operation. For this study focus is on hot rolling, in hot rolling semi-finished products (billets, slabs or blooms) are first pre-heated to temperatures above 1200 degrees Celsius before rolling works starts. The objective of raising the temperature is to produce uniform equiaxed ferrite grains before performing the rolling operations. Hot rolling is conducted at high speeds and large thickness reductions because of the plasticity of the hot steel.

1.2 Problem Statement

The South African iron and steel industry currently faces stiff competition from Asian and European steelmakers resulting in shrinking markets and straining local steel value chain. The applications of continuous improvement techniques which include lean manufacturing in South African steel industry are limited. Whilst the implementation of the technique in automotive, beverage and food processing industries have yielded significant dividends in process waste elimination, product value streaming and quality improvement (Dondofema et al. 2017). Continuous improvement is a production culture that focuses on minute incremental innovation steps in organisations. Transformation processes of raw materials should consist of activities in which the customer is willing to pay for, any additional production costs will be a burden to the customer or will encroach into firm's profit. Production cost advantage strengthens firm's superiority or competitive advantage which boosts sales and usher the company into a bright future. Through the implementation of continuous improvement activities, organisations can establish themselves as market leaders due to affordable quality products enhanced by production cost advantage. Thus the aim of the study is to develop a continuous improvement framework for a small scale steelmaking organisation in South Africa.

1.3 Research Objectives

To achieve the aim of the study the following objectives were pursued:

- To investigate applications of continuous improvement techniques in South African (SA) industry.
- To investigate the development of SA steel industry and applications of Industrial engineering principles.

- To develop a continuous improvement framework for a small scale steelmaking company.

1.4 Importance of the Research Problem

The research work is meant to benefit Unica in terms of improving production process through the implementation of continuous improvement framework.

1.5 Limitations and Assumptions of the Study

The framework developed will be applied to Unica and the study is limited to production improvement. The study does not seek to generalise its findings and results to every steelmaking company in South Africa.

1.6 Summary of the contents of the chapters in this thesis

The introductory chapter has successfully managed to outline the problem statement and develop research objectives. Chapter two is the literature review which is divided into three sections. The first section of Chapter two is a review of continuous improvement techniques and the application of continuous improvement techniques in South African industry. The second section focuses on the development of South African steel industry and applications of IE principles in the industry. The last section of literature review explores continuous improvement through conceptual framework analysis. Chapter three is the research methodology which explains research methods used to conduct this study. Chapter four is the development of a CI implementation framework for a small scale steelmaking organisation. Chapter five is the implementation of the framework into the steel organisation and verification of suggested improvements through Technomatix simulation software. Chapter six is the conclusion of the thesis and contains contributions of this research study and recommendations.

1.7 Chapter summary

The aim of this research project is to develop a continuous improvement framework for a small scale steel industry. To achieve this aim, research objectives have been generated that include: investigations on applications of continuous improvement in SA and development of SA steel industry with applications of IE principles. The succeeding section literature review, focuses on continuous improvement applications and development of SA steel industry.

2 LITERATURE REVIEW

2.1 Chapter Introduction

The literature review is divided into three sections; the first section is a general review on continuous improvement and is conducted through a narrative approach. The continuous improvement section concludes by investigating the applications of lean manufacturing, a continuous improvement technique, in South African industry. The second section is narration of the development of South African steel industry from industrial engineering perspective. Third section uses grounded theory technique to review continuous improvement applications to develop a conceptual framework to be used later in the research.

2.2 Continuous Improvement (CI)

Continuous improvement (CI) is a production philosophy focused on incremental innovation involving small progressive steps, high frequency and short cycles, such that when the steps are combined they make significant impact on organisational performance (Bessant et al. 1994). The procedure is focused on breeding a culture of conscious unceasing improvement program driven by the desire to attain perfection (Danreid & Sanders 2007). The objective is to create an atmosphere of continuous learning that embraces change. The philosophy of continuous improvement sustains a competitive advantage for the organisation among its competitors (Ramadan et al. 2016). Thus this section will review continuous improvement techniques; the section is divided into two sub sections. The first sub section describes continuous improvement techniques identified during this literature search. The second sub section will investigate the applications of lean manufacturing, a continuous improvement technique, in South African industry in order to identify gaps of research concerning the application of continuous improvement.

2.2.1 Continuous Improvement Techniques

Techniques under review in this sub section consist of Toyota Production System, Lean Manufacturing, Six Sigma, Theory of Constraints, Cost Saving and Business Restructuring, Total Quality Management, Performance Centred Maintenance, Statistical Process Control and Integrated Quality Management Systems.

2.2.1.1 Toyota Production System

Toyota Production System (TPS) is a continuous improvement methodology that focuses on building an improvement culture and was developed by Ohno to focus on improving the production of Toyota Motor Corporation (Ohno 1988). TPS emphasises on treating employees as knowledgeable workers and empowers them with autonomy of correcting any problem within their work stations to ensure high standard of work. Toyota Production System pillars are Just in time (JIT) and process automation. JIT focuses on moving necessary parts from one work station to another when required thus avoiding inventory which hides process wastes. Process automation is using fully automated systems or semi-automated systems to aid humans and avoid mistakes. The two fundamental concepts of TPS are complimented by levelled production, standardised process, Visual Management and Toyota way philosophy as shown Figure 2. 1.

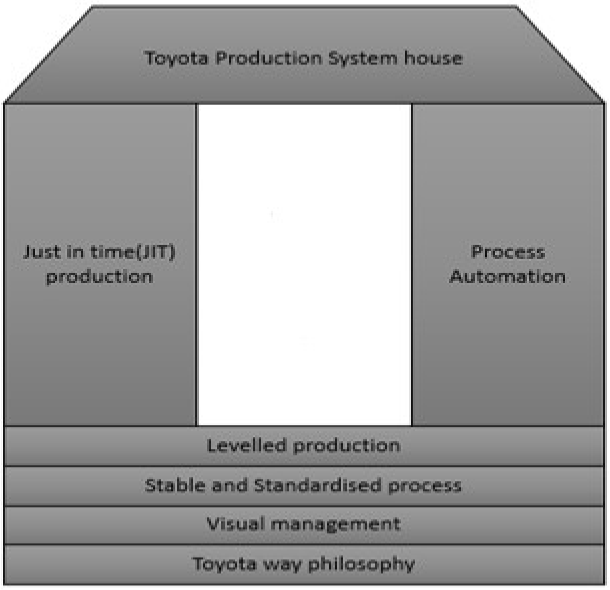


Figure 2. 1: Toyota Production System (Ohno 1988)

The Toyota way philosophy is a set of principles and behaviour norms that an organisation should cultivate for successful implementation of TPS. The principles are categorised into two groups which consist of respect for people (employees) and continuous improvement as shown in Table 2. 1. Respect for people category focuses on cultivating the appropriate culture conducive for CI activities and CI category consists of steps to follow for successful improvement cycles.

Table 2. 1: Toyota Way philosophy (Liker & Meier 2004)

The Toyota Way	Continuous improvement	Challenge	1. Long-term philosophy
		Kaizen	2. Create flow
			3. Use a pull system
			4. Level out the workload
			5. Stop and fix the problem
			6. Standardise tasks
			7. Use visual control
			8. Use reliable, tested technology
			14. Continual organisational learning through *kaizen*
	Respect for people	*Genchi genbutsu*	12. Go and see for yourself to understand the situation
			13. Make decisions slowly by consensus
		Respect	9. Grow leaders who live the philosophy
			11. Respect, challenge, and help your suppliers
		Teamwork	10. Respect, develop, and challenge your people and teams

2.2.1.2 Lean Manufacturing

Lean Manufacturing (LM) is an improved version of TPS meant to be applied in any industrial context. LM is focused on maximising product value (Womack & Jones 2003; Ramadan et al. 2016; Dondofema et al. 2017) by systematically eliminating process waste within the production system. Process waste is any activity that consumes resources, adds cost and cycle time without creating value. LM focuses on minimising and eliminating process wastes which include inventory, overproduction, waiting, unnecessary transport, incorrect processing, defects and unused employee creativity. These process wastes are briefly described below:

a) Overproduction is waste that occurs as organisations attempt to improve overall equipment effectiveness, and personnel effectiveness thus producing as much as possible without proper synchronisation of demand and production. This results in a work station producing more than what the succeeding work stations can consume per unit time resulting in over production (Liker & Meier 2004; Ohno 1988; Bicheno & Holweg 2009; Womack & Jones 2003).

b) Waiting waste is associated with stock outs, lot processing delays, and equipment downtime and capacity bottleneck. This results in idle time of personnel and equipment in anticipation of a task to be completed. From the customers perspective, waiting is a non-value adding activity therefore a waste (Liker & Meier 2004; Ohno 1988; Bicheno & Holweg 2009; Womack & Jones 2003).

c) Unnecessary transportation is any unnecessary movement of raw materials or work in progress during the manufacturing processes (Liker & Meier 2004; Ohno 1988; Bicheno & Holweg 2009; Womack & Jones 2003).

d) Incorrect processing waste is when the product is processed beyond customer specifications. Waste is generated through consumption of more materials per unit product. The overall effect is consumption of more production resources thus increase in the production cost per unit product (Liker & Meier 2004; Ohno 1988; Bicheno & Holweg 2009; Womack & Jones 2003).

e) Excess inventory waste can be excess raw materials, excess work in progress or excess finished products. Due to different lead times on different workstations, accumulation of work in progress (WIP) inventory is inevitable and there is need to enforce aggressive inventory control measures. Another source of WIP inventory waste is due to critical equipment failure which results in stoppage of the production and accumulation of inventory. An excessive inventory level in any of the three forms is a waste since there is storage and carrying costs associated with the parts (Liker & Meier 2004; Ohno 1988; Bicheno & Holweg 2009; Womack & Jones 2003).

f) Unnecessary movement waste is excessive motion of production resources without any cause in the manufacturing setup. Motion waste can be in form of excessive human motion that is unnecessary and production equipment travelling long distances (Liker & Meier 2004; Ohno 1988; Bicheno & Holweg 2009; Womack & Jones 2003).

g) Defects wastes are products that do not conform to the standards and specifications of the customer requirements. Defects are a waste because there is loss of manufacturing resources invested into the defective product. In some instances, there is need to repeat some manufacturing procedures to rectify the product defect (Liker & Meier 2004; Ohno 1988; Bicheno & Holweg 2009; Womack & Jones 2003).

h) Unused employee creativity is failure to tap employee creativeness during problem-solving and process improvements (Liker & Meier 2004; Bicheno & Holweg 2009).

When employee novelty is not extracted or recognised up to its potential this results in wasted human capital contribution.

To eliminate the stated process wastes a methodology in Table 2. 2 is used which consist of five steps and these are: value specification, value stream identification, establish flow, pull production and seek perfection.

Table 2. 2: Lean Methodology (Womack & Jones 2003)

Step	Objective of Step	Tools
1) Specify value	Understanding Customer needs and product characteristics. Identification of production aspects that provide value to the customer.	• Process analysis • Value analysis
2) Identify the value stream	To identify specific steps required to make the product.	• Value stream mapping • Process flow chart • Basic activity mapping
3) Establish Flow of products	To eliminate process wastes and produce the product with value adding steps.	• 5S (Sort, Set in order, Shine, Standardize & Sustain) • 5 Whys • Spaghetti diagrams • Standard Work • Cellular designs • Total productive maintenance (TPM) • Mistake proofing • Visual management
4) Pull production	Enforce a pull system by synchronise production of other work stations to the pace maker work station	• Just in time(JIT) • Pacemaker
5) Seeking Perfection	Facilitates the continuous improvement process by constantly repeating the cycle in search of a perfect production process.	

2.2.1.3 Six Sigma

Six Sigma (SS) is a comprehensive and flexible system for achieving, sustaining and maximising business success (Vermeulen et al. 2013) through elimination of quality defects in the production process (Mabizela et al. 2015). SS is facilitated by the Define, Measure, Analyse, Improve, and Control (DMAIC) cycle that improves and reinvents business processes. The SS methodology should be applied into the entire value stream of the product from raw materials to finished goods (or products). The objective of the methodology is a defect free manufacturing process that produces 3.4 defects per million translating to quality rate of 99.99966%. Table 2. 3 display the tools that are used for each phase during the DMAIC cycle. The define phase consist of setting the scope and objectives of the DMAIC cycle, it also includes problem clarification and setting targets. Measuring phase focuses on quantifying the current production capacity and quality performance of the production process and the analysis phase seeks to identify the root cause of variations in products. The improvement phase modifies the production process to rectify the root cause of variations and defects and control phase for monitoring the production process to avoid process variations.

Table 2. 3: Six Sigma DMAIC Tools (Basu 2009)

Define	Measure	Analyse	Improve	Control
• Set objectives • Set targets	• Process map • Spaghetti diagram • Pareto chart • Production records • Job measurement	• Failure mode & effects analysis • 5 Whys • Basic statistics • Sampling • 5 S (Sort, Set in order, Shine, standardize & Sustain)	• Recommendations improvement plan • Action plan • Cost benefit analysis • Dashboards • Employee training plans	• Control plan • Dashboards • Visual management

2.2.1.4 Theory of Constraints

Theory of Constraints (TOC) is a systematic approach that promotes the management of system constraints in the production line and all dependencies affecting production performance. A constraint is anything that limits a system from achieving higher performance towards its goals (Pretorius 2014). The systematic procedure is based on five steps which are as follows (Barnard 2010):

a) Identification of the system constraint which assist in determining the bottleneck process for the production line. This is achieved by mapping all production steps involved within the production process and measure time taken to complete each step. The step which takes longest time to complete is the system constraint.

b) Deciding on how to exploit the system's constraint discourages the traditional approach of getting rid of constraints by making a huge investment at the constraint (Pretorius 2014). Exploitation of the constraint seeks to optimise the use of the limitation imposed by maximising constraint capacity.

c) Subordinating non-constraint steps production under the constraint production capacity step avoids the waste of work in progress inventory. The level of utilisation of non-constraints should be determined by the capacity and utilisation of the constraint.

d) Elevation of the constraint is when further system improvement is not possible thus addition of physical capacity. Once capacity is added to the existing constraint, the constraint might be broken and a new constraint will be elsewhere within the production line.

e) If the constraint is broken inertia should not be the system constraint and for continuous improvement the systematic approach should restart the procedure from step one. Inertia is when complacency prevents returning to step one. If the constraint has not been broken by the elevation in step four then there is need to continue with steps two and step three which are exploiting and subordination.

2.2.1.5 Cost Saving and Business Restructuring

Cost Saving and Business Restructuring (CSBR) focus on re-organising the enterprise to improve business performance through the rationalising strategy thus cutting cost and saving money which translates to bottom line savings and improving profit (Darnton 2016). The rationalising procedure entails company size reduction, policy adjustment and products alteration. This exercise does not guarantee long term improvement of the organisational performance but can have a negative impact on the long-term profitability of the organization if other operations dynamics are not considered (Claassen 2016).

2.2.1.6 Total Quality Management

Total Quality Management (TQM) is a philosophy that focuses on customer satisfaction and employee involvement as drivers of continuous improvement for high quality products and process performance (Vermeulen & Edgeman 2000; Erickson 1992). Implementation of TQM improves and increase productivity and quality efficiency with the objective of producing functional without reworks. The eight concepts of TQM include customer-focus, employee involvement, process centred, integrated system management, strategic and systematic approach, continuous improvement, decision making based on facts and communication.

2.2.1.7 Performance Centred Maintenance

Performance Centred Maintenance (PCM) is focused on ensuring that physical assets continue to perform at the required level. Common maintenance strategies include breakdown maintenance, corrective maintenance, preventive maintenance, time based maintenance, condition based maintenance and reliability centred maintenance (Groenewald et al. 2015).

a) Breakdown maintenance is initiated by the occurrence of a breakdown, also known as 'run to failure'. It is implemented if the failure will not have impact on either production, safety of employees and environmental hazard.
b) Corrective maintenance is the upgrading of equipment to improve reliability.
c) Preventative maintenance is based on actions performed to maintain the expected functional stature of equipment to prevent failures.
d) Time-based maintenance plan is based on the time failure analysis. Time failure analysis is to determine the failure characteristics of the equipment relative to previous recorded failure time data. The aim of time-based maintenance is to determine a maintenance policy that would result in optimal system performance at the lowest possible cost.
e) Condition based maintenance entails applying maintenance actions relative to the condition of equipment interpreted by equipment monitoring system.
f) Reliability centred maintenance is focused on identifying and spending maintenance effort on items that are critical to the overall reliability of the system.

The strategy for implementing PCM maintenance techniques is based on the Plan, Do, Check, Act (PDCA) cycle for continuous improvement shown in Figure 2. 2.

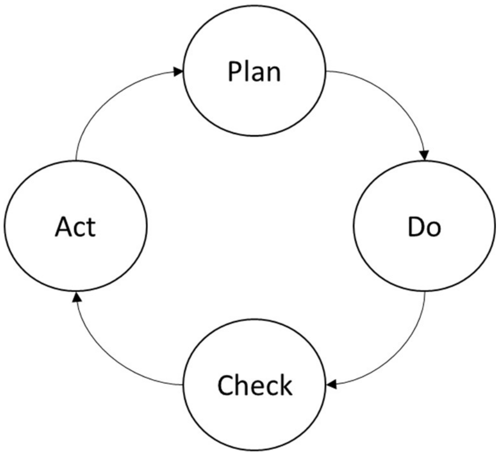


Figure 2. 2: Performance Centred Maintenance cycle (Groenewald et al. 2015)

The PDCA methodology is a continuous improvement maintenance strategy and is shown in Figure 2. 2. It has four distinguished phase which are: plan, do, check and act (Groenewald et al. 2015).

a) Plan phase sets the desired objective of the process and develop action plans to achieve the objective.
b) Do phase implements the action plans developed in the plan phase
c) Check asses if the achieved result was the desired objective.
d) Act phase is based on the achieved results and if the achieved result does not satisfy the objectives in the plan phase then the "Do" phase is repeated until the outcome is satisfy the set objectives. If the objective is achieved a new cycle with new objectives is initiated at the plan phase.

2.2.1.8 Statistical Process Control

Statistical Process Control (SPC) is a process improvement methodology utilised for monitoring, managing, maintaining and improve process performance using statistical methods (Groover 2010). SPC effectively reduces product recalls, reworks, scrap rate, warranty costs, and improve customer satisfaction, increase market share, profit margins and productivity. SPC utilises control charts to determine when a process is going out of statistical control and adjust it before it diverges out of the statistical limit. Input data for statistical control include product quality, quality costs and process performance. Through statistical analysis of process behaviour, quality levels of the process can be deduced. The statistical results must be interpreted such that they can provide useful information on how to achieve quality products by appropriately adjusting the process where it is deemed necessary. The objective is transforming the organisation to a defect free organisation associated with minimal production waste (Mabizela et al. 2015).

2.2.1.9 Integrated Quality Management System

Integrated Quality Management System (IQMS) is a quality management system consisting of three policies which consist of Development Appraisal System (DAS); Whole School Evaluation (WSE) and Performance Management System (PMS), tailor designed to foster a culture of continuous improvement in South African schools (Pylman 2014). The IQMS aims at identifying specific needs of teachers, schools and district offices; providing support for continued growth and development, promoting accountability, monitoring institutions overall effectiveness; and evaluating teachers' performance. (Pylman 2014)

2.2.2 Applications of CI techniques in South African Industry

To comprehend the application of continuous improvement in South African industry the student conducted a search of the applications of lean manufacturing a continuous improvement technique. Lean manufacturing technique was selected due to its Kaizen philosophy which has been successfully implemented by Toyota Motor Corporation. To avoid bias during literature collection the study used the systematic literature review. Systematic literature review methodology involves use of procedures to study a specific subject and determine different conceptual patterns of the subject. The stages used to complete this section are shown in Table 2. 4 and consist of planning the review, conducting the review and evaluating the results.

Table 2. 4: Systematic Literature Review Methodology (Dondofema et al. 2017)

Stage	Steps	Accomplished objective	How was it accomplished	Where it is presented
1) Planning the review	a) Review specification	a) Research questions development b) Selection of data sources c) Search terms definition	Determined the objectives of the study. The search term used was.	Section 2.2.2.1
2) Conducting the Review	a) Identification of the research	a) Identify publications on the application of lean manufacturing in South African industry	A total of 638 studies was yielded from the initial search	Section 2.2.2.2
	b) Study selection	a) Analysis of studies to ascertain the applications of lean methodology	Only 32 publications qualified for the survey after the removal of duplicates and non-relevant publications	Section 2.2.2.2
3) Evaluation	a) Data extraction and analysis	a) Determine the trends in terms of research on the application of lean manufacturing in South African industry		Section 2.2.2.3 and Section 2.2.2.4

2.2.2.1 Data sources and data collection

The search was conducted through Scopus and Web of Science search engines with the search term "lean manufacturing". To avoid an ad hoc list of publications, the search filters was set on South Africa (Territory), 1970-2015 (Publication Year) and Article and Conference Paper (Document Type).

2.2.2.2 Data selection

The 638 publications reaped in the primary search were subjected to a rigorous examination to ascertain if the publication perfectly fit for the final review. The initial criteria measure was to check if the publication was in any way related to lean manufacturing. The vetting process was accomplished by checking the relevance of the tittle of the publication with respect to applications of lean manufacturing. In case of any uncertainty of relevance of the tittle, the abstract of the publications was investigated. In this preliminary vetting process 490 publications were eliminated from the sample list. The second evaluation procedure was to check if there were no duplicates across the publications list and 60 duplicates were removed from the list. Another 46 publications were eliminated from the list because they were irrelevant to the scope of the study. The last selection criteria was to check if the geographical focus of the study was South African industry and six publications were eliminated upon this criterion with an additional of four publications removed because they were inaccessible. A final data set of 32 publications listed in Appendix 1 was collected and the document progression during the publication selection process is shown in Figure 2. 3. (This figure was developed by the student after analysing the relevant literature which pertain to this research, this also applies to all figures and tables referenced as Dondofema et al.2017)

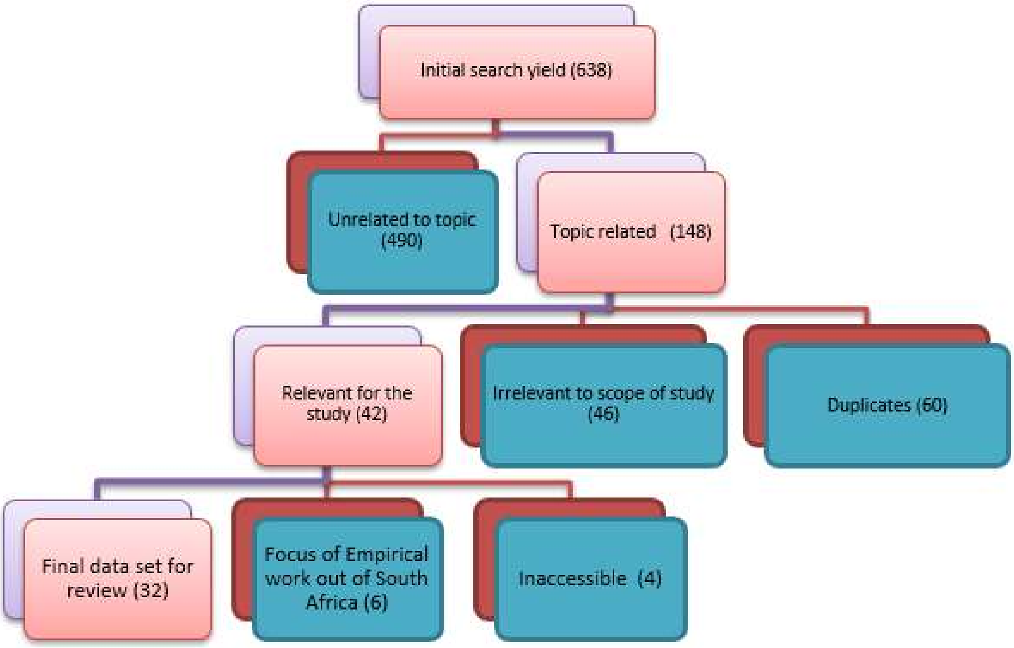


Figure 2. 3: Document Progression (Dondofema et al. 2017)

2.2.2.3 Data extraction and analysis

Intensive reading and assignment of specific codes and data categories to publications aspects was individually accomplished by the student. For each publication, conceptual aspects and empirical aspects were extracted and their respective sub components of interest are shown in Table 2. 5. The year of publication, type of publication and publishing institution were captured to understand the context of the research work. Development of trends concerning the application of lean methodology was developed per industrial domains, industrial sub sectors and manufacturing layout strategies.

Table 2. 5: Data Extraction Categories (Dondofema et al. 2017)

Conceptual Aspects	Empirical Aspects
•Document file name •Title of the document •Type of document (e.g. Journal or conference) •Year published •Published in (e.g. Journal name, conference name) •Authors •Geography of authors (country of affiliation) •Affiliations •Abstract •Lean tools applied (e.g. Kanban, Kaizen) • Framework for application of lean principles	• Focus of study • Industrial Domain (manufacturing or services) • Industrial sub sector (e.g. beverage, construction) • Manufacturing System (e.g. line, batch, continuous) • Conclusion

2.2.2.4 Findings and Discussions

This section shows the empirical and conceptual aspects of publications on applications of lean manufacturing in South African industry. Between 1989 and 2015, 32 papers for South African industry on lean manufacturing were published as shown in Figure 2. 4.

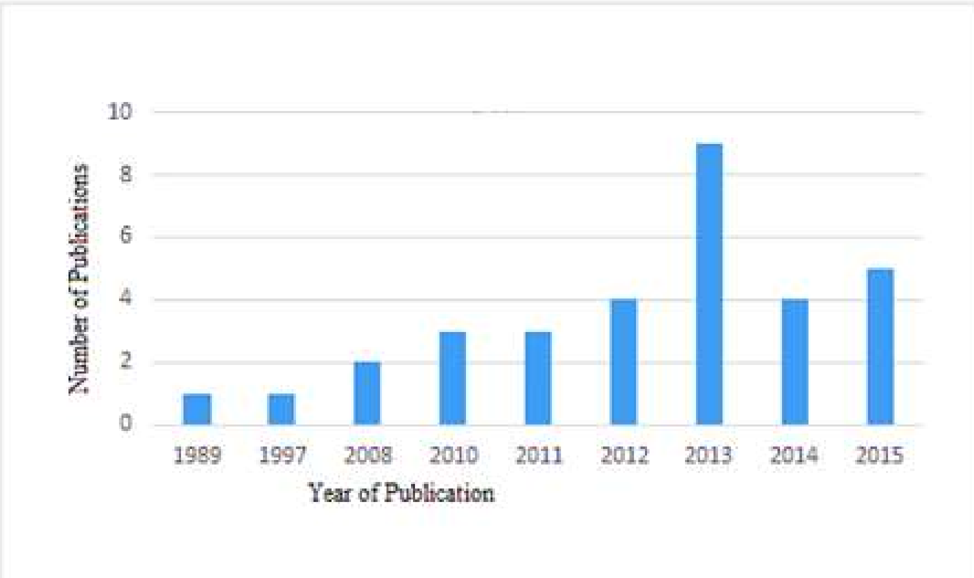


Figure 2. 4: Lean Manufacturing Research Output Chronology for South Africa (Dondofema et al. 2017)

The papers were published by different institutions, Table 2. 6 show 12 journal articles and 20 conference papers (proceedings).

