Development of a lean optimisation plan for a wire manufacturing process

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ABSTRACT

The growing demand for maximum operational efficiency has driven organisations towards implementing lean manufacturing as a management philosophy. However, a gap still exists between the available information on lean manufacturing practices in the automobile industry and the non-automotive sectors in South Africa. The primary focus of this research was to establish which lean principles are applicable to a continuous manufacturing environment and to identify existing process and optimisation challenges within a wire-manufacturing process. A literature study was conducted to determine the differences between the application of the lean philosophy in a discrete and continuous manufacturing setting. The material and information flow of the wire manufacturing was further mapped using both a current and an ideal future state value stream map (VSM). The study also incorporated an empirical approach to measure the "leanness" of the wire-manufacturing process by using an efficiency, flow and variability (EFV) metric. Lastly, an aggregate root cause analysis (RCA) was conducted with a chartered team who had knowledge on the subject matter. The EFV metric suggests that the wire-manufacturing process falls within the "potential for improvement" region and that non-value-added waste can be reduced by 36.6% when kaizen (continuous improvement) methods are used. However, analysis of the RCA points to process variables being the most dominant optimisation challenges. The findings from this study were summarised using a Hoshin Kanri matrix. An iterative Delphi technique was used to verify the Matrix based on a 24-item questionnaire. The study in hand adopts a structured approach to support the applicability of lean principles and suggests that such an approach can be adapted to manufacturing environments similar to the case study.

Key words

Continuous manufacturing, Delphi technique, Discrete manufacturing, Hoshin Kanri matrix, Just-in-time, Lean, Leanness, Optimisation, Toyota production system, Value stream mapping, Root cause analysis.

PREFACE

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Maqhawe Shongwe

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LIST OF ABBREVIATIONS

4P:	Problem solving, People and Partners, Process, Philosophy
5S:	Sort, Straighten, Shine, Standardise, Sustain
AME:	Association for Manufacturing Excellence
CSVSM:	Current state value stream map
CT:	Cycle time
CTQ:	Critical-to-quality
CVR:	Content validity ratio
DMAIC:	Define, measure, analyse, improve, control
EFV:	Efficiency, flow and variability
FSVSM:	Future state value stream map
JIT:	Just-in-time
KPI:	Key performance indicator
KRNW:	Knowledge resource nomination worksheet
LAT:	Lean assessment tool
RCA:	Root cause analysis
SABS:	South African Bureau of Standards
SANS:	South African National Standard
SIPOC:	Supplier, input, process, output, control
TTI:	Targets to improve
TPS:	Toyota Production System
VSM:	Value stream mapping
WIP:	Work-in-progress

LIST OF DEFINITIONS

Absenteeism: According to the South African Labour guide, absenteeism is not limited only to employees who are not at work, but may also refer to employees who abuse an organisation's working hours. For the purpose of this study, absenteeism refers to employees who do not turn up for work for various reasons, i.e. Sick leave, Family Responsibility leave, Absent Without leave (AWOL).

Andons: Also commonly referred to as Andon (Japanese word that refers to a system to report a quality or process problem) boards, Andons are visual control devices used in production areas as signalling devices. Andons are used to alert production personnel of emerging problems within production lines (Womack & Jones, 2003).

Bad casting: In the context of this study, bad casting refers to a non-uniform pattern layout that occurs when wire is being coiled onto a casting former. This non-uniform pattern layout often results in the wire tangling and breaking when it is being used at various machines with high "paying-off" speeds (i.e. inlet speeds).

Hoshin Kanri matrix: The Hoshin Kanri matrix is a strategic decision-making tool that is used on a managerial level to prioritise an organisation's resources (people included) according to the critical initiatives that are required to achieve strategic goals (Womack & Jones, 2003:349). According to Womack and Jones (2003:349), the visual matrix that is presented by the Hoshin Kanri aligns and establishes clearly measurable goals and objectives.

Lean Thinking: Lean thinking is a term that is attributed to Womack and Jones (2003)'s book *Lean Thinking: Banish waste and create wealth in your corporation*. Lean thinking is described by the authors as a way of making work more satisfactory by providing immediate ways to convert waste (muda) into value. Lean thinking can be summarised as using five principles: (1) Specifying *value* by a specific product; (2) Identifying the *value stream* for each product; (3) Making value *flow* without interruptions; (4) Letting the customer *pull* value from the producer; and (5) Pursuing *perfection.*

Muda: A Japanese word that refers to waste, "Muda" is often used to describe the eight forms of waste in lean process thinking. It is used in conjunction with the elimination of Muri (overburden) and Mura (unevenness) (Liker, 2004).

Non-conformance: Non-conformance is a term used to describe products that do not meet the minimum final customer-driven product specifications. Specifications on the different rod and wire types are mostly governed by SABS and SANS specification guidelines.

Over- and undersized: In the context of this study, over- and undersize refers to a wire rod or wire coil with a diameter that is above or below the maximum or minimum wire diameter specification required by a customer.

Project charter: A document used during process improvements to summarise the why, how, who, and when of a project. Project charters are mainly used to establish the objective or purpose of an organisation's business need for process optimisation projects.

Rod coil: In this study, a rod coil refers to an un-galvanized unit stack of wire with a diameter greater than 5.50 mm (see Figure 10.1-1).

Short- or long-dip galvanizing: Short- or long-dip galvanizing refers to the amount of time that a product that is being galvanized is immersed into a molten zinc bath.

Strapping: Strapping refers to the fastening of a rod coil or wire coil to form a bundled product. Various types of strapping materials are used, and these are driven by both internal and external customer needs.

Wire coil: In this study, a wire coil refers to a galvanized unit stack of wire with a diameter less than 5.50 mm (see Figure 10.1-3).

LIST OF EQUATIONS

CHAPTER 1: INTRODUCTION

The growing demand for maximum operational effectiveness has driven organisations to implement the Toyota Production System (TPS) and to adopt lean manufacturing principles as operating strategies. The lean philosophy, which originated from the automotive industry, has expanded into a wide range of sectors, such as the steel industry and service sectors. However, in their widely reviewed book, *Lean Thinking*, Womack and Jones (2003:9) highlight that a number of industries interested in venturing into lean production still ask: "How do we do it?"

1.1 Background and case study

In recent years, changes in markets, import and export levels and a general decline in the global demand for steel have had a significant impact on the global steel industry (International Trade Administration, 2016:2). Except in the year 2010, performance indicators from the *Global Steel Report* (see Figure 1.1-1) illustrate that annual growth rates have been trending downwards since the 2008-2009 global financial crisis, with stagnant steel demands predicted for the forthcoming years (International Trade Administration, 2016:3).

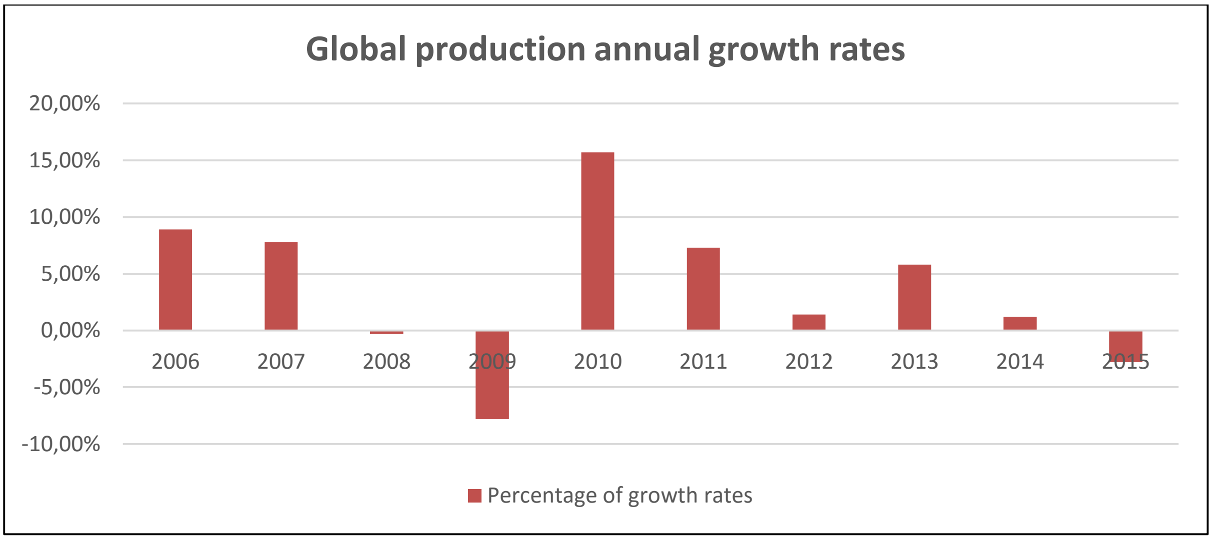

Figure 1.1-1: Global production annual growth rates from 2006 to 2015

Adapted from International Trade Administration (2016:3)

At the time of conducting this research, China emerged as the world's largest steel-producing nation and accounts for nearly half of the annual global steel production (International Trade Administration, 2016). With a market share of 69%, the Asia and Oceania region (see Figure 1.1-2) significantly overshadows the 1% market share exhibited by struggling African steel-manufacturing industries. The steel production market share shown by the Asia and Oceania region is increasingly forcing African steel manufacturing industries to consider changes in their management philosophies to ensure economic sustainability.

In a report on the challenges and opportunities facing the South African steel industry, local companies expressed manufacturing and supply chain concerns (Merchantec Research, 2015:30). According to

Merchantec Research (2015:31), South Africa's geographical location relative to its European and American markets is a major contributor to its steel market share being increasingly reduced by Asian manufacturers. South Africa's geographical location also presents a challenge when the economies of scale are taken into account, due to an increasing demand for smaller batches of steel products (with shorter lead times). Besides a decreasing export market share and the increasing cost of doing business, an inefficient railway system is also blamed as having a negative impact on the local market's growth projections (Merchantec Research, 2015:31).

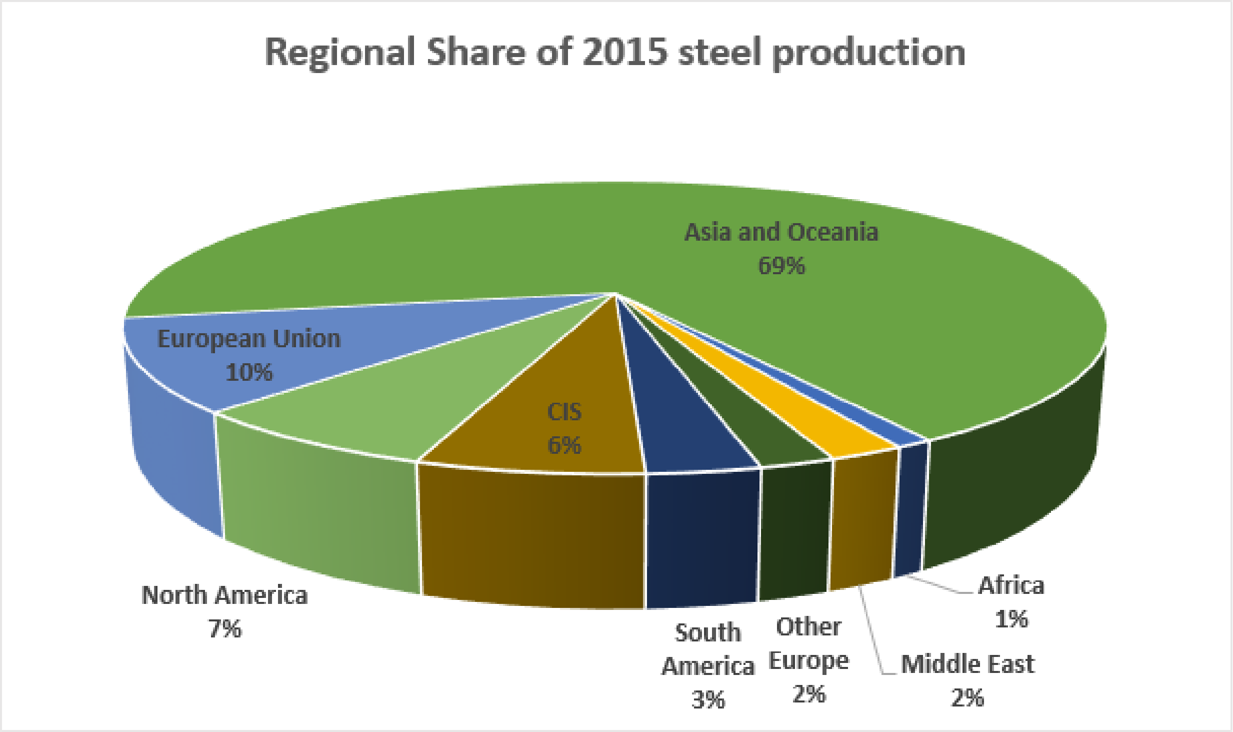

Figure 1.1-2: Regional share of 2015's steel production

Adapted from Global Steel Report (2016)

The steel- and wire-manufacturing company[1] that was used as a case study produces steel and galvanized customer-driven products. The organisation has three main divisions, namely the Raw Material Division (RMD), Rolling Mills (RM) and the General Wire Division (GWD). The primary focus of this study was on the GWD plant that has ongoing operational changes to meet different customer and market demands. The company's GWD produces final products through specialised wire-drawing machines, Hot Dip Galvanizing (HDG) and numerous intermediate shape-forming machines.

In addition to the global challenges that were highlighted in this section's introductory paragraph, increasing manufacturing costs have driven continuous improvement or "kaizen" (Japanese term) initiatives across various departments within the GWD in an effort to eliminate non-value-added work.

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[1] The company used as a case study has a strict non-disclosure policy on the information that may be made available for public use.

Strategic objectives and targets were also identified as Key Performance Indicators (KPIs) on a balanced scorecard in an effort to optimise the wire-manufacturing process. This balanced scorecard, which in the context of this study, is used to identify and improve various internal functions is based on the following:

1. Cost control
2. Production control
3. Scrap yield control

Even though these control measures were introduced, the combined averages for scrap (a scrap yield control measure), non-conforming material holds (a production, cost and scrap yield control measure) and absenteeism (a production control measure) are continuously measured above key performance targets. Table 1.1-1 provides a summary of the case study's combined averages, and the information presented below was measured over an 18-month period during this study.

Table 1.1-1: Combined averages for scrap, non-conforming holds and absenteeism measured over an 18-month period

Average KPI figures over an 18-month period		
KPI	**Target**	**Actual**
Scrap	2,30%	3,05%
Non-conforming material holds	1,00%	4,00%
Absenteeism	2,00%	3,79%

In contrast to the operational and optimisation challenges encountered in the case study, a number of lean manufacturing philosophies are apparent within the wire-manufacturing process. Pull systems, work cells and the use of andons[2] are examples of the systematic measures that have been introduced to improve quality, productivity, and process lead-times. Even though these manufacturing philosophies have been implemented with great success in predominantly discrete environments, key company stakeholders argue that the continuous nature of the wire-manufacturing process is the root cause of unsatisfactory results being measured as performance metrics.

1.2 Lean manufacturing

In their book, *The Machine that Changed the World,* Womack, Jones, Roos and Carpenter (1990) discovered that double-digit absenteeism and excessive rework of non-conforming products were typical problems of traditional mass production organisations. Lean manufacturing, as a production philosophy that is widely accredited to the founder of Toyota, Taiichi Ohno, has come to be an extensively used production method for eliminating non-value-added waste from organisations. According to Liker (2004:47), a traditional approach towards process improvements is to focus on local efficiencies (i.e. key performance indicators), which often lead to an unsatisfactory impact on the overall value stream of a manufacturing process. Womack and Jones (2003:15) further argue that "lean thinking" provides a

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[2] In lean terminology, "Andons" mostly refer to systems or any device that is [are] used to alert operators and managers of process abnormalities (in real-time). The case study mostly makes use of Andons in the form of alarms.

strategic way to specify value, to eliminate non-value-added waste, but more importantly, for organisations to operate more effectively. Liker (2004) emphasises that strategies such as defining and explaining what the goal is, sharing a path to achieving it, and motivating and engaging people to support and contribute to the ideas of an organisation, are critical when “lean” is applied as the operation’s management system.

1.3 Problem statement

Against this background, the key performance averages which are cost control, production control and scrap yield control show that the strategic objectives and targets established on a managerial level of the organisation, are not achieved on all operational levels.

1.4 Research aim and objectives

The aim of this research is to develop a lean optimisation plan that drives and communicates the organisational strategic goals at every level of the wire-manufacturing process. This aim will be supported by achieving the following research objectives:

- Determine the differences between the application of lean manufacturing in discrete events and continuous events.
- Determine the value-added time of the wire-manufacturing process by applying value stream mapping (VSM).
- Measure the leanness of the wire-manufacturing process by applying DMAIC and an efficiency, flow and variability (EFV) metric.
- Use root cause analysis (RCA) to determine the root causes that are considered to lead to unsatisfactory lean optimisation initiatives.
- Develop an overall lean optimisation strategy by applying lean production principles.
- Verify the overall lean optimisation strategy to ensure that it can be used to achieve this research’s aim.

1.5 Research questions

Based on the problem statement, research aim and objectives of this study, the following research questions are presented:

1. What are the differences between the application of lean in discrete events and continuous events?
2. What is the current value-added time of the wire-manufacturing process?

3. What is the leanness of the wire-manufacturing process?
4. What are the root causes that are considered to lead to unsatisfactory lean optimisation initiatives?
5. How can the wire-manufacturing process be optimised by means of lean principles?
6. How can this study's overall lean optimisation strategy be verified to ensure that it can be used to achieve the research aim and objectives.

1.6 Deliverable

The deliverable of this study is in the form of a strategic optimisation planning matrix, the Hoshin Kanri matrix. The Hoshin Kanri matrix is used to summarise the findings of this study and presents a visual matrix that aligns the critical optimisation initiatives that are required to achieve the strategic goals on all operational levels.

1.7 Research strategy

Johnson and Christensen (2008:1) contend that research strategies fall into three major categories in any research environment, namely – quantitative research, qualitative research and mixed methods research (also referred to as triangulation) – The key differences between quantitative research, mixed methods research and qualitative research are summarised as follows by Johnson and Christensen (2008):

- Quantitative research – Deductive due to the researcher testing the hypotheses and the theory with data
- Mixed research – Deductive and inductive
- Qualitative research – Inductive due to the researcher generating a new hypothesis from data that is collected during fieldwork.

In this study, a mixed research process (further elaborated on in Chapter 3) was used to achieve the aim and objectives established in Chapter1.

1.8 Chapter layout

In addition to this chapter, the current study was divided into the following chapters:

Chapter 2: Literature review

Chapter 2 focuses on "lean thinking" and the value-creating actions that are required to eliminate waste ("Muda") from an organisation. This chapter summarises lean manufacturing principles that are commonly used by lean organisations/practitioners and reviews lean optimisation tools that align an organisation’s performance with its organisational goals. A literature study on visual management (strategic planning) is also reported on in this chapter. Lastly, the Delphi technique is also presented in this chapter’s literature review.

Chapter 3: Research method

Chapter 3 presents the research method that was used to address this research’s aim. A research method involving six phases was used to synthesise the literature from Chapter 2 and to examine the aim and objectives introduced in Chapter 1. The Delphi technique was also introduced in this chapter as a verification technique for the final deliverable presented in this study (i.e. the Hoshin Kanri matrix).

Chapter 4: Research results and findings

The results and findings of this research are presented in Chapter 4. The empirical and qualitative findings were chronologically grouped according to the research phases worked through in Chapter 3. Furthermore, a discussion and analysis of the findings used as input data for the optimisation plan is conducted in this chapter.

Chapter 5: Optimisation plan

In Chapter 5, the Hoshin Kanri matrix was used to present an optimisation plan (roadmap). This matrix was also used to present a visual representation of the critical resources, people and initiatives that are considered necessary to bridge the gap between the current performance and the strategic goals of the case study.

Chapter 6: Verification

In Chapter 6, an iterative Delphi technique was used to verify the final deliverable of this study – the Hoshin Kanri matrix. A discussion of the findings from the verification that was conducted in this study is also presented in Chapter 6.

Chapter 7: Conclusion

Chapter 7 presents an overall summary of this research’s key results and findings. The limitations that are associated with this study’s results and findings are also discussed in Chapter 7.

CHAPTER 2: LITERATURE REVIEW

In their widely reviewed book, *The Machine that Changed the World*, Womack et al. (1990:256) emphasise the fact that it took more than 50 years for mass production techniques to become widespread. An extensive amount of work has since been done on a manufacturing philosophy aimed at eliminating non-value-added processes often associated with traditional mass production techniques – namely, lean manufacturing. At the time of conducting this research, lean manufacturing and its core principles as a production optimisation strategy still remain relatively new in the South African manufacturing environment. The literature presented in this chapter covers a number of widely reviewed sources on lean manufacturing and it is also supported by recent work covered on the management philosophy.