Table 2. 6: Publications (Dondofema et al. 2017)

Studies published	**Number of Studies**
Journal Article	**12**
African Journal of Business Management	1
International Journal of Industrial Engineering	1
Journal of Manufacturing Technology Management	1
Learning Organization	1
South African Journal of Industrial Engineering	8
Conference Proceedings	**20**
2012 Proceedings of PICMET '12	1
2013 Proceedings of PICMET '13	1
2014 Proceedings of PICMET '14	2
2015 Proceedings of PICMET '15	1
IAMOT 2015 - 24th	2
Proceedings - 2010 IEEE 17th	1
Proceedings of IGLC16: 16th	1
Proceedings of CIE	3
SAIIE Conference proceedings (2009-2014)	8
Grand Total	**32**

The application of lean manufacturing was divided mainly into two industrial domains which are the production of goods (manufacturing) and services. Publications on manufacturing contributed 66% and 25% of the publications were from the service sector and 9% of the publications encompassed both sectors and was classified under generic category as shown in Figure 2. 5.

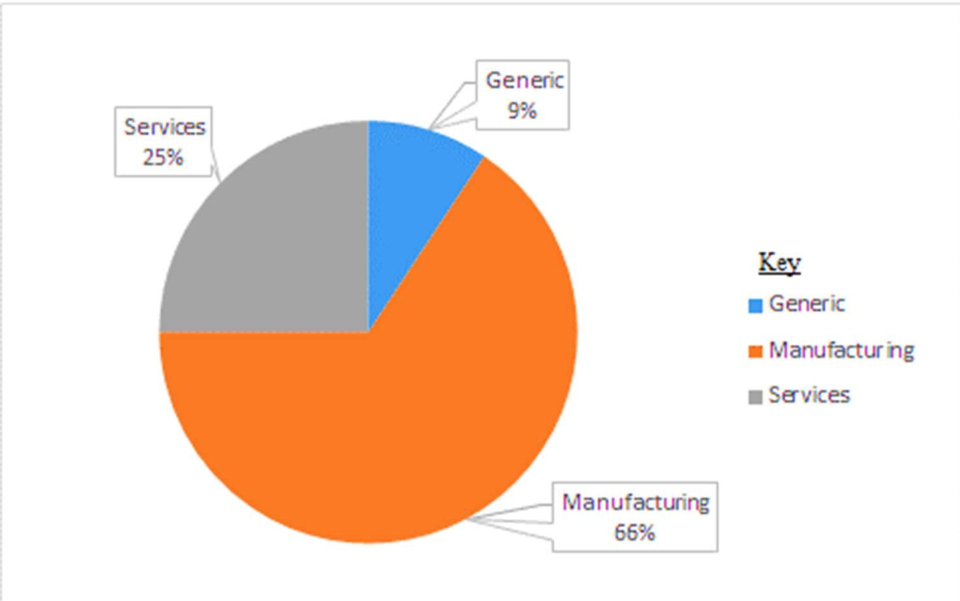


Figure 2. 5: Industrial Domain (Dondofema et al. 2017)

Figure 2. 5 show that lean manufacturing is being slowly adopted into the service industry though the technique originates in manufacturing industry. Its application in the service sector is gradually increasing due to immediate benefits of waste elimination. The technique has caught much attention in automotive enterprise management, food processing & beverages and assembling of electronic components as shown in Table 2. 7. There has been much interest towards improving the public health care service delivery system and education system, throughput. Also in the rail, and road transport activities lean tools have been implemented. Notably is the absence of steelmaking a key economic activity in Table 2. 7.

Table 2. 7: Industrial Sub sectors (Dondofema et al. 2017)

Domain & Sub sector	Manufacturing system	Number of publications
Generic		**3**
Generic		3
Manufacturing		**21**
Assembly (Electronic Components)	Batch	1
Automotive (Product Engineering & Design, Part manufacturing)	Line, Supply chain, product design	6
Beverage & Food Processing	Line	3
Biomedical (orthopaedic implant manufacturing)	Job Shop	1
Construction (Road & Earthworks)	Project	1
Fabrication	Job Shop	1
Forge Shop	Job Shop	1
Generic		4
Mining & Mineral Processing	Continuous	1
Textile (clothe manufacturing)	Batch	2
Services		**8**
Education		3
Generic		1
Health		2
Transport		2
Grand Total		**32**

Absence of publications (in Table 2. 7) on the application of lean in steelmaking and limited publications on application of lean manufacturing in construction, mining and mineral processing may be due to the perception on the origins of lean manufacturing. Lean manufacturing originates from Toyota Production system which was initially aimed at improving assembly line production systems. This explains the trends observed in Figure 2. 6, where focus of published research has been directed on batch manufacturing (31%) and line production (38%) which contributes 69% of total publications under the manufacturing domain.

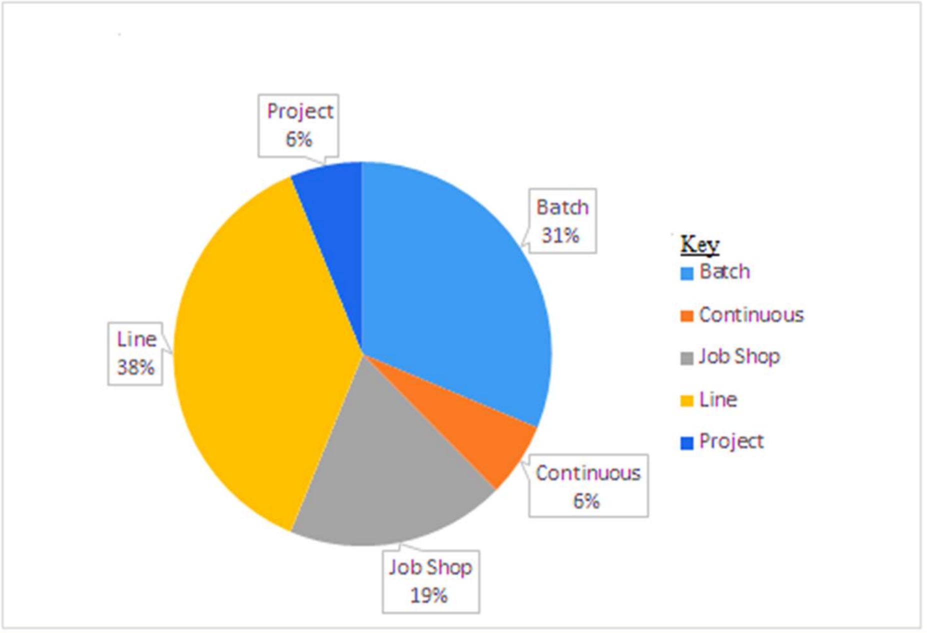


Figure 2. 6: Publications with respect to layout strategies (Dondofema et al. 2017)

Despite Lean philosophy being an emblem of Industrial Engineering, the technique is yet to be fully applied South African steelmaking industry. Based on this finding Section 2.3 will investigate the development of South African steelmaking industry and the applications of IE principles in steelmaking.

2.3 Evolution of Steelmaking Industry in South Africa and Application of Industrial Engineering principles

This section outlines the development of South African steel industry from Industrial Engineering perspective. The review covers events leading to the formation of the South African steel value chain. A report by Anglo American Private limited on iron and steel value chain indicated that South Africa now has a capacity of producing between 11.9 million tonnes annually (Anglo American 2011). This shows a considerable advancement and technological development in steelmaking from the Iron Age to modern industrialisation. The section concludes by investigating the applications of Industrial Engineering principles in South African steel industry.

2.3.1 Ancient Iron Production

In South Africa, iron ore smelting started in the ancient times and through carbon dating of slag deposits discovered in Broederstroom in the Transvaal, the industry roots can be traced back to fourth century (Taylor et al. 1988). Evidence of these primitive furnaces and slag accumulations is an indication of how iron products have played a pivotal role in the development of our society. Another study by Mason shows that as early as 460 A.D. going onwards in Tzaneen at a site called Silverclaves, iron smelting was conducted. Excavations at this site revealed artefacts which include slag deposits and furnace debris (Mason 1974). During the iron age, smelters were men of great skill and importance in the community and their products include household tools like axes, spears and hoes whilst iron of high purity was for jewellery (Klapwijk 1974). Friede and Steel (1985) classified iron age furnaces into two groups which are:

- Pit (bow) furnace
- Shaft furnace

2.3.1.1 Pit or Bow Furnace

Typical pit furnace was discovered in Tugela Basin Colenso during excavations conducted in 1975. The excavations exposed smelting sites of sedimentary iron ore that occurs in the siderite form known as the ferrous carbonate. This outcrop of ore was the raw material in the smelting processes (Maggs 1982).

Figure 2. 7: Pit Furnaces (Maggs 1982)

The pit furnace is shown in Figure 2. 7 and its architecture consist of pits dug into the ground and sprouts standing above the ground. The base of the sprout contained tuyeres inclined at 30 degrees to the surface for easy tapping (Maggs 1982; Hall 1980).

2.3.1.2 Shaft Furnace

Shaft furnaces are categorised into three types that includes Kaditshwene, Buispoort and Melville Koppies.

i) Kaditshwene Furnace

The furnace was sunk into the ground and another portion just slightly above the surface level as shown in Figure 2. 8 (Friede & Steel 1985).

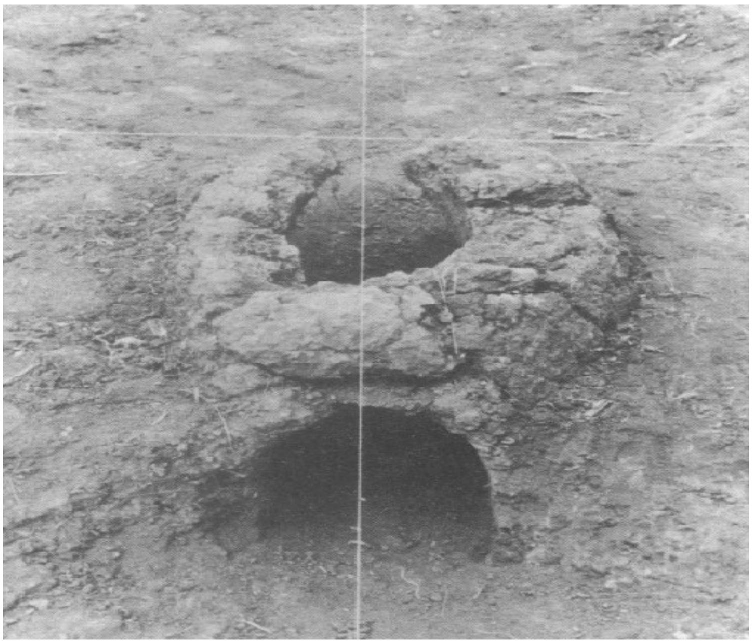


Figure 2. 8: Kaditshwene Furnace (Friede & Steel 1985)

The furnace contained a top circular opening for feeding raw materials and an arch shape opening extending to the ground. The opening was useful to supply air in the furnace. The top inlet would give access to rake out fire and the smelted bloom after the melting process.

ii) Buispoort Furnace

The Buispoort furnace had a larger portion free standing above the ground and oval walls. As the furnace rise upwards, it converges forming a round top and the fuel chamber was sunk into the ground (Van Hoepen & Hoffman 1935). A redrawn sketch by Friede and Steel (Friede & Steel 1985) of the Buispoort furnace is shown in Figure 2. 9.

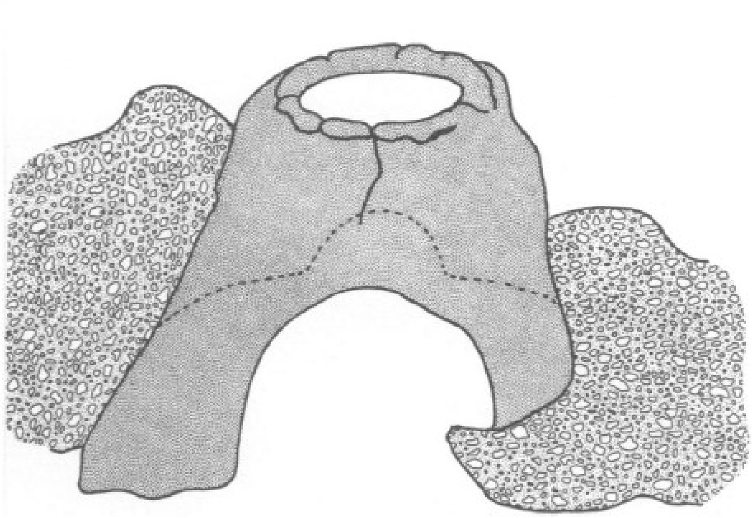


Figure 2. 9: Buispoort Furnace (Friede & Steel 1985)

iii) Melville Koppies Furnace

The Melville Koppies furnace had a larger firing area and a diameter of 700mm (Campell 1822). More than half of the furnace was in the ground and an early photograph taken by Campbell is shown in Figure 2. 10.

Figure 2. 10: Melville Koppies Furnace (Campell 1822)

2.3.1.3 Summary

Despite all the architectural differences in the construction of traditional furnaces discovered in South Africa the basic principle for smelting was the same. Analysis of slag from 12 different ancient smelting sites across South Africa conducted by the Institute of Mining and Metallurgy concluded that impurities and type of slag collected from these sites affirms that same smelting techniques were used (Friede et al. 1982).

2.3.2 Iron and Steel Production: pre-Union period

The discovery of gold at Witwatersrand in 1886 and diamonds in Kimberly made the demand for steel to increase in South Africa. With developing mines in West Rand, Orange Free State Goldfields and Kimberly diamond fields, the economy could not rely on steel imports anymore. The breakthrough of making steel using coal instead of charcoal (Taylor et al. 1988) excited local merchants to venture into steelmaking. This section will outline the developments in steelmaking industry prior to the establishment of the Union Government of South Africa.

2.3.2.1 Iron and Steel Production Pre-Anglo Boer War

Coal mining In South Africa begun in 1870 as a source of energy to the diamond fields in Kimberly and towards the end of the 19th century, coalfields in Natal roared into action servicing the Witwatersrand gold fields (Prevost 2004). The steel industry had to anchor on the positive atmosphere and this lead to the establishment of the Prospectus of the South

African Coal and Iron Company in 1882. The purpose of the company was to acquire the right to work in the mines of coal, iron, iron ore, shale, lime, limestone and clay within the region of Dundee. Lack of capital meant that there would be no meaningful exploitation of these resources and this period is the dark period of steel industry in South Africa (Richards 1940).

Another steel enterprise in 1880s is Transvaal Government Iron Concession Limited which had acquired concession from John Crosbel who had disposed the investment due to the perceived gloomy steel industry in Transvaal (Richards 1940; Drake 1971). The company had a larger market share in the railways during the construction of the railway line to Lourenco Marques present day Maputo. When the construction of the railway line was completed in 1895, the company liquidated.

Both in Transvaal and Natal colonies, deposits of iron ore were untapped and as political tensions rose towards the Anglo-Boer war of 1899-1902 all attempts to start a successful steel operations botched. Absence of technical expertise and practical experience regarding steel smelting (Richards 1940) was also a factor for unsuccessful steel operations during this period. Despite availability of resources, the transformation of raw materials into useful products proved to be difficult in the absence experts to manage operations.

2.3.2.2 Iron and Steel Production Post Anglo Boer War

The first attempt to smelt native iron ore was in Maritzburg by Mr Samuel Light Green at Sweetwaters in 1901. He was a former manager at Stanhope Gold Mining Company in Witwatersrand who had relinquished his manager-ship when deep level mining was undertaken (Drake 1971). He started his experimental works by first constructing a blast furnace shown in Figure 2. 11 (Weston & White 1975). Coke was prepared at the premises but limestone proved to be a challenge in Sweetwaters area. The targeted marble stone turned to be dolomite and was useless for flux purposes in the furnace. The Sweetwaters Company did a test run once and Greens account state that the furnace produced not more than two tonnes of pig iron (Robinson 2003; Meyer 1952). The operations could not continue without a proper supply of limestone thus production of iron ceases (Richards 1940).

Figure 2. 11: Sweetwater Blast Furnace (Richards 1940)

After this development a commission in Natal was set to investigate the state of the industry in the colony, Natal Industries and Tariff Revision Commission was set in 1906. Concerning iron ore, the commission reported that Natal had vast mineral resources which was the most valuable asset (Richards 1940). The report highlighted that there was no effort to develop facilities to exploit these resources. The commission recommended the government to appoint a man of integrity as a mining engineer in whom the British investors will have confidence. The engineer was to come up with a comprehensive report of other mineral deposits in the colony other than coal (Natal Government 1906).

Natal government then signed a contract with Mr Bonas a successful diamond miner, Bonas was to supply the government with coal and in return, Bonas was to establish a steelmaking company in the colony. The contract was enacted through Act No. 55 of 1906 which lead to the formation of Vryheid Railway, Coal and Iron Company limited. (Richards 1940; Drake 1971). Mr Dickie and associates created Alverstone Iron Ore Syndicate Limited in 1907, its purpose was to develop surface limonite deposits in Alverstone and carry out tests of the ore with limestone. The primary objective of the syndicate was to establish iron and smelting works on a larger scale. Due to lack of funds, the syndicate liquated in 1911 (Richards 1940).

Inspired by Green effort, in 1909 a small syndicate in Maritzburg was born to fund further tests on Sweetwaters Blast furnace. The main objective was to continue with further analysis and establish if a working iron smelting could be organised. Maritzburg Iron Company Limited was registered in 1909, the company smelted almost 12 tonnes of Sweetwaters ore and the pig iron casted was shipped to John Brown and Company in England. The limonite deposits for limestone were patchy and limestone was not locally available, labour supply was inadequate and this affected production (Richards 1940).

In Transvaal Mr Wright discovered iron deposits in 1903 at Magnet Height in Lydenburg but the government of Transvaal did not grant him the discovery rights immediately (Lewis 1926). The government of Transvaal needed an assurance that Wright could establish a steel works to exploit the deposits. When finally granted the rights to the resources, Wright in 1908 took ore from the Magnet Heights to try luring British steel masters in Middlesbrough, North England and South Wales. Most investors were not convinced that the current local market could sustain local steelmaking operations. Wright later then resorted to exportation of ore to Europe, but with no exemption on transportation rates a dead rubber was meet (Drake 1971). Recession period followed and this slowed all prospects in steel industry (Houghton 1975).

The leader of Transvaal colony was under pressure from individuals and company directors to establish a steel factory to resolve scrap accumulation problems (Lewis 1926). In 1905 the Transvaal Iron and Steel Company Limited was established and its main objective was to transform scrap through a rolling plant acquired in New Zealand. The company was looking forward to assistance and guarantee from the government, they receive none resulting in liquidation and the plant auctioned as scrap.

The Railways of Pretoria decided to endeavour in smelting of their own scrap combined with some Pretoria ore in an electric furnace. The Railways of Pretoria succeed in smelting of scrap and local ore but this did not provide evidence of profitable operations at large scale (Richards 1940). The Transvaal government then set a commission between 1907 and 1908 to investigate the state of the local industry and assistance the government should provide. The Transvaal Customs Commission of 1907-1908 recommended the use of a blast furnace to smelt scrap and native iron (Customs and Industries Commision 1908).

Mining Engineer of Transvaal Kotze released a memorandum in 1909 called "Memorandum re Iron and Steel Industry" (Kotze 1909). Kotze insisted that an established iron industry was the greatest asset of any economy and any country that could supply its own demand of this indispensable (iron and steel) material would conserve a large sum of money. The memorandum also highlighted that it was not only the immediate benefits the government would reap but a flow of industry will also develop. Principal deposits in Transvaal were Magnetic, Haematite, Ferruginous Quartzes, Limonite and Chrome Iron ore. Kotze had a vision of making South Africa an iron master amongst its neighbours. Installation of the blast furnace was necessary and raw materials would be from the Pretoria beds. Though the bulky of the deposits occurred on private ground, the mining engineer insisted that the ferruginous quartzes and magnetite ore was in government grounds. The use of Transvaal coal as coke for the blast furnace was a subject for future research and experimentation. Australia and Canada models were two models to follow, the respective governments assisted in the establishment of the iron industry. Sir Kotze gave a recommendation in which the government of Transvaal was to follow in the establishment of iron industry. The government was to assist by either inducement of capital with financial support during the initial phase of the organisation. This was to be accomplished either by a way of bounties or guarantee on interest on capital spent. The bounty system was less adoptable because the company was to produce before it gets any assistance. This would be inadequate to begin operations on the basis that as the firm is in its initial stages, production will be small and production increases with the growth of the company. This translated to small bounty claims during the initial years of production. Kotze came up with a combination of bounty system and guarantee on interest of actual capital spend. Kotze insisted that for the business to prosper monopoly was justified and no room for external competition. The government was to assist in securing of iron ore deposits and such company when firmly established paternal assistance and interference would be of no use. Huge capital was required and a large period for planning would be required before actual production. In closing remarks of the report, Kotze objected the exportation of scrap which was a valuable raw materials and he proposed a prohibitive export duty on scarp iron and higher railway rates (Kotze 1909).

For clarity and independent opinion, the government sought the services of a foreign expert F.W. Harbord (Drake 1971; Lewis 1926). In his report, Harbord believed the demand of pig iron for foundry purposes was small thus it was necessary to erect only a modern electric steel plant for conversion of imported pig iron to steel. He discouraged the government from constructing a blast furnace stating that it was premature. The recommended electric steel furnace would resolve the crisis of accumulating scrap in the colony. In concluding his report, Harbord pointed out that if the colony was to export steel it would not be able to compete with already established firms. He finally recommended systematic prospecting of accessible ores in the colony for future development (Harbord 1910). The government accepted Harbord's recommendations and 2 February 1910 they issued out a notice calling for tenders to purchase railway scrap (Transvaal Government 1910). The tender was given to South Africa Steel Corporation represented by Mr Wright who had proposed to install an open-hearth furnace and crucible furnaces to work with scrap and experiment with native ores (Lewis 1926).

2.3.2.3 Summary

A summary of the developments discussed in this section (Section 2.3.2) is shown in Table 2.8.

Table 2. 8: Summary of Iron and Steel establishments pre-Union (developed by the student)

Year of Establishment	**Name of Firm**	**Comments and Analysis**
1882	South Africa Coal and Iron Company Limited	• The steel industry was under the "Gold shadow", whereby investment focus was on the gold industry, which had quick and higher returns • Political landscape also presented South Africa as a high-risk investment area. Political crisis leads to the Anglo Boer war of 1899-1902.
1895	Transvaal Government Iron Concession Limited	• Market for the concession dried up after completion of the Lourenco Marques- Pretoria railway line. • Poor marketing strategy.
1901	Sweetwaters Blast Furnace	• Absence of support from the Government in form of bounties and other financial support system crippled production. • Limestone for flux purposes was not available locally • Inadequate metallurgical processing skills
1903	M H Wright Concession	• Absence of capital
1905	Transvaal Iron and Steel Company limited	• Lacked feasibility studies prior to acquiring of scrap recycling equipment.
1906	Vryheid Railway Coal and Iron Company	• The main figure Mr G H Bonas a successful diamond miner did not commit enough resources to establish the iron and steel industry
1907	Alverstone Iron Ore Syndicate Limited	• Did not receive the expected support from the Transvaal government or British investors
1909	Maritzburg Iron Company Limited	• Government did not provide any guarantee or protect the local investment against any foreign competition
1910	South Africa Steel Corporation	• Had Transvaal government support and had been given monopoly over the acquiring of approximately 15 000 tonnes of railway scrap.

The establishments in Table 2.8 marks significant transformation towards the establishment of a functional steelmaking industry in South Africa. Other syndicates excluded in this research have made little or no significance towards the establishment of the industry.

2.3.3 Post Union Development: Iron and Steel Industry in South Africa

The Union of South Africa spans the period between 31 May 1910 and 31 May 1961 and this section focus on developments in steel industry during this period. The Union Government appointed a commission on 10 October 1910 to report on condition of industry in the union (Department of Commerce and Industries 1910). Concerning the establishment of a functional iron and steel industry the commission noted the efforts by the Transvaal and Natal governments through contracting of Harbord and Dr Hatch respectively (Commerce and Industries Commision 1912). The commission also applauded the effort of Green (Meyer 1952) in 1901 by constructing the Sweetwaters blast furnace in Natal. The committee recommended intensive testing on the known local iron ore deposits and to investigate if suitable limestone was present in sufficient quantities in Maritzburg. The committee recommended the government to erect and operate a blast furnace to treat native iron ore.

2.3.3.1 Union Steel Corporation of South Africa

The Union Government could not lure foreign investment to sponsor the establishment of a functional steel industry. The government had to reconsider the agreement between Transvaal Government and Mr Wright with his company South Africa Steel Corporation (Department of Railways and Harbours 1912). The agreement had enabled the company to carry trades of iron, steelmaking, steel converting, smelters and foundry works in South Africa. There was a provision for the company to sell iron ore and other mineral substances towards the establishment of steel works and installation of rolling mills in the Transvaal Province or elsewhere within the union. The company was to treat local ores in viable quantities that could sustain commercial operation. Almost 15 000 tonnes of railway scrap metal was issued to the company and a minimum of 500 tonnes was to be purchased at a rate of £1 per tonne annually. In the third year of operations, the company was required to carry out smelting experiments and treatment of the native ores. The agreement was signed between Honourable Smuts the then Minister of Mines and Mr Wright (Department of Railways and Harbours 1912).

The company then registered on 15 November 1911, however South Africa Steel Corporation failed to meet other obligations and the concession was awarded to Union Steel Corporation of South Africa Limited (USCO) (Richards 1940; Leigh 1964; Stanley 1917). This lead to an appeal by South Africa Steel Corporation highlighting that the concession terms was too harsh and awarding the contract to USCO was unfair (Drake 1971). This lead to formation of a select committee on 16 April 1912 that examined the scrap iron agreement (Select Committee 9 1912)

2.3.3.2 Establishment of Independent Iron and Steel Firms

An immigrant from Scotland George Stott and blacksmith supervisor at Meyer and Charlton Gold Mine formed George Stott and Company in 1910 after he had seen the market for forged products in the blooming gold mines. The blacksmith workshop started with open die forging operations and built a good reputation among its clients (Drake 1971). The company started trading in 1911 and the picture in Figure 2. 12 is of the original anvil used during the forging process in 1911.

Figure 2. 12: George Stott Anvil (George Stott and Company 2016)

Due to good reputation of satisfying customer needs, production increased and in 1917 the company was converted to a limited liability company with a capital deposit of £5 000 from George Stott and £1 000 from Mr Rennie a mechanical engineer (George Stott and Company 2016).

Cartwright and Eaton trading as machine merchants decided to convert their company in 1911 to form Union Iron and Steel works in 1911. The company was in Benoni near Johannesburg but on 26 June 1914, the company changed to Dunswart Iron and Steel Works Limited following the resignation of Eaton (Drake 1971). The company depended so much on railway scrap as its raw material and in 1917, it set up a small plant to produce wrought iron and rolled iron and steel bars (Van der Byl 1929). The principal market for the company was the railways, mines and during World War 1 steel imports were curtailed thus the company expanded rapidly as one of the domestic suppliers. The fruitful years of Dunswart Iron and Steel Works were short lived with post war depression.