The literature presented in Chapter 2 has been arranged as follows:

- 2.1 History of craft, mass and lean manufacturing
- 2.2 Principles of lean manufacturing (LM)
- 2.3 Lean applications in discrete and continuous events
- 2.4 Lean optimisation tools
- 2.5 Lean Six sigma
- 2.4 Visual management
- 2.5 Delphi technique

2.1 History of Craft, Mass and Lean manufacturing

To fully comprehend the concepts of lean manufacturing, Womack et al. (1990:12) argue that an understanding of the differences between craft and mass production is critical for any researcher or organisation interested in undergoing lean transformation. Section 2.1 presents a brief summary of the history of craft and mass production, followed by the introduction of lean manufacturing. *The Machine that Changed the World* has been used extensively by researchers to track the changes that have occurred in the automobile industry since the days of craft production (Womack, et al., 1990). Craft production is described by Womack et al. (1990:13) as a method of using extremely knowledgeable and highly-skilled workers to produce products for consumers – one item at a time. According to Womack et al. (1990:13), it requires

1. a workforce that is highly skilled in design, machine operations and fitting;
2. goods to be produced using general purpose tools;
3. departments within organisations to be decentralised; and
4. low overall production volumes/yields.

The sole use of craft production was phased out mainly as a result of the excessive manufacturing costs associated with this production technique. According to Womack et al. (1990:13), the introduction of mass production enabled suppliers to provide a larger variety of finished goods to customers. Mass production, as argued by Womack et al. (1990:130), also enabled manufacturing industries to employ a less specialised workforce to manage technological advances in machinery. Industrialists later discovered that the use of a less specialised workforce had the adverse effect of an increase in manufacturing disruptions (downtimes) and consequently led to the use of production buffers (Womack, et al., 1990). "Lean production" or "lean manufacturing" (as it is commonly referred to in this study) was introduced after the persistent efforts of Taichii Ohno as a collective strategy for exploiting both the principles behind craft production and mass production – however, with the distinct advantage of eliminating non-value-added work.

According to Floyd (2010), an understanding of the applicability of various lean philosophies in different industries is required to successfully adapt lean practices. Floyd (2010) further believes that enterprises need to assess the various lean practices to determine if they are applicable to their desired environment.

Besides adapting lean practices to suit the operational needs of the industry in which they are applied, structuring management decisions based on a long-term philosophy have been lauded as one of the key successes of lean manufacturing. Liker (2004) describes this management philosophy as an organisation's ability to not only use profit margins as a short-term goal, but to rather focus on the long-term goals that benefit the company, its employees, the customer and the community. Robert B. McCurry, a former executive of Toyota Motor Sales, argues as follows in (Liker, 2004): "The most important factors for success are patience, a focus on long-term rather than short-term results, re-investment in people, product and plant, and an unforgiving commitment to quality."

A section from *Stakeholder Theory of the Modern Corporation* by R. Edward Freeman strengthens this notion by referring to how a corporation should "run primarily in the interests of the stakeholders in the firm and exist in contemplation of the law with a personality of a legal person" (Freeman, 2001).

2.2 Principles of Lean manufacturing (LM)

Lean or lean manufacturing, as highlighted by Hall (2004:22), became an offshoot of the Toyota Production System (TPS) when the term "lean" became widely used following the publication of two books: *The Machine that Changed the World* (Womack & Roos, 1991) and *Lean Thinking* (Womack & Jones, 1996). In their revised *Lean Thinking* edition, Womack and Jones (2003) define lean manufacturing as a five-step process that involves defining value, defining the value stream, making it flow, pulling from the customer, and striving for excellence. According to Womack (2004:21) and Coetzee et al. (2016:79), the merits of a lean manufacturer involve a philosophy that focuses on

- one-piece flow through the elimination of non-value-added processes,

- a pull system that is driven by customer demands; and
- an element that has often been neglected by a number of lean practitioners – the human aspect in organisational culture that motivates everyone to improve continuously.

However, it has been argued that various lean implementation frameworks have not yielded expected results for companies that implemented lean as a philosophy. Matt and Rauch (2013:420) are of the opinion that production methods and instruments currently available for lean manufacturing are not equally applicable to companies of varying sizes and production capacities. This, according to the Matt and Rauch (2013:422) can be attributed to the continuing competitive pressures small organisations experience – which is a good starting point for lean. Sections 2.2.1 to 2.2.5 present a summary of the 5-step "lean thinking" process that Womack and Jones (2003) consider to be essential for organisations to successfully adopt the lean philosophy.

2.2.1 The principle of value

According to Womack and Jones (2003:16), value is a fundamental component of lean thinking. Value is created by suppliers, but it is mainly driven by the needs of the customer (Womack & Jones, 2003:16). Since the introduction of and increased interest in lean manufacturing as a management philosophy, the principle of value has been greatly misunderstood. This notion is further highlighted by Womack and Jones (2003:19) in relation to companies providing the "wrong goods or services the right way", through a term called muda.

The principle of value, according to Liker (2004) and with reference to the TPS, is defined primarily in terms of what the customer wants from a process. Liker (2004:43) is of the opinion that using customers as the focal point provides an efficient strategy to separate value-added steps from non-value-added steps. According to Liker (2004), application of the TPS in any business or organisation is predominantly driven by elimination of the non-value-added work which is commonly described as the eight forms of waste as discussed in Table 2.2-1.

Table 2.2-1: Eight forms of non-value-adding wastes

Adapted from Liker (2004)

	Form of waste	Description	Impact
1	Over-production	Producing products even though customer orders have not been confirmed	· Additional excessive labour · Increased transportation and labour costs
2	Waiting	Wasted time due workers waiting for a prerequisite part or the next downstream process to finish.	· Excessive idle waiting times or no work
3	Transportation	Excessive transportation distances or high frequency of movement of work-in-process (WIP) or finished goods	· Transportation waste time
4	Over-processing	Additional processing of parts which often results in higher-quality products than required by customers (or what customers are willing to pay for).	· More steps than required are taken to produce final products
5	Inventory	Excessive WIP, raw material and finished products around shop floors that results in longer lead times, additional transportation and storage costs, and increased leads times	· Waste in the form of inventory often results in hidden problems being covered up, i.e. delayed deliveries from suppliers, non-conforming material and increased maintenance related work.
6	Motion	Motion wasted time is mostly attributed to unnecessary time spent as a result of workers walking long distances, getting tools, stacking parts etc.	· Increased lead times
7	Defects	This form of waste mostly refers to production of non-conforming material from a quality perspective which often results in the re-work or replacement production	· Additional inspection · Wasteful handling time and effort
8	Unused employee creativity	The 8th form of waste is described by Liker (2004) as waste that results from unused employee creativity and can mostly be attributed to not engaging or listening to your employees.	· A lack of continuous improvement projects that can affect the competitive nature of an organization

2.2.2 The value stream

Value stream mapping, but more specifically, a "value stream", is defined by Rother and Shook (1999:9) as all the actions, both value-added and non-value-added, that are required to take a product through the production flow from raw material into the arms of the customer. The importance of VSM has been argued by Rother and Shook (1999:11) to not only support the visualisation of the different processes within an organisation, but to also help organisations with the elimination of waste (muda). An analysis of the VSM stages presented by Rother and Shook (1999) shows that there are four main steps that should be considered when a continuous improvement project is conducted, and these can be summarised as follows:

1. Analysing material and information flow
2. Selecting a product family
3. Appointing a value stream manager
4. Using a mapping tool

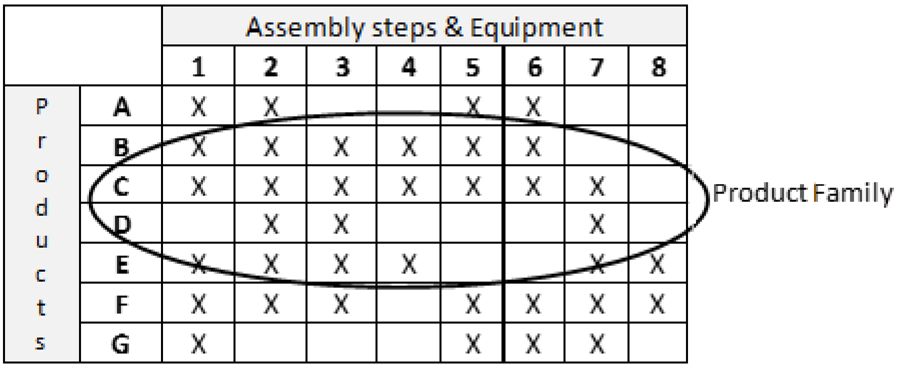
The research presented by Rother and Shook (1999) and the four main steps presented above have been used extensively by industry experts. However, Irani and Zhou (2011) also highlight the disadvantages of VSM, namely that it does not only "fail to map multiple products that do not have identical manufacturing routings or assembly process flows", but also "tends to bias a factory designer to consider **only** those strategies such as continuous flow, assembly line layouts, kanban-based pull scheduling, etc., that are suitable mainly for high-volume low-variety (HVLV) manufacturing facilities" (Irani & Zhou, 2011).

1. Analysing material and information flow

Rother and Shook (1999) distinguish between material and information flow and underline the importance of information flow by articulating that it "ensures that one process will only make what the next process needs when it needs it" (Rother & Shook, 1999).

2. Selecting a product family

Selection of a product family is viewed as a critical measure to ensure the elimination of difficulties associated with a mapping process that consists of all customer-driven products. A product family is defined by Rother and Shook (1999) as any group of products that pass through equivalent processing steps and over common equipment in the downstream processes. Figure 2.2-1below illustrates the selection criteria that is often used for product families, where it can be observed that products A to G require common assembly steps and equipment 1 to 8 for fabrication.



		Assembly steps & Equipment							
		1	2	3	4	5	6	7	8
Products	A	X	X			X	X		
	B	X	X	X	X	X	X		
	C	X	X	X	X	X	X	X	
	D		X	X				X	
	E	X	X	X	X			X	X
	F	X	X	X		X	X	X	X
	G	X				X	X	X	

Figure 2.2-1: Criteria for product family selection

Adapted from Rother and Shook (1999)

3. Appointing the value stream manager

According to Rother and Shook (1999), the value stream manager is responsible for what they consider the pivotal role of tracing the value stream of any product family across all organisational boundaries within a company. In their widely reviewed workbook, they also argue that firms that are solely driven by one value stream manager (in contrast to departmental managers for any continuous improvement project) mitigate the risk that is often experienced as “final isolated islands of functionality” (Rother & Shook, 1999). The authors define the role of a value stream manager as follows:

- Reporting lean implementation progress to the top person on site.
- Having the capacity as a line manager to make change happen across functional and departmental boundaries.
- Leading the creation of the current state and future state value stream maps and the implementation plan for getting from the present to the future.
- Monitoring all aspects of implementation.
- Being present at the implementation site every day.
- Making implementation a top priority.
- Maintaining and periodically updating the implementation plan.
- Insisting on being a hands-on manager driven by results.

A summary of the primary focus of a value stream manager is presented in Figure 2.2-2. Figure 2.2-2 emphasises that the focus of value stream manager is not only limited to improvements to an organisation’s value-added activities, but should also include kaizen activities that eliminate waste. Figure 2.2-2 also highlights that for a value stream manager to achieve an organisation’s primary focus, collective effort is also required from all operational levels within the organisation.

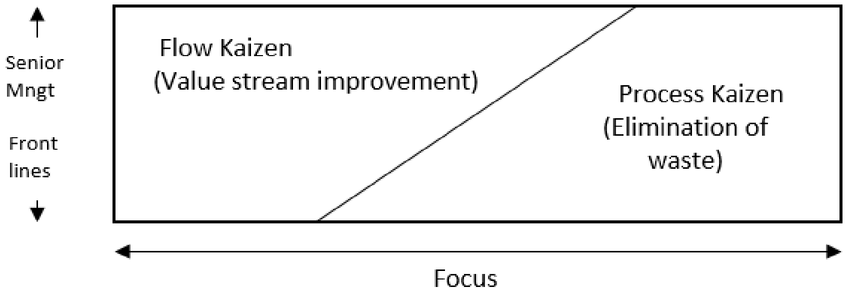


Figure 2.2-2: The primary focus of a value stream manager

Adapted from Rother and Shook (1999)

4. Using a mapping tool

Rother and Shook (1999) contend that the most important component of VSM occurs during the evaluation of the future state, as it is usually driven by a continuous improvement or business planning framework. Despite the importance of future state mapping, it is widely accepted that the first step taken during any VSM project is to define the product family, followed by drawing the current state VSM. The emphasis of VSM (i.e. using a mapping tool) is shown in Figure 2.2-3, where it can be observed that the arrows between current and future states are overlapping efforts.

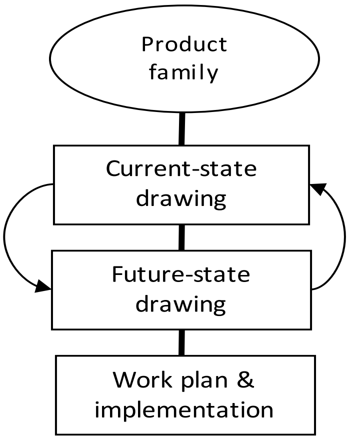


Figure 2.2-3: Value stream mapping cycle

2.2.3 Continuous flow

Creating continuous process flow is viewed as one of the first deliverables that need to be achieved by organisations undergoing a lean transformation process. The concept of continuous flow is not limited to the flow of material, and also includes the flow of information (Liker, 2004).

According to Liker (2004), the lead time from raw material to finished goods is significantly reduced when continuous flow is implemented in any production area. (The built-in quality that is introduced with continuous flow of material is discussed in Section 2.2.6.) Liker (2004) also believes that other principles are implemented when flow of material occurs continuously – a belief that is further strengthened by Rother and Harris (2001) when they argue that "[c]ontinuous flow is the ultimate objective of lean production". The insights of Rother and Harris (2001) and Liker (2004) are expanded on in the current research by considering the defining and critical factors as identified by them.

Liker (2004) argues that continuous flow creates a foundation for the main forms of waste to be eliminated in an organisation (i.e. overproduction, waiting, unnecessary transport, over-processing, excess inventory, unnecessary movement, defects and unused employee creativity). According to Liker (2004), higher productivity, more working space, improved safety, improved morale and a reduced cost of inventory are the different forms of muda that are eliminated when continuous flow is present in an organisation or working area. In contrast, he also critically evaluates the difficulties of implementing continuous flow in an organisation, mainly because of the "fake flow" that can be created and cause reversion back to initial production processes once problems occur with continuous flow initiatives. The takt-time philosophy, which was introduced to counter the difficulty presented by one-piece flow, is defined as the rate at which customers buy products. Liker (2004) views takt-time as a simple measure of addressing both labour and machine components that are needed for one-piece cells to work.

Figure 2.2-4 summarises the benefits that organisations gain when they employ continuous flow of material throughout their production cycle.

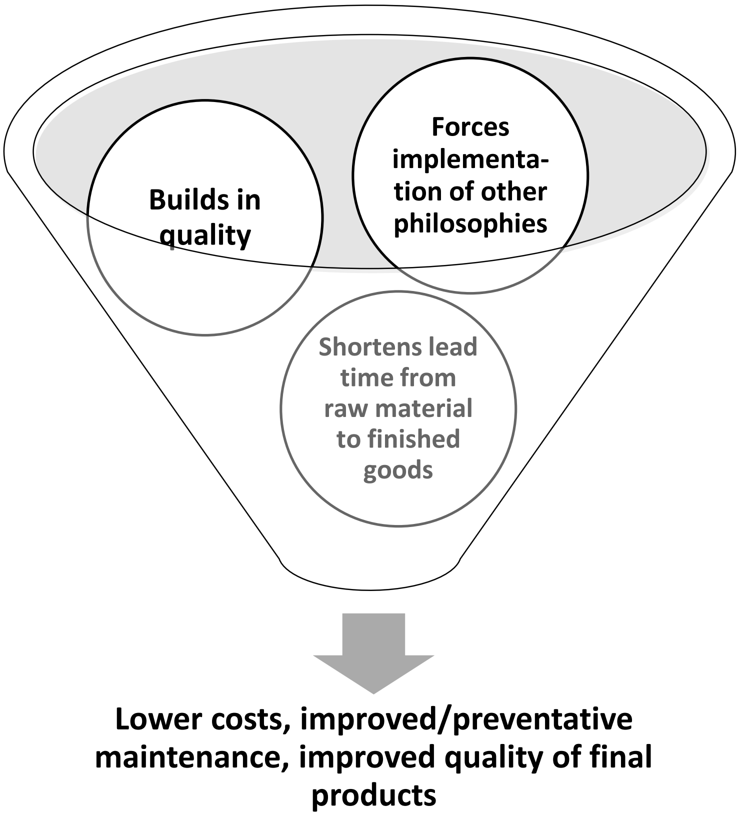


Figure 2.2-4: Benefits of continuous process flow

Adapted from (Liker, 2004)

MacDuffie and Helper (1997) also discovered that there is a direct relationship between the general efficiency of a lean organisation and the consistency of flow of material from their suppliers. In Womack et al.’s (1990:60) opinion, a lean or a would-be lean organisation that does not adequately project a supplier’s flow of input material encounters downstream production delays and waste. Womack et al. (1990:144) also contended that one of the most significant difficulties experienced by lean organisations is ensuring that poor-quality and defective products are identified before they form part of work-in-progress (WIP) material. Significant progress has however been made with the mediums that are available for enhancing the relationship between suppliers and customers (e.g. customer feedback surveys).

MacDuffie and Helper (1997) deliberate on whether there is a significant difference between outsourcing from a lean supplier or non-lean supplier. They, MacDuffie and Helper (1997:120), further argue that organisations that procure from lean suppliers are less burdened by the risks involved in product development, engineering changes and the manufacturing process. Risk mitigation is also emphasised by Womack et al. (1990:148) as a value analysis strategy for lean producers to analyse a component or part that is being produced before it goes through every step of the production cycle. For a local and more centralised South African market with emerging lean manufacturing interests in other economically active sectors, the impact of creating a business relationship with a lean supplier can be summarised as follows (Womack et al., 1990:148):

- Larger and more talented first-tier suppliers will engineer whole components for the assemblers. They will supply these components at more frequent intervals under longer-term contracts.
- Much higher quality standards.
- Much lower costs through the elimination of non-value-added waste.

2.2.4 Just-in-time

One of the founding philosophies of The Toyota Way does not only concern dealing with excessive inventory, but eliminating it altogether (Liker, 2004). Inventory buffers are an example of the manufacturing “enhancements” that were introduced as a method of maintaining continuous production throughout mass production departments (push systems). However, the father of the Toyota Production System, Taiichi Ohno, also realised that this systematic approach of using inventory buffers often leads to overproduction. Liker (2004) agrees that pull systems were preceded by push systems, in which final products were manufactured based on projected customer demands. This production technique (using push systems) often led to increases in inventory and was later discovered to be one of the leading contributors to high waste yields.

A kanban in Toyota’s production system is described as any form of medium that can be used to signal a need to replenish a critical manufacturing element or sub-system – as is required during a production cycle (Liker, 2004). The introduction of production kanbans played a critical role in exposing the frailties of using push systems in which products were manufactured using projected customer demands. According to Liker (2004), the need to use traditional systems was eliminated by using a pull-replenishment system, in other words “just-in-time” production. Sugimori et al. (2007) highlight that this just-in-time principle avoids problems with inventory unbalances, equipment and labour surpluses, but most notably prepares for changing production demands by producing the necessary parts at the right time. For the just-in-time-principle to work, Sugimori et al. (2007) caution that jidoka ("automation with a human touch") plays an equally important role in ensuring that all production-related problems are addressed before they affect downstream processes. The importance of both the just-in-time and jidoka principles are shown in Figure 2.2-5, where it can be observed that a balance needs to be maintained to incorporate lean as a management philosophy.

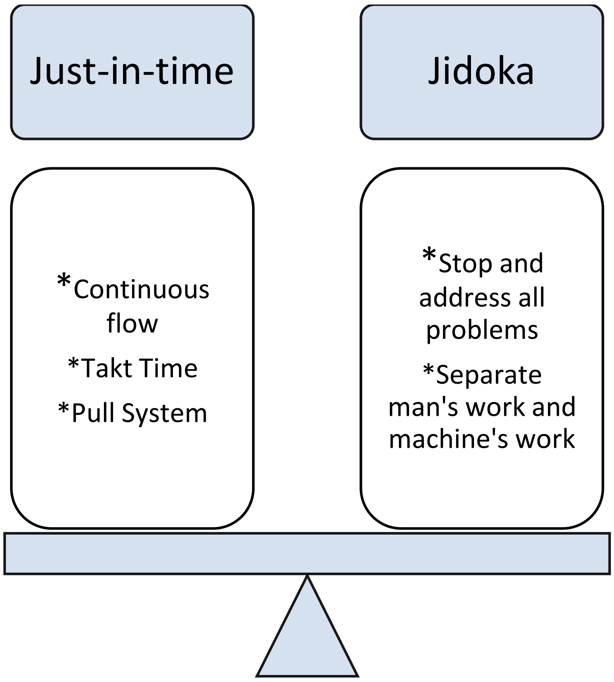


Figure 2.2-5: A balance between just-in-time and Jidoka

Adapted from Sugimori et al. (2007)

Shingo (1989) considers the kanban system as a control measure for the just-in-time and Jidoka principles (introduced in Section 2.2.6) to work, and distinguished between traditional kanban systems and the kanban system implemented by the Toyota Production System (TPS). According to Shingo (1989), traditional kanban systems perform the following three main functions:

1. “Identification tag – indicates what the product is.
2. Job instruction tag – indicates what should be made, for how long and in what quantities.
3. Transfer tag – indicates from/to where the item should be transported.”

Shingo (1989) further argues that the most significant differences between the Toyota Production System’s kanban and the traditional kanban system are that the former only requires two tags to perform the same functions of the latter, namely:

- “Work-in-progress tag – serves as identification and job instruction tags, and
- Withdrawal tag – serves as identification and transfer tags.”

The order-to-delivery cycle (D) and the production cycle (P) are considered as two critical elements for the just-in-time principle to work (Shingo, 1989). The order-to-delivery cycle refers to the amount of time required to receive products (i.e. from the time the order is placed), while the production cycle refers to the amount of time required to make a product. Rahman et al. (2013) conclude that ineffective inventory management systems, lack of supplier participation, lack of quality control/improvements and lack of employee participation are the key elements that prevent the successful implementation of kanban systems (Rahman, et al., 2013).

Klier (1995) points out that “efforts to reduce inventory stocks and arrange for ‘just-in-time’ delivery function most effectively when the supplying and receiving plants are in reasonably close proximity”. Several challenges are still evident when the prospect of geographic location is considered. In the South African manufacturing environment, this can be attributed to the relatively recent time-frame in which non-automotive manufacturing industries have taken an interest in lean manufacturing. Klier (1995) does however admit that larger countries will not have industries that are nearly as geographically concentrated as Japan’s and this opinion is quoted as follows:

“A state’s ability to attract an assembly plant does not necessarily mean that a significant number of suppliers will set up shop nearby.”

A sharp contrast to Klier’s (1995) views is however presented by Gale (1999), who argues that in non-metropolitan locations, close vicinity to other firms and national highway access do not appear to be important components of lean initiatives. Furthermore, Gale (1999:158) reasons that dependable transportation, advanced communication and the advent of freight-forwarding firms reduce the importance of physical distance as a barrier.

2.2.5 Levelling production

According to Womack et al. (1990:33), a need to level production is required when a transition is made from traditional mass production to lean manufacturing. In addition to other operational benefits, lean has come to be viewed as an effective way of eliminating the difficulties associated with levelling production in a traditional mass producing organisation. In their conceptual model for production levelling (‘heijunka’), Araujo and Queiroz (2010) argue the applicability of lean manufacturing concepts to address the various difficulties when batch processing characterises a significant proportion of the production value stream. They consider a traditional operational planning system to comprise of three levels, namely strategic (long-term), tactical (medium-term) and operational (short-term) planning (Araujo & Queiroz, 2010). According to Araujo and Queiroz (2010), the two-tier operational planning strategy shown in Figure 2.2-6 presents a sharp contrast to traditional operational planning -and it assists in prioritising the fabrication of products from different raw materials.

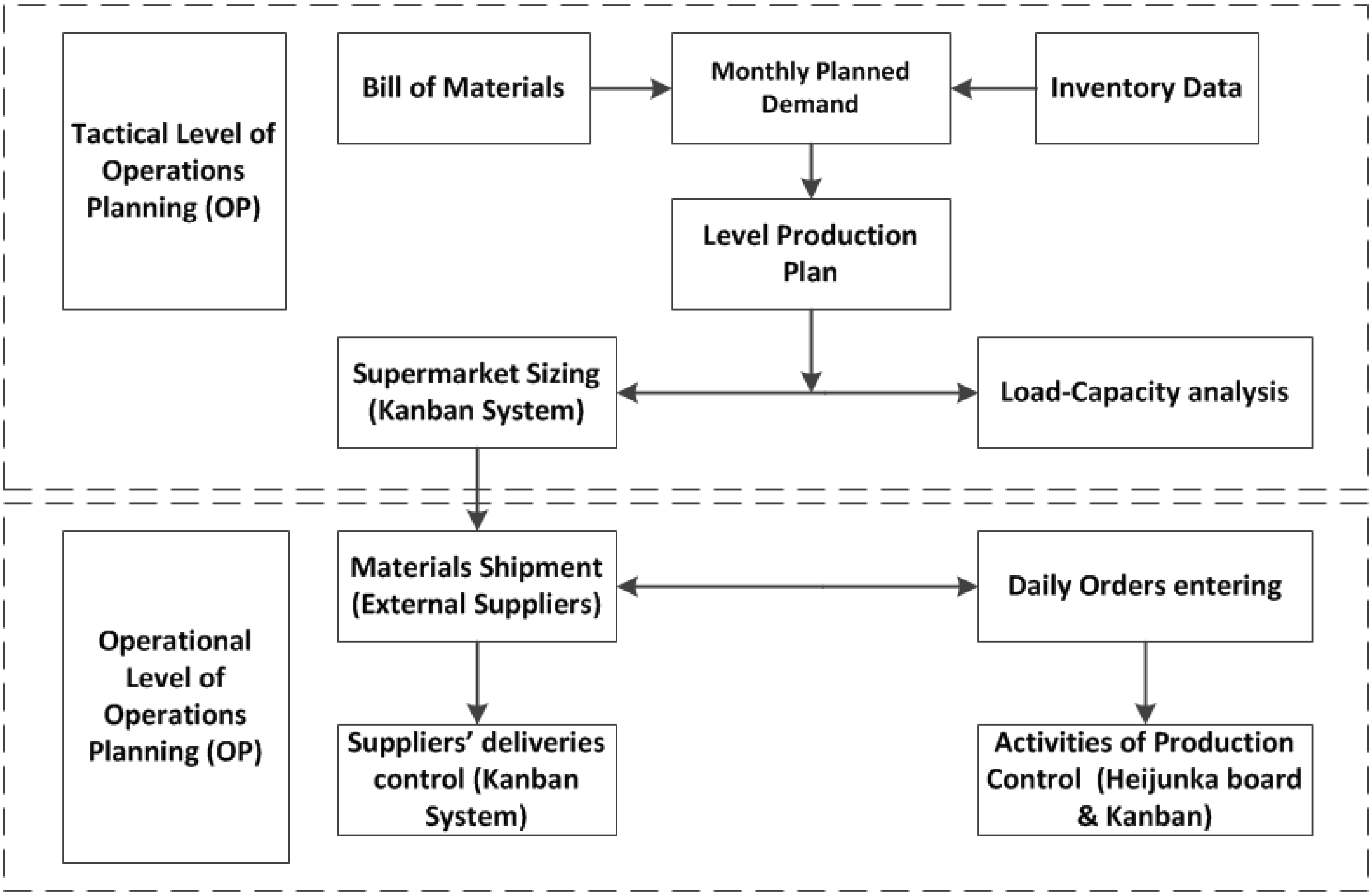


Figure 2.2-6: Theoretical framework of production levelling and its main activities

Source: A Conceptual Model for Production Levelling (Heijunka) Implementation in Batch Production Systems

In addition to the operational planning presented in Figure 2.2-6, one-piece production and conveyance is viewed as a production approach in which all processes are produced one item at a time (Sugimori, et al., 2007). According to (Pyzdek & Keller, 2010), a number of challenges of production levelling are mitigated when level loading is seen as a process in which a production schedule is generated to be stable and responsive to the market needs and is primarily driven by the takt time concept described by the equation 1:

$$\text{Takt time} = \frac{\text{Daily work time}}{\text{Daily quantity needed}} \qquad [1]$$

Furthermore (and as highlighted in the preceding sub-sections), Liker (2004) emphasises that in order for production of any levelled system to work efficiently, the three M's described by the basic Venn diagram in Figure 2.2-7 must be eliminated, namely: (1) Muda – Non-value-added work; (2) Muri – Overburdening people or equipment; and (3) Mura – Production unevenness.

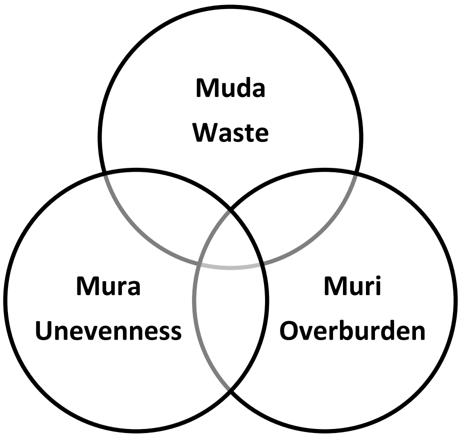


Figure 2.2-7: The Three M's

Adapted from Liker (2001)

In the previous paragraphs, the ability to achieve production levelling was mostly attributed to an organisation's operational planning and the ability of the organisation to prioritise the fabrication of raw material. In Chhajed and Lowe's (2008) opinion, Little's Law relates two metrics via the average rate of arrivals into the system. This paragraph introduces Little's law, which provides a simpler understanding of the main components that are needed to achieve production levelling. Little's Law is further described in terms of the queueing system concept, from which discrete objects, described as items, arrive into the system at a given rate. This theory is illustrated in Figure 2.2-8 below.

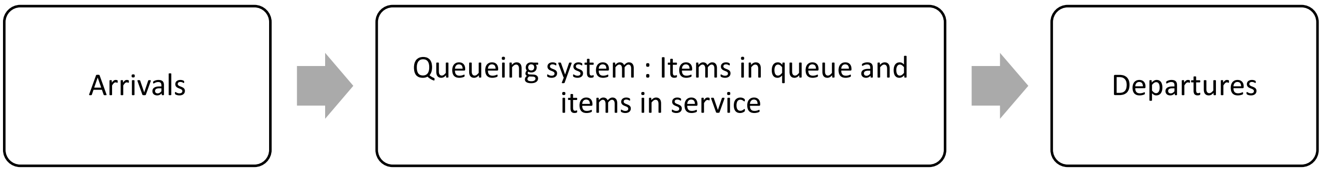


Figure 2.2-8: Schematic view of queueing system

Adapted from Figure 5.1, Chhajed and Lowe (2008)

Under steady state conditions, Little's Law is represented by Chhajed and Lowe (2008) using equation 2 as follows:

$$L = \lambda * \omega \qquad [2]$$

Where:

L = Average number of items in the queueing system

λ = Average waiting time in the system for an item

ω = Average number of items per unit time

Little's Law has in recent years been adapted to include three critical principles of operations management, namely work-in-progress (WIP), cycle time (CT) and throughput (TH). The formula can be seen in Equation 3 as follows (Chhajed & Lowe, 2008):

$$TH = \frac{WIP}{CT} \qquad [3]$$

2.2.6 Jidoka (quality within production)

Jidoka is considered as the second pillar of the TPS and according to Rosenthal (2002), this pillar is as important as the just-in-time principle discussed in Section 2.2.4. Jidoka, also referred to as "autonomation"[3] by Liker (2004), was contrived from Sakichi Toyoda's persistent efforts at building quality within production[4] to ensure that defects are fixed before they continue downstream. A summary of the Jidoka process is shown in Figure 2.2-9. The first step in the cycle commences when a machine detects a deviation in normal operating conditions and immediately provides feedback (to an operator for example) when the problem is detected. Claims that the Jidoka process relies solely on machine efficiency have been pointed out to be misleading, and a report from *Art of Lean* (2006) stresses that Jidoka is a two-part system that not only builds in quality during the "machine" process, but also empowers men to work in separation from the utilised machinery. The second component in Jidoka (separation of man from machine) has been widely accepted to increase the value-added work that can be performed during scheduled production times, in contrast to traditional systems in which machine operators constantly have to monitor machines during normal production use (Art of lean, Inc, 2006).

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[3] Automation with human intelligence.

[4] Sakichi Toyoda introduced revolutionary changes in designing loom machines that stop automatically as soon as a problem is detected.

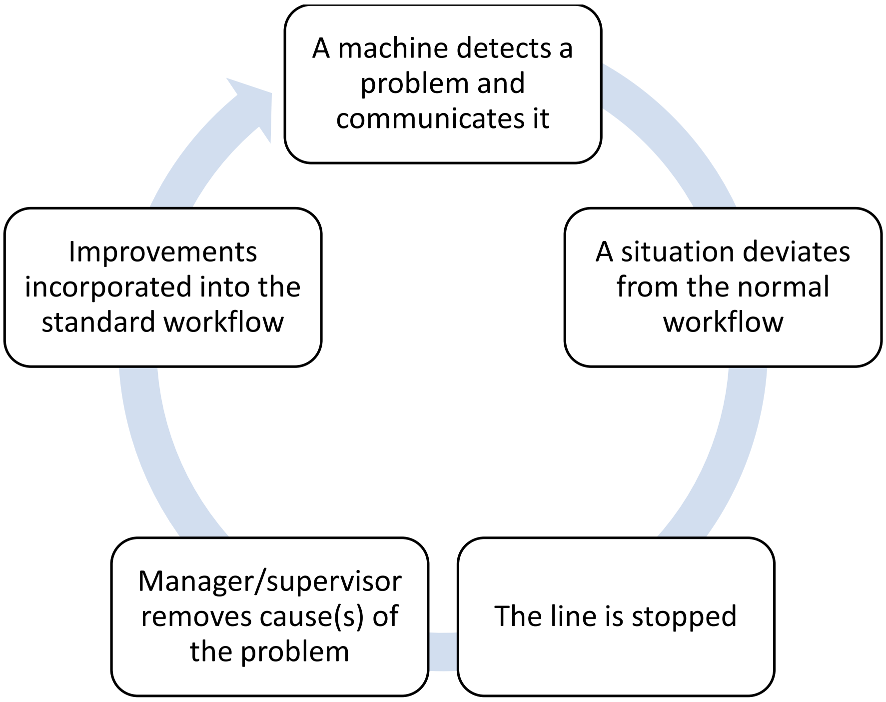


Figure 2.2-9: Jidoka process

(Art of lean, Inc, 2006)

(Shingo, 1989) argues that traditional judgemental inspection techniques, in which non-conforming material is separated from products that meet quality standards, do not manage to reduce the defect rate of an organisation. To counter the limitations introduced by traditional judgement inspection, Shingo (1989) introduces the following inspection techniques that he believes may eliminate defects as follows:

- Self-inspection and successive inspection – the worker inspects the product he/she is processing.
- Enhanced self-inspection – feedback is provided through devices that automatically detect defects or unintended mistakes.
- Source inspection – prevents defects by controlling the conditions that influence quality at their source.
- Poka-yoke inspection – makes use of both mechanical and physical control methods, and is often used as a control or a warning measure during production cycles.

Rosenthal (2002:1) believes that inspection techniques similar to those introduced by Shingo (1989) are non-value-adding work activities, unless a follow-up is actually made when a problem is detected. Rosenthal (2002) and Liker (2002:149) see Jidoka as a four-stage process and the views of these authors are compared in Table 2.2-2.

Table 2.2-2: Jidoka process steps

Rosenthal (2002)	Liker (2004)
(1) Detect the abnormality	(1) Go and see
(2) Stop	(2) Analyse the situation
(3) Fix or correct the immediate condition	(3) Use one-piece flow and Andons to surface problems
(4) Investigate the root cause and install a counter-measure	(4) Ask "Why" five times

2.2.7 Continuous improvement

As industries look to diversify and improve their operational strategies, lean principles have shown that the implementation of continuous improvement policies often results in the identification of a number of constraints that are not directly related to the organisation. As observed in the preceding sub-sections, production planning is a key obstacle that a number of lean transitioning organisations need to contend with and overcome when adopting the lean philosophy.

Womack et al. (1990:39) emphasise the impact of centralised decision making (i.e. one person or certain individuals in an organisation making all the key decisions) by reviewing the decline of Ford's monopoly, which almost led to a complete dissolution of the company. On the contrary, researchers have since come to observe that an increase in the number of stakeholders in the form of trade unions and the "job control unionism" has had a negative impact on the efficiency of high-volume yielding organisations (Womack et al., 1990:42). The South African manufacturing environment has been no exception, with cultural barriers and increasing union involvement being viewed as some of the causal elements that have yielded slow lean transformation rates (Katari, 2015). These challenges have been widely accepted as some of the human elements of project management that need to be overcome as industries seek not only to diversify their management strategies, but especially to improve them on a continuous basis.

In Section 2.3, the applicability and practicality of the lean principles discussed in this section are reviewed in the form of lean optimisation tools. The lean optimisation tools reviewed in Section 2.3 create a foundation for the research method that is introduced in Chapter 3.

2.3 Application of lean in discrete and continuous events

As highlighted in Section 2.1, the origins of lean manufacturing have accepted to be from the automobile industry, which is a predominantly discrete manufacturing environment. The applicability of lean manufacturing in other industries presents a number of challenges, and many organisations that have implemented lean manufacturing indicate that it does not always yield expected results. According to Howell (2010), not all traditional lean tools are applicable to continuous manufacturing environments, and the forceful implementation of lean as a management philosophy might eventually have an adverse effect on an organisation’s operational requirements. In addition to the views of Howell (2010) and according to Clotet (2015), the applicability of lean methodologies in continuous sectors remains largely ineffective due to inflexible equipment and long set-up and changeover times.

For continuous flow to be successfully adopted in a continuous manufacturing setting, the use of Andons to stop production lines when problems are detected has been contended to be less effective in a process manufacturing environment. Floyd (2010) argues that in continuous process environments, the use of line-stopping Andons is mainly not feasible because most processes in continuous environments do not start and stop in the same way as in discrete manufacturing environments. In addition to the arguments and concerns that have been raised on using Andons in continuous manufacturing, the effectiveness of using the kanban and heijunka principles to achieve the Just-in-time and Heijunka (Japanese work for levelling) philosophies respectively has been questioned. According to Powell et al. (2010), heijunka and kanbans are difficult to apply in continuous manufacturing because resource utilisation and large batch processing are required to increase production efficiencies. Similarly, Eng and Ching (2014) admit that the challenges presented by the use of heijunka and kanbans inadvertantly require more complex scheduling so as to achieve these lean principles.

According to Esfanyari et al. (2007), to effectively implement production levelling, cellular manufacturing needs to be established within the organisation. Cellular manufacturing is however argued to be difficult to implement in continuous manufacturing sectors, due to machines being predominantly large and difficult to move (Esfanyari et al., 2007). In their research paper on “learning how to evolve”, Rich et al. (2004) suggest that the original lean pioneers came from fairly stable demand environments such as the automobile industry. They contend that the repetitive nature of the discrete industry (high volume and low variability) has attracted criticism from a number of authors who argue that the application of lean principles in continuous sectors presents a number of challenges. The arguments presented by Rich et al. (2004) are supported by Gill et al. (2009) who agree that the high volume and low variability of discrete sectors (e.g. automobile industry) is better suited for supply chain management than for the high mix, low volume that is mostly presented by continuous industries. Despite lean having been integrated successfully into a number of organisations, Hines et al. (2004) maintain that lean is critised for its lack of human integration and for being ideally suited to discrete manufacturing environments.

In Panwar et al. (2015)’s opinion, lean manufacturing has been adopted successfully in the discrete manufacturing sector mainly because of a highly skilled workforce that enables quicker set-up times and improved productivity. They further argue that continuous manufacturing sectors generally have a lower skilled workforce (Panwar et al., 2015).

Regardless of the differences in the application of lean in continuous manufacturing environments, emphasis on lean as a management philosophy and not a collective organisation of optimisation tools is the focal point of this literature study. Billesbach (1994) states that every continuous process eventually creates a discrete component, and it is with these discrete components that the principle of lean production can be applied to any manufacturing setting. The principle of value was introduced in Section 2.2.1, where the eighth form of waste was identified as “unused employee creativity”. Corbett (2007) emphasises this eighth form by arguing that people and partners need to collectively find innovative ways to ensure that lean initiatives can be tailored to meet the specific demands of their environment. Deflorin and Scherrer-Rathje (2011) conclude that lean manufacturing elements depend on the specific environment in which they are being implemented – and it is with the principle of value that is defined in lean production that organisations can achieve the state of lean manufacturing.