Mr Eaton decided to venture into the treatment of native ores (Stanley 1920b) after he resigned in 1913 from being the joint managing director of the Dunswart Iron and Steel Works Limited. He formed Newcastle Iron and Steel Works Limited in 1920 (Drake 1971). Construction of the blast furnace for the treatment of native ores started in January 1919 for Newcastle Iron and Steel Works Limited, in 1920 the company registered as a public enterprise (Stanley 1920b). The project failed to get approval from some of the British Knights like Sir Hoy who described the site in Newcastle as improper for successful commercial production of iron and steel. Eaton's endeavour ceased without any cast from the furnace. In 1921 USCO took over the project and completed Newcastle blast furnace in 1926 (Scott 1951; Lewis 1926).

The Witwatersrand Cooperative Smelting Works was established in 1916 on Robinson Gold Mine as a demonstration plant to test the feasibility of preparing steel shoes and dies for stamp batteries through melting the worn and discarded shoes. This contingency plan was a mitigation measure to cover up for shortages of imports during the World War 1. The company installed a Kjellin type induction furnace with a capacity of one tonne per heat and could manage only four heats per day (Stanley 1917). With post war depression, market dried up and the company was dissolved.

2.3.3.3 Steps towards establishment of South Africa Iron and Steel Corporation Limited

The Municipality of Pretoria granted mining rights over certain iron ore reserves in the region to Delfos. Delfos like his forerunners attempted without success to attract European investment. The European iron masters thought the South African coal could not produce the right quality of coke to treat iron ore in the blast furnace. Delfos took the challenge and constructed an experimental blast furnace in 1917 November. The furnace was the brainchild of Professor Stanley and with assistance of a mechanical engineer and a chemist, in June 1918 production of pig iron commenced (Stanley 1920b). The operation of the furnace was with difficult and by the end of 1919 almost 1286 tonnes of pig iron had been produced but the quality of the product was inconsistent (Department of Mines and Industries 1920). However, the objective of experiential blast furnace had been meet and the quality of ore and fluxes were good for iron works. Figure 2. 13 shows Pretoria Iron works where the experiments was conducted (Iscor Limited 1953).

Figure 2. 13: Pretoria Iron Works (Iscor Limited 1953)

The experience gained during the operation of the experimental blast furnace was a learning curve and the company started exploring expansion avenues. In 1920, the organisation had an agreement with the Railways Administration to supply 50% of the projected railway iron and steel requirements (South Africa Railways and Harbours 1920). The agreement between the company and Minister Henry Burton required the company to operate on full capacity to meet the 50% requirements target. Failure on part of the company to supply any products within the contract time of delivery would permit the Railways Administration to order those products elsewhere and the extra cost incurred will be indebted to Pretoria Iron Mines Limited. The arrangement was a working formula in promoting local iron and steel industry and Government Mining Engineer Kotze concluded annual report for 1919 describing the events as the eve of a large and expanding industry (Department of Mines and Industries 1920).

The contract landed by Pretoria Iron Mines Limited awakened interested of various industrial and financial groups like National Industrial Corporation, Anglo American, Central Mining and Investment Corporation and Delagoa Bay Collieries. A partnership was formed to create South Africa Iron and Steel Corporation and Pretoria Iron Mines had 200 000 shares in the corporation. Union Steel Corporation who had a previous agreement on railway scrap received the development with bitterness. The 50% market share was an infringement to the agreement on railway scrap (Department of Railways and Harbours 1912). A select committee was appointed to investigate the complaint from the Union Steel Corporation (Richards 1940). The commit applauds the effort and steps by Railways Administration in promoting establishment of local iron and steel industry. The committee did not see it fit for the deal signed by Minister Burton to be binding to Railway Administration concerning 50% purchase of iron and steel requirements (Select Committe on Railways and Harbour 1920) thus there was no infringement. However, the committee recommended establishment of a large state steel enterprise or a private enterprise in which the government was to support with bounties.

2.3.3.4 Transvaal Blast Furnace Limited

Union Steel Corporation Limited agreement on railways scrap was required to start experimenting and treating native ores within three years of production (Department of Railways and Harbours 1912). Dunswart Works had started constructing the experimental blast furnace at Vereeniging (Stanley 1920b) and Union Steel Corporation invested £5500 in 1916 to complete the furnace as Transvaal Blast Furnace Limited. Union Steel Corporation was the largest shareholder in the investment but other stakeholders included Central Mining and Investment Corporation (Select Committe 1927). Experimental smelting started in October 1918 and pig iron produced was of good quality, however influenza epidemic and other operation difficulties affected production.

In connection with operating a blast furnace, Professor G H Stanley recommendation was the installation of one large modern blast furnace that can produce 1000 tonnes of pig iron per week (Stanley 1920a). Professor Stanley stated that fireclay and other refractory material was abundant in the Union of South Africa. Difficulty in importation of iron and steel during war times had caused a shortage and with a demand of 50 000 tonnes annually from the railways and 37 500 tonnes from mines, there was a need for a functional iron and steel industry using native ores (Stanley 1920c).

2.3.3.5 The Gutehoffnungshutte Technical Commission

The Gutehoffnungshutte a continental iron producer offered to send a technical team to South Africa to investigate the possibility of establishing a local iron and steel industry in the country. Upon the approval of the Union Government of South Africa, the team linked with South African Steel Corporation and began investigations in February 1924 (Van der Byl 1929). The detailed report from the Gutehoffnungshutte Technical commission was completed towards the end of 1924 (Iscor Limited 1953). The original copy was in German and an unofficial translation copy of the report presented to the Senate in 1928 had eight segments that are as follows (Select Committe 1 1928):

- The Background of the South African industry in relational to the possibility of iron and steel works establishment.
- Assets of the South African Iron and Steel Corporation Limited
- The raw material for the proposed works
- Results of coking tests with the native coal
- Estimates of installation and operational costs for the mining activities
- Analysis of technical factors
- Economic and Cost factors
- Summary of the report

Dr F Meyer applauded the report by the technical commission and he highlighted that the work was completed with extraordinary thoroughness (Verkouteren 1927). Every aspect concerning the industry had been examined in an exclusively objective and scientific manner. The experts had based their report on a site in Pretoria and considered a market within the Union borders but did not rule out the fruits of exportation. An ample market within the Union could sustain products of iron and steel works with a capacity of 150 000 tonnes per annum. Empowered with the report Mr Delfos of South Africa Steel Corporation attempted to arouse the British Steel makers but to no avail (Iscor Limited 1953). Mr Delfos then shifted his focus towards the Union Government for assistance in the establishment of the steel company. Pressure was mounting on party of the Union Government as the Labour Party members were demanding the Government to assist towards the establishment of the industry and motions were proposed in the House of Assembly between 1925 and 1926 for government assistance (Iscor Limited 1953).

2.3.3.6 The Iron and Steel Industry Act 1928

In 1927, the proposed Steel bill was discussed in parliament and controversies arouse on the issue of state control on the proposed company. Proposed on 10 February 1927 the Bill had vested authority on the Governor-General to appoint Board of Directors that would control and manage the company on the basis that the Government will have special shares. The opposition argued that this clause was a threat to the company considering the state interference to company's operations. The Bill managed to sail through the House of Assembly but was rejected by the Senate in which the opposition had the majority. The Bill proposal was re-introduced to the Senate again in October of 1927 and after a lengthy examination, the Bill could not pass for the second time on 23 March 1928 (Iscor Limited 1953). A deadlock was reached but the constitution had a provision for a joint sitting and on 30 March, the sitting ensued. The Bill succeeded on the joint sitting and on 14 April 1928, the Iron and Steel Industry Act (No.11 of 1928) became a law. The Act was to promote the development within the Union of the iron and allied industries and for that purpose to constitute the South African Iron and Steel Industrial Corporation Limited (Iscor) with a capital of £3.5 million (Select Committe 1 1928). The share structure was divided into "A" shares and "B" shares, group "A" shares was allocated to the Government and Government will contribute £500 000 and the "B" shares was reserved for the public and worthy of £3 million. Since the Government had "A" shares, the Governor-General was to appoint four of the seven Company Directors and select the Board Chairman for the company. The "A" shares had one vote aggregate over the "B" shares. To strike a balance between state control and private business operation, the employees were not under the Public Service and the Union Government had no direct intervention on routine operations of the company.

2.3.3.7 South African Iron and Steel Industrial Corporation Limited (Iscor)

The proclamation of South African Iron and Steel Industrial Corporation Limited in June of 1928 in the Government gazette marked the eve of massive iron and steel industrial development in the Union of South Africa (Ministry of Mines and Industries 1928). Dr van der Bijl landed the Board Chairman post with Mr Delfos as fulltime Director and their

Technical Assistant was Dr Meyer (Iscor Limited 1953). The company had gained the legal status but its woes were far from over, the opposition declared war in the Parliament and the streets over Government involvement in the company. Eventually "B" shares could not raise the expected £3 million and the Government stood by its commitment and acquired majority stake in "B" share category. The Government had vowed earlier on that if the public will not subscribe the capital, the Government would use public funds (Verkouteren 1927). The iron and steel industry was successfully established with the assistance of the national funding and the great lesson for the generations to come is the involvement of the Government in establishing and protecting the local steel investments. Production commenced in 1934 in Pretoria and the infant steel works had a capacity of 160 000 ingot tonnes per annum. The local demand for the iron and steel products increased such that the production figures had doubled by 1939 (Weston & White 1975). In 1942, a plate mill was installed at Vanderbijlpark and by 1950, the corporation had a capacity of producing 1 million tonnes of liquid steel with Vanderbijlpark works the major contributor (Iscor Limited 1953).

2.3.3.8 Anglo American Investments in Iron and Steel Industry

South African Iron and Steel Industrial Corporation (Iscor) was the dominant local steel producer in the country during the 1950s. The vast wealth and untapped resources of the country would not pass the eye of the world rich investors. The Rockefeller family through the Minerals Engineering of Colorado opened a subsidiary in South Africa known as Minerals Engineering Company of South Africa (Rohrmann 1985). The plant was set up in Witbank in 1957 to produce approximately 1.4 million tonnes of vanadium pentoxide annually (Highveld Steel and Vanadium Corporation Limited 2000). The company targeted the United States market but the use of vanadium remained limited to highly specialised products like high-speed steel tools and heat-treated engineering components. The relatively small market coupled with high production costs lead the Colorado Company to offload its South African subsidiary. In 1959, Anglo America Corporation of South Africa acquires two-thirds shares in Minerals Engineering and by August of 1960, the name of the company changed to Transvaal Vanadium Company Limited (Bassan et al. 2007). In 1960, the Highveld Steel Development Company was established and it started investigating the viability of processing titaniferous magnetite ore to produce liquid pig iron (Highveld Steel and

Vanadium Corporation Limited 2000). The pilot plant was set up in Witbank and used new smelting techniques of a four-stage electrical process. Recording success in the pilot experiments Anglo America sort to construct a full-scale plant and turned to Iscor for a joint venture. The proposal had a provision for a foreign steel company, which would provide the capital, Iscor board rejected the proposal (Fine & Rustomjee 1995).

2.3.3.9 Other Iron and Steel Enterprises

Scaw Metals started operations in Eloff Street Extension in Johannesburg in 1924 and the company acquired a 49-hectare site in Germiston to locate its works. The railway was the main market for the company such that by 1956 it became the leading supplier of steel bogies (Scaw Metals Group 2014). Dr H.J van der Bijl pioneered the Ferro alloy industry in South Africa by forming the African Metals Corporation (Amcor) limited. On 23 July 1937, the company was registered and the production of pig iron and high ferromanganese commenced using a hearth blast furnace in Newcastle (Bassan et al. 2007). The company expansion programme was to construct two electric furnaces in Vereeniging to produce Ferro alloys.

Iron and steel production during the Union of South Africa is summarised in Figure 2. 14. Early production is attributed to USCO, Newcastle Blast furnace and Transvaal blast furnace. The establishment of Iscor and its major contribution is traced from year 1933 as shown in Figure 2. 14 and by 1950 production of steel in the union had reached 1 million tonnes annually.

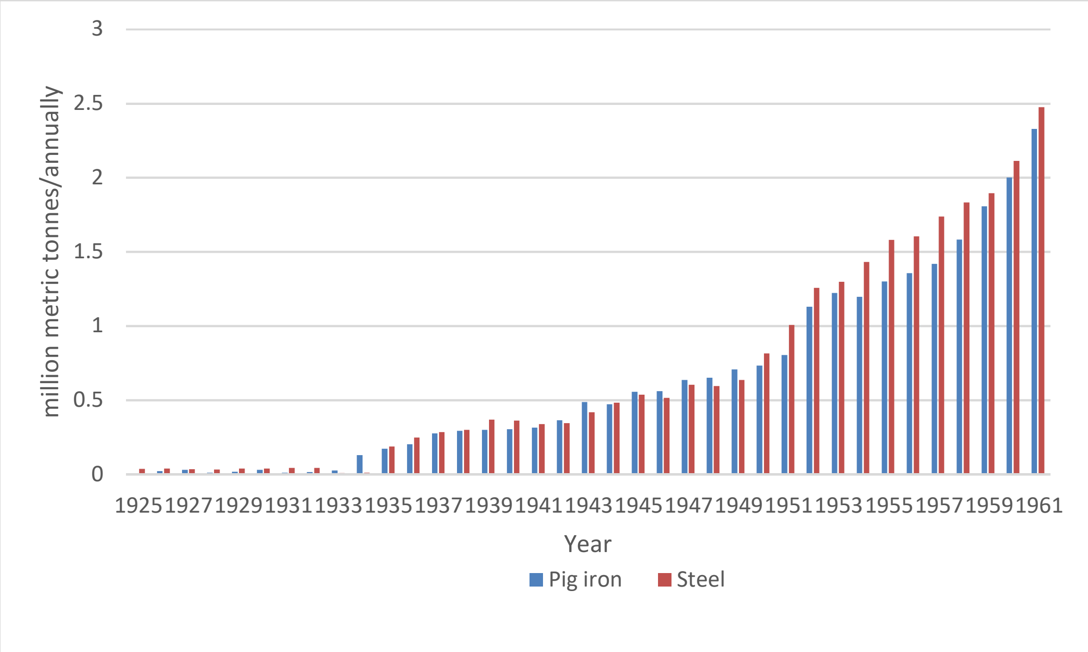


Figure 2. 14: South Africa Iron and Steel Production (1925 – 1961) (World Steel Association 2015)

2.3.4 Iron and Steel Industry in the Republic of South Africa

The Union of South Africa was dissolved in 1961 and became the Republic of South Africa. In this section, focus is on major developments of the iron and steel industry in the Republic of South Africa. The survey will highlight key important developments in the sector which are summarised as Iscor developments, Anglo America Corporation expansion in steel industry and expansion of other significant independent enterprises.

2.3.4.1 South African Iron and Steel Industrial Corporation Limited (Iscor)

The plan to establish the third works for Iscor was set in 1969 in Newcastle, the choice of the location of the works gave a chance of development of a major agglomeration outside of Gauteng. The development came with modern optimism of creating new production spaces elsewhere besides Gauteng in the Republic (Todes 2001). Iscor started erecting an integrated iron and steel works through a sub-contractor the Gutehoffnungshutte Company (GHH). (Weston & White 1975). The integrated steel works and long products mill construction was completed in 1976.

In 1973, Cape Town Iron and Steel-works (Pty) Limited (CISCO) became a wholly owned subsidiary of Iscor (Cisco - Cape Town Iron and Steel Works 2015) and in 1988, Iscor embraced the technology of corex process. The first commercial corex unit in the world commenced at Iscor Pretoria (Iscor Limited 1989). The plant had a production capacity of 300 thousand tonnes of liquid iron per annum and initially it operated on full capacity using sponge iron.

Iscor was privatised and listed on the Johannesburg Securities Exchange on 8 November 1989 and in 1991 Iscor gained full control of USCO steel works and named the facility Iscor Vereeniging Works (ArcelorMittal South Africa 2016a). The Saldanha steel plant operations was commissioned in 1998 as a niche operation and the plant served as a steel export hub for Iscor (ArcelorMittal South Africa 2016b). The aging Pretoria Steel Works was decommissioned in 1997 and in year 2001 Iscor transferred its shares to Kumba Resources Limited.

2.3.4.2 Anglo American Investments (Highveld Steel and Vanadium Corporation)

The trials conducted by Highveld Development Company Limited on the viability of processing titaniferous magnetite ore to produce liquid pig iron and vanadium bearing slag were a success. In 1964, Anglo American acquired Scaw Metals (Scaw Metals Group 2014) and in 1966 production commenced at Highveld and the company rebranded to Highveld Steel and Vanadium Corporation (HSVC) (Highveld Steel and Vanadium Corporation Limited 2000). Transalloys (Proprietary) Limited (Transalloys) had been successful in production of manganese alloys, subsequently in 1965 HSVC acquired 65% shares of the company in 1976 and by 1985 Transalloys was a wholly owned subsidiary of HSVC. During the same year HSVC took over the manufacturing of drums, pails and crown closures by acquiring Rheem South Africa (Proprietary) Limited (Rheem).

Despite the privatisation of Iscor in 1989, HSVC expansion became inevitable, in 1991, the company acquired Middleburg Steel and Alloys, and to extend its span the company had shares in Hochvanadium Holdings operating in Austria. The turn of the millennium brought new polices for Anglo American, there was a shift from steel industry, and the group embarked on a series of portfolio trimming. In 2002 the company offload 64% of its shares in Columbus Stainless (Proprietary) Limited and retained only 12% in the entity. In 2003, Highveld sold out 50% of its shares to South Africa Japan Vanadium (Proprietary) Limited. In year, 2006 Anglo American plc sold its main stake to EVRAZ Group and by year 2010, HSVC rebranded to EVRAZ Highveld Steel and Vanadium (Evraz Highveld Steel and Vanadium Limited 2014).

2.3.4.3 Other Iron and Steel Enterprises

After the dissolution of the Union, there was a major expansion in the iron and steel industry from the private investors. Despite the heavy presence of Anglo American Corporation and Iscor, the Cape Gate Private Limited was established in 1962 through the purchase of a small netting plant (Cape Gate (Pty) Limited 2016). The company in 1967 did establish the Sharon Wire Mill to produce uncoated and galvanized wire, welded mesh, diamond mesh, barbed wire, field fence. In 1975, the company rolled out the Davesteel division to produce wire rod, rebar and rounds and in 1980 the company ventured into the first melting operations (Cape Gate (Pty) Limited 2016). Another private enterprise was CISCO, established in 1965 but in 1973, Iscor acquired the company. Following the privatisation of Iscor, Murray and Roberts in 1999 acquired the company (Cisco - Cape Town Iron and Steel Works 2015). The latest steel company is Unica iron and steel which was started in 2006 and is located in Pretoria (Unica Iron & Steel (Pty) Ltd 2015).

2.3.4.4 Status of the Steel industry

Production of iron and steel from 1962 to 2014 is shown in Figure 2. 15 (World Steel Association 2015). From 2006, South African steel industry has been facing stiff challenges which include decrease in commodity prices and external competition (imports). Steel production has dropped rapidly from 9.7 million metric tonnes in 2006 to 6.55 million metric tonnes in 2014.

Figure 2. 15: Iron and Steel Production (1962 – 2014) (World Steel Association 2015)

Consequently imports of iron and steel products are on the rise thus pressuring local steel producers. From year 2005 to year 2014, South African market had absorbed 38.8 million metric tonnes of steel in form of semi-finished and finished steel products, ingots and semis, long products, flat products, tabular, direct reduced iron and indirect imports of steel (World Steel Association 2015). Figure 2. 16 display the trends in terms of quantity of iron and steel production against imports. A drop of 30% local steel production corresponds to 90% iron and steel imports.

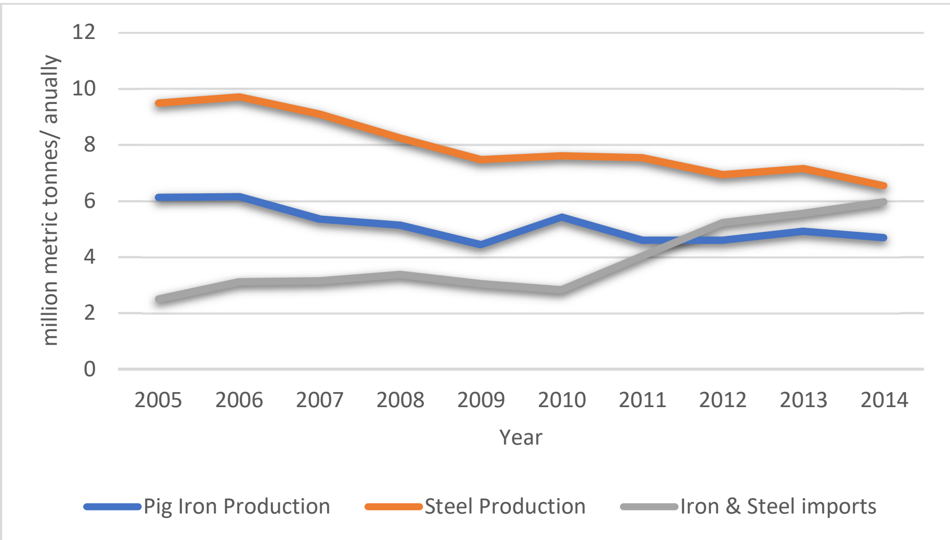


Figure 2. 16: Local Iron and Steel Production vs Imports (World Steel Association 2015)

Effects of steel imports are inevitable, CISCO stopped operations in 2009, AMSA Vanderbijlpark mini mill plant in 2012, AMSA Vereeniging mini mill plant in 2015 and EVRAZ HSVC production was temporarily halted in 2016. With the current trends of local iron and steel production, extinction of local iron and steel industry is a possible threat. Currently players in the industry include AMSA, Scaw Metals Group, Cape Gate Private Limited, Columbus Stainless Private Limited, South Africa Steelworks and Unica Iron and Steel Private Limited.

2.3.5 Applications of IE principles in South African steel industry

The rise of steel imports is caused by high production costs of local steel products thus customers opt for affordable steel imports. It is crucial to establish the applications of Industrial Engineering (IE) research in steelmaking industry in South Africa that aims on minimising production costs and maximise value generation. Industrial Engineering (Ngetich & Moll 2013) is a discipline based on knowledge and information centred on five pillars which are: enterprise engineering, systems engineering, operations management, applied industrial engineering and engineering management. Enterprise engineering focuses on engineering the enterprise holistically through application of industrial engineering principles on every operational level of the organisation (Ngetich & Moll 2013). Systems engineering consists of the systematic approach in developing and operating systems through the identification of system objectives then align sub-components' goals towards the main objective. Operations management focus on systematic improvement of organisational operation like supply chain management (Kumar & N 2009; Ngetich & Moll 2013) and engineering management consists of application of engineering techniques and coordinating the synergy of employees in business practice with the objective of accomplishing organisational goals and objectives (Industrial Engineering-Stellenbosch University 2013).

In this section, the study focused on the progression of application of Industrial Engineering techniques in the steel industry in South Africa. A survey on publications by industrial engineers in steel industry was conducted through a search on the official advocate of industrial engineering research in South Africa, the South Africa Journal of Industrial Engineering (SAJIE) database. The period reviewed was from 1987 the year of its first publication to 2016 and the analysis period was divided into three time frames 1987-1996, 1997-2006 and 2007-2016. The results from survey are shown in Table 2. 9.

Table 2. 9: Published Research on Application of IE Techniques in Steelmaking (developed by the student)

Phase of Analysis	Number published	Year of Publication	Title of paper	Sub Discipline focused	References
1987-1996	1	1993	Reducing inventory holding costs for consumable items in a large steelwork	Inventory management	(Adams & Petrarolo 1993)
1997-2006	1	2001	Investigation of the maintenance organisation for hot rolling mills	Maintenance management	(Pretorius & Visser 2001)
2007 - 2016	0	0	None	None	None

From 1987 to 2016 only two research papers had been published by SAJIE (related to steelmaking) and the sub disciplines of industrial engineering covered are maintenance management systems (Pretorius & Visser 2001) and inventory management (Adams & Petrarolo 1993). Despite the successful evolution of steel industry in South Africa, published research input from local industrial engineering journal is lagging. IE avenues which include operation management, enterprise engineering and application of industrial engineering tools like lean manufacturing, six sigma and theory of constraints are yet to be fully applied.

2.4 Systematic Review of Continuous Improvement

In this section the grounded theory is used to perform an inductive content analysis of existing literature on continuous improvement for South African industry to identify conceptual categories of continuous improvement. Grounded theory focus on systematic generation of theory through a rigorous systematic research procedure (Rhine 2014). The methodology (systematic review) allows exhaustive literature search in an analytical manner. The advantage of systematic literature review is it’s repeatability thus aiding transparency and minimizing bias on the literature collected (Bryman & Bell 2011). Table 2. 10 outlines the phases followed in conducting the systematic review and the first phase is identification of literature sources. The second phase is the identification of the relevant studies which focus on continuous improvement; third phase is analysis of the studies to identify the continuous improvement aspects covered by those studies. The fourth phase is evaluation of the results and continuous improvement attributes identified.

Table 2. 10: Study Methodology (developed by the student)

Phase	Steps	Accomplished objective	Where it is presented
1) Planning the Review	a) Review specification	Generating review aim, data sources selection and defining search term	Section 2.4.1
2) Conducting the Review	a) Identification of the literature on continuous improvement techniques in South African industry.	The initial search from Google Scholar, Scopus and Web of Science search engines yielded 868 publications	Section 2.4.2
	b) Study selection	Only 22 publications were relevant to the scope of this study	Document progression is in Section 2.4.2 with full list in of publications in Appendix 2
3) Evaluation	a) Data extraction and analysis	Identified and examined the continuous improvement techniques implemented in different industrial sectors in South Africa	Section 2.4.3

2.4.1 Mapping Data Sources and Search Term

The search term used to locate the desired publications was continuous improvement and the search field was inclusive of title, abstract and keywords and search filters were year of publication, territory and publication type as shown in Table 2. 11.

Table 2. 11: Searching Criteria and Search Yield (developed by the student)

Search Engine	Search Term	Search Field	Publication Type	Territory	Year	Yield
Scopus	Continuous improvement	Title, Abstract and Keywords	Journal article, Conference paper	South Africa	1990 to 2016	262
Web of Science	Continuous improvement	Title, Abstract and Keywords	Journal article, Conference paper	South Africa	1990 to 2016	138
Google Scholar	Continuous improvement	Title, Abstract and Keywords	Journal article, Conference paper	South Africa	1990 to 2016	468

2.4.2 Data Collection and Selection Criteria

The initial search from the three search engines yielded 868 publications as shown in Figure 2. 17 and the first selection criteria were conducted through inspection of the study title and abstract. Upon this criterion 675 studies were discarded and the next selection procedure was to check if the paper's focus was on the implementation or examination of continuous improvement techniques in South African industry. This was done through a rigorous but careful examination of the remaining 193 publications. The criterion eliminated 162 papers and another 9 papers were duplicates. The final analysis list consists of 22 studies as shown in Figure 2. 17.

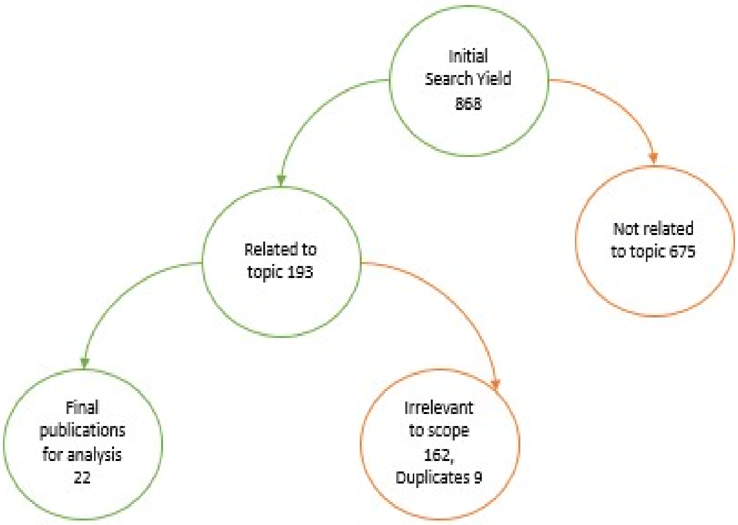


Figure 2. 17: Document Progression (developed by the student)

2.4.3 Data Extraction and Analysis

The 22 studies were manually coded by the student per evaluation criteria in Table 2. 12. The evaluation criteria are divided into two groups which consist of descriptive statistics and empirical aspects & conceptual aspects. The results of the analysis phase are shown in Section 2.4.4.

Table 2. 12: Evaluation Criteria (developed by the student)

Descriptive Data	Empirical and Conceptual Aspects
•Document file name •Title of the document •Type of document (e.g. Journal, conference) •Year published •Citations (from Google Scholar)	• Focus of study • Abstract • Industrial domains • Sub sector •Techniques improvement • Unit of analysis • Implementation procedure •Conclusion drawn by authors of the document

2.4.4 Findings and Analysis

The results are grouped in three classes which consist of descriptive statistics, empirical aspects and conceptual aspects.

2.4.4.1 Descriptive Statistics

The 22 studies collected consisted of 12 conference papers and 10 journal articles as shown in Figure 2. 18. From the evidence gathered in this study, the first paper on continuous improvement was produced in the year 1994. From year 2011 to 2016 there has been consistency in terms of published research in the field on continuous improvement.

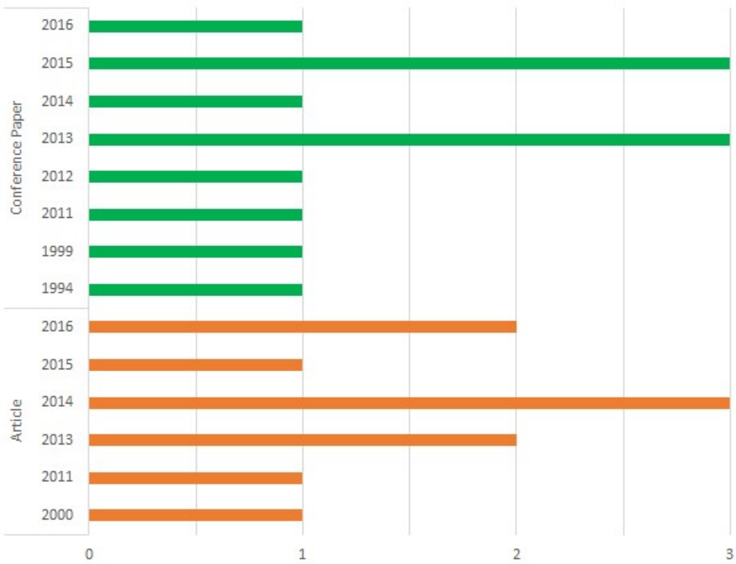


Figure 2. 18: Publication Chronology and Publication Type (developed by the student)

The amount of citations by peer researchers of the collected literature is displayed in Figure 2. 19.

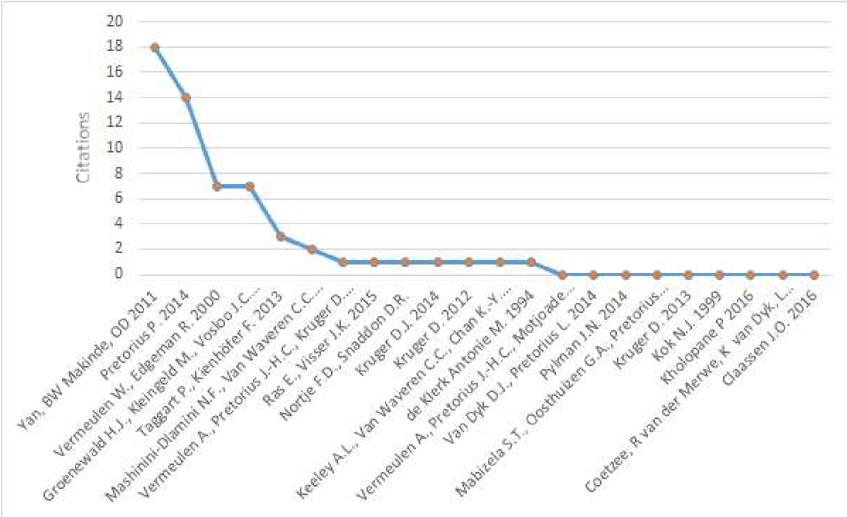


Figure 2. 19: Citations of Publications (developed by the student)

2.4.4.2 Empirical Aspects

Empirical analysis focused on analysing and examining the industrial domains and industrial sub sectors in which the techniques were developed targeting. Continuous improvement techniques had been applied to both manufacturing and services domains as shown in Table 2. 13. The sub sectors outstanding in the services sector comprised of health industry, education and consultancy services. In the manufacturing domain, the sub sectors include mining and mineral processing, food and beverages, power generation and distribution, aerospace components manufacturing, pharmaceuticals, jewellery manufacturing industry and fabrication shop. Studies that could not be determined their domain focus were classified under generic category.

Table 2. 13 : Industrial Domains and Sectors (developed by the student)

Industrial Domain	**Sectors**	**References**
Manufacturing	Mining & Mineral, Food & Beverages, Power generation & distribution, Aerospace components manufacturer, Pharmaceutical manufacturer, Jewellery manufacturer, Fabrication shop	(Claassen 2016)(Ras & Visser 2015)(Keeley et al. 2011) (Kholopane 2016) (Kruger 2013)(Kruger 2012) (Nortje & Snaddon 2013) (Groenewald et al. 2015) (Vermeulen et al. 2015) (van Dyk & Pretorius 2014) (Kruger 2013) (Taggart & Kienhöfer 2013)
Services	Health, Education, Banking, resource consultancy, Consultancy	(Nortje & Snaddon 2013) (Kruger 2014) (Mabizela et al. 2015) (Pylman 2014) (Vermeulen & Edgeman 2000) (Kok 1999)
Generic	Not specific	(Coetzee et al. 2016) (Pretorius 2014) (Vermeulen et al. 2013) (Mashinini-Dlamini & Van Waveren 2013) (Yan & Makinde 2011) (Klerk 1994)

2.4.4.3 Conceptual Aspects

Conceptual aspects of continuous improvement concepts identified were grouped into three categories. These categories are: CI techniques & tools, enabling infrastructure and supportive framework, and CI process management. Techniques and tools of CI focus on systematic procedures and proven scientific practices used for problem identification and solution generation. CI process management entails on planning how the CI activities will be implemented, monitored and evaluating key performance indicators. Enabling infrastructure and supportive framework category focus on shared beliefs and artefacts of underlying cultural values, and behavioural norms within the organisation.

2.4.4.3.1 CI Techniques and Tools

CI techniques are proven scientific methods implemented for problem identification and solving during the incremental improvement phases. Table 2. 14 outlines all the techniques identified corresponding to industrial subsectors in which the technique was applied.

Table 2. 14: Sector and Techniques Implemented (developed by the student)

Sector	Techniques Implemented	References
Mining & Mineral Processing	Cost saving and business restructuring, Total Quality management, Theory constraints, Six sigma, Lean manufacturing,	(Claassen 2016)(Ras & Visser 2015)(Keeley et al. 2011)
Food & Beverages	Six Sigma	(Kholopane 2016)
Fabrication shop	Lean manufacturing	(Kruger 2013)(Kruger 2012)
Aerospace components manufacturer	Toyota Production Systems	(Nortje & Snaddon 2013)
Consultancy	Toyota Production Systems	(Nortje & Snaddon 2013)
Pharmaceutical manufacturer	Toyota Production Systems	(Nortje & Snaddon 2013)
Jewellery manufacturer	Toyota Production Systems	(Nortje & Snaddon 2013)
Construction material manufacturing	Toyota Production Systems	(Nortje & Snaddon 2013)
Human resource consultancy	Toyota Production Systems	(Nortje & Snaddon 2013)
Power generation & distribution	Performance Centred Maintenance, Total Quality Management	(Groenewald et al. 2015) (Vermeulen et al. 2015)
Health	Lean manufacturing	(Kruger 2014)
Education	Six Sigma, Statistical process control-charts, Theory of constraints, Lean manufacturing, Integrated Quality Management System	(Mabizela et al. 2015) (Pylman 2014)
Banking	Total quality management	(Vermeulen & Edgeman 2000)

Ten techniques were identified from the literature to have been implemented in South African industry and these include: Cost Saving & Business Restructuring (CSBR), Total Quality Management (TQM), Theory of Constraints (TOC), Six Sigma (SS), Toyota Production Systems (TPS), Lean Manufacturing (LM), Performance Centred Maintenance (PCM), Statistical Process Control (SPC) and Integrated Quality Management System (IQMS).

2.4.4.3.2 CI Process Management

Managing CI focus on how small incremental improvements will be sustained to long term success. This entails development of an implementation strategy for sustaining small improvement steps towards long term success and developing regular short-term targets and milestones with proper measurement and display channels to stimulate energy and enthusiasm of employees. Clear targets should be communicated to every employee and monitoring structures helps to determine the performance of the CI program. The organisation should monitor different manufacturing attributes. Attributes identified during literature search include quality, process waste elimination, equipment availability, throughput, employee creativity and organisation administration improvement. Based on the analysed literature the student synthesised the CI techniques and manufacturing attributes and developed Figure 2. 20 to be used later in this research.

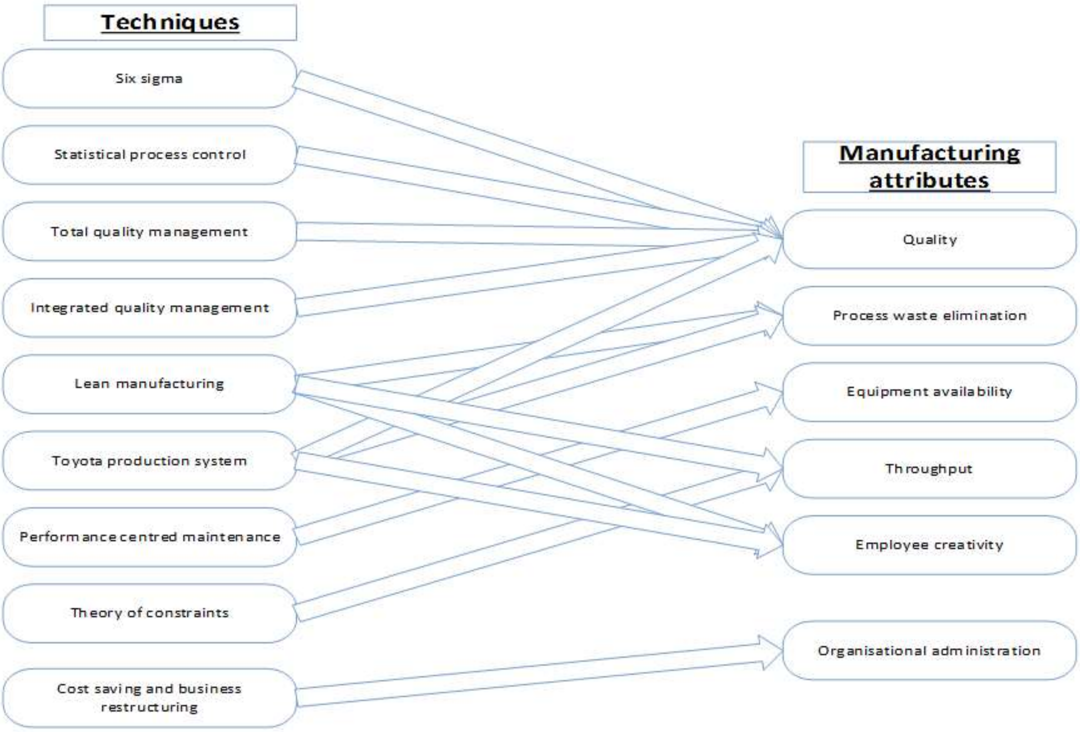


Figure 2. 20: CI Techniques and Manufacturing Attributes (developed by the student)

After analysing the literature presented in this chapter, the student went on to synthesise the strategy to implement CI in this research. The strategy is comprised of a CI process management cycle which includes the following steps: process audits, identification of areas of improvement, optimise, sustaining the improvement and review and the CI process cycle is shown in Figure 2. 21.

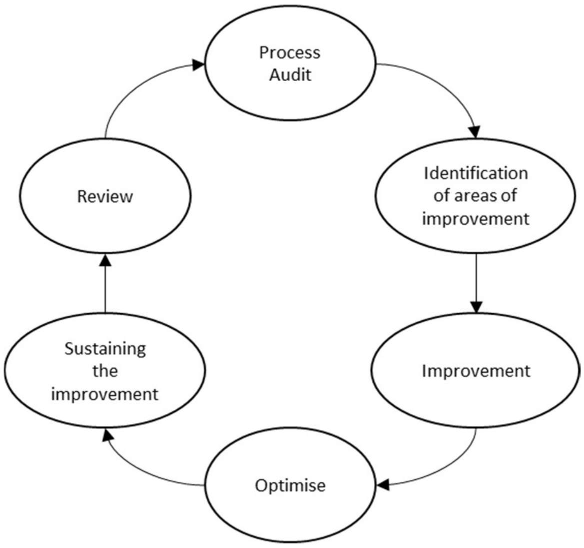


Figure 2. 21: CI Process Cycle (developed by the student)

a) Process audit is the initial step of every improvement cycle and it is to determine the state of the current production process. This is accomplished through assessment of production records, observations and measuring different key performance indicators of the organisation.

b) Identification of areas of improvement is an analysis of the audit results using different problem identification tools like root cause analysis, Pareto charts, 5-Whys and fishbone Ishikawa tools.

c) Improvement phase is focused on correcting errors and removing production inefficiencies exposed in the analysis phase.

d) Optimise phase is to reaffirm if the production line is operating at optimum level after the correction. If the line is operating below optimum levels further improvements are initiated to make sure we yield the best from the correction made.

e) Sustaining the improvement is a monitoring phase until the change initiated has diffused within the production environment.

f) Review phase is a final assessment conducted regarding the methodology used during the cycle. The cycle practices are scrutinized and areas of improvement for the methodology are identified.

2.4.4.3.3 Enabling Infrastructure and Supportive Framework

CI infrastructure refers to organisational structure, teamwork, decision making protocols, autonomy and communications channels between line employees and management (Bessant et al. 1994). A proper organisational structure for effective continuous improvement has proper channels of communication between line employees, supervisors and operational managers. This enables unregulated exchange of ideas and encourages teamwork across all departments. Centralised decision making structures with top down communications and restricted lateral communication suffocates social learning between employees and thus prohibits CI objectives attainment.

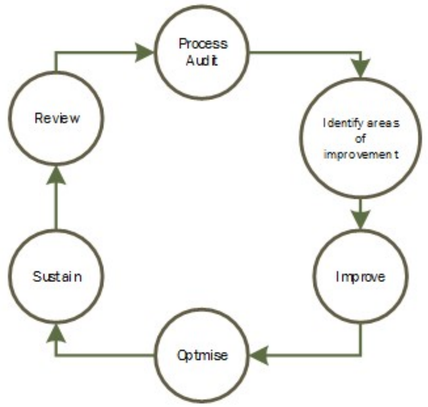
Creativity is possessed by all humans and individuals who work in small, repetitive tasks have repertoire of creative abilities (Kirton 1980; Bessant et al. 1994). Adoption innovation is a basic dimension of personality and it is important to devolve autonomy to work station level (Kirton 1976) . Devolving autonomy to line workers empower line workers to identify work station problems and suggest solutions on how they can improve their work place and production process. The organisation should condition the production environment fertile for nurturing maximum employee involvement. Cultural concepts for a successful continuous improvement program consist of appreciating and recognising small incremental innovation, recognition of creative potential of every employee through adaptive creativity, encouraging learning and experimentation.

2.4.5 Conceptual Framework

The conceptual framework for continuous improvement is a plane of interlinked concepts that provides a comprehensive understanding of CI process. From the foregoing literature review, the student synthesised a CI conceptual framework as shown in Figure 2. 22 for later use in this research. The framework includes three interlinked concepts which consist of continuous improvement process management, enabling infrastructure & supportive framework and continuous improvement techniques. Process management aspects encompass how the improvement steps will be conducted, evaluation and control of the exercise. Improvement steps are conducted in six step cycle which consist of process audit, identification of areas of improvement, improve, optimise, sustain and review. Control and evaluation is measured on different performance indicators and manufacturing attributes which include quality, equipment availability, throughput, process waste elimination, employee creativity and organisational administration.

Process Manangement

1)Implementation Cycle



2)Performance Indicators and Manufacturing attributes monitoring and evaluation
-Quality
-Process waste elimination
-Equipment availability
-Throughput
-Employee creativity
-Organisational administration

Organisational Infrastructure and Supportive Framework

1)Behavioural norms
2)Organisational values and beliefs
3)Organisational structure

Techniques

1)Six Sigma
2)Lean Manufacturing
3)Statistical Process Control
4)Total Quality Management
5)Integrated Quality Management
6)Toyota Production System
7)Performance Centred Maintenance
8)Theory of Constraints
9)Cost Saving and Business Restructuring

Figure 2. 22: Continuous Improvement Conceptual Framework (developed by the student)

Organisational infrastructure and supportive framework consists of behavioural norms, organisational values, beliefs and organisational structure. The aspects address issues related to daily production activities and decision making protocols in the production plant. For a successful continuous improvement exercise the organisation should incubate an environment that stimulates maximum worker participation. Techniques are different set of proven methods and procedures implemented in diagnosis of production line weakness and conducting improvement. These techniques include six sigma, lean manufacturing, statistical process control, total quality management, integrated quality management, Toyota production system, performance centred maintenance, theory of constraints, cost saving and business restructuring.

2.5 Chapter Summary

The chapter has successfully managed to trace the evolution of South African industry from the iron smelting practices in the 4th century. USCO is the first organisation to start commercial production of steel, but significant transformation of South African steel industry started with the formation of Iscor in 1927. Currently the steel industry faces immense competition from foreign steel producers' thus shrinking local steel production. The crises in local steel industry coincide with absence of Industrial Engineering research in steelmaking. Thus this research will focus on developing a continuous improvement system for South African steelmaking organisation.

Continuous improvement (CI) as a technique for incremental innovation to improve organisational processes has been successfully implemented in South Africa. From the literature collected CI methodology has been implemented in both manufacturing and service industrial domains. However, in terms of published research, there is no systematic research on application of CI in steelmaking industry. The chapter also contains a section in which three conceptual aspects of continuous improvement were identified which includes CI techniques, CI process management and CI supporting infrastructure. Techniques are set of tools used during problem identification and solution generation; process management focus on the guidelines and rules on how improvement exercise will be conducted and enabling infrastructure covers the organisational structure and production culture.

Two journal articles have been submitted to SAJIE from this section. The first journal article focused on the investigation of applications of continuous improvement in South African industry through the applications lean manufacturing in the industry. The article “Lean applications: A survey of publications with respect to South African industry” was published in the 28th volume, first issue of the SAJIE publication (most of its contents are in this chapter). The second journal article “South African iron and steel industrial evolution: Industrial Engineering perspective” is based on development of South African iron and steel industry and applications of Industrial Engineering research.

3 RESEARCH METHODOLOGY

3.1 Research approach and strategy

The research was conducted in three stages which are literature analysis, conceptual framework development and case study as shown in Figure 3. 1.

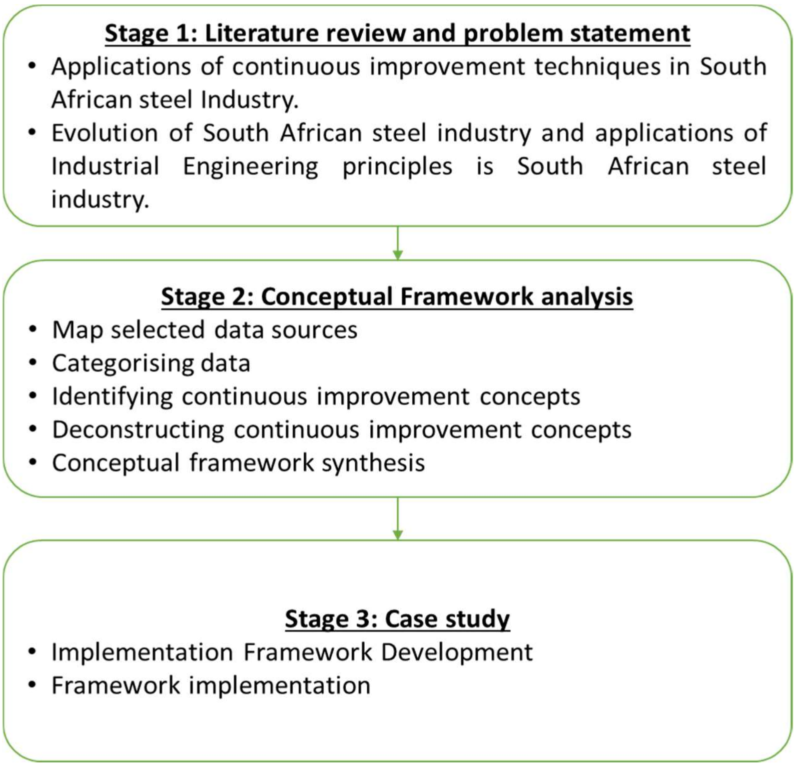


Figure 3. 1: Research strategy

Literature review and problem statement stage consisted of two steps which include continuous improvement review and the evolution of South African steel industry from industrial engineering perspective. Continuous improvement review was completed by outlining continuous improvement techniques and by investigating applications of lean manufacturing a continuous improvement technique in South African industry. Investigation of lean manufacturing applications was conducted through a systematic literature review methodology. Systematic literature review follows explicit procedures that aids credibility of the review and eliminates bias of the literature analysis. Three steps of systematic review which were employed in this study are: specifying review, conducting the review and reporting the results of the review as shown in Figure 3. 2.

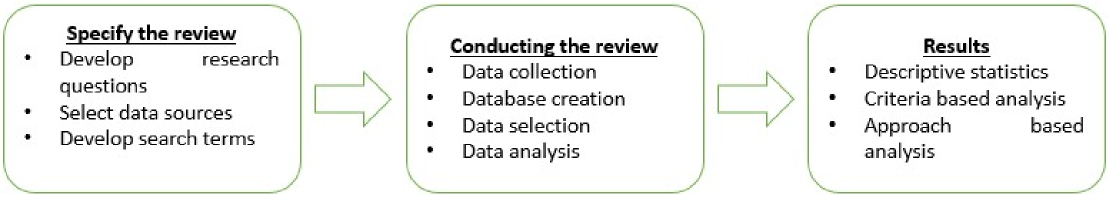


Figure 3. 2: Systematic review steps

The findings on the applications of lean revealed the absence of systematic research on applications of continuous improvement techniques in South African steel industry. In an effort to analyse the identified gap, a second step was executed which was a comprehensive review on the development of South African steel industry and application of industrial engineering techniques into the industry. The review was completed through the review of government publications, organisational websites and academic publications in the public domain.

Based on the identified need of continuous improvement in steelmaking in stage one, the second stage was aimed in understanding continuous improvement as an industrial engineering tool. Due to vast volume of research on the subject the research opted for conceptual framework analysis proposed by Jabareen (2009) which is a qualitative grounded theory technique. Grounded theory is a theory discovery research tool which enables generation of knowledge on processes; the methodology is contextual, procedural and inductive. Conceptual framework analysis allows creativity and generation of knowledge by the researcher. The analysis provides a process oriented perspective in explaining continuous improvement and ensures detailed data analysis rather than the description of the subject. Steps for conducting the framework analysis are shown in Figure 3.1 under Stage 2 heading.

The conceptual framework was used to develop a continuous improvement implementation framework for Unica Iron and Steel Company. The developed implementation framework targeted to improve quality, throughput and waste elimination in mini mill steel rolling operations. The developed implementation framework steps include process audit, identification of areas of improvement, improvement, optimise, sustain and review. Unica iron and steel company was selected after the student first preliminary visit in March 2017 and the board of directors were receptive and positive to cooperate in research that will improve their production. The process audit step, identification of areas of improvement was conducted at the company's plant in Hammanskraal Pretoria from 8 May 2017 to 26 May 2017. During this field work the student was assisted by mill line supervisors, plant quality inspectors and the plant manager. A presentation of field work findings was conducted by the student to company's top management which included plant manager, finance manager, managing director and financial director. The panel was pleased with the results and started implementing some of the recommendations whilst the student was further developing a comprehensive production plan and control system for a specific product. To validate the improvements and the production control system the student used Technomatix simulation software to simulate both current state and improved production state.

3.2 Tools and Software used

The research study employed the following IE tools:

- Value Stream Mapping was used to determine current processing time and lead time for production of the angle iron. The technique was used because it allows analysis of series of production activities in rolling operations.
- 5-Why (Root Cause Analysis technique) was implemented to investigate the root cause of quality defects within the rolling operations. The technique was used because it is interrogative when investigating the root cause of process wastes.

- Facility Layout was used to determine the production layout and distance travelled by the product during manufacturing. The technique allows process efficiency by improving work stations arrangements to reduce distance travelled by work in progress.
- Pacemaker was used to regulate production in the production line.
- Basic Activity Mapping was used to determine the current production strategy and generate an improved production strategy.

Computer software packages used include:

- Autocad a drafting software package was used to generate drawings on the facility layout of Unica plant.
- Technomatix a discrete event simulation tool was used to simulate the current production line and improved production line.
- Creately software was used to generate Production Flow Chart and Value Stream Map.

3.3 Chapter summary

The research study implemented a variety of research tools and software applications as presented in this Chapter. Three main stages of the research exercise are: literature review, conceptual framework analysis and case study. Chapter 4 shows the development of the CI framework to be implemented at Unica (Case study).

4 DEVELOPMENT OF THE FRAMEWORK TO BE IMPLEMENTED

4.1 Chapter Introduction

This chapter will focus on developing the guidelines, steps and strategy on how continuous improvement will be implemented in steelmaking operations based on the conceptual framework developed and synthesised by the student in literature review Section 2.4.5.