2.4 Lean optimisation tools

Total quality management (TQM), Theory of constraints (TOC), Lean six-sigma and Business process re-engineering (BPR) are examples of existing continuous quality improvement approaches that are widely used in industry to optimise existing processes. The lean six sigma approach has in recent years been at the heart of both profit and non-profit organisations in their aim to improve processes and reduce variations that relate to their mission statements. As described by Pyzdek and Keller (2010), “Six Sigma is a rigorous, focused, and highly effective implementation of proven quality principles and techniques”. Even though the scientific concepts introduced by lean six sigma have been regarded to yield high results for organisations that have implemented its programmes - Devane (2004) remarks that a number of industry researchers still argue that six sigma is merely a re-organisation of traditional quality management techniques, therefore presenting hidden limitations. Nonetheless, Devane (2004) also reasons that the six sigma approach provides “a more measurable, objective and quantifiable capability which is less emphasized in other quality management programs”. As a derivative of lean six-sigma, the Define-measure-analyse-improve-control (DMAIC) tool is considered the backbone of Six Sigma-based lean optimisation management. Devane (2004) furthermore argues that the DMAIC tool is used when a product or process exists, but is performing inadequately.

In the subsequent sections (2.4.1 to 2.5.4), the DMAIC approach is used to summarise the various optimisation tools that are commonly used to improve existing processes.

2.5 Lean Six sigma

The lean six-sigma approach is introduced in this subsection because it provides a systematic approach to incorporate lean principles using the DMAIC approach introduced in Section 2.4.

2.5.1 The define phase

According to Pyzdek and Keller (2010:165), project charters are used as official summaries of project plans and for the authorisation of a Six Sigma project before it can commence. They also view the project charter to contain the why, how, who and when of a project and thus it can be summarised in a table that contains the following elements:

Table 2.5-1: Summary of project charter components

Component			
1	Problem statement	5	Stakeholders
2	Objectives/Purpose	6	Team members
3	Scope	7	Project schedule
4	Deliverables	8	The resources required

The Critical to Quality (CTQ) deliverables of Six Sigma projects have been described as the most familiar metrics for operational personnel, as they are directly related to the functional requirements specified by the internal and external customers (Pyzdek & Keller, 2010). According to Pyzdek and Keller (2010), CTQ metrics are "derived by comparing process observations against the process requirements". CTQ metrics are mostly used as an analytical tool to decide whether a process was acceptable or unacceptable (i.e. defective), and the output is in the form of defects-per-million opportunities (DPMO).

The define phase requires projects to be broken down or, as Pyzdek and Keller (2010:167) put it, to be decomposed into smaller projects to clearly define the work elements and tasks. Work Breakdown Structures (WBS) and Pareto diagrams are considered to be useful when used in conjunction with other tools during the define phase of a project and both these techniques can also be used to allocate resources within a project's lifecycle (Pyzdek & Keller, 2010). The next phase in the DMAIC process, the "measure phase", is covered in the next section.

2.5.2 The measurement phase

Any process is defined by Pyzdek and Keller (2010:197) as any repeatable task that is conducted in a structured manner. Clearly defined processes are considered fundamental in ensuring flow of material. It has often been found that when a process or procedure is not adequately communicated to all major stakeholders, delays are experienced during production cycles. The measure phase is considered to include all metrics that can be used to determine the probable outcome of optimisation and implementation changes within a production system. Flowcharts and Suppliers-Inputs-Process-Outputs-Customers (SIPOC) are common tools used in the measurement stage to document current states in processes. Pyzdek and Keller (2010:199) contend that standardised questions which can be used as guidelines for any process optimisation initiatives can be used to determine future states in a process. The standardised questions proposed by Pyzdek and Keller (2010:199), which can also be used to determine future states in production are summarised as follows:

- Who are the stakeholders involved and what is the basis of this process?
- What value does it create? What output is produced?
- Who is the owner of this process?
- Who provides inputs to this process?

- What are the inputs?
- What resources does this process use?
- What steps create the value?
- Are there sub-processes with natural start and end points?

The main objective of the measure phase, as defined by Pyzdek and Keller (2010:201), is to determine a process baseline in order to quantify the performance baseline before any improvement efforts can be initiated. Furthermore, a suitable metric that will be used to establish any process improvements is considered critical during the measurement phase of the DMAIC cycle.

2.5.3 The analyse phase

The analyse phase mostly examines all the value-adding processes that are needed to bridge the gap between the current and the desired performance within an organisation (Pyzdek & Keller, 2010). Kumar and Kaushish (2015:9) briefly describe the primary objective of the analyse phase as a method of identifying and prioritising the root causes of defects, but Pyzdek and Keller (2010:321) argue that the value stream encompassed in this stage includes all forms of “Muda of defective work, not just defective products”. Value stream mapping (VSM), a tool commonly cited by Pyzdek and Keller (2010:325) in the analyse phase, is referenced by the authors as assisting in the identification of information flow from a process to its customer. VSM is also considered to play a critical role in the identification of non-value-added waste (Pyzdek & Keller, 2010).

Lean practitioners argue that the lean optimisation tools reviewed so far have yielded great success since the advent of Toyota’s production principles. However, Deif et al. (2015:44) contend that practitioners often struggle to assess how lean their system is after implementing different lean tools and techniques. In their paper, “*An integrated metric to assess leanness level based on efficiency, flow and variation*”, they introduce a combined metric to measure and analyse the leanness level of an organisation. The Efficiency, Flow and Variation (EFV) presented by Deif et al. (2015:47) is also considered as a process improvement technique that can be used to identify which elements in a system require additional improvement. The technique is summarised by the following equation:

$$EFV = \sum_{i=1}^{m}\sum_{j=1}^{n} E_{ij} + \sum_{i=1}^{m-1} F_i - \sum_{i=1}^{m} CV_i \qquad [4]$$

In Equation 4, $\boldsymbol{E_{ij}}$ represents the total process efficiency, $\boldsymbol{F_i}$ represents the flow type of goods and CV_i represents the coefficient of variation (Deif, et al., 2015). The EFV metric uses six quantitative measures, namely Time efficiency; WIP efficiency; Throughput efficiency; Quality efficiency; Process flow types; and Process variability. In addition to the leanness assessment model of Deif et al. (2015:47), Vinodh and Vimal (2011) introduce an integrated 30-criteria-based fuzzy logic approach to measure the leanness of the organisation that they used as a case study. This 30-criteria leanness model is preceded by a 20-criteria-based leanness model commonly used by other researchers. Vinodh and Vimal (2011) argue that the fuzzy logic presented in their paper eliminates the “impreciseness and vagueness” that characterise other scoring methods. In addition to these lean assessment tools (LATs) presented by Deif et al. (2015:47) and Vinodh and Vimal (2011), a LAT that incorporates both qualitative methods and quantitative perceptions is proposed by Pakdil and Leonard (2014) to provide a comprehensive view on an organisation’s leanness.

In the previous paragraph, the primary focus of the analyse phase centred on examining the value stream of a process and the various lean assessment tools that are available to measure the leanness of existing processes. In this paragraph, we focus on identifying and analysing the root causes of unsatisfactory process optimisation initiatives by analysing a commonly used tool, the Root Cause Analysis (RCA). The Root Cause Analysis (RCA) technique is described by James-Ward et al. (2012) as an instrument for “deciding on which area of the organisation” should be used as a central point of a study. Lehtinen et al. (2011:1045) further argue that it is a structured investigative approach that yields an effective problem detection framework by identifying the root causes of defects or undesired outputs from processes. In their research paper, Lehtinen et al. (2011:1045) present a lightweight RCA method and contend that the RCA consists of three steps: target problem detection; root cause detection; and corrective action innovation. Jayswal et al. (2011:2786) go further and point out that due to the multi-dimensional nature of most organisations, a “good” RCA takes into consideration economic, environmental and societal factors which they consider integral to an organisation’s needs.

An aggregate RCA (initially introduced to improve patient safety) is presented by Tool Tutorial (2003:434), in which it is argued that an aggregate RCA can be used in any setting. Table 2.5-2 presents a summary of the aggregate RCA steps suggested in Tool Tutorial (2003:435). Participation from senior management and frontline employees highlighted to be critical in identifying underlying problems in various settings.

Table 2.5-2: Aggregate root cause analysis technique

Steps	Aggregate root cause analysis (adapted from Tool Tutorial, 2003)	Applicable to this research?	
1	Charting a team with expertise on the subject matter	✓	
2	Drawing of flow chart involved in the process	✓	
3	Use text to describe how the team reviewed the general process in the system	✓	
4	Identification of resources	✓	
5	Using data and flowcharts to determine the focus of this aggregate review	✓	
6	Determine the root cause/contributing factors	✓	
7	Develop root causes/contributing factors	✓	
8	Develop root causes/contributing factors by using the five rules of causation	✓	
9	Write outcome measures	✓	
10	Present analysis and actions to leadership for concurrence		✓
11	Implement actions and determine if outcome measures were met		✓

The next phases presented in the DMAIC cycle are the improvement and control phases. These are discussed cursorily since the deliverable of this study involves optimisation and not implementation.

2.5.4 Improving phase

Pyzdek and Keller (2010:393) describe the primary objective of the improvement phase as the implementation of a new system during the DMAIC cycle. Similarly, the control phase presents tools that focus on the long-term sustainability of a system once the new system has been implemented. Iwao Kobayashi introduced what has come to be widely known as the “20 Keys to workplace improvement”, and these focus primarily on quality, delivery and the cost associated with continuous improvement (Kobayashi, 1995). According to Kobayashi (1995), cleaning and organising constitute a fundamental starting point that ensures that problems and wasteful activities are easily identified before any long-term lean optimisation initiatives can be started. Three additional focus areas are described by Kobayashi (1995), in which the author highlights that rationalising the management objectives, identifying the improvement team activities and reviewing the organisation’s site technology are required to guide lean initiatives within an organisation. A summary of the 20 Keys Relations Diagram is presented in Figure 2.5-1 and the link between each key is presented to strengthen manufacturing quality and to energise the workplace.

Kobayashi (1995:6) argues that the 20 keys make existing management goals easier to achieve and more likely to be maintained over time.

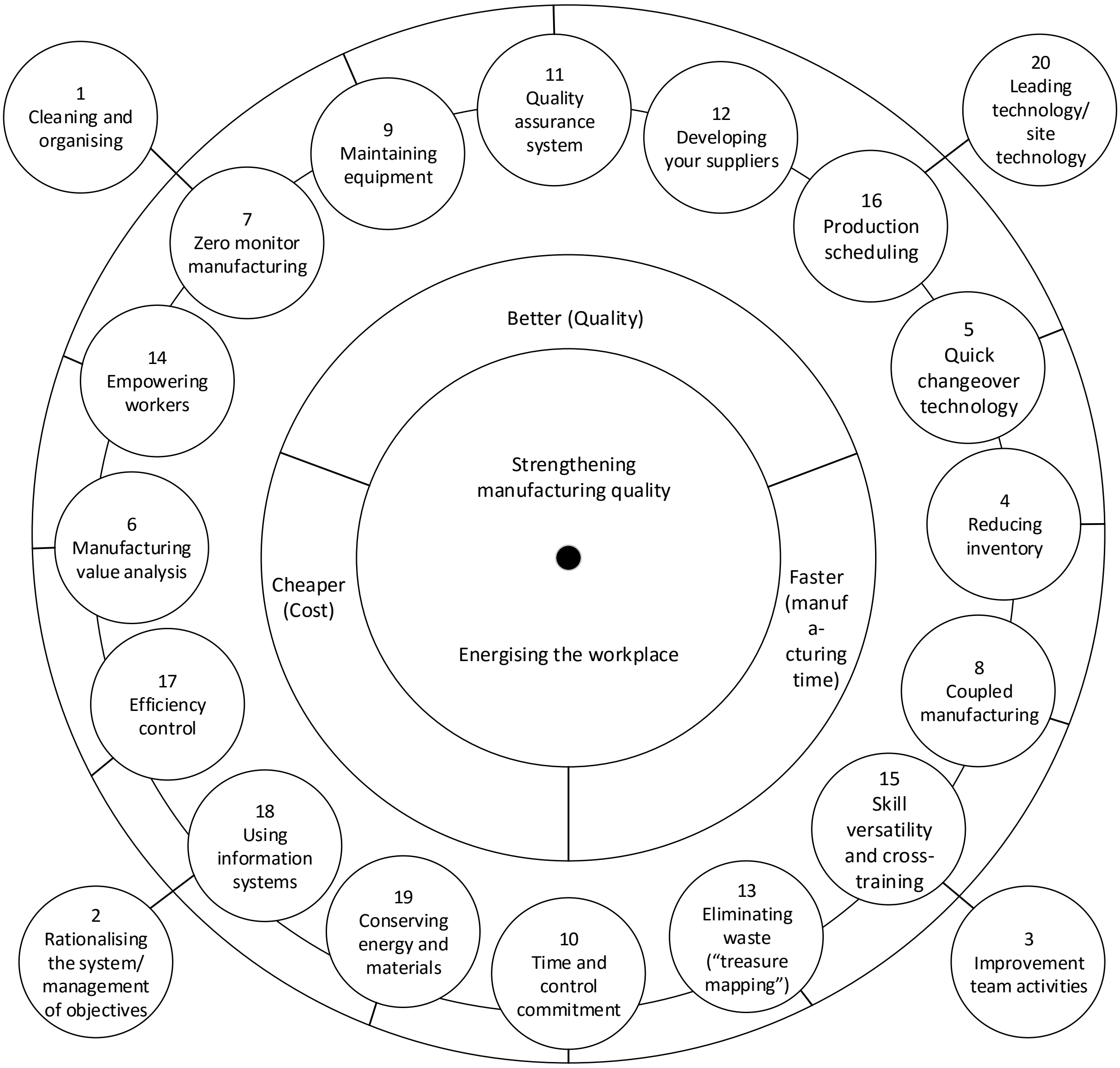


Figure 2.5-1: Summary of the 20 Keys Relations Diagram

2.6 Visual Management and Policy deployment

The use of visual control has widely been accepted to be one of the most innovative changes introduced through lean manufacturing principles. Moser and Santos (2003) believe that for modern-day organisations to strive in an increasingly competitive environment, stakeholders within the organisation should not be required to spend much time searching for work-related information. Toyota's lean principle, the "*use of visual control so no problems are hidden*" was adopted when it was realised that a number of production-related problems were created by areas within a plant that were dysfunctional, but could not be seen (Liker, 2004). Moser and Santos (2003) emphasise that the transparency created through visual control techniques will most likely increase worker motivation and reduce the likelihood of work-related errors.

The philosophy of cleaning it up and making it visual is also introduced through the 5S system (which is widely accredited to Japanese manufacturing industries). The 5S system is "a series of activities for eliminating wastes that contribute to errors, defects, and injuries in the workplace" (Liker, 2004). It is derived from the Japanese words *seiri*, *seiton*, *seiso*, *seiketsu* and *shitsuke* (sort, straighten, shine, standardise and sustain) and involves the waste elimination process presented in Figure 2.6-1 :

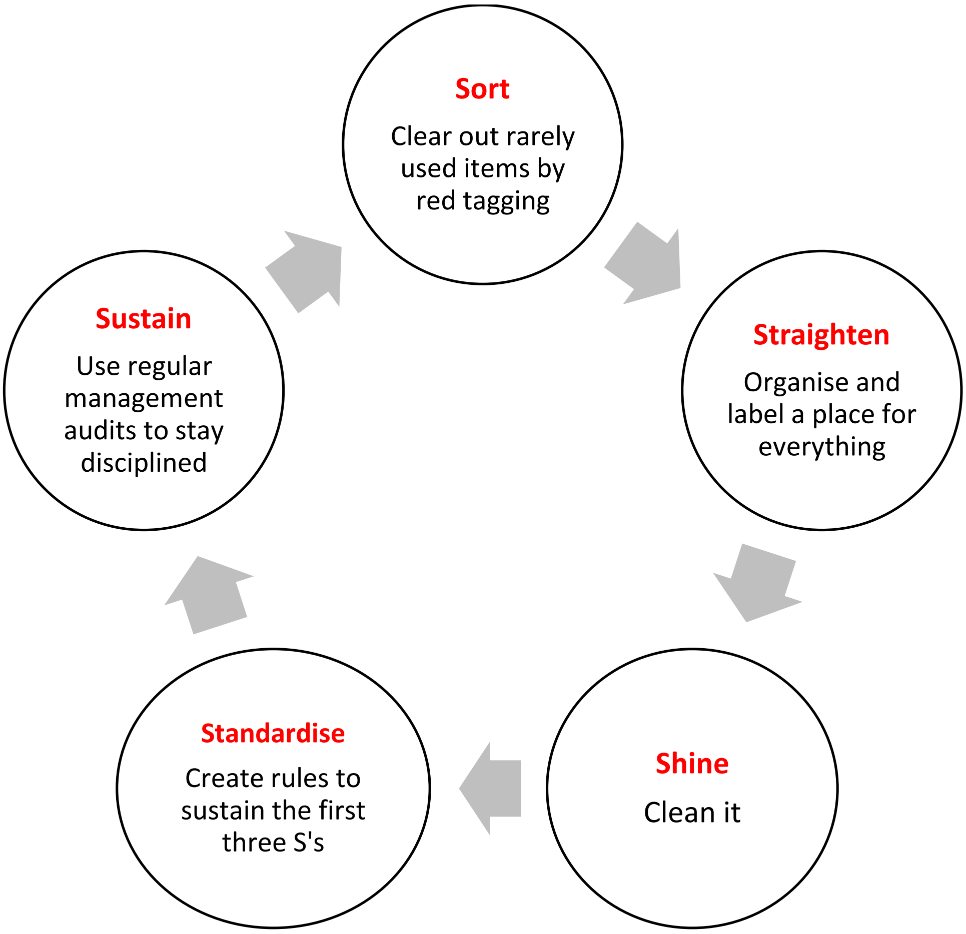


Figure 2.6-1: 5S cycle

Adapted from Liker (2004)

The Hoshin Kanri matrix, often referred to as the Hoshin Policy deployment matrix is another type of visual management tool commonly used by lean practitioners. According to Womack and Jones (2003:349), the Hoshin Kanri matrix is a strategic decision-making tool that is used on a managerial level to prioritise an organisation's resources (people included) to the critical initiatives that are required to achieve strategic goals. In contrast to the single-minded pursuit argued to be the problem with traditional KPIs, the Hoshin Kanri matrix provides a visual "catchball" that ensures an alignment of the strategies and goals that are desired at every operational level. This matrix is further viewed as an effective medium or tool that can be used to document an organisation's optimisation initiatives.

To achieve the objectives of the Hoshin Kanri matrix, Waldo (2017) suggests that the following action steps are taken:

- Establish an organisational vision, including all strategic, tactical and coordinated goals across manufacturing processes.

- Pursue 3-5-year breakthrough objectives, which emphasise that lean is a long-term thinking philosophy.
- Develop annual objectives that are aligned with the 3-5-year breakthrough objectives mentioned above.
- Identify annual improvement opportunities and priorities to meet the annual objectives affiliated with the long-term 3-5-year objectives.
- Set up targets to improve (TTI) to ensure that the annual improvement opportunities and priorities are achieved.
- Identify experienced individuals who will be responsible and accountable for each TTI required to meet the improvement opportunities and priorities.

A summary of how to interpret the Hoshin Kanri Matrix is also presented in Figure 2.6-2

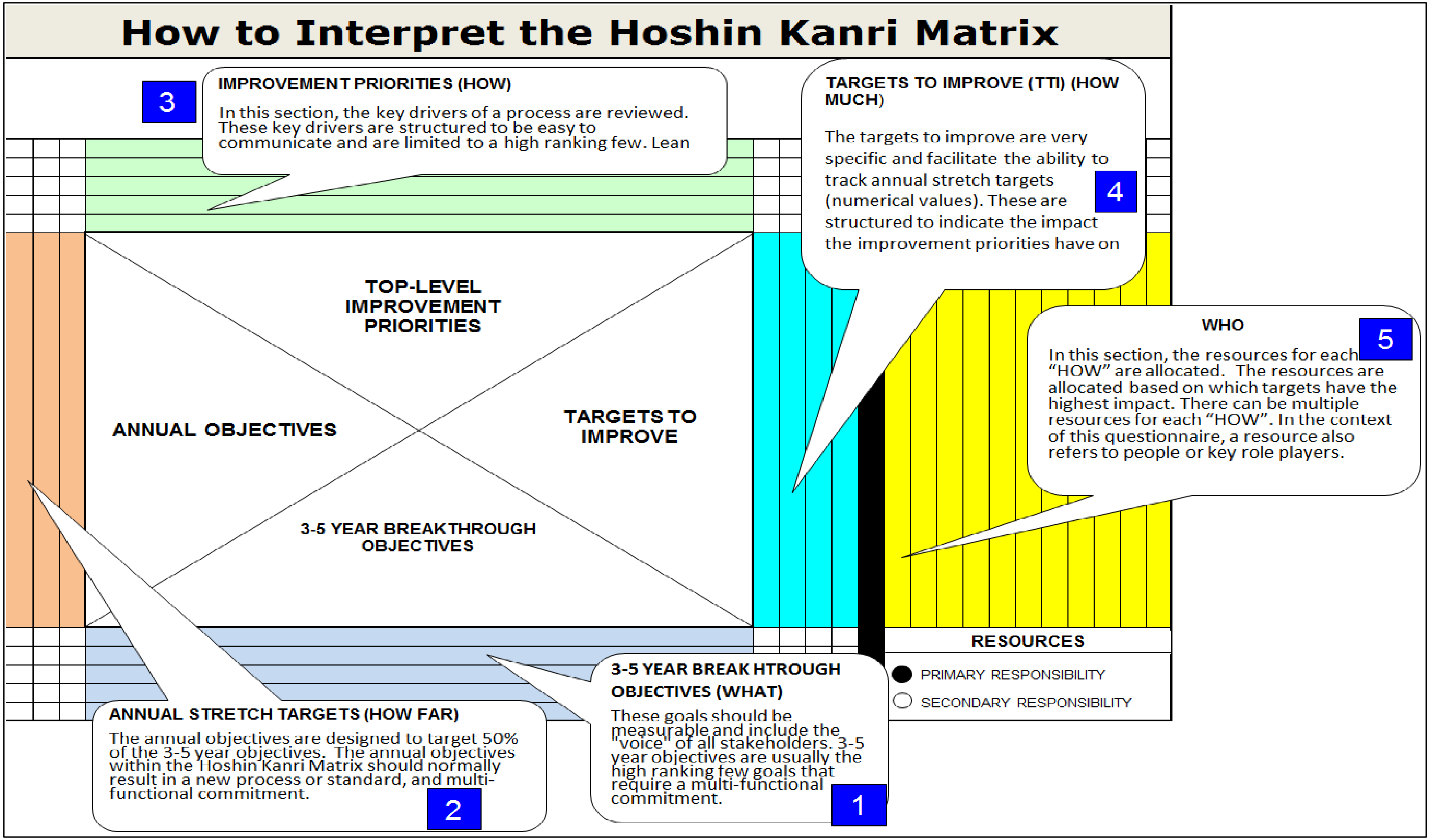


Figure 2.6-2: How to interpret the Hoshin Kanri matrix (source[online]: www.leanmethods/com)

A summary of the linkage between the organisational needs, the Hoshin planning steps and the Hoshin methods is presented in Table 2.6-1.

Table 2.6-1: Linkage of organisational needs, Hoshin planning steps, and Hoshin methods

Organisational needs	Hoshin Planning steps	Hoshin methods
Core vision	5-year vision 1-year Plan	Hoshin strategic plan summary
Alignment	Deployment	Hoshin plan summary
Self-diagnosis	Implementation	Hoshin action plan
Process management	Monthly reviews	Hoshin implementation plan
Target focus	Annual reviews	Hoshin implementation review

2.7 Delphi Technique

The Delphi technique is a commonly used and recognised method for gathering data from respondents within their field of expertise. Hsu (2007) and Green (2014) are of the opinion that the Delphi technique is well suited as a method of consensus building on a specific topic. The Delphi technique has been used in a broad array of studies; however, in their research on the use of the Delphi technique as a forecasting tool, Rowe and Wright (1999:354) argue that the following four key features are necessary for defining a procedure as a Delphi technique.

1. Anonymity
2. Iteration
3. Controlled feedback
4. The statistical aggregation of group responses

The Delphi technique, whether used as a forecasting tool or as a validation technique, has been accepted widely to be a three-iteration process. Green (2014:3) contends that the Delphi process can be summarised as follows:

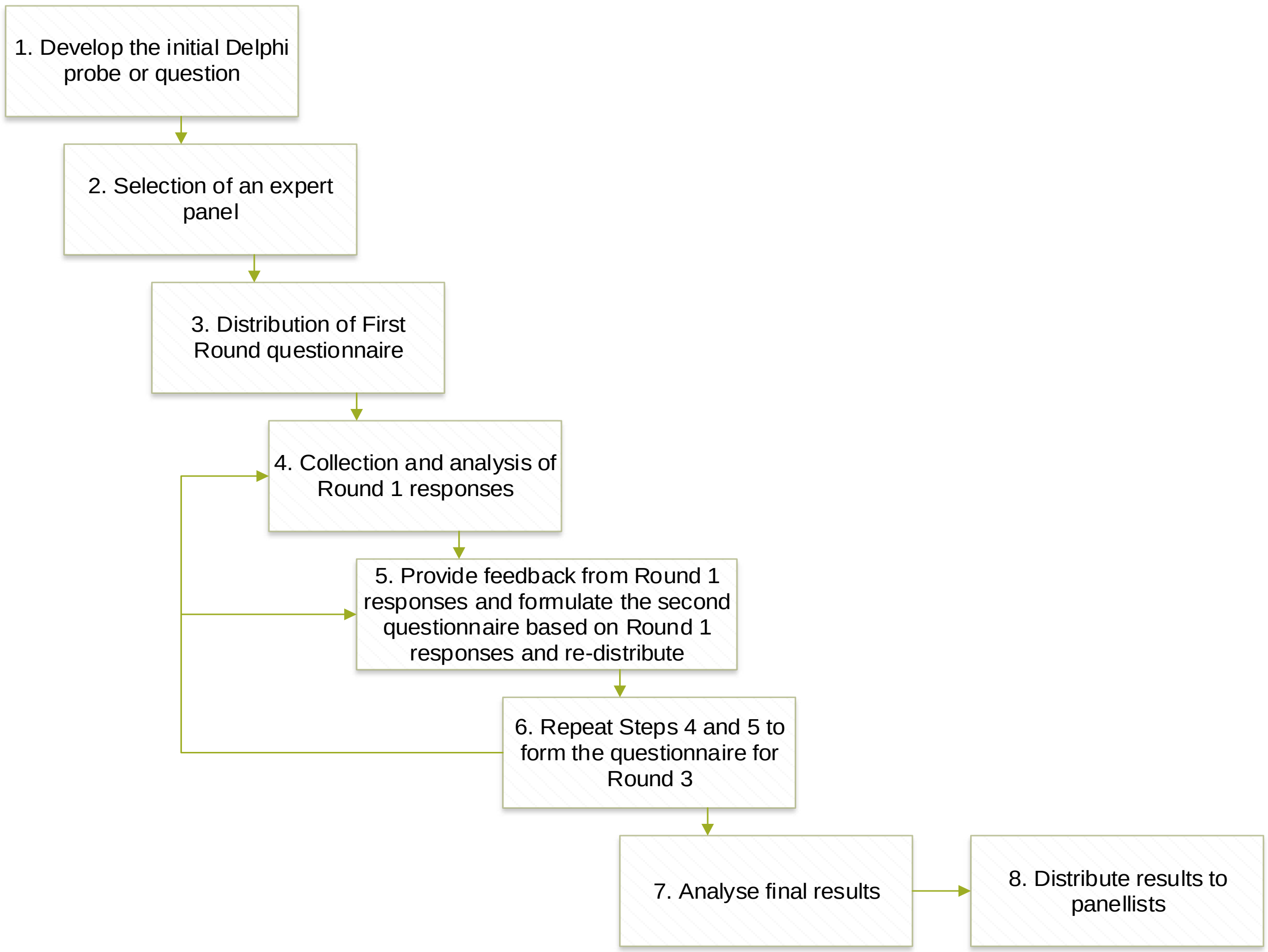


Figure 2.7-1: Three-iteration-based Delphi process

Adapted from Green (2014:3)

Contrary to the iterative advantages highlighted through the use of the Delphi technique, Hsu (2007:3) suggests that the information gathered from the Delphi study may have shortcomings and weaknesses due to low response rates and argues that the study can consume a large block of time. In addition to these shortcomings, Hsu (2007:3) views the Delphi to have the potential of moulding opinions and identifying general statements instead of specific topic-related information.

2.7.1 Selecting a panel

A key component of the Delphi technique is to identify an appropriate audience during the establishment of an expert panel. Okoli and Pawlowski (2004:20) present a multiple iteration process for the selection of the expert panel used for the Delphi process. They consider this method to be an effective way of eliminating various limitations of the process, and summarise the selection of the expert panel as follows:

- Step 1: Prepare Knowledge Resource Nomination Worksheet (KRNW)
- Step 2: Populate KRNW with names
- Step 3: Nominate additional experts
- Step 4: Rank experts

- Step 5: Invite experts

In their research on the value of Delphi Technique as an educational design research method, Bunag and Savenye (2013:1064) conclude that the technique “can be used to gather information from experts for a number of possible purposes, including model development”. The next paragraph covers Lawshe’s content validity ratio (CVR), which is commonly used to measure consensus on different subject matters.

2.7.2 Content validity ratio (CVR)

The measurement of content validity is widely attributed to the Content validity ratio (CVR) that C.H. Lawshe developed to measure the empirical worth of an object, product or a person in question (Taylor, 2017). According to Lawshe (1975), an important question to consider when performing academic achievement testing is to decide whose judgement is critical in determining how closely test content measures the instructional objectives of a study. As with the Delphi technique discussed in the previous section, Lawshe (1975:566) argues that a content evaluation panel with knowledgeable persons is critical to ensure that the communality or overlap of a test can be measured.

Lawshe’s content validity framework is founded on the principle of anonymity that is also associated with the Delphi technique, and Lawshe (1975:566) highlights that to achieve the outcomes of the CVR, feedback from the panelists needs to be independent from each other. Furthermore, Lawshe (1975:566) proposes that the contents or items that are quantified by the CVR can be sufficiently answered by using the following three options:

- Essential
- Useful but not essential
- Not necessary

The validity of judgement and quantifying consensus are two measures that are critical outcomes of content validity. Lawshe (1975:567) argues that the former, validity of judgement, potentially presents contrasting feedback, because all participants can be either “all wrong” or “all right”. To mitigate the limitation that is presented by the validity of judgement, Lawshe (1975:567) suggests that quantification of the consensus with regard to the feedback (results) received is essential and the feedback can generally be summarised as follows:

- Any item that is perceived to be "essential" by more than half of the participants, has some degree of content validity.
- The greater the number of participants (beyond 50%) who perceive the item as "essential," the greater the extent or degree of its content validity.

Lawshe (1975:567) summarises the computation of the Content Validity Ratio by using the following formula:

$$\mathrm{CVR} = \frac{\mathrm{N}_{\mathrm{essential}} - \frac{\mathrm{N}}{2}}{\frac{\mathrm{N}}{2}} \qquad [5]$$

where $N_{essential}$ represents the number of participants who indicated that an item being reviewed is “essential’, and N represents the number of participants. Lawshe’s (1975) CVR can be summarised as follows:

- When fewer than half of the participants say "essential," the CVR is negative.
- When half of the participants say "essential" and half do not, the CVR is zero.
- When all the participants say "essential," the CVR is computed to be 1.00. (It is adjusted to 0.99 for ease of manipulation.)
- When the of the participants number saying "essential" is more than half but less than all, the CVR is somewhere between zero and 0.99.

Based on Lawshe (1975)’s findings, a minimum value for convergence can be predicted using a one-tailed test (i.e. p = 0.05) and a summary of his findings is presented in Table 2.7-1

Table 2.7-1: Lawshe's minimum values for a different number of experts

Minimum value of CVR and CVR_t	
One-tailed test, p =0,05	
Number of Experts	Minimum Value
5	0,99
6	0,99
7	0,99
8	0,75
9	0,78
10	0,62
11	0,59
12	0,56
13	0,54
14	0,51
15	0,49
20	0,42
25	0,37
30	0,33
35	0,31
40	0,29

2.8 Discussion and summary of literature review

This chapter introduced lean manufacturing as a management philosophy by reviewing the extensive work that lean practitioners have conducted in eliminating the non-value-added work associated with craft and traditional mass production techniques. The literature covered in Section 2.1 does however argue that current lean principles were adapted from exploiting both traditional craft and mass production techniques, with this observation often omitted by lean practitioners.

The principle of value was introduced in Section 2.2.1 with Womack and Jones (2003:16) further contending that value, from a lean perspective, is driven by the needs of the customer. The views of Womack and Jones (2003:16) in Section 2.2.1 were strengthened by Liker (2004:43) who also emphasised that customer focused lean strategies are efficient in separating value-added activities from non-value added activities. Amin & Karim (2013:1147) do however argue that inclusive quantitative approaches (which are not too customer orientated) that focus on the organisation's needs are more practical in identifying which lean principles will add value to manufacturing and service organisations. Mathematical models that are developed to quantitatively assess the perceived contribution of lean strategies according to an organisation's improvement targets are however viewed by Amin and Karim (2013:1147) as optimum solutions. The principle of value introduced in Section 2.2.1 was followed by reviewing Rother and Shook (1999)'s widely used value stream mapping techniques, with emphasis on a 4-step VSM process that is considered critical for the elimination of muda in any organisation. The 4-step process introduced by Rother and Shook (1999) highlights that the most important component of VSM is the evaluation of the future state map in any process. On the contrary and in their review of lean manufacturing implementation techniques, Sundar et al. (2014) argue that the traditional and static value stream mapping technique introduced by Rother and Shook (1999) is limited by not being able to analyse inventory turns from future state VSMs. According to Sundar et al. (2014), the static nature of traditional future state mapping can be eliminated by using simulation tools to project inventory turns that are a result of changes in customer demands.

Section 2.2.3 introduced continuous flow by underlining that it [continuous flow] is one of the first deliverables that organisations undergoing lean transformation need to achieve within their manufacturing processes. The lean concept of continuous flow as highlighted by Liker (2004) is not limited to the flow of material, but can also be applied to information flow. Liker (2004)'s concept of information flow is further supported by Poppendieck (2002)'s previous reference to EBay's innovative use of lean trading to eliminate non-value added steps in the trading value chain. Even though Section 2.2.3 primarily focuses on the flow of material within an organisation and concept of lean suppliers, a gap still exists between literature that elaborates how lean can be used to maximise the flow of information and delivered value. The relationship between merits of continuous flow that were introduced in Section 2.2.3 were also shown in Figure 2.2-5, where continuous flow, takt time and pull systems were considered necessary for the Just-in-time principle to work.

In Chapter 2's introductory paragraph, it was highlighted that lean manufacturing is considered by Womack and Jones (2003) as a five step process that constitutes of Value, the Value stream, Flow, Pull and Perfection. The philosophy of a Pull system, which is the main component of the Just-in-time principle, is simply described by Womack and Jones (2003) as not producing goods or services until the customer downstream asks for it. A comparison of the challenges of Just-in-time (JIT), which [JIT] is considered as the first pillar of Toyota's Production System (TPS), have however been covered to a lesser degree in this research's literature review. In previous work on the challenges experienced in high variety production environments, Bennett & Forrester (1994) question the influence of JIT in relation to its role of inventory management. Bennett & Forrester (1994) emphasise that inventory reductions are achieved when JIT is implemented correctly, but argue that high variety production environments are often required to keep large stocks of different material or part-completed items – and conclude that "there is a dichotomy between inventory reduction and product variety". In a more recent study, Rahman et al (2013) also view inventory management as a challenging problem due to real life situations and consider supplier commitment as critical in ensuring the continuous flow of production lines.

The previous paragraphs have covered the lean principles of continuous flow and pull systems which are required to support the JIT management philosophy. In Section 2.2.6 of this chapter, Jidoka was introduced as the second pillar of Toyota production system (TPS) but more importantly and from a lean perspective, as the management philosophy that is required to support JIT. It is the author's view that Jidoka is however often omitted or commonly overlooked during lean transformation. Rosenthal (2002:1) supports this view by stressing that lean practitioners commonly focus on mechanisms of implementation (i.e. flow, takt time, standard work etc.), and contends that most lean implementations that fail can be traced back to not focusing on Jidoka as a second pillar. Finally and in Section 2.2.7, continuous improvement which is also referred to as "continuous and radical improvement" by Womack and Jones (2003:94) was introduced to underline the impact of centralised decision making. A conclusion is drawn by Womack and Jones (2003:94) that every organisation has the ability to radically improve as a whole if the correct value stream mechanisms of analysis are in place.

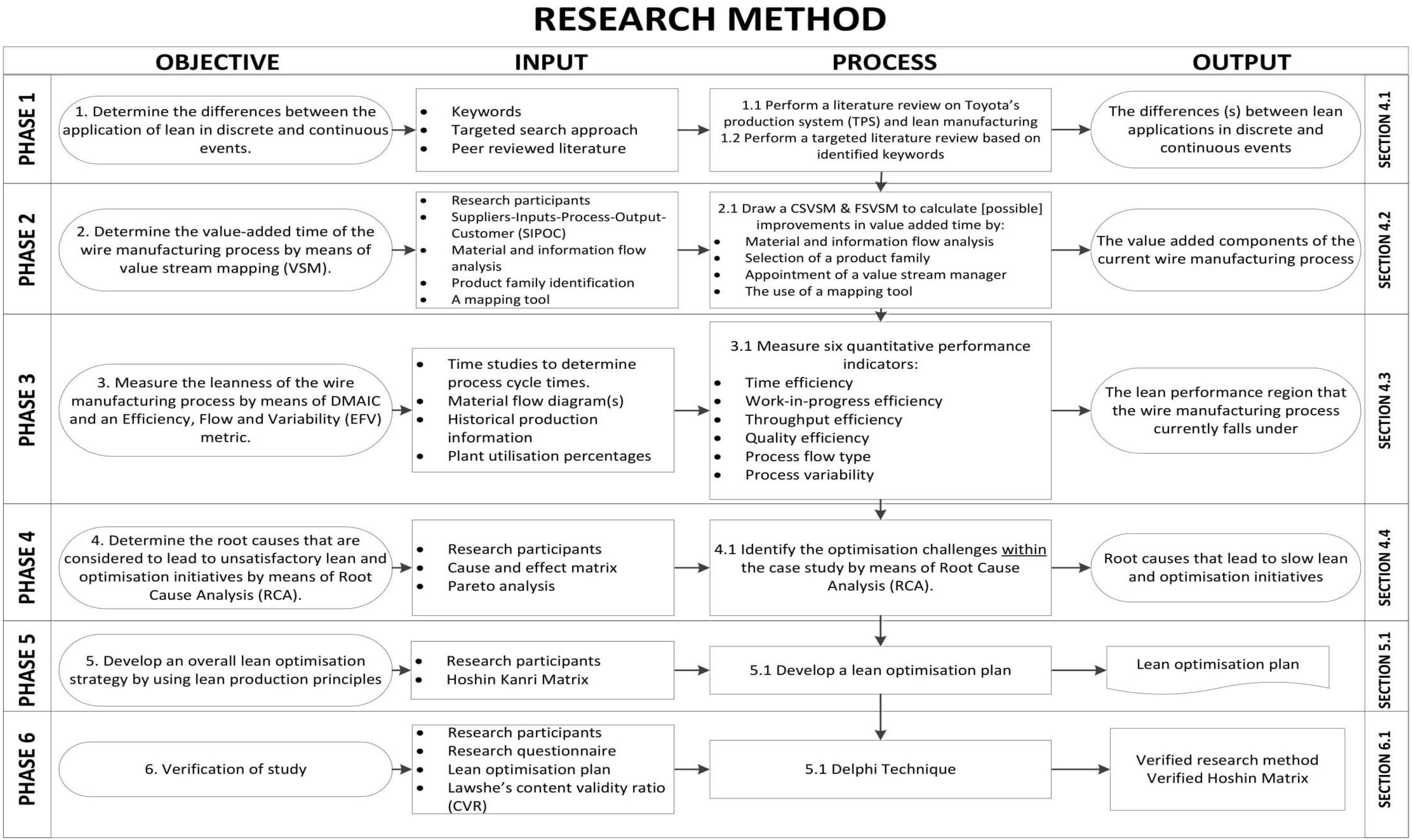
An overview of the applicability of lean principles was introduced in Section 2.3 to deliberate the effectiveness of lean manufacturing in various setting – namely, in discrete and continuous events. From the literature presented in this subsection, it can be argued that not all lean tools are viewed as applicable to continuous manufacturing environments primarily due to the large and rigid machinery used in traditional continuous organisations. The literature covered in Sections' 2.1 to 2.3 created a preamble for chapter 1's research aim and objectives, and this was followed by a literature review of lean optimisation tools, the lean six sigma methodology, visual management and policy deployment. The latter, policy deployment is considered a critical lean technique required to align an organisation's goals and vision. The lean concept of policy deployment is further viewed by Womack and Jones (2003:94) as follows – "The idea is for top management to agree on a few simple goals for transitioning from mass to lean, to select a few projects to achieve these goals, to designate the people and resources for getting the projects done, and finally, to establish numerical improvement targets to be achieved by a given point in time”. Therefore and from the literature review covered in this research, it is evident that lean as a management philosophy is required to banish muda but more especially to address this research’s problem statement introduced in Section 1.3.