4.2 Continuous Improvement Framework

The framework is developed based on continuous improvement techniques that had been applied and tested in other sectors of South African industry as reviewed in Section 2.4. Fourteen studies were identified to have empirical evidence of implementation of continuous improvement techniques. Table 4. 1 displays techniques employed versus study reference, a weight of one was awarded when a technique was employed in a case and the total weight for each technique is summed in the last row of Table 4. 1**.**

Table 4. 1: Case versus Technique Mapping

Study Reference	CSBR	TQM	TOC	SS	PCM	TPS	LM	PCM	SPC	IQMS
(Kholopane 2016)				●						
(Groenewald et al. 2015)					●					
(Mabizela et al. 2015)			●	●			●		●	
(Kruger 2014)							●			
(Pylman 2014)										●
(van Dyk & Pretorius 2014)				●						
(Mashinini-Dlamini & Van Waveren 2013)				●			●			
(Vermeulen et al. 2015)		●								
(Kruger 2013)							●			
(Taggart & Kienhöfer 2013)							●			
(Kruger 2012)							●			
(Keeley et al. 2011)				●						
(Vermeulen & Edgeman 2000)		●								
(Kok 1999)										●
Total	**-**	**2**	**1**	**5**	**1**		**6**	**-**	**1**	**2**

To properly rank the techniques the study first clustered the techniques in different segments based on the production attributes in Figure 2. 20. The study narrowed to three productions attributes which consist of waste elimination, quality improvement and throughput. Table 4. 2 display technique rankings of the three attributes.

Table 4. 2: Continuous Improvement Technique Ranking

Production Attributes			
Waste elimination	**Ranking**	**Technique**	**Weight**
	1	Lean Manufacturing (LM)	6
	2	Toyota Production System (TPS)	0
Quality	**Ranking**	**Technique**	**Weight**
	1	Six Sigma (SS)	5
	2	Total Quality Management (TQM)	2
	3	Integrated Quality Management System (IQMS)	2
	4	Statistical Process Control (SPC)	1
	4	Toyota Production System (TPS)	0
Throughput	**Ranking**	**Technique**	**Weight**
	1	Lean Manufacturing (LM)	6
	2	Theory of Constraints (TOC)	1

Under the waste elimination category lean manufacturing has been widely used in South African industry, however in practice there is no significant difference between lean and TPS. Lean manufacturing is a generic version of TPS that was developed to be applied in any industrial activity (Womack & Jones 2003; Coetzee et al. 2016). Thus, the framework under development will consist of TPS and lean manufacturing principles for process waste elimination. In the quality segment, Six Sigma with a weight of 5 will be implemented. Since TPS has been selected to focus on waste elimination it is expected that it will also contribute towards quality improvement. In throughput segment since lean manufacturing had been selected already, TOC will be added to assist in throughput rate improvement.

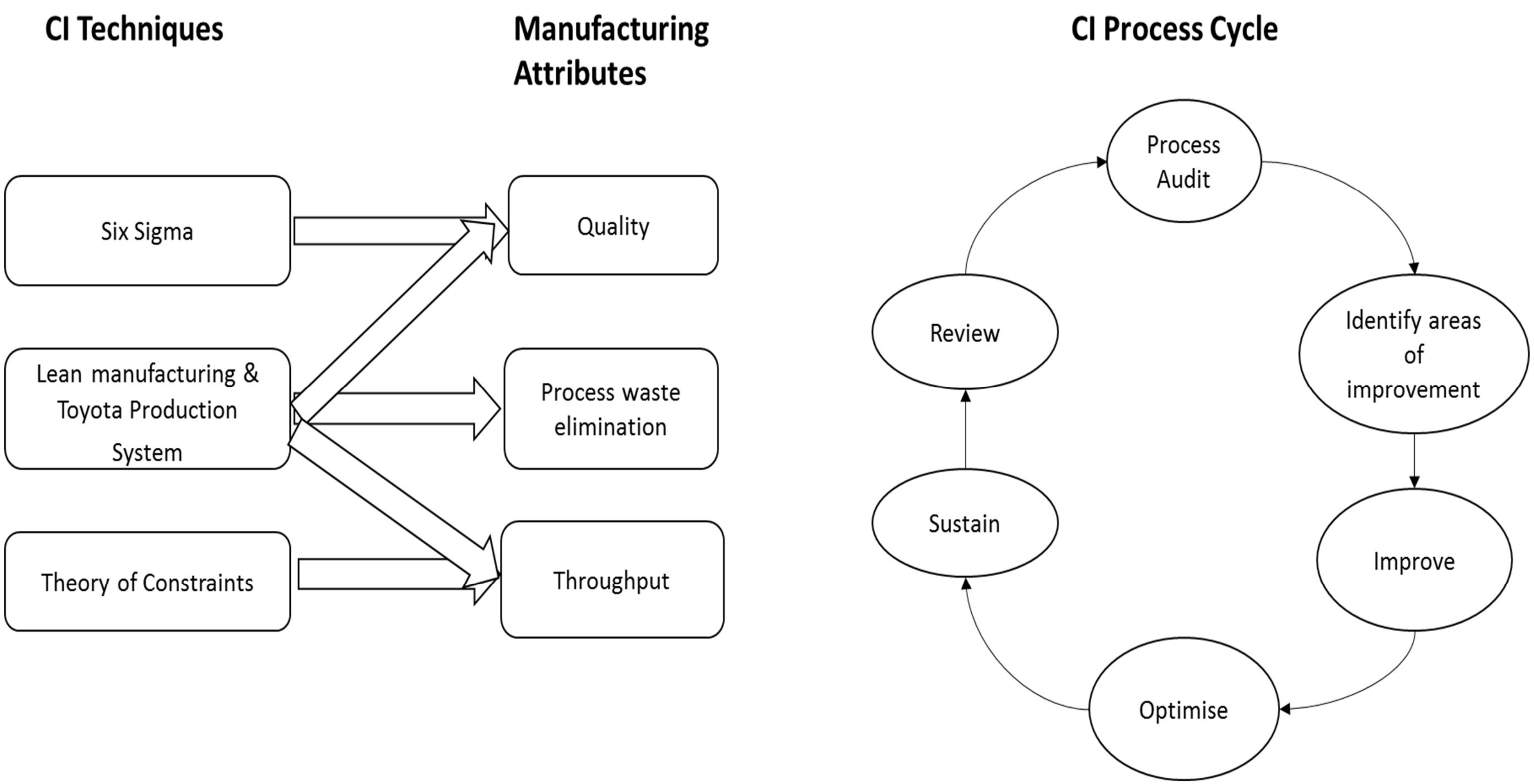


Figure 4. 1: Developed CI Implementation Framework

The developed framework is shown in Figure 4. 1 and consists of four techniques which comprise of Toyota Production System, Lean Manufacturing, Six Sigma and Theory of constraints. The integrated structure will influence quality, process waste, employee creativity and throughput within the steelmaking organisation. The techniques will be applied systematically in six stages on a continuous basis as shown in Figure 4. 1. The processing audit step is to determine the current production capacity and operating parameters of different work stations. This includes total furnace capacity, casting capacity and rolling capacity per shift and the processing time for each production step. Identifying areas of improvement is application of problem identification tools to expose inefficiencies within the production line. Improvement step is concerned with removing inefficiencies during the continuous casting and rolling operations to improve product value. Optimising step is to effectively use the production machinery after the inefficiency has been corrected. The improvement made needs to be sustained and protected until it is incorporated as part of the production culture. The review phase seeks to promote the hansei culture in steelmaking, which is focused on self-reflection and responsibility (Liker & Meier 2004). Reflection on the activities of the improvement cycle allows lessons to be drawn thus translating to a learning organisation.

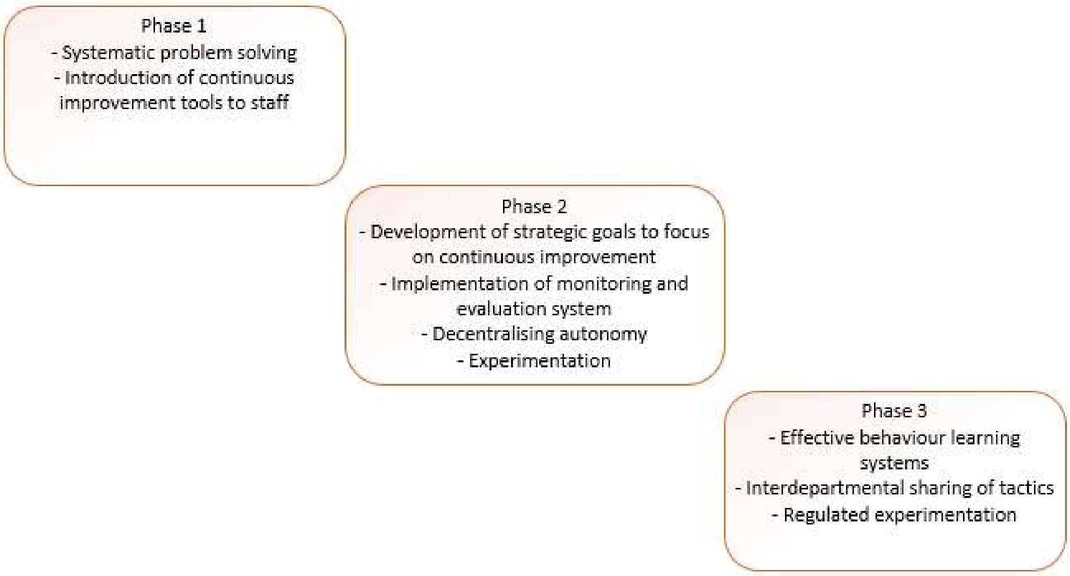


Figure 4. 2: Developed CI Implementation Strategy

To facilitate smooth transition in the production culture towards a supportive framework for effective learning the study has adopted a three-phase approach as shown in Figure 4. 2. The first phase consists of implementing continuous improvement problem solving tools to allow familiarisation of production staff with CI techniques. Phase 2 expands CI by embedding CI as part of manufacturing strategy in which strict CI monitoring and evaluating systems are incorporated with production staff empowered to make suggestion on how to improve their respective work stations. Phase 3 consist of implementing effective behaviour learning systems and allowing interactions between departments.

4.3 Chapter Summary

This chapter has managed to develop a continuous improvement methodology that will be implemented in steelmaking operations. The methodology consists of four CI techniques which include Toyota Production System, Lean Manufacturing, Theory of Constraints and Six Sigma. The techniques will improve product quality, reduce process waste and improve throughput. Six process management steps will facilitate CI activities and these consist of process audit, identification of areas of improvement, improve, optimise, sustain the improvement and review steps. To avoid overwhelming production staff the organisation will transform through a three phase programme towards a learning organisation.

5 CASE STUDY

5.1 Company Audit: UNICA Iron and Steel Limited (Unica)

Unica Iron and Steel Private limited is a manufacturing organisation focusing on recycling of scrap to produce mild steel square bars, mild steel window sections, mild steel angle irons, mild steel channels and mild steel flat bars. The manufacturing organisation was established in 2006 and currently has 704 employees (Unica Iron & Steel (Pty) Ltd 2015). The company uses mini mill production route to produce steel products. The production route is characterised by continuous casting process and rolling operations. In this section, the focus is on continuous improvement of rolling operations.

5.2 Implementing Continuous Improvement

The continuous improvement framework developed in Section 4.2 is implemented according to the CI process cycle in Figure 4. 2. The cycle consists of six steps which include process audit, identifying areas of improvement, improve, optimise, sustain and review. The framework utilises Six Sigma tools, Lean Manufacturing tools, Toyota Production System and Theory of Constraints. The improvement cycle is implemented on the production of an angle iron of height 25 mm, width 25 mm, thickness 2 mm and 5400 mm (5.4 m) length as shown in Figure 5. 1 and the selection of the product was by snowball basis. The company runs a single shift a day with nine working hours for production of the angle iron.

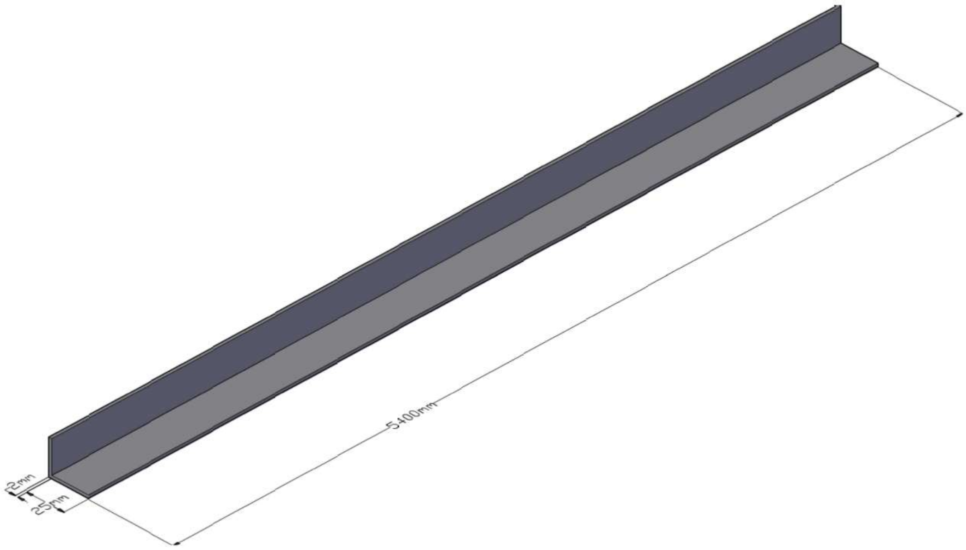


Figure 5. 1: Angle Iron

5.2.1 Process Audit and Identification of areas of improvement

5.2.1.1 Production Audit

Production process audit was conducted through analysis of production records of the product from January 2017 to April 2017 and the results are summarised in Table 5.1. A total of 9645 tonnes of billets were rolled between January and April of 2017 and the A grade product was 6790 tonnes as shown in Table 5. 1.

Table 5. 1: Unica Production Record January - April 2017

	Billet Input (tons)	A Grade (tons)	B Grade (tons)	Defects (tons)	Quality Rate for Grade A (%)	Productivity (for production of Grade A and B) %	Defect Rate %
January	2088	1415	77	596	68%	71%	29%
February	2505	1781	82	642	71%	74%	26%
March	2715	1899	115	701	70%	74%	26%
April	2337	1695	114	528	73%	77%	23%
Average	**2411**	**1698**	**97**	**617**	**70.5%**	**74%**	**26%**
Total	**9645**	**6790**	**388**	**2467**			

The B grade product amounted to 388 tonnes and 2467 tonnes were scraped off as defects because they did not meet specifications. The definition of the quality rate adopted in this study is amount of A grade product produced as compared to input tonnage as shown in Equation 5.1.

$$Quality\ Rate = \frac{A\ Grade\ product}{Billet\ Input} \times 100 \qquad \text{Equation 5. 1}$$

Productivity is the ratio of final products output to input raw materials (Danreid & Sanders 2007) and Equation 5.2 shows the mathematical calculation of productivity.

$$Productivity = \frac{Total\ Output\ (A\ Grade + B\ Grade)}{Billet\ Input} \times 100 \qquad \text{Equation 5. 2}$$

The defect rate shown in Equation 5.3 is the tonnage of defects produced relative to the billet input.

$$Defect\ Rate = \frac{Defects}{Billet\ Input} \times 100 \qquad \text{Equation 5. 3}$$

The average quality rate for the period from January to April 2017 of the production process was 70.5% as shown in Table 5. 1. Average productivity for the four months was 74% and average defect rate was 26%.

5.2.1.2 Defining value and value mapping

Value is derived from meeting customer specifications and standards. In the context of steelmaking this encompasses material strength, product geometry and tolerances. The study scope was limited to rolling operations and did not include melting and continuous casting operations. The raw material for the rolling process are billets weighing 110 kilograms (kg) and 140 cm length and 10 cm square face shown in Figure 5. 2.

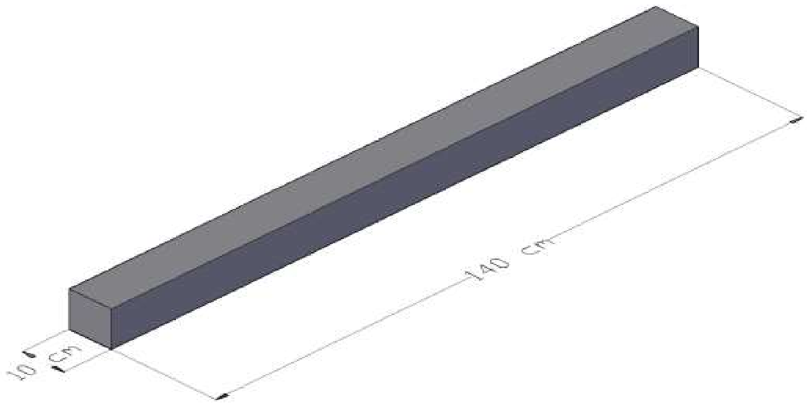


Figure 5. 2: Billet

As the billets are loaded into the furnace the objective is to raise the temperature of the raw material to a temperature above 1200 degrees Celsius. From the reheat furnace the hot billet will first go through roughing phase as shown in Figure 5. 3, and from roughing the work in progress will be cut into six pieces. Each piece will go through rolling process to produce a 24-meter angle iron that will be cut to produce four pieces of 5.4 meters in length. The pieces will be packed together in bundles weighing two tonnes with approximately 475 angle iron pieces.

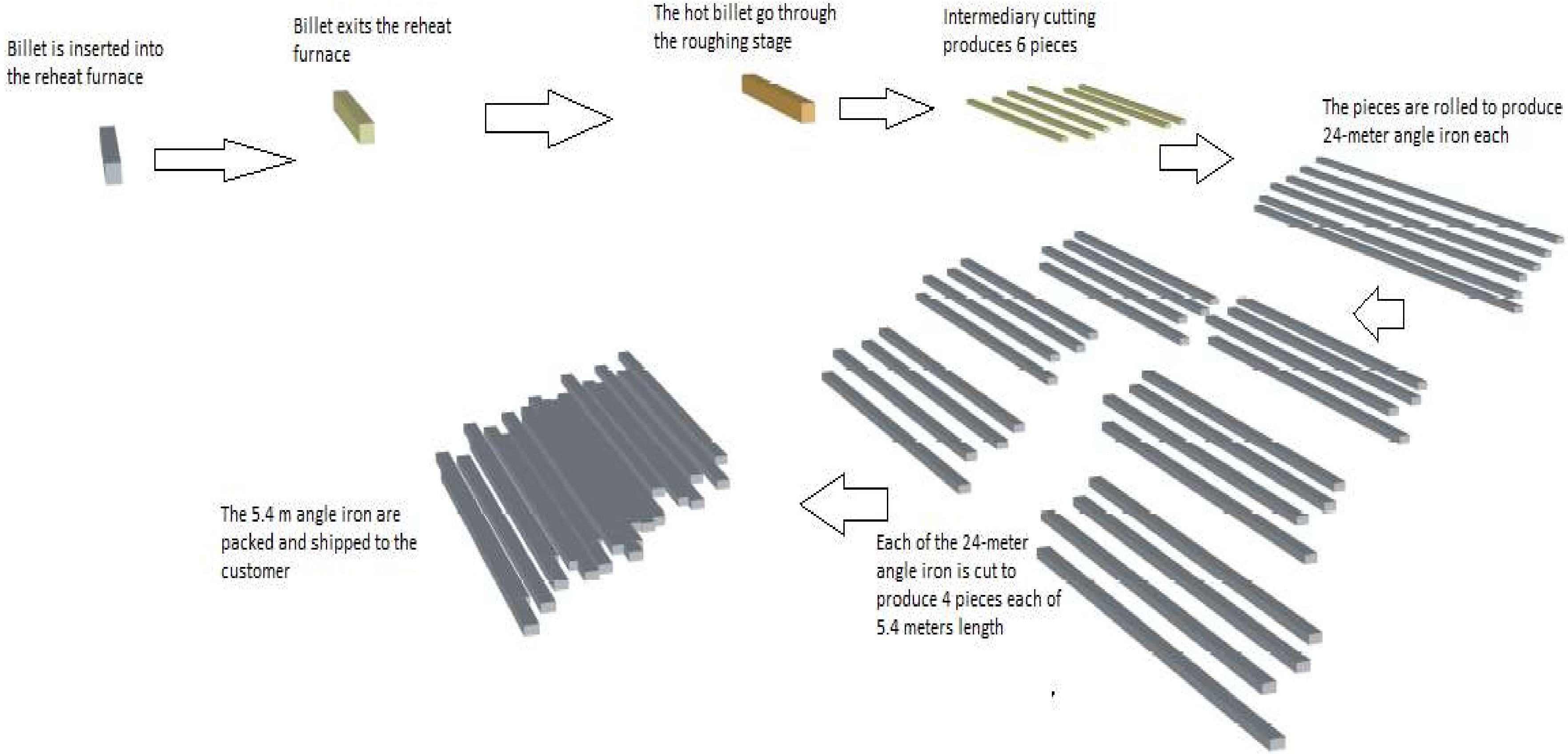


Figure 5. 3: Angle Iron Value Addition Process

The product flow chart is displayed in Figure 5. 4, production starts when the raw materials (billets) are transported from the billet yard to the reheat furnaces. The billet temperature is raised to 1200 degrees Celsius and if the temperature is not achieved the billet is resend for reheating. If the billet temperature is within the specified region, the raw material will go through the roughing phase. From the roughing phase, hot steel is cut into four pieces which will go through rolling stage then final cutting. Figure 5. 4 also highlight sources of process waste and potential sources of process wastes. At position A in Figure 5. 4 the waste of overproduction is when the reheat furnace eject more billets per unit time than what can be consumed by the succeeding roughing process. At position B, the waste of incorrect processing is registered when the exit temperature of the billet from the furnace is less than 1200 degrees Celsius. Incorrect processing at position B results in recommitment of production resources to reheat the billet. The waste of waiting at position C, position E and position F are at roughing station, intermediary cutting station and rolling station respectively and registered when machine and operator idle in anticipation of receiving a work part from preceding stations. Defect wastes are present at position D, position H, position I, position K and position L. Defects identified include miss rolls, large cold shear, bends and scabs and these defects are discarded as scrap in the production environment. The waste of unnecessary transport is at position G at the rolling phase. The waste of excessive inventory was observed at the final cutting work station position H, and packing station, position L. A waste of incorrect processing at position J is at the straightening machine and if the product is not straight after the first attempt the work piece is resend for another attempt of straightening.

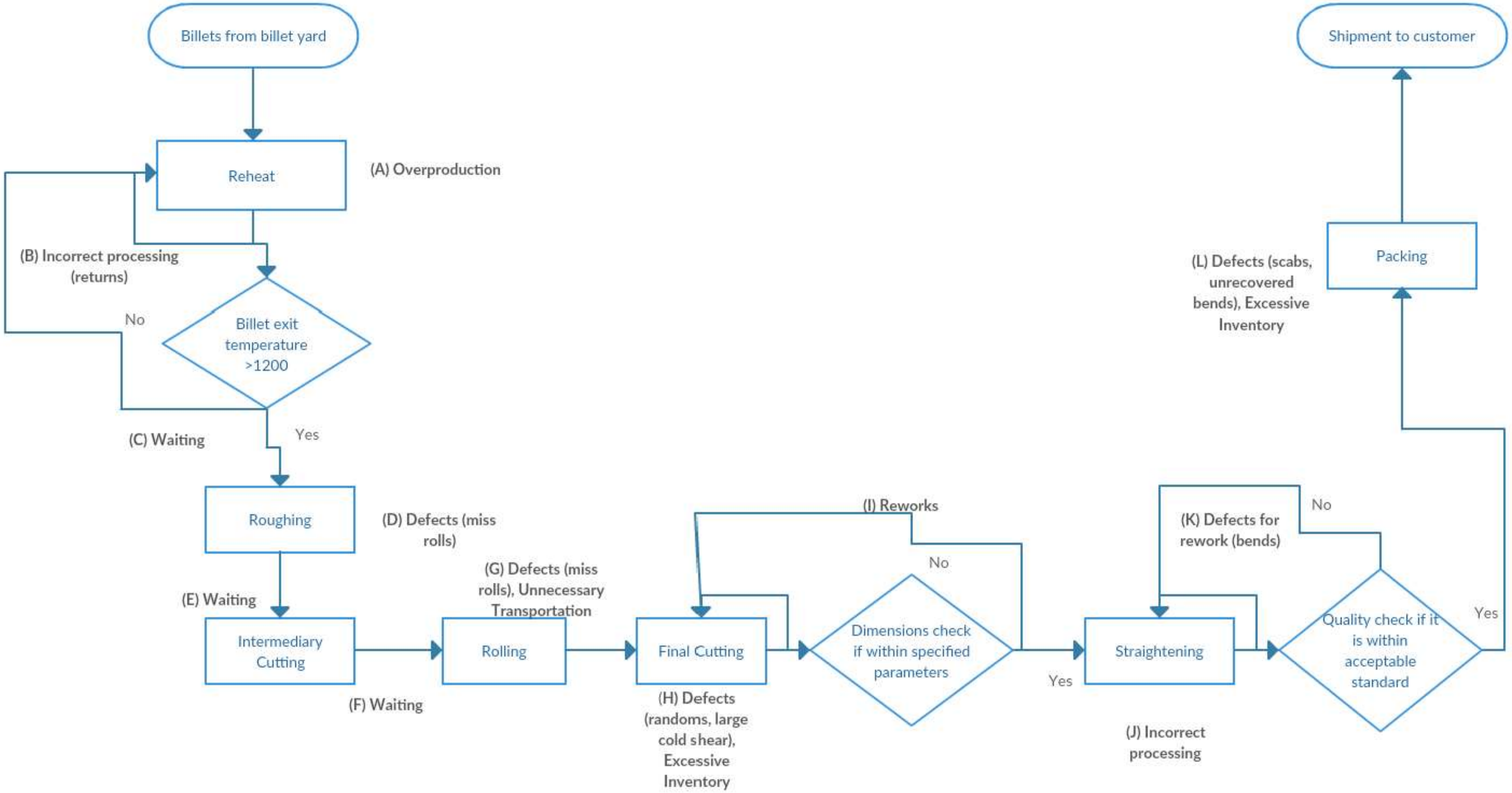


Figure 5. 4: Production Floor Chart and Sources of Waste Identification

The basic activity map for the production process is shown in Figure 5. 5. The activity map displays the average cycle times for each activity to complete a single batch of products produced by a single billet of mass 110 kilograms. The reheat furnace supplies a billet to the roughing station once in every 30 seconds. The roughing step is completed in 31 seconds and the work in progress (WIP) is conveyed to the intermediary cutting station. The WIP is cut into six pieces and the process is completed in 29 seconds. The rolling operation of the batch which consists of six pieces is completed in 54 seconds to produce each a 24-meter angle iron.