CHAPTER 3: RESEARCH METHOD

3.1 Introduction

This chapter covers the research method used in this study. A mixed methods research approach founded on both quantitative and qualitative methods was used to gather the necessary data on which to base our empirical findings and to verify this study's final deliverable. In the next paragraph, a brief summary is given of this study's research flowchart.

In Figure 3.1-1, the objectives presented in each phase are introduced as part of Chapter 1's research aim and objectives. The intermediate inputs and the process required to achieve each output are also summarised for each objective. In Phase 1, for example, the objective was to determine the differences between the application of lean in discrete and continuous events. To achieve Phase 1's output, a literature review on Toyota's production system and Lean manufacturing was conducted in conjunction with a targeted literature review. Three inputs were identified for this phase, namely keywords, a targeted search approach, and peer-reviewed literature. The cognitive approach applied in Phase 1 was also adopted in the remaining five phases and it should be noted that the output of each phase was completed before the next phase commenced (as shown by the flow arrows used to link the processes in Phase 1 to Phase 6). A detailed analysis of the research method used for each phase is covered in the next subsections, with the results and findings from Chapter 3's research method also available in Chapter 4.



RESEARCH METHOD

	OBJECTIVE	INPUT	PROCESS	OUTPUT	
PHASE 1	1. Determine the differences between the application of lean in discrete and continuous events.	• Keywords • Targeted search approach • Peer reviewed literature	1.1 Perform a literature review on Toyota's production system (TPS) and lean manufacturing 1.2 Perform a targeted literature review based on identified keywords	The differences (s) between lean applications in discrete and continuous events	SECTION 4.1
PHASE 2	2. Determine the value-added time of the wire manufacturing process by means of value stream mapping (VSM).	• Research participants • Suppliers-Inputs-Process-Output-Customer (SIPOC) • Material and information flow analysis • Product family identification • A mapping tool	2.1 Draw a CSVSM & FSVSM to calculate [possible] improvements in value added time by: • Material and information flow analysis • Selection of a product family • Appointment of a value stream manager • The use of a mapping tool	The value added components of the current wire manufacturing process	SECTION 4.2
PHASE 3	3. Measure the leanness of the wire manufacturing process by means of DMAIC and an Efficiency, Flow and Variability (EFV) metric.	• Time studies to determine process cycle times. • Material flow diagram(s) • Historical production information • Plant utilisation percentages	3.1 Measure six quantitative performance indicators: • Time efficiency • Work-in-progress efficiency • Throughput efficiency • Quality efficiency • Process flow type • Process variability	The lean performance region that the wire manufacturing process currently falls under	SECTION 4.3
PHASE 4	4. Determine the root causes that are considered to lead to unsatisfactory lean and optimisation initiatives by means of Root Cause Analysis (RCA).	• Research participants • Cause and effect matrix • Pareto analysis	4.1 Identify the optimisation challenges within the case study by means of Root Cause Analysis (RCA).	Root causes that lead to slow lean and optimisation initiatives	SECTION 4.4
PHASE 5	5. Develop an overall lean optimisation strategy by using lean production principles	• Research participants • Hoshin Kanri Matrix	5.1 Develop a lean optimisation plan	Lean optimisation plan	SECTION 5.1
PHASE 6	6. Verification of study	• Research participants • Research questionnaire • Lean optimisation plan • Lawshe's content validity ratio (CVR)	5.1 Delphi Technique	Verified research method Verified Hoshin Matrix	SECTION 6.1

Figure 3.1-1: A flow diagram of this study's research method

3.2 Phase 1: Application of lean in discrete and continuous events

In addition to the literature reviewed in respect of Toyota's Production System (TPS) and lean manufacturing principles in Chapter 2, a literature review was conducted to determine the key differences between the application of lean in continuous and discrete events. A five-step literature review was followed as shown in Figure 3.2-1 and the following key components were analysed (De Montfort University, 2013):

1. Selection of research question (conducted in Chapter 1)
2. Search plan
3. Evaluation and capturing of findings
4. Review of search plan
5. Synthetisation of findings

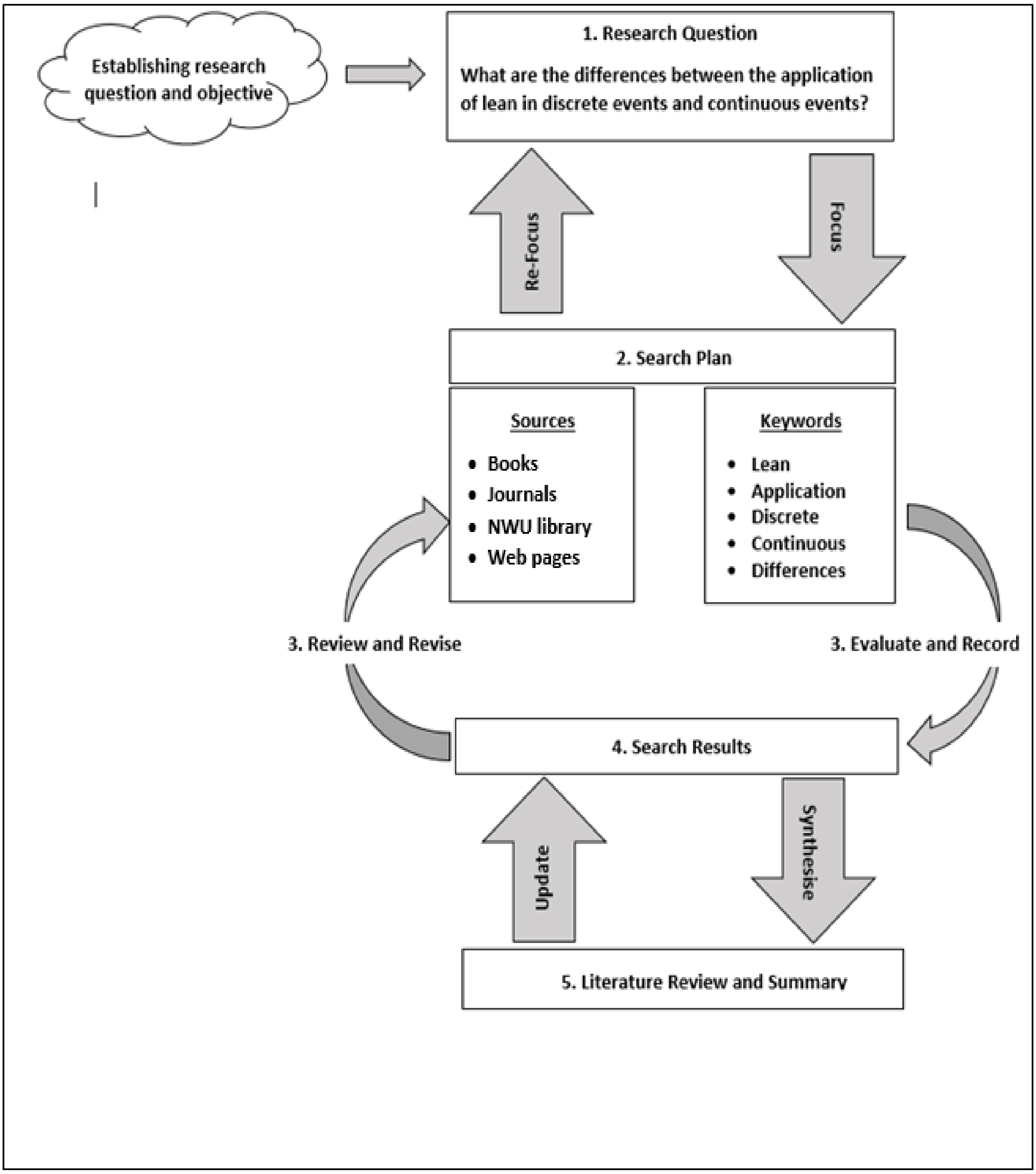


Figure 3.2-1: Interaction between literature search and review steps

Adapted from De Montfort University (2013)

3.2.1 Step 1 – Selection of research question (Chapter 1)

The research question presented in this section was formulated to meet one of the study's objectives, namely to identify the fundamental differences between lean applications in discrete and continuous events. The research question was presented as follows (see Section 1.4):

> 1. What are the differences between the application of lean in discrete events and continuous events?

3.2.2 Step 2 – Search plan

Four different search approaches, namely a systematic search approach, retrospective search approach, citation-based search approach and targeted search approach were considered in this sub-section of the search plan. A targeted search approach was chosen to ensure that the search topics were restricted to focus on the narrow study of lean and lean manufacturing methodologies.

Table 3.2-1 summarises the targeted search approach that was used to gather the information in this section. The keywords, expanders, limiters and language restrictions are also provided in Table 3.2-1 (De Montfort University, 2013)

Table 3.2-1: Search plan used to identify the differences between lean applications in continuous and discrete events

Search mode and expanders	Search terms
Keywords	Lean **AND** manufacturing **AND** process **OR** discrete **OR** continuous **OR** challenges **OR** differences
Expanders	· Also search within the full text of the articles and e-books · Apply equivalent subjects
Limiters	· Peer reviewed · Date published: 1998 to 2018
Limit by language	· English

3.2.3 Step 3 – Evaluation and capturing of findings

The search results were evaluated to determine whether they were aligned with the research question presented in Step 1. The references of all search results that fell within the scope of the research question were captured in Table 4.1-1 under Chapter 4's findings for further review and synthesis as highlighted in the subsequent steps (4 and 5).

3.2.4 Step 4 – Reviewing of search plan

As was illustrated in Figure 3.2-1, the most relevant search results were identified to determine if they contain the minimum keywords that can be used to describe the differences between lean applications in discrete and continuous events. The search plan was further reviewed to substantiate whether sufficient information was available, and an additional search was conducted using the search plan in Step 2 (where necessary).

3.2.5 Step 5 - Synthetisation of findings

The findings were grouped according to Liker's (2004) 4P dimensions of lean transformation, namely Problem Solving; People and Partners; Process; Philosophy. The findings from Phase 1 are summarised and tabulated under the research findings for Chapter 4.

3.3 Phase 2: Value stream mapping (VSM)

The value stream of the wire-manufacturing process was modelled using the four value-stream-mapping (VSM) steps introduced by Rother and Shook (1999) for creating value and eliminating Muda:

1. Analysis of material and information flow
2. Selection of a product family
3. Appointment of a value stream manager
4. Drawing of value stream maps

Each value proposition presented by Rother and Shook (1999) is analysed in the sub-sections below, and emphasis is placed on the method used to draw the current and ideal future state maps.

3.3.1 Analysis of material and information flow

A suppliers-input-process-output-customer (SIPOC) analysis was used to determine the main components required to deliver finished products to both internal and external customers. The SIPOC analysis also facilitated the mapping of the material and information flow diagram presented in Annexure A, and an analysis was made of all customer-driven wire sizes so as to determine the product family.

3.3.2 Product family analysis

The product family was determined by analysing all wire sizes produced prior to and during the research period (18 months) to determine the most frequently produced wire size range(s). The analysis of the product family also helped to identify a product that was produced from the first until the last stage of the wire-manufacturing process reviewed in this study.

3.3.3 Appointment of value stream manager

In the context of this study, the value stream manager was the main author of this research dissertation.

3.3.4 Drawing of value stream maps

The wire manufacturing's value proposition was drawn using the generic VSM symbols shown in Annexure A. A time-and-motion study was conducted for each intermediate production process, and a list of the various work elements required for each complete cycle is summarised in Annexure A. Altogether three observations for each work element were captured and used as the basis for computing the mean and the standard deviation of each element.

Microsoft's Visio© was used to model the average process lead time for the product family used in this case study. The current state map's value-added and non-value-added components were displayed in the timeline segment shown at the bottom of the current state value stream map presented under Chapter 4's findings (see Figure 4.2-2).

The current state map was later used to conduct a kaizen meeting with internal research participants to identify continuous improvement opportunities within the wire-manufacturing process. The research participants consisted of departmental managers including their respective subordinates, and each research participant was provided with an opportunity to highlight any concerns they had with the data that was captured and presented in the current VSM. Value-added process recommendations were identified and these [recommendations] were used to compute the ideal future state process lead time. The findings for both the current state and future state maps are presented in Chapter 4.

3.4 Phase 3: Measuring the leanness of wire-manufacturing processes

The leanness of the wire-manufacturing process was measured using an integrated efficiency, variability and flow (EFV) metric adapted from Deif et al. (2015). The EFV metric used in Phase 3 of this study is based mainly on lean principles and involves six quantitative performance measures:

1. Time efficiency
2. Work-in-progress (WIP) efficiency
3. Throughput efficiency
4. Quality efficiency
5. The process flow type
6. The process variability

Prior to the adaptation and use of the EFV metric to establish the leanness of the wire-manufacturing process, data was collected using the mediums listed below.

- Historical production information from all wire diameters produced
- Motion and time studies required to produce the selected product family identified in Phase 2
- Plant utilisation percentages
- Historical non-conforming production figures

The results that emerged from the leanness assessment of the wire-manufacturing process were further compared against the EFV's metric scale as presented in Table 3.4-1.

Table 3.4-1: EFV performance rating scale

	Performance rating	Scale
Zone 1	Inefficient performance	-1 < EFV < 0
Zone 2	Potential improvement	0 < EFV < 1
Zone 3	Good performance	1 < EFV < 2

Source: Deif et al. (2015:50)

Note: The number of stages (n) and the number of machines (m) were computed using the process flow diagram provided in Figure 4.3-3. In this study, 12-stages (n) were observed and the galvanizing line from which the identified product family was produced was considered as one machine (m).

3.4.1 Time efficiency

The time efficiency for the wire-manufacturing process was measured using Equation 6 and it [time efficiency] was denoted as E_t (Deif et al, 2015:48):

$$E_t = \frac{\sum V_t}{\sum W_t + \sum V_t} \qquad [6]$$

From Equation 6, it can be observed that the time efficiency of the wire manufacturing process was composed of the value-added-time (V_t) and the process waste-time (W_t). It should also be noted that the value-added time and the process-waste time were calculated using Section 3.3's research method. The process waste time above was calculated using three forms of waste introduced in Table 2.2-1 as follows (Deif et al, 2015:48):

$$\sum W_t = \sum [T_i + T_m] \qquad [7]$$

Where the idle-waiting time (T_i) was computed using equation 8 as follows (Deif et al, 2015:48):

$$T_i = \sum_{i=1}^{m} I_m + \sum_{i=1}^{n} \sum_{j=1}^{m} I_w \qquad [8]$$

From Equation 8 above, I_m and I_w represent the ideal machine waiting-time and the ideal worker waiting-time, respectively. Both of the preceding forms of waste were computed from the time and motion studies that were conducted in this study.

Similarly, the motion waste-time (T_m) which is composed of the forms of waste associated with employee motion and transportation waste-time during the measured manufacturing process was calculated using equation 9 as follows:

$$\mathrm{T_m} = \sum_{i=1}^{m} M_{\mathrm{w}} + \sum_{i=1}^{m} M_{\mathrm{p}} \qquad [9]$$

3.4.2 Work-in-progress efficiency

The work-in-progress efficiency was calculated using Equation 10 as follows (Deif et al, 2015:48):

$$\mathrm{E_{wip}} = \frac{\sum_{i=1}^{n}\sum_{i=1}^{m} \mathrm{TH} \text{ x } \sum_{i=1}^{n}\sum_{i=1}^{m} \mathrm{V_t}}{\sum_{i=1}^{n}\sum_{i=1}^{m} \mathrm{WIP}} \qquad [10]$$

With reference to Little's law which was introduced in Equation 2, the throughput (TH) and the work-in-progress (WIP) were calculated using the number of galvanized coils produced per hour, and the number of coils that are being processed at any given time (- respectively). The value-added time used to calculate the work-in-progress efficiency was the same value ($\mathrm{V_t}$) that was used in Equation 6 to calculate the time efficiency.

3.4.3 Throughput efficiency

The throughput efficiency was mainly used as a measure of calculating one of the forms of lean waste introduced in Table 2.2-1 – Overproduction. The throughput efficiency was calculated using equation 11, and it was measured as a ratio of the minimum over the maximum process throughput as follows (Deif et al, 2015:49):

$$\mathrm{E_{th}} = \frac{\min\{\mathrm{Throughput}\}}{\max\{\mathrm{Throughput}\}} \qquad [11]$$

In conjunction with Equation 11, the throughput of the wire manufacturing process was calculated using historical production figures from the three shifts that are were used to produce the product identified in Section 3.3.2.

3.4.4 Quality efficiency

The Quality efficiency was mainly used as a measure of calculating another form of lean waste introduced in Table 2.2-1 – Defects. The quality efficiency was calculated using Equation 12 and it was measured as a ratio of the number of products with defects (referred to non-conforming products in this study) over the overall production during the specified period. The weighted average of non-conforming production holds was measured as a percentage, and this percentage was used to represent the number of "parts with defects" in Equation 12 as follows (Deif et al, 2015:49):

$$E_q = \frac{\sum_{i=1}^{m} \text{parts with no defects}}{\sum_{i=1}^{m} \text{parts with no defects} + \sum_{i=1}^{m} \text{parts with defects}} \quad [12]$$

The weighted efficiency of the wire manufacturing process was calculated using findings from Equation 6, 10, 11 and 12 as follows (Deif et al, 2015:49):

$$\text{Weighted efficiency} = \frac{E_t + E_{wip} + E_{th} + E_q}{4} \quad [13]$$

3.4.5 Wire-manufacturing process' flow type

The Process' flow type was established by reviewing the push, pull and continuous nature of the various stages used during the product family's manufacturing process. Intermediate processes that were established to be of a "push" nature were assigned with a value of zero. Similarly, intermediate stages of a pull or continuous components were assigned with values of one and 0.5, respectively. The overall system's flow type was calculated using Equation 14 as follows (Deif et al, 2015:49):

$$\text{Process flow type} = \frac{\sum_{i=1}^{m-1} F_i}{m-1} \quad [14]$$

With reference to Equation 14, it should be observed that the system's flow type used in this study falls within a region of $0 \leq F_i \leq 1$.

3.4.6 Wire-manufacturing process' variability

The variability of the wire manufacturing process was measured by considering the standard deviation of the different stages used during the manufacturing process. This was achieved by performing a motion and time study which is presented in Table 8.2-4 and the process' variability was calculated as follows (Deif et al, 2015:49):

$$\text{Overall process variability} = \sum_{i=1}^{m} CV_i \quad [15]$$

Where CV is the ratio of the standard deviation over the mean as follows (Deif et al, 2015:49):

$$\mathrm{CV} = \frac{\sigma}{\mu} = \frac{\text{standard deviation}}{\text{mean}} \qquad [16]$$

3.5 Phase 4: Determining the root causes that are considered to lead to slow lean transformation and optimisation initiatives

Section 3.5 contains a review of the research process that was used to establish the root causes that are considered to lead to slow lean transformation and optimisation initiatives in the wire-manufacturing process (by the research participants). The research method for the Pareto analysis, founded on the root cause analysis (RCA)'s findings, is also discussed in Section 3.5.