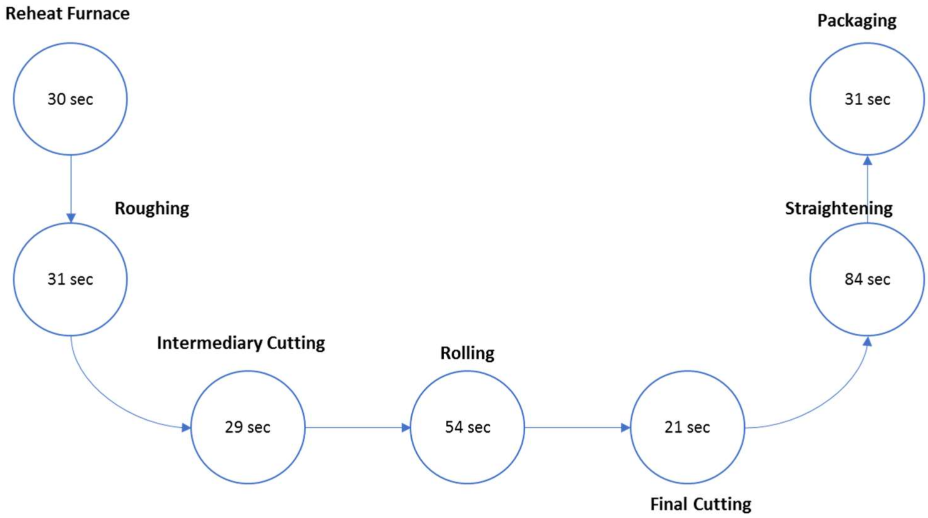


Figure 5. 5: Angle Iron Manufacturing Basic Activity Map

Each 24-meter angle iron is cut at the final cutting station into four pieces of standard length 5.4 meters in 21 seconds. At the straightening station, it takes a total of 84 seconds to complete the whole batch and the batch is packed in 31 seconds. To assist in value streaming, a value stream map was generated and is shown in Figure 5. 6. Value adding activities identified in the production cycle are: reheating, roughing, intermediary cutting, rolling, final cutting and straightening. Non-value adding activities were categorised between necessary and unnecessary non-value adding activities. Necessary non-value adding activities are cooling and packing. Unnecessary non-value adding activity identified is processing delays between work stations.

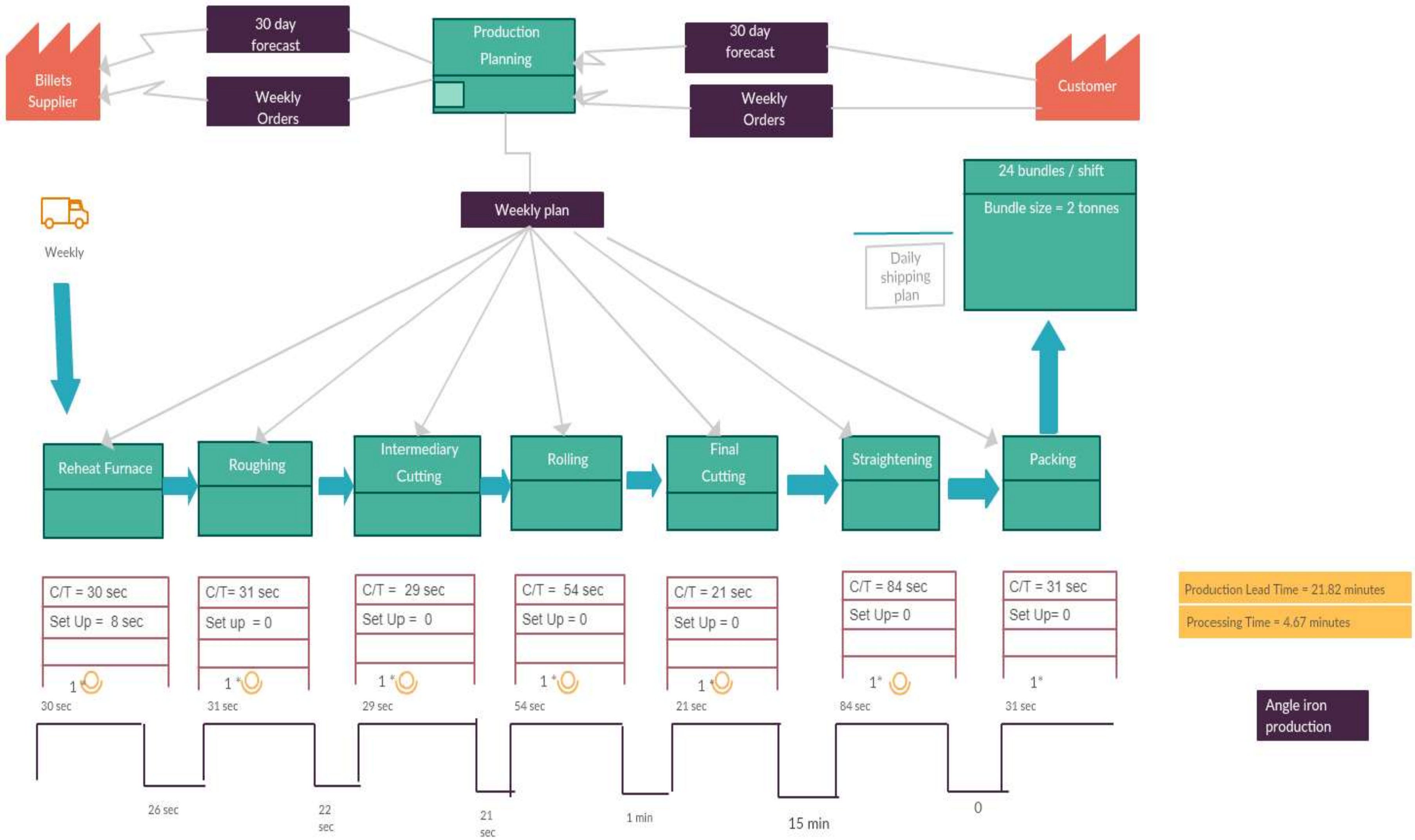


Figure 5. 6: Current Value Stream Map

From the current value stream map in Figure 5. 6, processing time is calculated by adding cycle times (C/T) of all work stations. Processing time for the production of the angle iron is 4.67 minutes. Lead time is calculated by adding processing time for all work stations, set up time for all work stations and total delay between work stations. Lead time for the angle iron is 21.82 minutes. Processing time represents the time taken to complete value adding activities and lead time represents the time taken to complete value adding activities and non-value adding activities. The current value stream map shows that value adding activities constitute only 21.40% of the lead time. Thus focus should be directed towards minimising non-value adding activities, this is achieved by minimising and eliminating process wastes.

5.2.2 Improvement

In this section, the 5-Why root cause analysis technique is used to investigate the root cause of each process waste identified in the organisation. This exercise was conducted with assistance of mill supervisors, quality inspectors and production staff. The process wastes identified are:

- Defects
- Overproduction
- Incorrect Processing
- Waiting
- Excess Inventory
- Unnecessary Transport

5.2.2.1 Defects root cause analysis

Table 5. 2 displays the tonnage of defects produced for the period of January to April 2017. Defects identified include miss rolls, randoms, scabs and large cold shear and unrecovered bends.

Table 5. 2: Production Defects and tonnage January - April 2017

	Miss-rolls (tons)	Randoms (tons)	Scabs (tons)	Cold shear (tons)	Unrecovered bends (tons)	Total
Jan	161	101	109	148	75	**596**
Feb	160	117	123	171	71	**642**
March	222	113	122	195	49	**701**
April	167	78	91	166	26	**528**

a) Miss-rolls defects are experienced when the WIP is removed from the production line before completing all rolling phases.

Figure 5. 7: Miss Rolls

Figure 5. 7 shows miss roll defects and in Figure 5. 8 is the root cause analysis of miss roll defects through the 5-Why root cause analysis. The root cause of miss rolls includes absence of a comprehensive production strategy, variation in fuel calorific content which is used to power reheat furnace, poor billet quality and poor maintenance techniques.

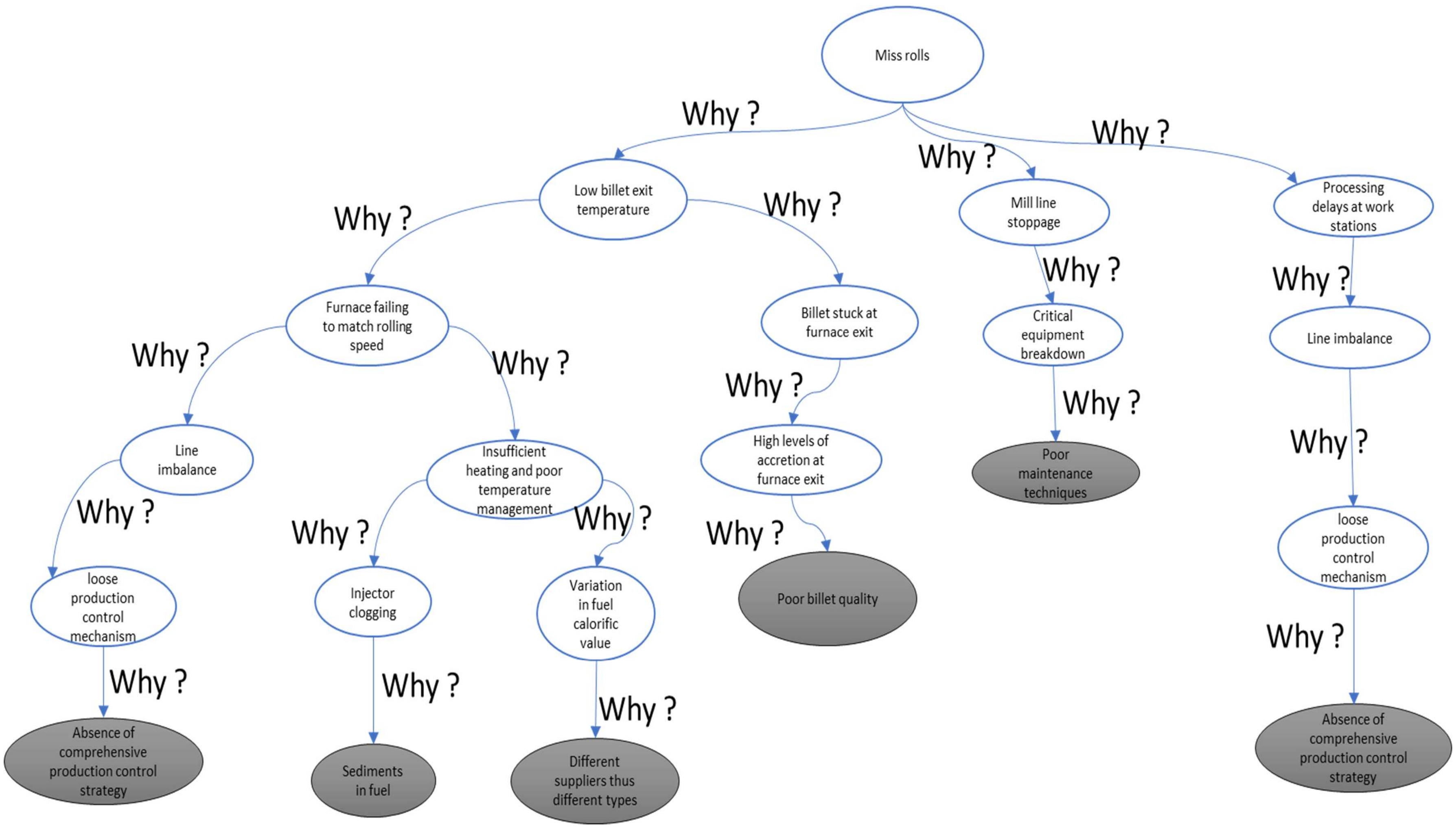


Figure 5. 8: Miss-rolls Root Cause Analysis

b) Scabs are defects that are exhibited by cracks on the product and poor surface finish of the product. Figure 5. 9 shows the root cause analysis of scabs, the root cause of scabs is poor billet quality and absence proactive maintenance techniques on the production equipment.

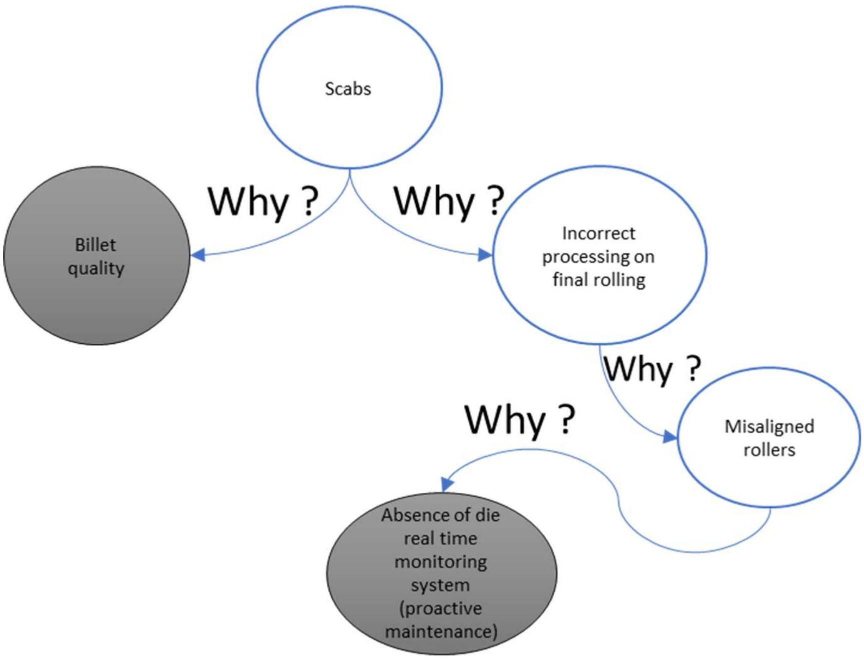


Figure 5. 9: Scabs Root Cause Analysis

c) Randoms and large cold shears are same in nature, but cold shears are detected before the final cutting operations and randoms are detected after the final cutting operations. Randoms are experienced when material left during final cuttings cannot fit final 5.4 meters length. Randoms and cold shear defects are shown in Figure 5. 10 and the root cause analysis for these wastes is shown in Figure 5. 11.

a) Randoms b) Cold Shear

Figure 5. 10: Randoms and Large Cold shears

The root cause analysis of randoms and large cold shear is shown in Figure 5. 11. The root causes identified are variation in billet specifications, absence of a comprehensive production control strategy and absence of a functional maintenance strategy.

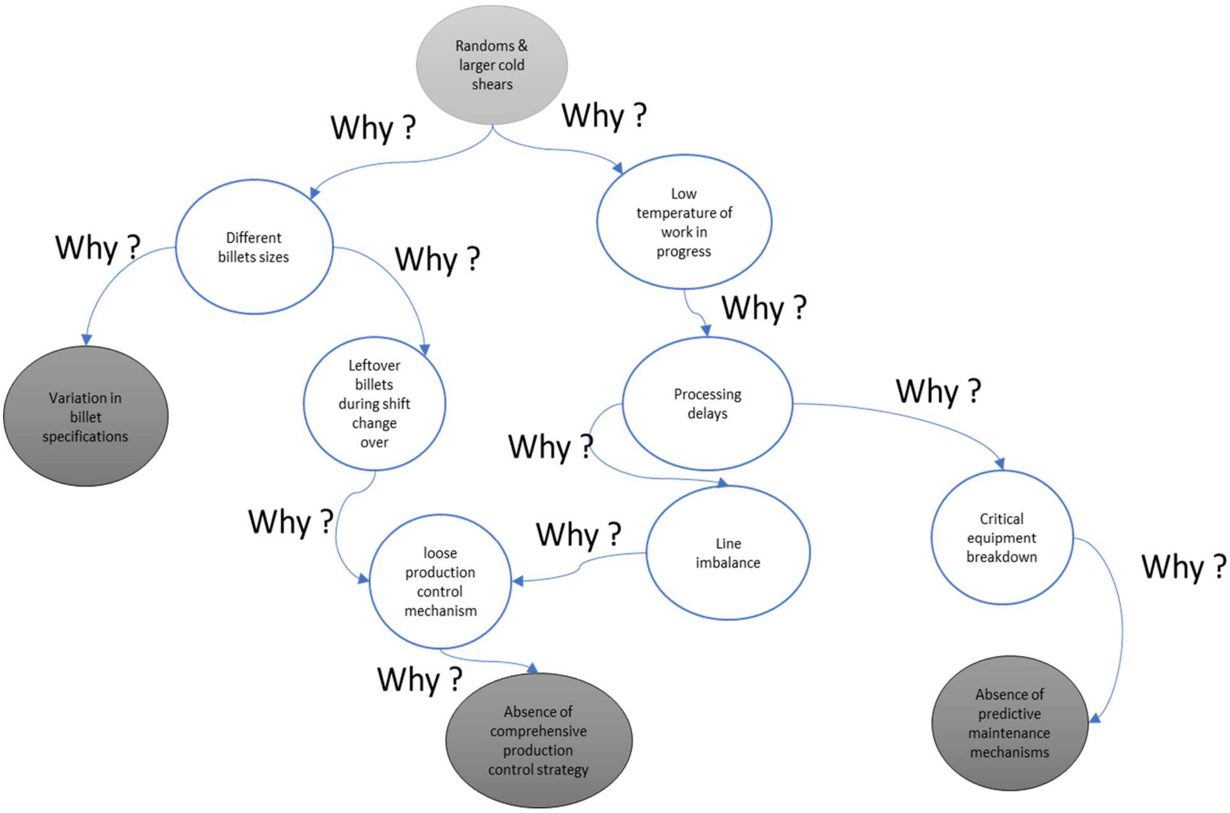


Figure 5. 11: Randoms and large Cold Shear Root Cause Analysis

d) Bends are deformities in the straightness of the product geometry as shown Figure 5. 12.

Figure 5. 12: Bends Defects

Figure 5. 13 show the root cause analysis of bends. The root causes of bends are absence of real time monitoring maintenance techniques on production equipment and absence of a comprehensive production control strategy.

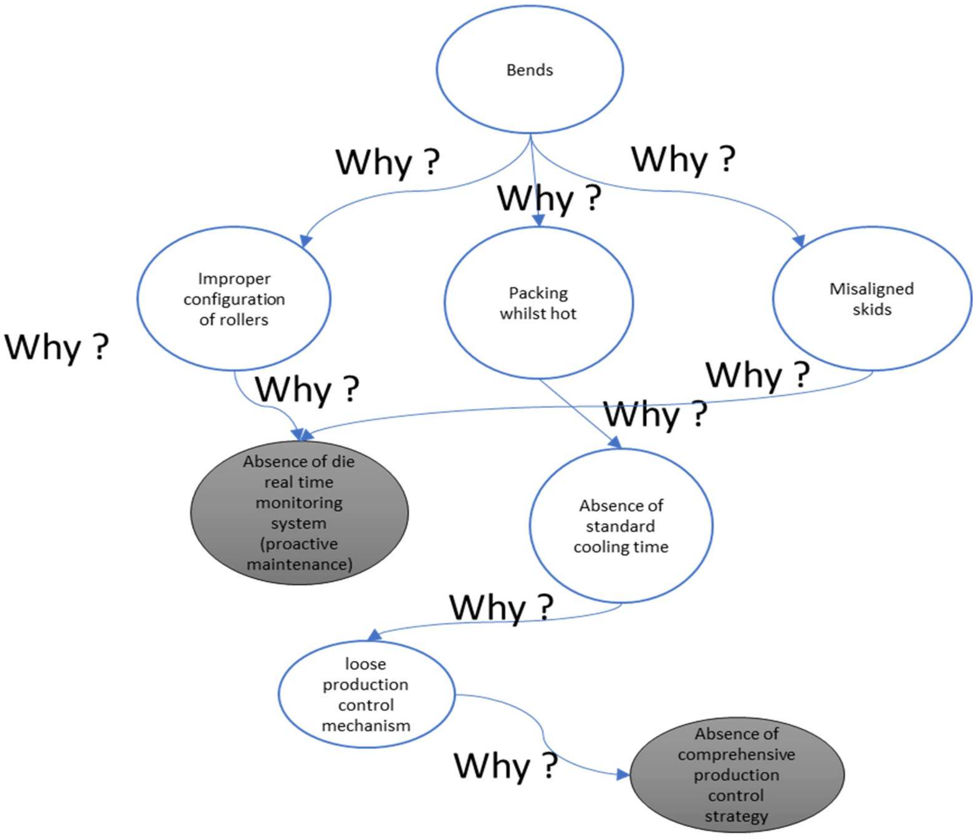


Figure 5. 13: Bends Root Cause Analysis

5.2.2.2 Process Waste Analysis

Defects wastes in mini mill steel rolling activities are a result of other five process wastes identified in mini mill steel operations which include overproduction, incorrect processing, waiting, unnecessary transportation and excess inventory wastes. From the root cause analysis carried in Section 5.2.2.1, miss rolls are connected to waiting and over production wastes whilst scabs' defects are a result of incorrect processing. Randoms and large cold shears are linked to waiting waste and unnecessary transportation and bends are linked to incorrect processing and excessive inventory. Table 5. 3 summarises the root causes of defects in the rolling plant and other process wastes linked to the defect.

Table 5. 3: Defect Root Cause Summary

Defect	Process waste linked to	Root Cause
a) Miss rolls	Waiting, Overproduction	- Absence of a comprehensive production control strategy - Variation in raw materials (furnace fuel) - Poor quality of billets - Poor maintenance techniques
b) Scabs	Incorrect processing	- Poor quality of billets - Poor maintenance techniques
c) Randoms and large cold shears	Waiting, Unnecessary transportation	- Poor quality of billets - Absence of a comprehensive production control strategy - Poor maintenance techniques
d) Bends	Incorrect processing and Excessive Inventory	- Poor maintenance techniques - Absence of a comprehensive production control strategy

The root causes of process wastes in the production process are absence of production control strategy, variation in raw materials, poor billet quality and poor maintenance techniques. This study will focus on the development of a production control strategy due to its high frequency as a root cause of most defects.

5.2.2.3 Production Control Strategy

To develop the production control strategy, production activities are decoupled between rolling and the final cutting operations as shown in Figure 5. 14. The reason for decoupling the manufacturing process is because reheating, roughing, intermediary cutting and rolling steps are performed at high temperature whilst final cutting and straightening operations are performed at standard room temperatures.

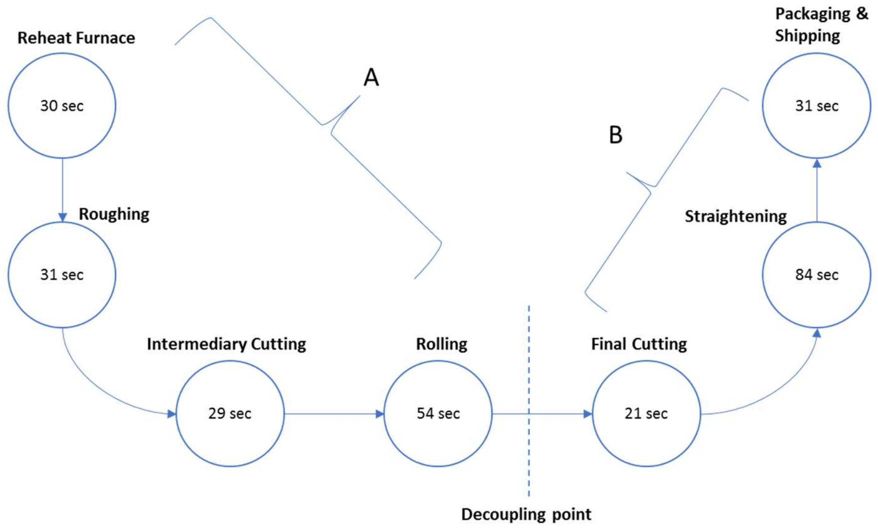


Figure 5. 14: Production line Decoupling

Part A of the production line is from reheat furnace to rolling operations whilst final cutting, straightening and packing is part B of the production line as indicated in Figure 5. 14. Theoretical throughput of part A of the production line is 1.11 billets being rolled per minute (66.67billets per hour) and is governed by the rolling stage thus the stage is selected as the pacemaker process as shown in Figure 5. 15.

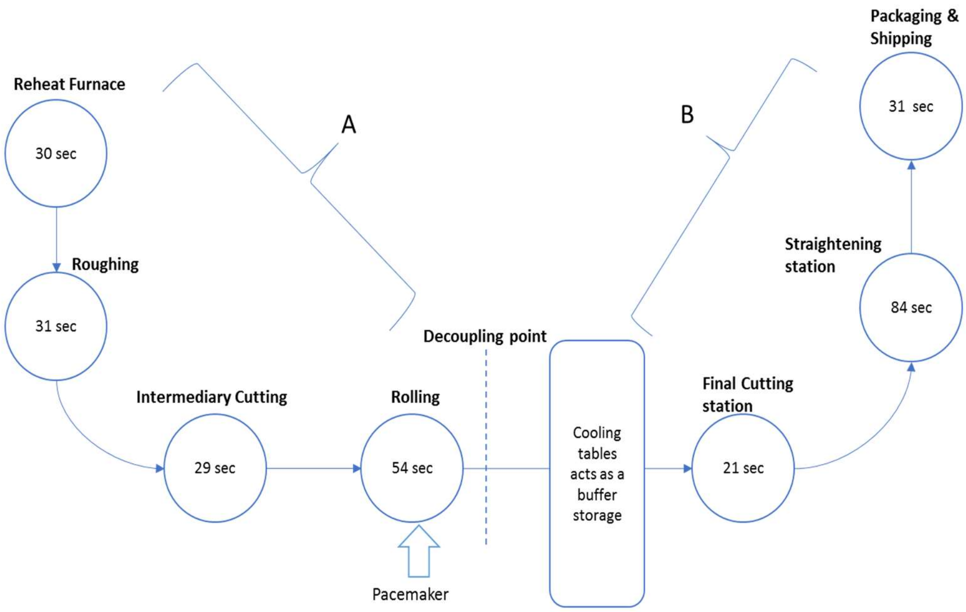


Figure 5. 15: Implementing Pull Strategy

The pacemaker step will be used to pull production in part A of the production line and this avoids processing delays (waiting waste) thus improving temperature management of the billet (work in progress). There is no need for pacemaker in part B since it relies on products from part A. Simulation of the current state on the rolling activities was conducted using Technomatix plant simulation software and a screen shot is shown in Figure 5. 16.