3.5.1 Root Cause Analysis (RCA)

The root cause analysis (RCA) technique, as described by James-Ward et al. (2012), was considered – from an optimisation perspective – as a medium to identify which area of the manufacturing process should be allocated the most resources. In addition to identifying which area (component) of the organisation to focus on, application of the RCA technique helped to achieve one of the aims of this research, namely to determine the root causes of unsatisfactory lean optimisation initiatives. A summary of the aggregate root cause analysis steps was presented in Table 2.5-2 and out of the eleven aggregate root-cause steps presented in this table, nine were used in total. Steps 10 and 11 were omitted mainly because they involve analysing the actions required for implementation, which are beyond the scope of this study. The nine RCA steps used in Phase 4 of this research method were broken down to achieve the following:

1. Charter a team with knowledge on the subject matter
2. Draw the current state value stream map of the wire-manufacturing process
3. Use text to describe how the participants view the general manufacturing process
4. Identify the resources required to produce products
5. Use data to determine the focus of this aggregate review
6. Determine the root cause by means of a fishbone diagram
7. Develop contributing factors
8. Review contributing factors by using the five rules of causation (5-why's)
9. Write outcomes measures

Six primary affinities, namely measurement, materials, method, manpower, machine and environment were used to group the root causes that emerged from the brainstorming session with the purposefully chosen research participants. The six primary affinities were presented to the chartered team in the form of a fishbone diagram and a brief explanation of what is required was communicated to the participants prior to the brainstorming session. The root causes(s) were subsequently used in the adaptation of a cause-and-effect matrix which facilitated the Pareto analysis discussed in Section 3.5.2.

3.5.2 Pareto analysis

A Pareto chart was used to establish which root causes the research participants considered as the leading optimisation challenges within the wire-manufacturing process. The input for the Pareto analysis was gathered by using the information obtained from the root cause analysis discussed in the preceding sub-section, and multi-voting was used to establish the weighted outputs for the cause-and-effect matrix. The identified root causes from each primary affinity were ranked and quantified using a rating scale of 1 to 10 (1 = Least Impact and 10 = Most Impact). The Pareto diagram was then analysed based on the percentage effect by input and the 80/20 rule was used to determine the leading “lean optimisation” barriers.

3.6 Phase 5: Documenting an optimisation plan

In Phase 5 of this research, a Hoshin Kanri matrix was used to meet the research’s objective of documenting an optimisation plan. The matrix facilitated the summary of all the results and findings gathered in Phases 1 to 4, and these findings were further fragmented to meet the strategic planning steps presented in the matrix as follows (see Figure 3.6-1):

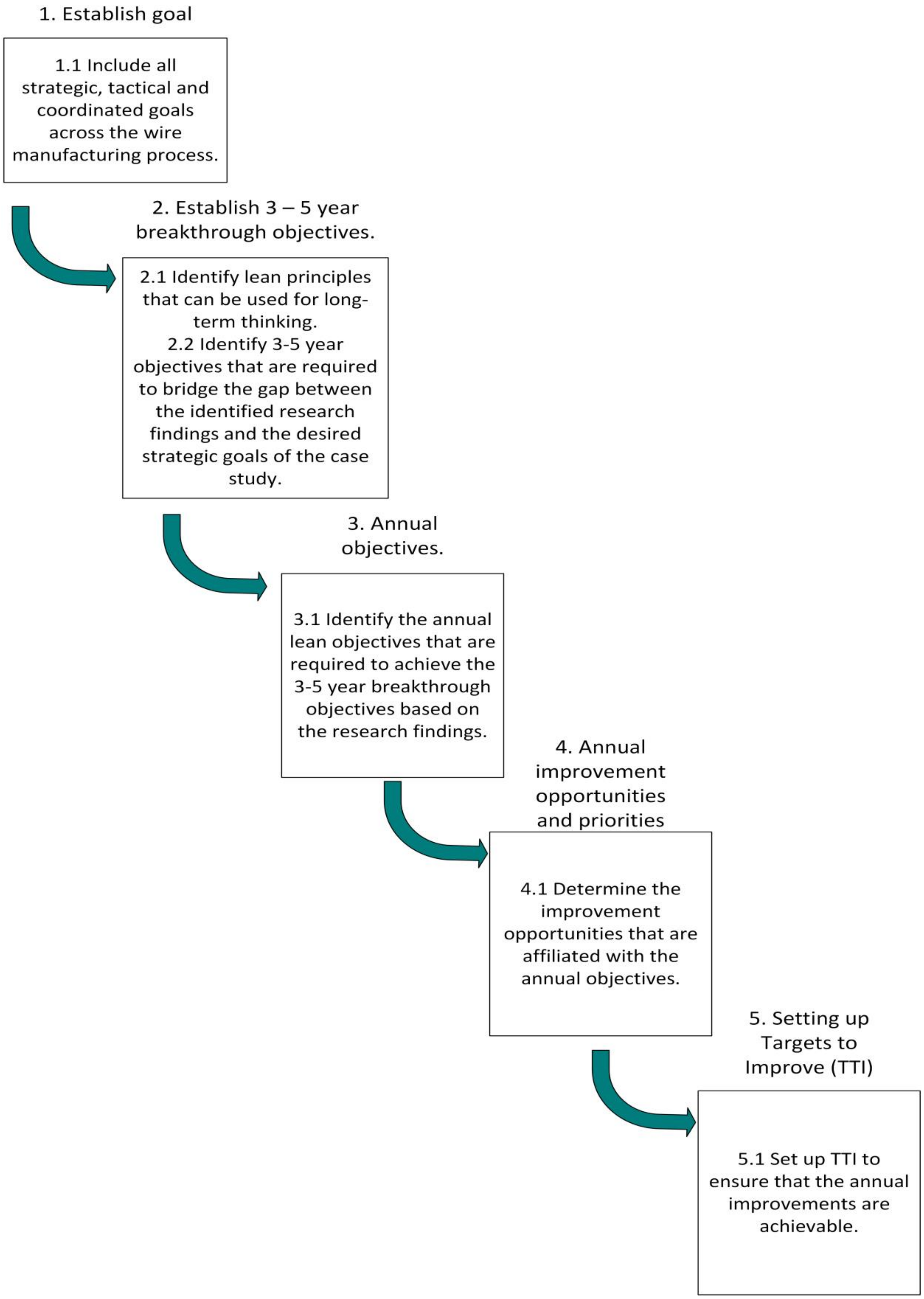


Figure 3.6-1: Hoshin Kanri steps used to achieve this study's deliverable

3.6.1 Establish the goal

The goal of the optimisation plan was established as part of the research aim and objectives stated in Chapter 1. The goal of the Hoshin Kanri matrix is to ensure that the strategic goals are driven and communicated at every level of the wire-manufacturing process by summarising and documenting a lean optimisation plan.

3.6.2 Establish 3- to 5-year breakthrough objectives

The 3- to 5-year breakthrough objectives were formulated to ensure that the goal of the Hoshin Kanri matrix is measurable and secures a multi-functional commitment from stakeholders in the wire-manufacturing processes.

3.6.3 Establish annual objectives

The annual objectives were introduced to meet at least 33-50% of the 3- to 5-year objectives that had been established as breakthrough objectives. The following coding system was used to highlight the linkage between the annual objectives and the 3- to 5-year breakthrough objectives:

- A filled-in circle (●) to indicate *a strong relationship* between the strategic goal and the annual objective.
- An open circle (○) to indicate *a direct relationship* between the annual objective and the 3- to 5-year breakthrough objectives. These are the annual objectives that were linked to the 3- to 5-year breakthrough objectives but were not necessarily considered to be a key driver for that strategic goal.

3.6.4 Identify annual improvement opportunities and priorities

The key drivers of the process improvements were identified and the high-ranking drivers that are required to lead to multi-functional commitment are presented in this section of the Hoshin Kanri matrix. The annual improvement opportunities and priorities were constructed to be measurable and a baseline for these metrics was further benchmarked on the current performance of the wire-manufacturing process.

3.6.5 Setting up Targets to Improve (TTI)

The Targets to Improve (TTI) were determined to be the specific targets that have an effect on the annual objectives of the optimisation plan.

3.7 Phase 6: Verifying the Hoshin Kanri matrix

The Hoshin Kanri matrix was verified using the key components covered in the literature review in Chapter 2. The connection between the research topics in Chapter 2 and the requirements for the verification of the Hoshin Kanri matrix is illustrated in Figure 3.7-1.

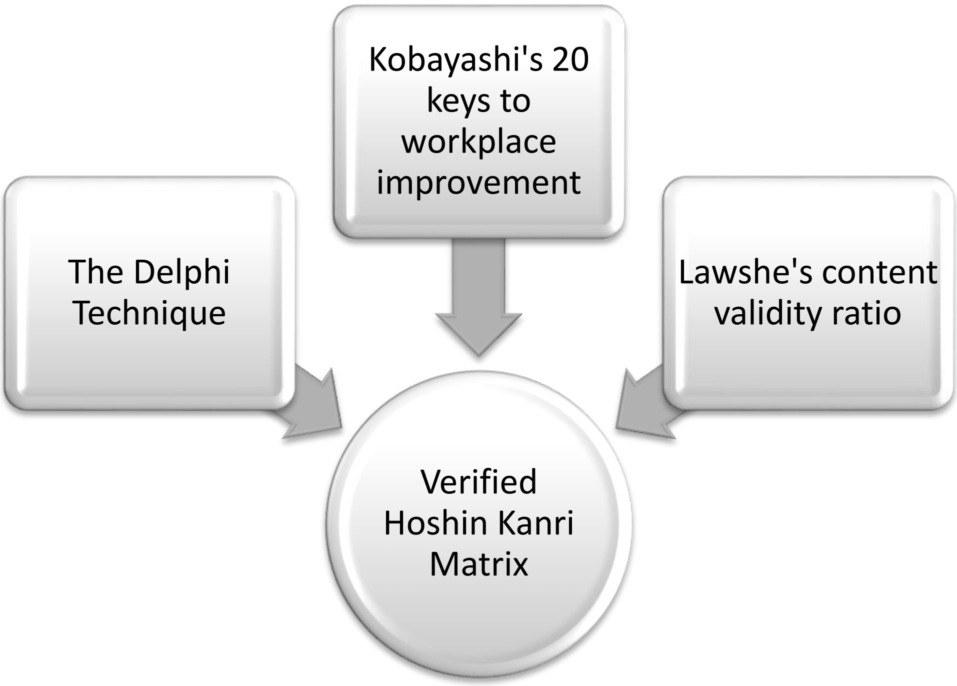


Figure 3.7-1: Framework used to verify this study's optimisation plan, the Hoshi Kanri Matrix

3.7.1 Design of research questionnaire

This sub-section discusses the research questionnaire that was prepared to verify the final deliverable of this study, namely the Hoshin Kanri matrix. The questionnaire was prepared to verify whether this matrix addresses the research aim and objectives as introduced in Chapter 1 (see Figure 3.7-2).

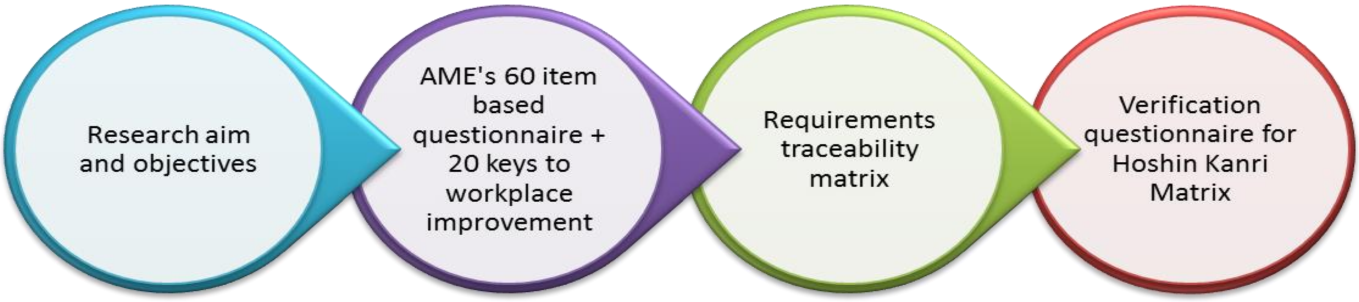


Figure 3.7-2: Aims and objectives considered by the research questionnaire

The research questionnaire was adapted from the 60-item self-assessment questionnaire from the Association of Manufacturing Excellence (AME), which focuses on benchmarking lean enterprises comprising the following sub-categories:

1. Management System
2. Human and Organisational Development
3. Safety and Environmental Health
4. Manufacturing Operations
5. Business Operations
6. Product Development
7. Supplier Development & Procurement
8. Quality
9. Cost
10. Delivery
11. Profitability

A Requirements Traceability Matrix (RTM) was created to establish which of the key sub-categories listed above are relevant to this study, and which could be used in conjunction with Kobayashi’s 20 keys to workplace improvement to verify the final deliverable of this study. The RTM is provided in Annexure B and it can be observed that some of the sub-categories provided in the AME questionnaire were **not** considered for this study’s verification questionnaire. The following sub-categories were excluded mainly because they did not fall within the scope of the research aim and objectives established in Chapter 1:

- Sub-category 3: Safety and environment
- Sub-category 6: Product development
- Sub-category 9: Cost
- Sub-category 11: Profitability

The remaining items from AME's initial 60-item self-assessment questionnaire were modified to resemble Lawshe's content validity questions. This was achieved by restricting each item to a closed response for which only one of the following options could be selected:

1. Essential
2. Useful, but not essential
3. Not essential

The final research questionnaire consisted of 24-items and a sample of the original questionnaire that was distributed to each participant can be found in Appendix B. In the next subsection, the research method used to determine the validity of judgements (i.e. convergence) in the research questionnaire is discussed.

3.7.2 Convergence and number of iterations of the Delphi Technique

An iterative Delphi technique was used to verify whether the Hoshin Kanri matrix could effectively be used as an optimisation plan for this study. A Knowledge Resource Nomination Worksheet (KRNW) was populated to identify and rank research participants who could help to verify the elements presented in the Hoshin Kanri matrix. An evaluation panel consisting of ten internal and five external experts[5] was identified based on either their industrial engineering or wire-manufacturing background. A summary of the KRNW can also be found in Appendix B.

In Round 1 of the Delphi technique, the Hoshin Kanri matrix that was documented in Section 3.6 was distributed to each research participant via electronic mail (email). A 24-item questionnaire was used to determine the extent to which a consensus or an overlap exists between the Hoshin Kanri matrix and its goal of being used to provide a road-map to address the gap between the current wire-manufacturing process and the desired performance.

The convergence after each round of the iteration was computed using Lawshe's content validity ratio (refer to the literature review in Chapter 2). According to Lawshe (1975), any item under review has a greater degree of convergence when more than half of the participants consider the item as "essential". In the context of this study, the minimum value required for convergence was established using the 15 participants in conjunction with the content validity formula introduced in Section 2.7.

$$\mathrm{CVR} = \frac{\mathrm{N}_{\mathrm{essential}} - \frac{\mathrm{N}}{2}}{\frac{\mathrm{N}}{2}} \qquad [5]$$

In the formula provided above, $\mathrm{N}_{\mathrm{essential}}$ represents the number of participants who marked an item as essential, with N indicating the total number of research participants. The minimum CVR value was

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[5] Internal experts refer to participants within the wire-manufacturing industry whereas external experts refer to personnel with knowledge on lean and lean optimisation tools.

established using Figure 3.7-3 below in conjunction with Table 3.7-1, where it can be observed that the minimum value required for consensus from a pooled validity of 15 judgements is 0.49. Figure 3.7-3 also provides a comparison of the CVRs that are required for varying panel sizes from two additional studies. It can be observed in the Figure 3.7-3 that a CVR of 0.49 is a valid approximation for a panel size of 15 participants (i.e. based on the critical normal approximation). This minimum CVR values shown in Figure 3.7-3 also fall within the 95% confidence interval for a varying number of research participants and are summarised in Table 3.7-1.

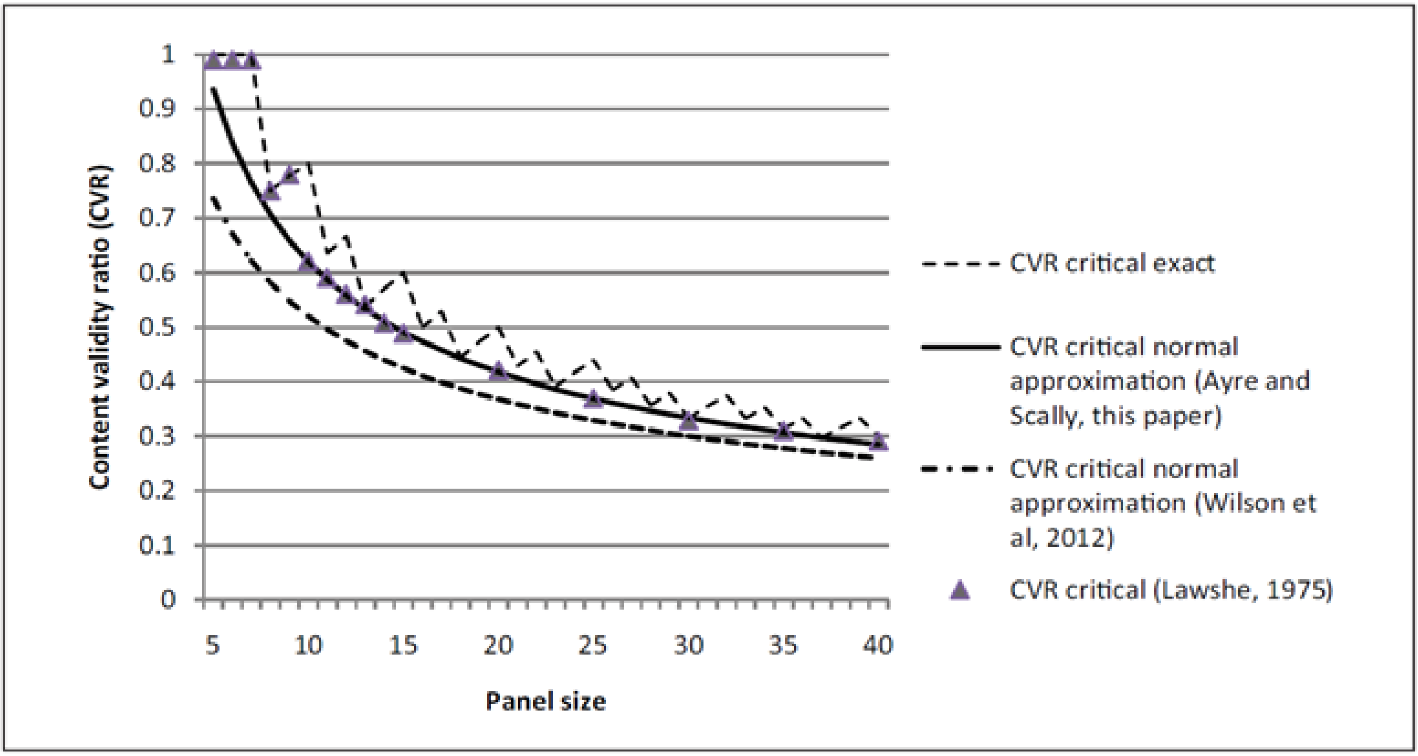

Figure 3.7-3: Comparison of content validity ratio approximations from different authors

Table 3.7-1: Lawshe's minimum values for a different number of experts

Minimum value of CVR and CVR_t	
One-tailed test, p =0,05	
Number of Experts	Minimum Value
5	0,99
6	0,99
7	0,99
8	0,75
9	0,78
10	0,62
11	0,59
12	0,56
13	0,54
14	0,51
15	0,49
20	0,42
25	0,37
30	0,33
35	0,31
40	0,29

Furthermore, a generic flow diagram that illustrates the number of iterations used to verify the optimisation plan is presented in Figure 3.7-4. Note that a content validity index (CVI), which is the mean value of the CVRs, was calculated for each item after each round of the Delphi (from the 24 items). The questionnaire used to verify this study’s Hoshin Kanri matrix was re-distributed until a minimum average CVI value of 0.49 was computed for the remaining items that were retained after each round of the Delphi.