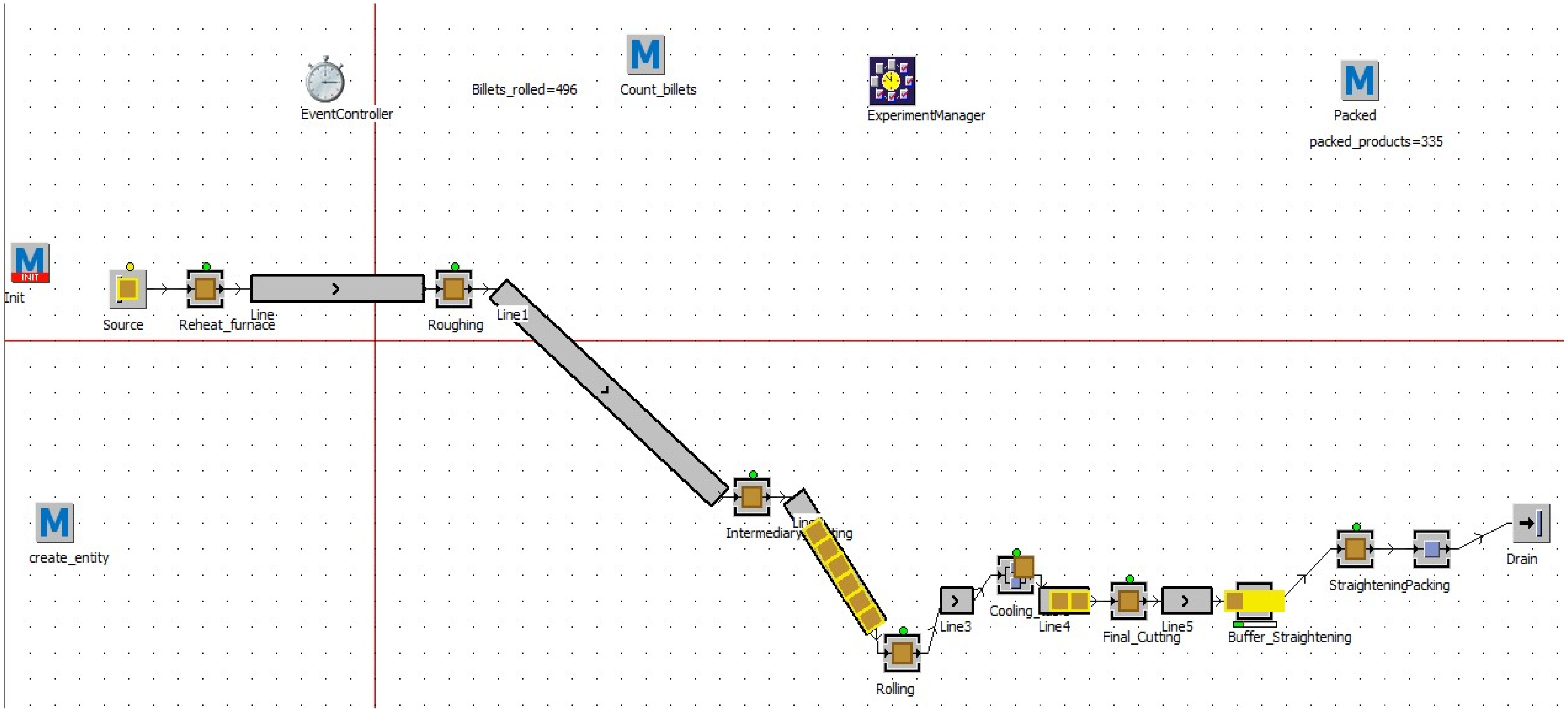
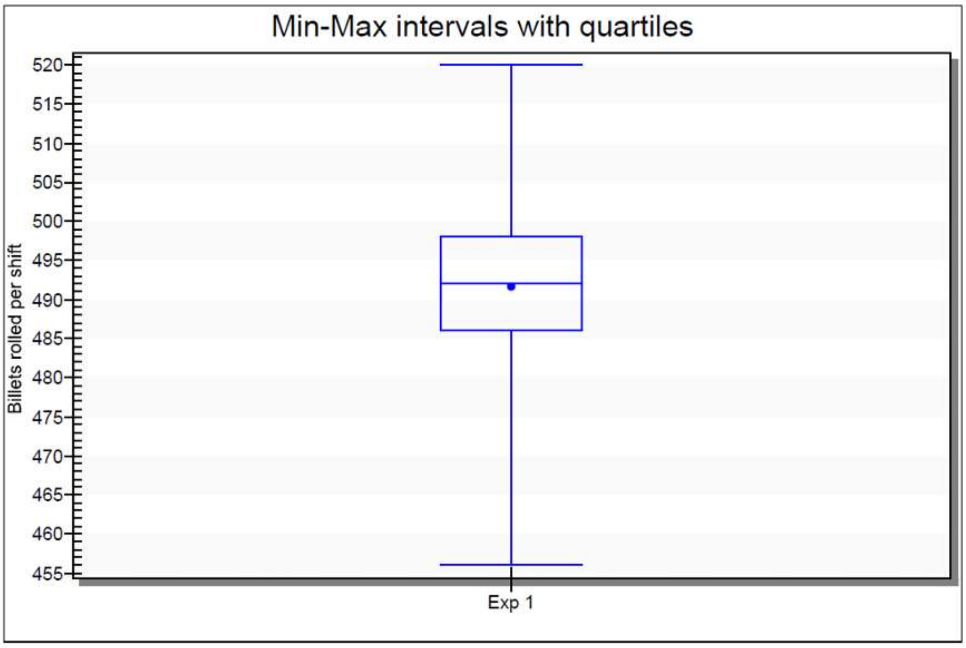


Figure 5. 16: Current status rolling simulation

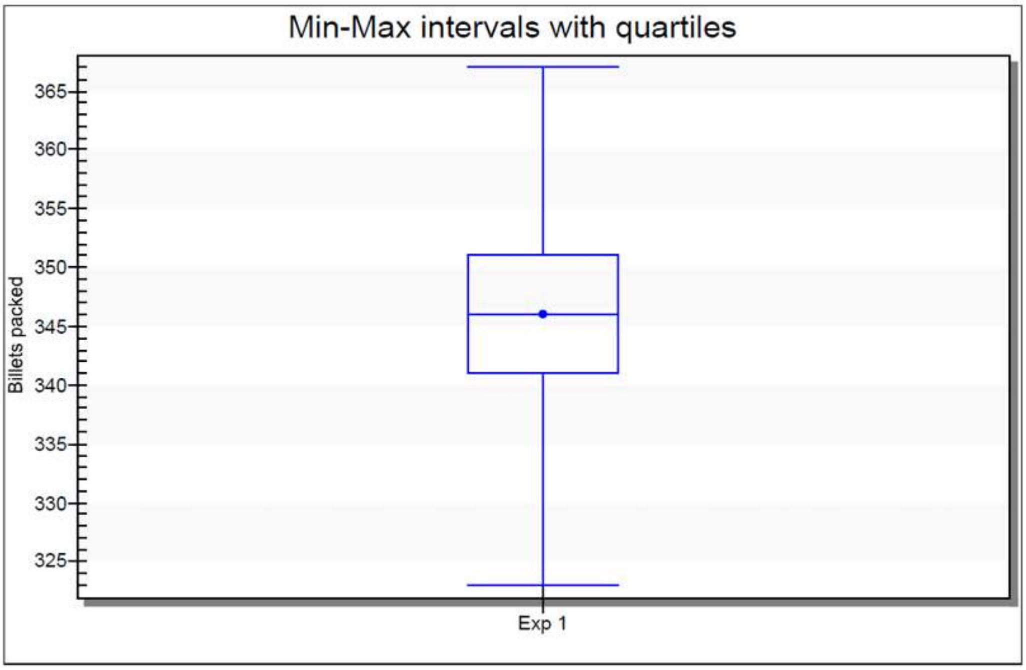
In the simulated rolling operations, availability of all work stations is 85% which is the targeted availability of Unica and mean throughput for part A operations is 492 billets for 1000 observations as shown in Figure 5. 17 for the nine hour shift.



Billets rolled per shift	Standard Deviation	Minimum	Maximum
491.5	9	456	520

Figure 5. 17: Statistical evaluation of part A observations

Mean throughput for part B is 346 billets for 1000 observations as shown in Figure 5. 18. Since part B immediately follows part A in the whole production line, and also that part B is slower and produces less output than part A per shift; according to TOC, the final output of the whole production line per shift is 346 billets per shift. The simulation observation result is accepted at 95% confidence interval as calculated by Technomatix simulation software in Appendix 3.



Billets packed	Standard Deviation	Minimum	Maximum
346	7	323	367

Figure 5. 18 Statistical evaluation of part B observations

5.2.3 Optimising

The optimise step is completed by implementing principles of theory of constraints on the production line. Figure 5. 19 display the current facility layout of the production line. The distance travelled by the product during manufacturing is calculated by adding the total distance of all the motions the WIP will make during the rolling cycle. The product travels 519 meters from the reheat furnace to the packing station. Rolling station is the bottleneck of part A with average cycle time of 54 seconds and straightening station is the bottleneck for part B with average cycle time of 84 seconds.

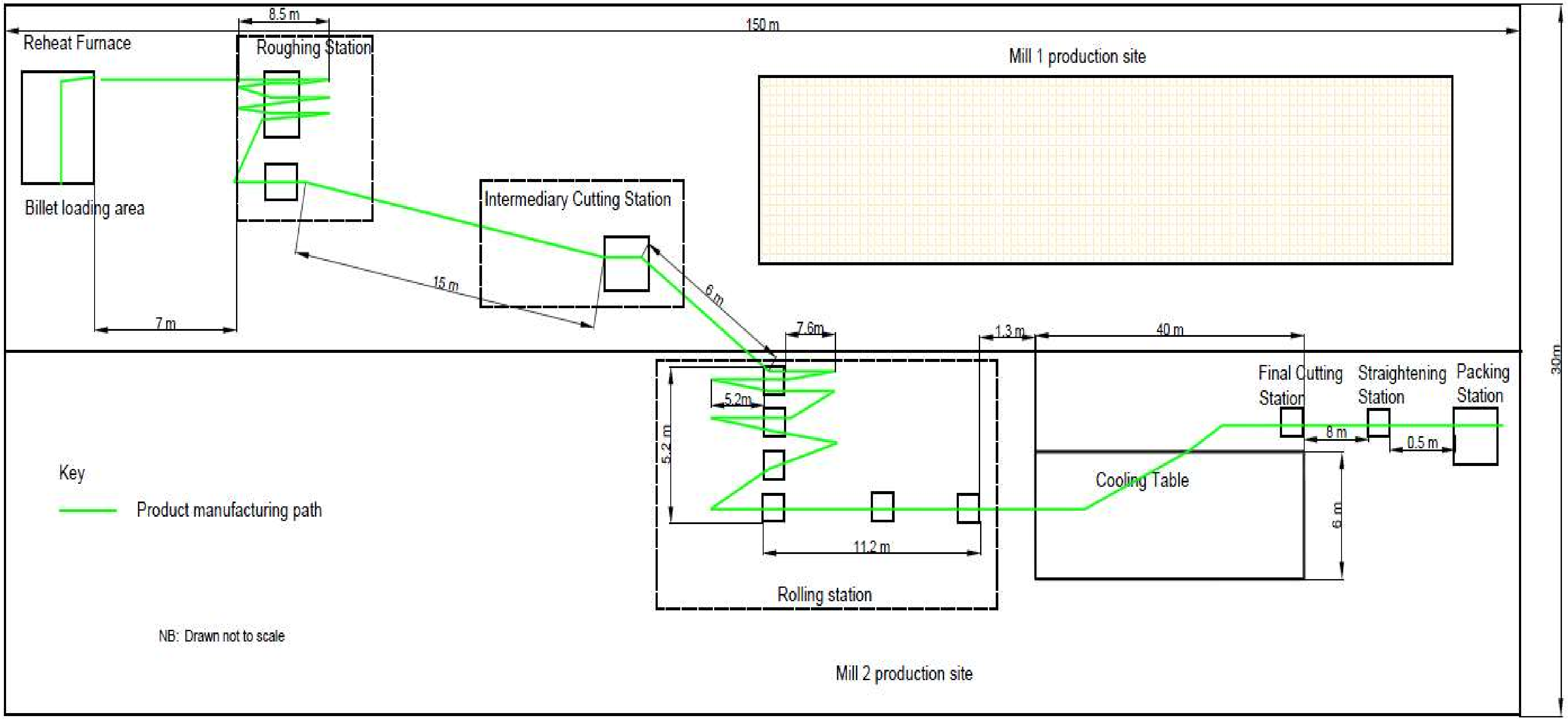


Figure 5. 19: Current Plant Layout

Rolling phase is the constraint of part A thus focus will be directed on improving the rolling phase facility layout. Rolling phase consists of six stages and in stage one the WIP go through three rolling passes as shown in Figure 5. 20. Stage two consists of two rolling passes and from stage two to stage three the WIP is conveyed manually between the two work stations. Stage three, Stage four, Stage five and Stage six each contains a single rolling pass. After Stage six, the product is conveyed to the final cutting station. The distance travelled by the product during rolling phase is calculated by summing the distances covered by the product during all rolling motions. The distance travelled in the current layout is shown in Figure 5. 20, the total distance for the rolling phase is 94.4 meters.

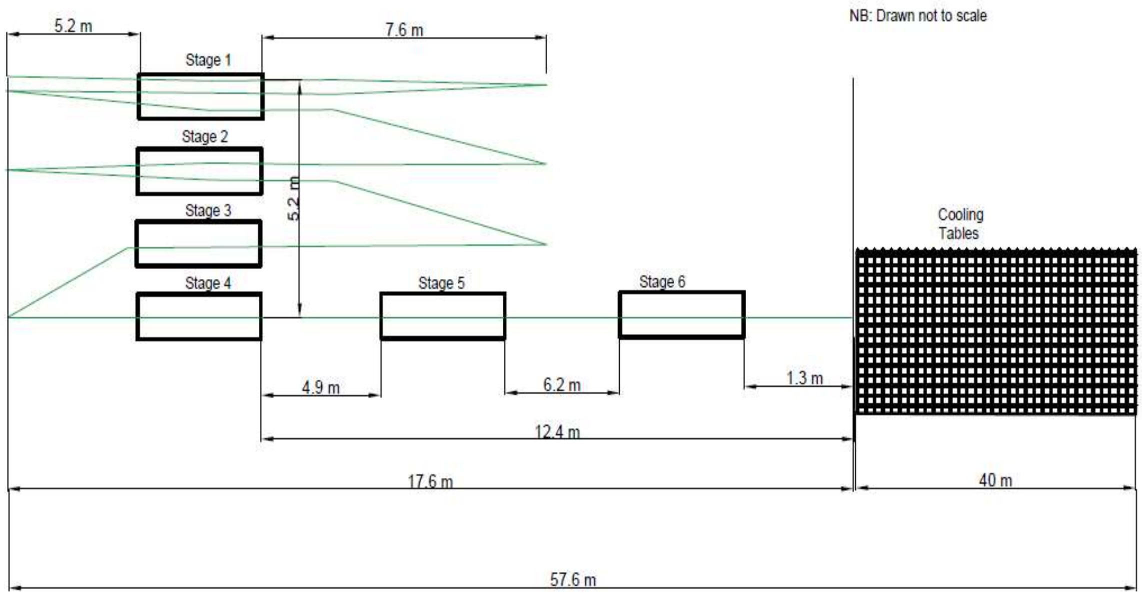


Figure 5. 20: Rolling Stage Current Layout

It takes 54 seconds to complete the rolling phase which spans a distance of 94.4 meters. Thus, the average production speed at rolling work station is:

$$Rolling\ work\ station\ speed = \frac{94.4\ m}{54\ s} = 1.75\ ms^{-1} \qquad \text{Equation 5. 4}$$

To minimising the waste of unnecessary transportation at the rolling station, a linear layout is proposed between stage two, stage three, stage four, stage five and stage six as shown in

Figure 5. 21. This arrangement also directs automatic conveying resources for the exit motion on stage two to be utilised to feed stage three which is currently manually operated.

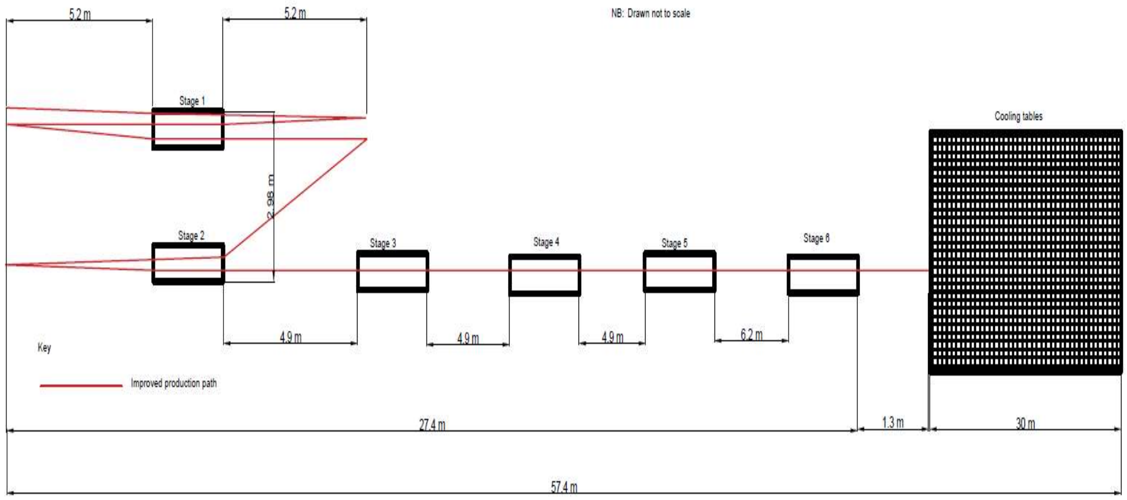


Figure 5. 21: Improved Rolling Stage Layout

The length of the current rolling station layout in Figure 5. 20 is 17.6 meters but the improved layout in Figure 5. 21 have 27.4 meters. To accommodate this new design, space was freed by reducing the length of the cooling tables to 30 meters from 40 meters. The maximum length of the product at the cooling tables is 24 meters thus the cooling table length is reduced to 30 meters.

In the improved layout (in Figure 5. 21) the product will travel 69 meters during the rolling stage. The value of 69 meters is the total distance the product travels during stage one, stage two, stage three, stage four, stage five and stage six of the rolling process. From Equation 5.4 the average rolling speed is 1.75 ms^{-1} as calculated in Equation 5.4. The improved cycle time for the rolling station after this improvement is calculated in Equation 5.5.

$$Improved\ Cycle\ time = \frac{Distance}{Average\ Speed} = \frac{69}{1.75} = 39.4s \approx 40\ s \qquad \text{Equation 5. 5}$$

The improved cycle time for rolling is 40 seconds.

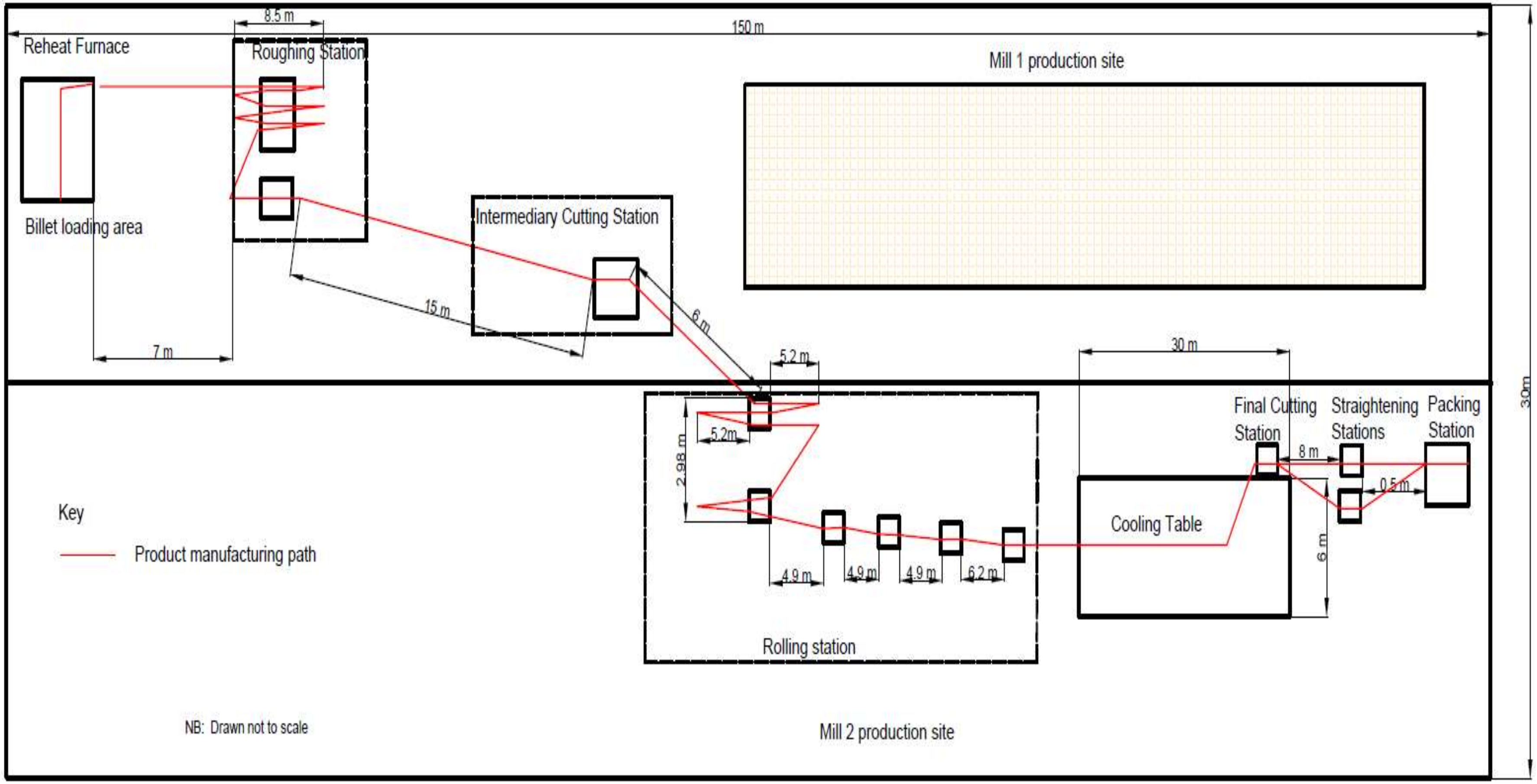


Figure 5. 22: Improved Layout

The improved mill layout is shown in Figure 5. 22 with an additional straightening station thus reducing straightening cycle time from 84 seconds to 42 seconds to improve the constraint of part B. The additional straightening machine will require an investment of R5.2 million and will increase daily income from R432 000 to R612 000. The improved production strategy is shown in Figure 5. 23.

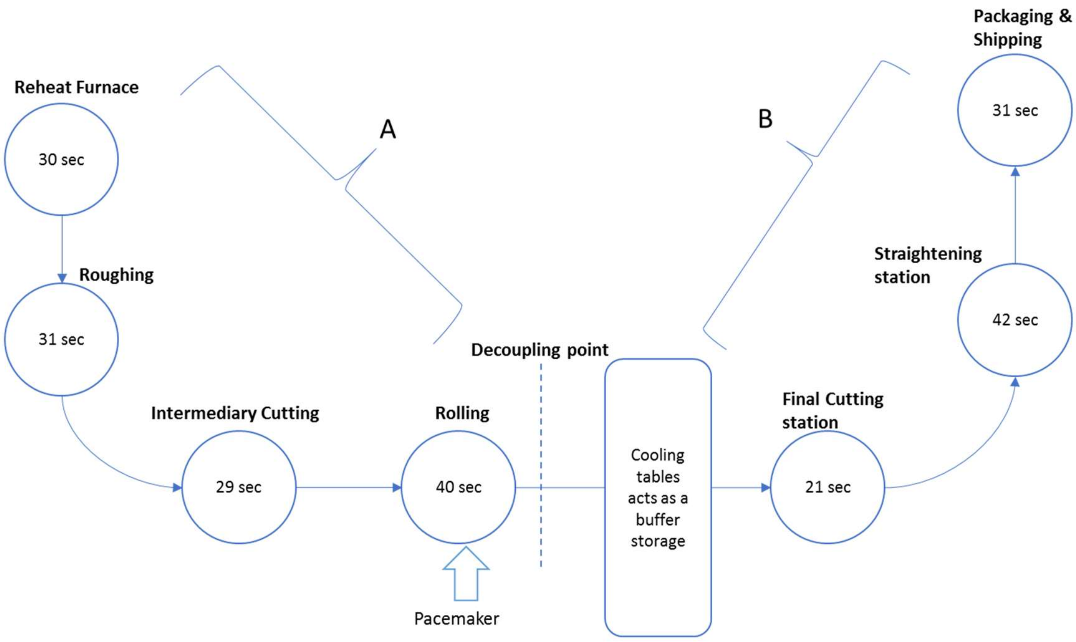


Figure 5. 23: Updated Production Strategy

To verify and ascertain the improvement, Technomatix plant simulation was used to model the improved rolling operations. Figure 5. 24 displays a snap shot of the simulation model with plant availability of 85%.

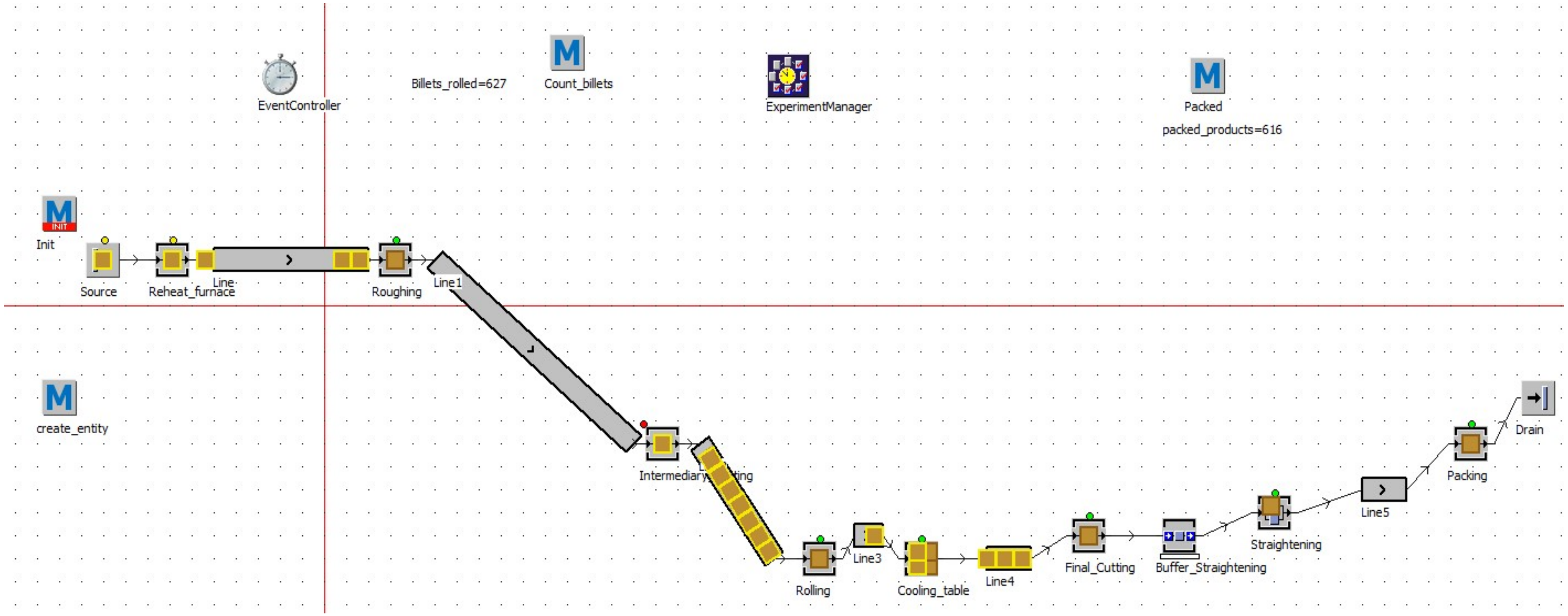
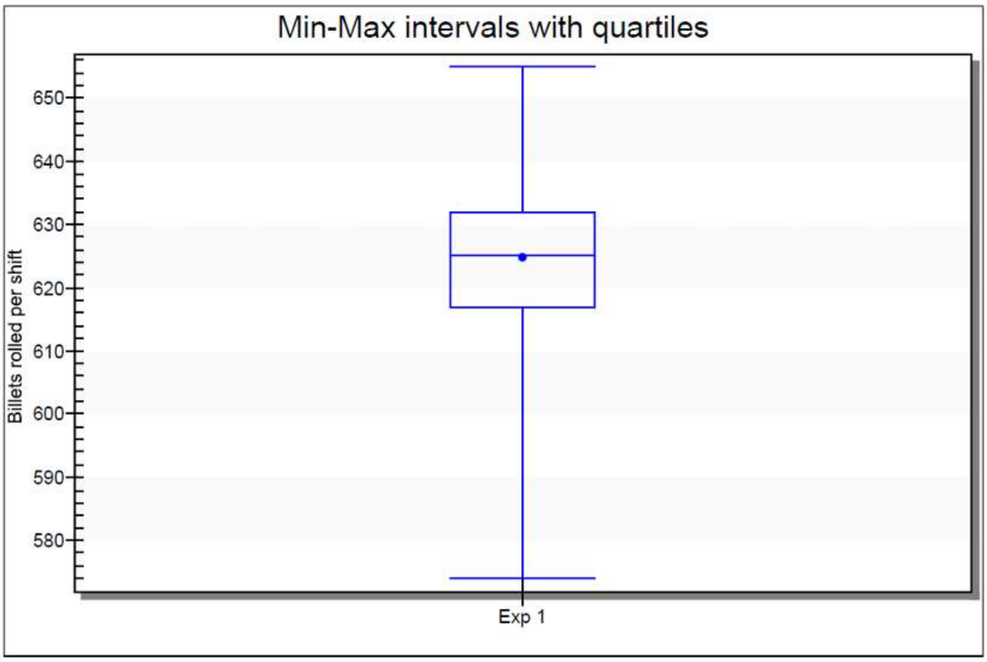


Figure 5. 24: Improved rolling operations simulation

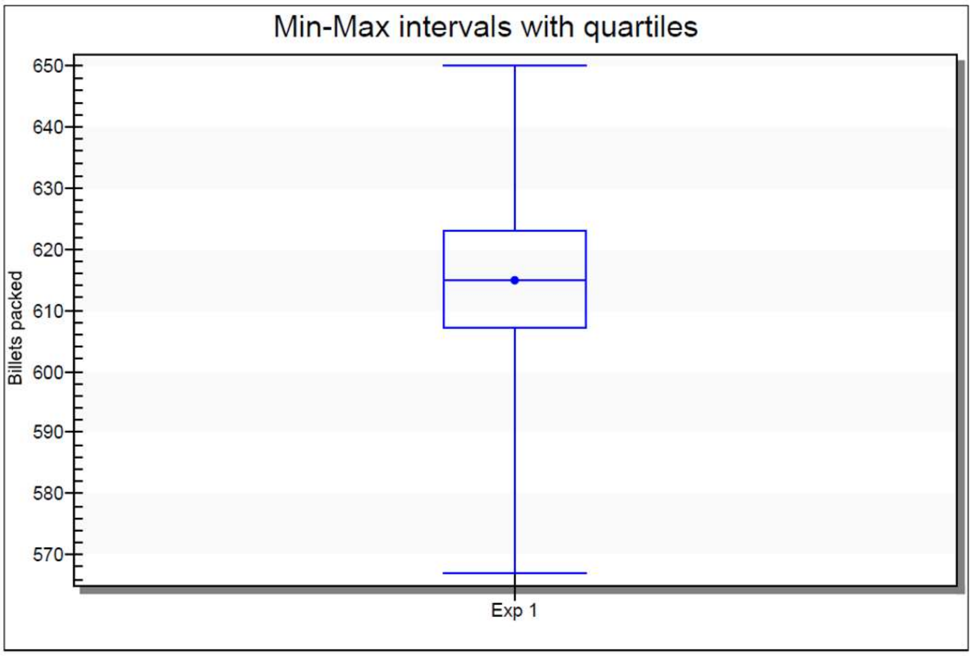
The mean throughput for part A of the rolling operations has improved to 625 billets per shift in 1000 observations as shown in Figure 5. 25.



Billets rolled per shift	Standard Deviation	Minimum	Maximum
624.7	11	574	655

Figure 5. 25: Statistical analysis of improved part A observations

Mean throughput for part B of the production line has improved from 346 billets to 615 billets in one shift as shown in Figure 5. 26. Since part A of the production line is immediately followed by part B, the final output of the whole production, according to the TOC is governed by the slower (i.e. part B). Hence the final output of the whole production line is 614.7 (rounded up to 615). The results of this simulation exercise are accepted at 95% confidence level as calculated by Technomatix simulation software in Appendix 4.



Billets packed	Standard Deviation	Minimum	Maximum
614.7	11.8	567	650

Figure 5. 26: Statistical analysis of improved part B observations

5.2.4 Sustain and Review

Sustaining the improvement achieved in the improvement cycle needs strict monitoring until the production employees embed the changes as part of the production culture. The updated production strategy is shown Figure 5. 23 and the rolling stage is the pacemaker, thus it should regulate the release of billets from the reheat furnace. Review of the improvement cycle will be completed after the implementation of the new strategy and when the new changes have been absorbed in the production. The review phase facilitates continuous learning in the organisation through self-reflection.

5.3 Chapter Summary

The study has managed to implement a continuous improvement framework based on Lean Manufacturing, Toyota Production Systems, Theory of Constraints and Six Sigma. Process wastes identified in steel rolling operations include defects, unnecessary transportation, over production, waiting, incorrect processing and excessive inventory levels. Through the "5-Why" root cause analysis technique the study managed to identify absence of a comprehensive production control strategy, variation in furnace fuel, poor billet quality and absence of preventive maintenance techniques to improve machine reliability as the root causes of defects. The study managed to establish the relationship between defects and other process wastes in rolling operations. To establish flow in the production line, rolling stage has been selected as the pacemaker process of the production process. Through facility layout improvement, overall production throughput per shift will increase by 78% from 346 billets to 615 billets as shown in Table 5. 4. The processing time from value stream mapping (Figure 5. 6) is 4.67 minutes and from the simulated results processing time will improve to 3.73 minutes.

Table 5. 4: Continuous Improvement Results

Production attribute	Initial value	Improved value	Percentage improvement
Processing time	4.67 minutes	3.73 minutes	25 %
Overall throughput (per shift)	346 billets	615 billets	78 %

The student managed to successfully submit a full conference paper from this section for the South African Institute of Industrial Engineering 28th annual conference focusing on identifying process wastes in rolling operations.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The current crisis faced by local steel industry of shrinking market due to influx of affordable steel imports can be mitigated if research focusing on improving production cost advantage for local steel manufactures is prioritised. Activities that focus on improving production cost advantage include continuous improvement and from the findings of this research there is absence of application of continuous improvement techniques which include lean manufacturing in the local steel industry. Further investigations highlights limited applications of IE research as a discipline in local steel industry. In the midst of these findings, the research attention was directed on developing a continuous improvement framework for a selected local small scale steelmaking company (Unica). To aid credibility of the framework, the student reviewed continuous improvement through conceptual framework analysis. Three conceptual aspects of continuous improvement identified are continuous improvement techniques, process management and organisational infrastructure. The conceptual framework assisted the student to fully comprehend the subject of continuous improvement thus an implementation framework targeting Unica was developed. To test the validity of the framework the student combined both plant testing and simulation through Technomatix simulation software.

The study has successfully managed to identify trends applications of continuous improvement techniques in South Africa. Through this exercise the study identified steelmaking industry in SA as a research gap for applications of continuous improvement research. The study managed to investigate the development of SA steel industry, the study further investigated application of IE research in steel industry. The development of a continuous improvement framework for local steel organisation (Unica) was successful and the improvements were validated through Technomatix simulation.

The research contributed to Unica by identifying process wastes in their rolling activities and developing solution to minimise and eliminate process wastes. The research has developed and tested (through simulation) a solution to increase production mill 2 throughput.

6.2 Recommendations

The developed implementation framework for Unica Iron and Steel Company was tailor suited to meet the immediate needs of that particular organisation. However the conceptual framework developed in this study is useful to understand and implement continuous improvement activities in both manufacturing and service industrial domains. To fully reap the dividends of the developed implementation framework Unica should apply improvement activities on a continuous basis and constantly engage researchers to assist in demand articulation.

6.3 Research papers written out of this study

The student has managed to make contributions in academic space and South African industry. In the academic fraternity, from this research the student has managed to produce three research papers which consist of two journal articles and one conference paper. At the time of submission of this research one journal article had been published by the South African Journal of Industrial Engineering (SAJIE) entitled "Lean applications: A survey of publications with respect to South African industry". The publication was developed as part of determining the trends of research in continuous improvement. The second journal article also submitted to SAJIE titled "South African iron and steel industry evolution: Industrial engineering perspective" is still in review. The journal article focused on the development of the South African steel industry and application of industrial engineering principles. At the time of submission of this research the conference paper had been successfully submitted for second round review for Southern African Institute of Industrial Engineering 28th annual conference. The title of the paper was "Process waste identification in rolling operations". The conference paper is based on the field work conducted by the student at Unica.

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8 APPENDICES

Appendix 1: Applications of Lean Manufacturing in South African Industry

Title of the document	References
Pursuing productivity improvement	(Faull 1989)
Benchmarking Organisational Capability using The 20 Keys	(Petrarolo 1997)
Lean healthcare: a casualty of inefficiency	(Mandavha & Hartmann 2010)
Improving loading times and truck rollover tendency using a pyramid stacking method	(Kienhöfer et al. 2010)
Using poka-yoke methods to improve employment potential of intellectually disabled workers	(Treurnicht et al. 2011)
The Toyota Production System's fundamental nature at selected South African organisations – a learning perspective	(Nortje & Snaddon 2013)
The effectiveness of lean manufacturing audits in measuring operational performance improvements	(Taggart & Kienhöfer 2013)
Applying Lean Principles in a School Environment to Reduce Lead Time and Improve Quality	(Chibaira & Hattingh 2013)
The Combined AHP-QFD Approach and its use in Lean Maintenance	(Tendayi & Fourie 2013)
Root Cause Analysis for Reduction of Waste on Bottle Filling and Crowning Operations	(Dewa et al. 2013)
Lean in Service Industry	(Kanakana 2013)
Improvement of Plant Facility Layout for Better Labour Utilisation: Case Study of a Confectionery Company in The Western Cape	(Jordaan & Matope 2013)
The development of a theoretical lean culture causal framework to support the effective implementation of lean in automotive component manufacturers	(van der Merwe et al. 2014)
Improving Forge Changeover Performance at an Automotive Component Supplier	(Durbach et al. 2014)
A model for continuous improvement at a South African minerals beneficiation plant	(Ras & Visser 2015)
Lean manufacturing challenges in a South African clothing company	(Chiromo 2015)
The impact of short interval control & visual management concepts to the organisation's operational performance	(Ndaba 2015)
Impacts of random demand and cycle times on workstation percentage load of flow-line production	(Tengen 2013)
Application of lean product development at a manufacturing organisation:	(Dem et al. 2012)

A case study	
Investigating the benefits of using selected lean techniques at a South African exhaust manufacturer - A case study	(Louw 2012)
Are agile and lean manufacturing systems employing sustainability, complexity and organizational learning?	(Flumerfelt et al. 2012)
Lean six sigma framework to improve throughput rate	(Kanakana et al. 2010)
Implementing LEAN Construction in a South African Construction company	(Roelandt 2008)
Lean product engineering in the South African automotive industry	(Mund et al. 2015)
Integrating 5S Principles with Process Improvement: A Case Study	(Ramdass 2015)
Lean Application in Student Finance Department within a Learning Institution Can Lead to High Academic Throughput: A Case Study	(Kholopane & Vandayar 2014)
Lean Implementation in the Gauteng Public Health Sector	(Kruger 2014)
Creating a Lean Manufacture Structure in a South African Organisation	(Kruger 2013)
Implementing Cellular Manufacturing in a Make-to-order Manufacturing System: A South African Case Study	(Kruger 2012)
An integrated utilisation, scheduling and lot-sizing algorithm for pull production	(Adetunji et al. 2012)
Improving quality and productivity at an automotive component manufacturing organisation in Durban South Africa	(Rathilall & Singh 2011)
Purpose - process - people a lean approach to biomedical manufacturing	(Kahlen & Patel 2012)

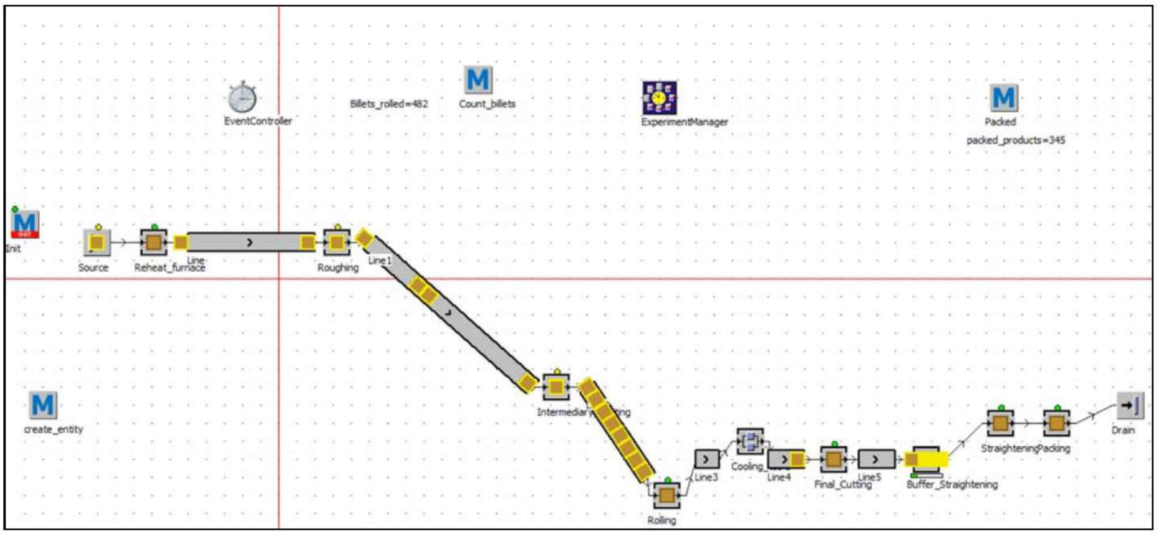
Appendix 2: Review on Continuous Improvement in South African Industry

Title	**Year**	**Industrial Domain**	**Sector**	**Reference**
Application of manufacturing management and improvement methodologies in the Southern African mining industry	2016	Manufacturing	Mining & mineral processing surveys	(Claassen 2016)
The Effect of the Implementation of Six Sigma in Reducing Obsolete Stock and Controlling Stock Inventory at a Flavour Manufacturing Company: A Case Study	2016	Manufacturing	Food & Beverages	(Kholopane 2016)
Lean Implementation Strategies: How are the Toyota Way Principles Addressed?	2016	Generic		(Coetzee et al. 2016)

A performance-centred maintenance strategy for industrial DSM projects	2015	Manufacturing	Power generation & Distribution	(Groenewald et al. 2015)
Developing and Improving Quality Efficiency in the South African Energy Industry	2015	Manufacturing	Power generation & Distribution	(Vermeulen et al. 2015)
Continuous process improvement applied to an engineering education system	2015	Services	Education	(Mabizela et al. 2015)
A model for continuous improvement at a South African minerals beneficiation plant	2015	Manufacturing	Mining & mineral processing	(Ras & Visser 2015)
Introducing in-between decision points to TOC's five focusing steps	2014	Generic		(Pretorius 2014)
Lean implementation in the Gauteng public health sector	2014	Services	Health	(Kruger 2014)
The Re-Invention of the Integrated Quality Management System towards a Culture of Continuous Improvement	2014	Services	Education	(Pylman 2014)
A systems thinking approach to the sustainability of quality improvement programmes	2014	Manufacturing	Unclear	(van Dyk & Pretorius 2014)
How Competitiveness is Achieved with Lean Synchronisation Implementation	2013	Generic		(Vermeulen et al. 2013)
Exploring Critical Success Factors for the Reintegration of Lean Six Sigma Black Belts into Line Function Roles in the Technology Environment	2013	Generic		(Mashinini-Dlamini & Van Waveren 2013)
Creating a lean manufacture structure in a South African Organisation	2013	Manufacturing	Withheld	(Kruger 2013)
The Toyota Production System's Fundamental Nature at selected South African Organisations – A Learning Perspective	2013	Manufacturing & Services	Survey on services & manufacturing sectors	(Nortje & Snaddon 2013)
The effectiveness of lean manufacturing audits in measuring operational performance improvements	2013	Manufacturing	Survey on manufacturing sectors	(Taggart & Kienhöfer 2013)
Implementing cellular manufacturing in a make-to-order manufacturing system: A South African case study	2012	Manufacturing	Fabrication shop	(Kruger 2012)
An empirical study on the indicators and factors for successful Six Sigma deployment in the mining industry: A South African case	2011	Manufacturing	Mining	(Keeley et al. 2011)

Impact of continuous improvement on new product development within SMEs in the Western Cape, South Africa	2011	Generic		(Yan & Makinde 2011)
Continuous Quality Improvement Strategies in the Retail Banking Industry of South Africa	2000	Services	Banking	(Vermeulen & Edgeman 2000)
Continuous improvement of teaching to promote student learning	1999	Services	Education	(Kok 1999)
Total quality in management decision making	1994	Generic		(Klerk 1994)

Appendix 3: Current status simulation Results



Overview

Overview of all executed experiments, their parametrizations and the mean values of the target values.

	Billets rolled per shift	Billets packed
Exp 1	491.576	346.065

Simulation effort: 0 experiments with 0 simulation runs
No special diagrams

Values of experiments

Output values (Results of the simulation study)

Target value	evaluated by	Technical Notation
Billets rolled per shift	Tab	root.Billets_rolled
Billets packed	Tab	root.packed_products

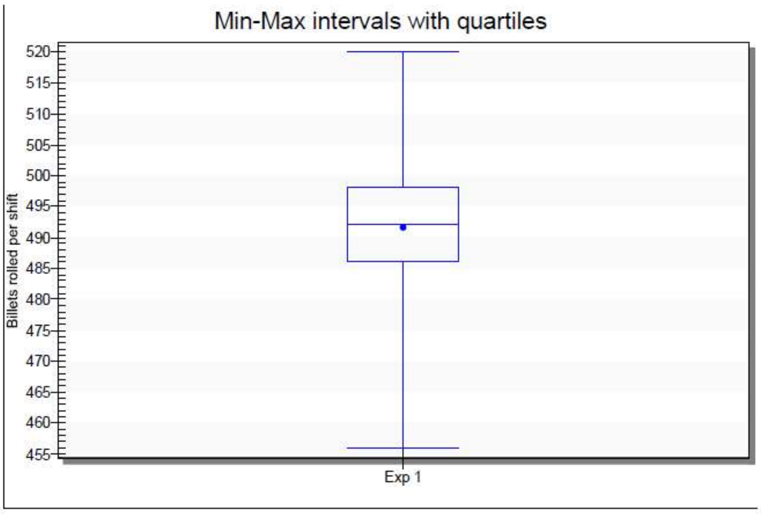
The Output values are evaluated by the table **ResultsTable** or by conditions of rules.

Statistical Evaluations

- Statistical reliability
  Observations per experiment: 1000
  Confidence level (%): 95

Statistics of output values

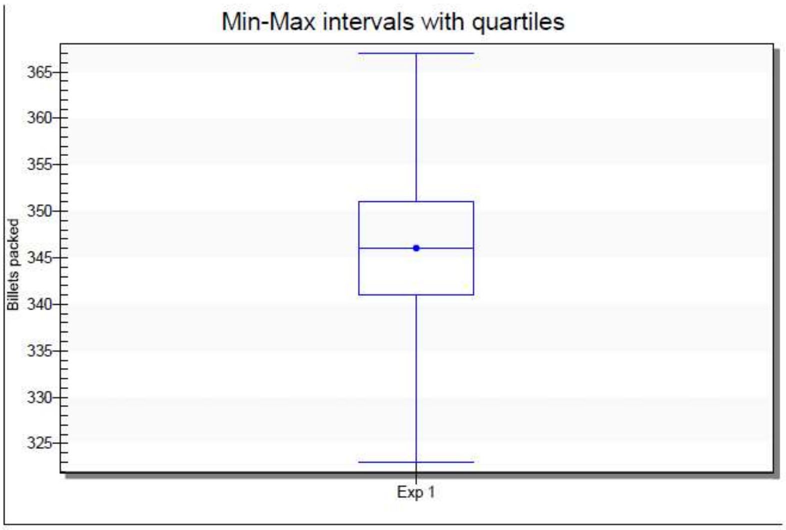
Evaluations of the output value 'Billets rolled per shift'



Billets rolled per shift	Standard Deviation	Minimum	Maximum	Left interval bound	Right interval bound
491.576	9.25645212302656	456	520	491.001467220358	492.150532779642

The analysis of variance is impossible.
At least two experiments with random output for 'Billets rolled per shift' are needed.

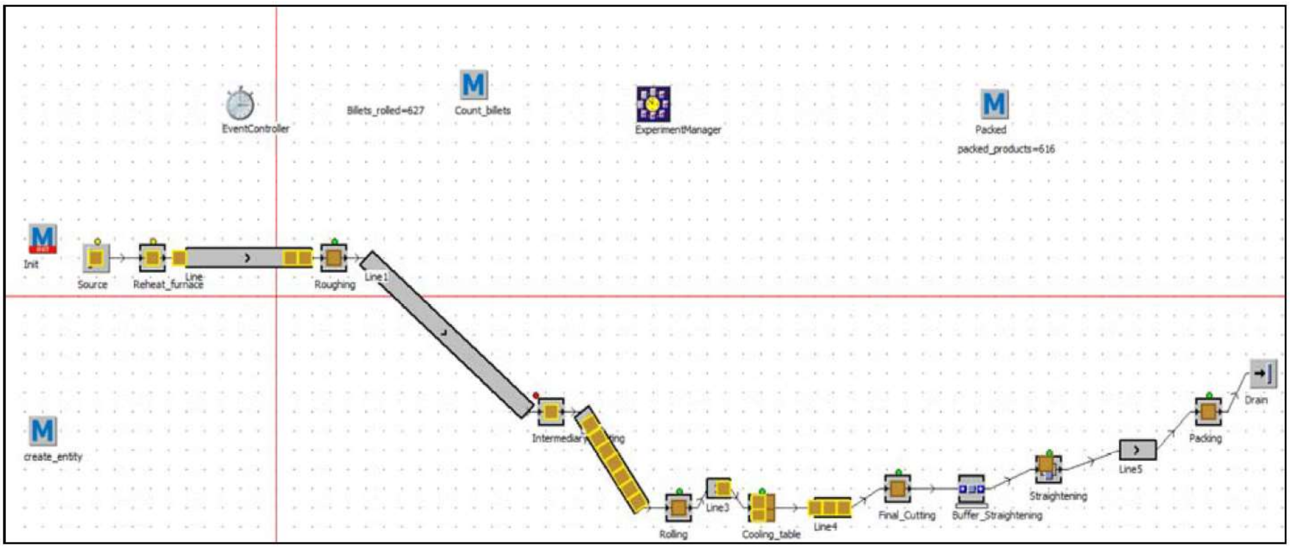
Evaluations of the output value 'Billets packed'



Billets packed	Standard Deviation	Minimum	Maximum	Left interval bound	Right interval bound
346.065	7.26894852180276	323	367	345.61382830443	346.51617169557

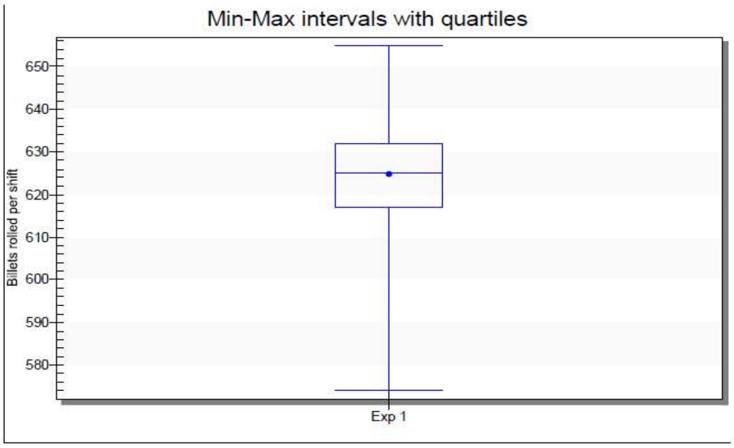
The analysis of variance is impossible.
At least two experiments with random output for 'Billets packed' are needed.
You can view the p-values for all pairs of experiments by selecting *Tools > Analysis of Variance* in the dialog of the ExperimentManager.

Appendix 4: Improved Status Simulation Results



Statistics of output values

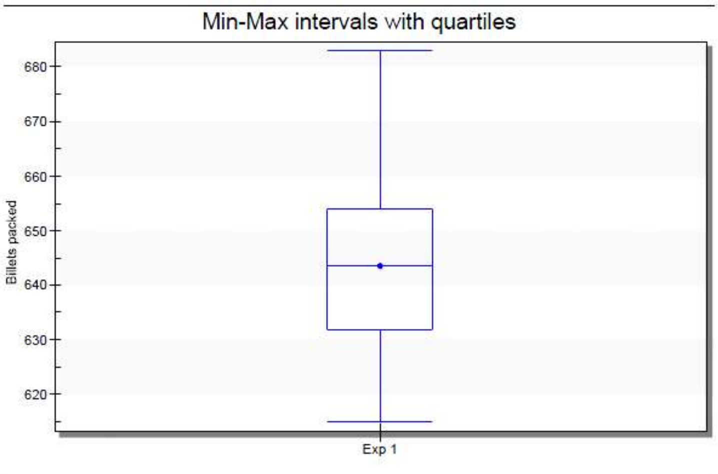
Evaluations of the output value 'Billets rolled per shift'



Billets rolled per shift	Standard Deviation	Minimum	Maximum	Left interval bound	Right interval bound
624.798	11.6919586852596	574	655	624.072299328336	625.523700671664

The analysis of variance is impossible.
At least two experiments with random output for 'Billets rolled per shift' are needed.

Evaluations of the output value 'Billets packed'



Billets packed	Standard Deviation	Minimum	Maximum	Left interval bound	Right interval bound
643.49	14.4875390552988	615	683	640.614704755244	646.365295244756

The analysis of variance is impossible.
At least two experiments with random output for 'Billets packed' are needed.
You can view the p-values for all pairs of experiments by selecting *Tools > Analysis of Variance* in the dialog of the ExperimentManager.