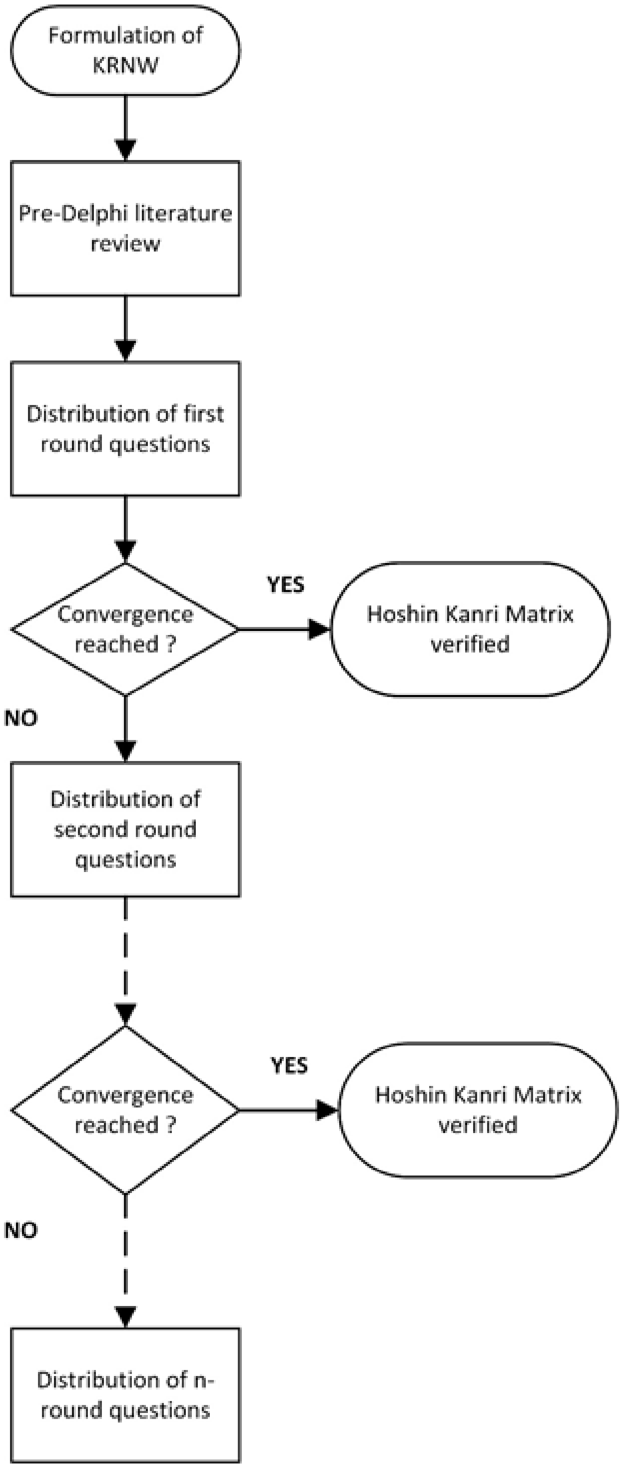

Figure 3.7-4: Flow diagram of the use of the Delphi Technique to verify this study's

Adapted from Bunag & Savenye (2013)

CHAPTER 4: RESEARCH RESULTS AND FINDINGS

4.1 Application of lean in discrete and continuous events

The research method used in Phase 1 of this study is presented in Figure 4.1-1. As previously mentioned in Chapter 3, the objective of Phase 1 was to establish the difference(s) between the application of lean in discrete and continuous events. A summary and a discussion of the findings from this phase 1 are also presented in this subsection.

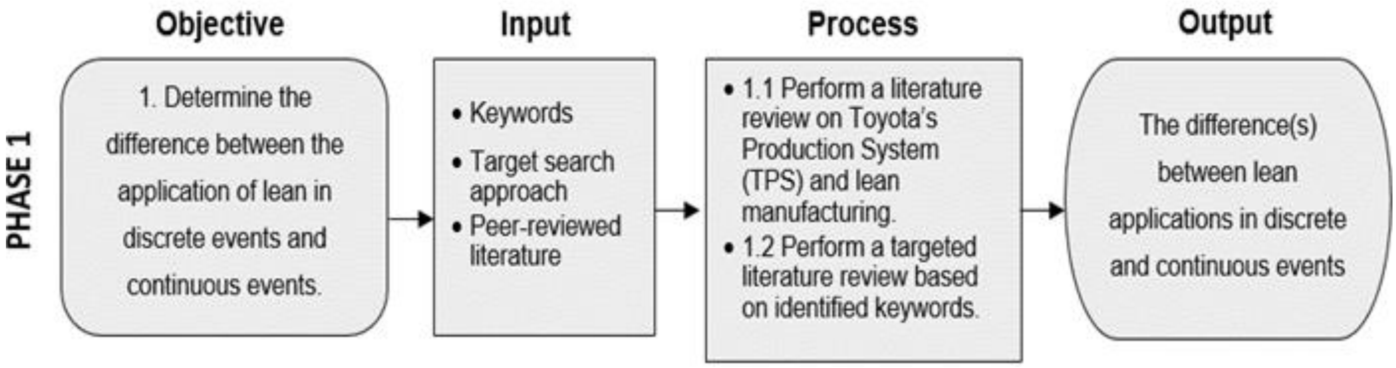

Figure 4.1-1: Phase 1 – Flow diagram

4.1.1 Phase 1's results and findings

Table 4.1-1 provides an overview of the key challenges that were identified from various studies in which lean was applied or considered as a management strategy. The differences between lean applications in discrete and continuous events were categorised using the 4P model of the Toyota Way (Liker, 2004), and these differences are summarised in section in Table 4.1-2.

Table 4.1-1: A summary of the literature review findings from Phase 1's research method

	4P dimensions of lean transformation	Quotation	Reference
1	Process/Problem & Solving	"The lean tool Andon, or 'line stop', which is immensely valuable in mechanical manufacturing, is inappropriate for use in most process manufacturing because our processes do not stop and start in the same way as theirs do."	(Floyd, 2010)
2	Process	"Not all traditional lean tools apply in continuous process environments (cells, intra-process Kanban). Forcing them can be disastrous."	(Howell, 2010)
3	Philosophy/Process	"It is difficult to use the cellular manufacturing concept in the process facility due to the fact that equipment is large and not easy to move."	(Esfanyari, et al., 2007)
4	Process	"It is much more difficult or impossible to produce in small lots in the process industry, where setup times tend to be long and it is costly to shut down the process for a changeover."	(Esfanyari, et al., 2007)
5	Process	"On the other hand, applicability of lean methodologies on process sectors still remains behind due to the rigid properties of these sectors (i.e. inflexible equipment, long set-up and changeover times)."	(Clotet, 2015)
6	Process	"Heijunka and Kanban are difficult to apply in process-type industries due to the capacities of the production system, where resource utilisation is the key and large batch runs are the answer."	(Powell, et al., 2010)
7	People & Partners	"Berry and Cooper (1999) suggest that batch process industry generally has a highly-skilled workforce which facilitates quick changes in set-ups and product variety, whereas continuous process industry generally has a lower skilled workforce."	(Panwar, et al., 2015)
8	Process	"Kanban and cell manufacturing are not manageable in the case of products of high mix and low volume environment, where machine cells cannot be devoted to a specific product; thus, complex scheduling techniques are required."	(Eng & Ching, 2014)
9	Process	"In the case of demand variability, these approaches have sought to flatten or control demand, as the original lean pioneers came from fairly stable demand environments industries, such as automotive sector supply chains (at	(Rich, et al., 2004)

		least downstream of the assembler). This high-volume and repetitive demand character suits the application of kanban pull-scheduling. However, such kanban-style solutions can be inflexible and thus have attracted criticism from authors such as Cusumano (1994) and Schonberger and Knod (1997)."	
10	Philosophy	"Difference in everything from culture to infrastructure mean that managers can't apply the lean tools and techniques used in manufacturing operations in Moline or Munich to non-industrial environments or to manufacturing plants in the developing world; the approach must be tailored to the realities of specific environments."	(Corbett, 2007)
11	Process	"Almost all continuous process facilities eventually produce a discrete part. It is with these discrete parts that many of the principles of lean production can be applied."	(Billesbach, 1994)
12	Process/Philosophy	"Continuous process generally involves a continuous flow of feedstock being converted into finished goods. The key point about continuous processing is that the processes are connected and that there is already effective 'one-piece flow'. The focus in these environments is keeping the flow going."	(TXM, 2017)
13	Supply chain	"Supply chain management challenges are unique in very high-mix, low-volume and volatile demand manufacturing environments compared to very high-volume and low-mix environments. More and more, manufacturers are confronted with this problem today."	(Gill, et al., 2009)
14	Process	"Jina et al. (1997) conducted two case studies analysing whether lean can be implemented in high-variety, low-volume industries and concluded that the lean manufacturing elements emphasised depend on the specific circumstances of the organisation. Those circumstances include volume considerations and variety specificities."	(Deflorin & Scherrer-Rathje, 2011)
15	Philosophy	"Despite successful 'lean' applications in a range of settings however, the lean approach has been criticised on many accounts, such as the lack of human integration or its limited applicability outside high-volume repetitive manufacturing environments."	(Hines, et al., 2004)

4.1.2 A summary and synthesis of Phase 1’s findings

A total of fifteen (15) literature sources were reviewed and synthesised using the 5-step literature research method summarised in Figure 3.2-1. A summary and discussion of the findings obtained from Phase 1 are next presented in Table 4.1-2.

Table 4.1-2: A summary of the differences between the application of lean in discrete and continuous manufacturing environments

A SYNTHESIS OF THE LITERATURE COVERED IN PHASE 1 – SUMMARISED USING LIKER (2004)’S 4P MODEL			
	Discrete Manufacturing	**Vs.**	**Continuous Manufacturing**
Problem solving	Analysis of the literature review covered in Phase 1 of this study underlines that shop floor work-groups are the focal point for problem solving in discrete manufacturing environments. Liker (2004) emphasises that shop floor workers are familiar with the actual work and problems associated with the machinery they work with – so they must be [are] considered as at the top of an organisation’s hierarchy.		This study’s findings highlight that in continuous manufacturing environments, white-collar and skilled staff are the focal point as far as problem solving is concerned. In addition to the findings from the literature covered in Phase 1, Liker (2004) identifies challenges with the concepts of bottom-up management and employee empowerment in most traditional industries - and refers to both [i.e. bottom-up management and employee empowerment] as a “cliché”.
Process	The ability of the manufacturing environment to produce in smaller lot sizes contributed to the hugely successful implementation of lean manufacturing in discrete manufacturing environments. These smaller lot sizes are considered to enable quicker change-over times and set-up times. From the literature covered in Phase 1, it can also be observed that these quicker change-over and set-up times also enable the lean principle of Heijunka (levelling of production by both volume and product mix) to be implemented. The use of Heijunka is summarised by Liker (2004) to present the following benefits: 1. Flexibility to make what customers want, when they want it 2. Reducing the risk of unsold goods 3. Balanced use of labour and machines 4. Smoothed demand on upstream processes and suppliers The literature review also argues that discrete manufacturing		Continuous manufacturing environments traditionally make use of large and rigid machinery. From the literature reviewed, it can be concluded that smaller lot sizes are generally not desirable in continuous manufacturing environments because a continuous flow is used to manufacture feedstock and deliver finished goods. The literature review also highlights that the continuous nature of material flow is considered the main reason why the principle of Heijunka is not commonly implemented in this manufacturing environment. Consequently, and in contrast to discrete manufacturing industries, overproduction and [unsold] inventory are common forms of waste that are exhibited by continuous manufacturing environments. The use of Andons is not (always) considered as effective because continuous manufacturing processes are not considered to start and stop in the same manner that discrete manufacturing processes do

	environments are characterised by low-variety, high-volume customer/production demands. The literature covered in this sub-section places great emphasis on the use of Andons in discrete manufacturing environments. Andons are visual control devices (alarms at times) commonly used to alert workers of any abnormalities within the manufacturing process. To effectively use Andons, production processes and lines need to be stopped immediately when an abnormality is detected. .	(longer set-up times, change-over times, etc.). It was also observed from the literature reviewed in this section that continuous manufacturing environments are considered to produce high-variety, low-volume, customer-driven products. In contrast to the problem-solving characteristics that are mentioned under “people and partners”, this production requirement is considered to require complex scheduling techniques – which require skilled and experienced personnel.
People and partners	The literature review emphasises that discrete manufacturing environments generally make use of a highly skilled workforce to ensure that quick set-up times and cycle times are achieved and maintained.	According to the review conducted in Phase 1, it can be concluded that continuous manufacturing environments frequently make use of a lower-skilled workforce. The common use of a lower-skilled workforce is considered to be sufficient in this manufacturing environment because quicker set-up times and cycle times are not always required to achieve the different production requirements. However, the literature covered in Phase 1 provides contrasting views on the skill levels required to maintain the high-variety, low-volume production mix that is discussed under the “process” dimension.
Philosophy	The literature review highlights the fact that lean manufacturing continues to be a focal management philosophy in discrete manufacturing environments. Furthermore, a vast amount of research is available to support the reduction in waste and non-value-added processes that discrete organisations have achieved through the implementation of lean manufacturing.	A cultural change is regarded as essential in continuous manufacturing environments for lean manufacturing principles to work. Furthermore, a cultural change from traditional management philosophies is considered essential to ensure that lean principles can be adapted to suit any continuous manufacturing environment in which they are implemented.

4.2 Value stream mapping (VSM)

The findings obtained in Phase 2 of the research method (see Chapter 3) are presented in Figure 4.2-1. The objective of Phase 2 was to determine the value-added components of the current wire-manufacturing process.

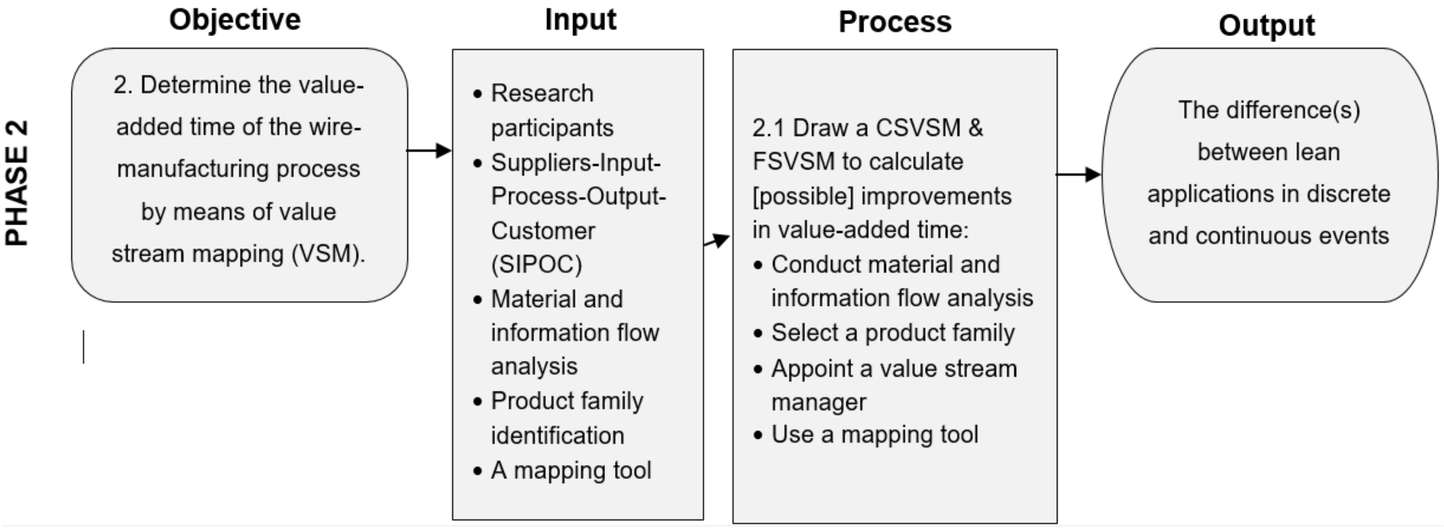

Figure 4.2-1: Phase 2 – Flow diagram

4.2.1 Current state map

A current state value stream map and an ideal future state value stream map are shown in Figure 4.2-2 and Figure 4.2-3, respectively. The value stream of the wire-manufacturing process was mapped using Microsoft Visio, with the required material and information flow data and the data used to identify the product family obtainable in Annexure A (Section 8.2). From the current state VSM, it was observed that the production schedule was updated on a daily basis (i.e. the high variety, low volume mix characteristic of continuous manufacturing environments as observed from the findings in Phase 1). The average total non-value-added time, which is described by Rother and Shook (1999) as production lead time from a customer's perspective, was measured as 82 hours per order-to-delivery[6] for the product family used in the mapping process.

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[6] The order-to-delivery cycle (D) was defined in Section 2.2.4 as the amount of time required to receive products (i.e. from the time the order is placed). In the context of this study, the order-to-delivery cycle refers to both internal and external customer driven orders for the identified product family.

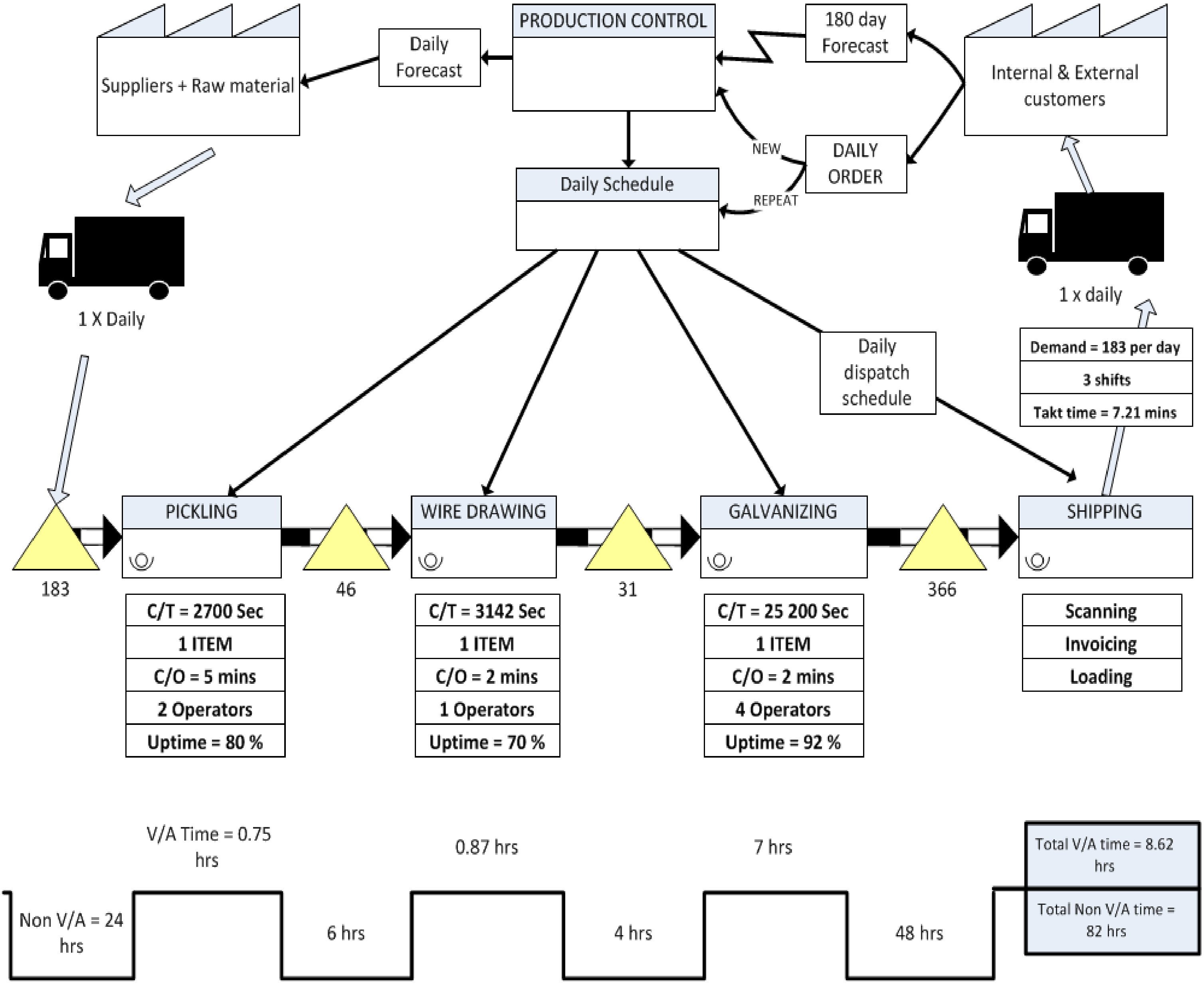

Figure 4.2-2: Current state value stream map

4.2.2 Future state map

An ideal future state map is shown in Figure 4.2-3, where kaizen bursts are shown for the wire-manufacturing process. The future state map proposes that a kaizen initiative could reduce the non-value-added time to 52 hours per order-to-delivery (which represents an improvement of 36.6%). This process improvement would eliminate the pickling process and possibly result in reduced job changes (and levelled production).

It should however be noted that mechanical descaling is considered as a “greener” alternative to traditional acid pickling using hydrochloric acid in the wire manufacturing industry Therefore and using the theory of constraints – the minimum value-added time considered in this study for the inline use of mechanical descalers was retained as 0.87 hrs from the current state map[7].

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[7] Theoretical calculations from combining the inline use of industrially available mechanical descalers with the wire drawing process showed that the minimum cycle time for the future state VSM would be 3889 sec. In the context of the study and to ensure continuous flow to downstream processes, the current state’s value-added time was used in this section.

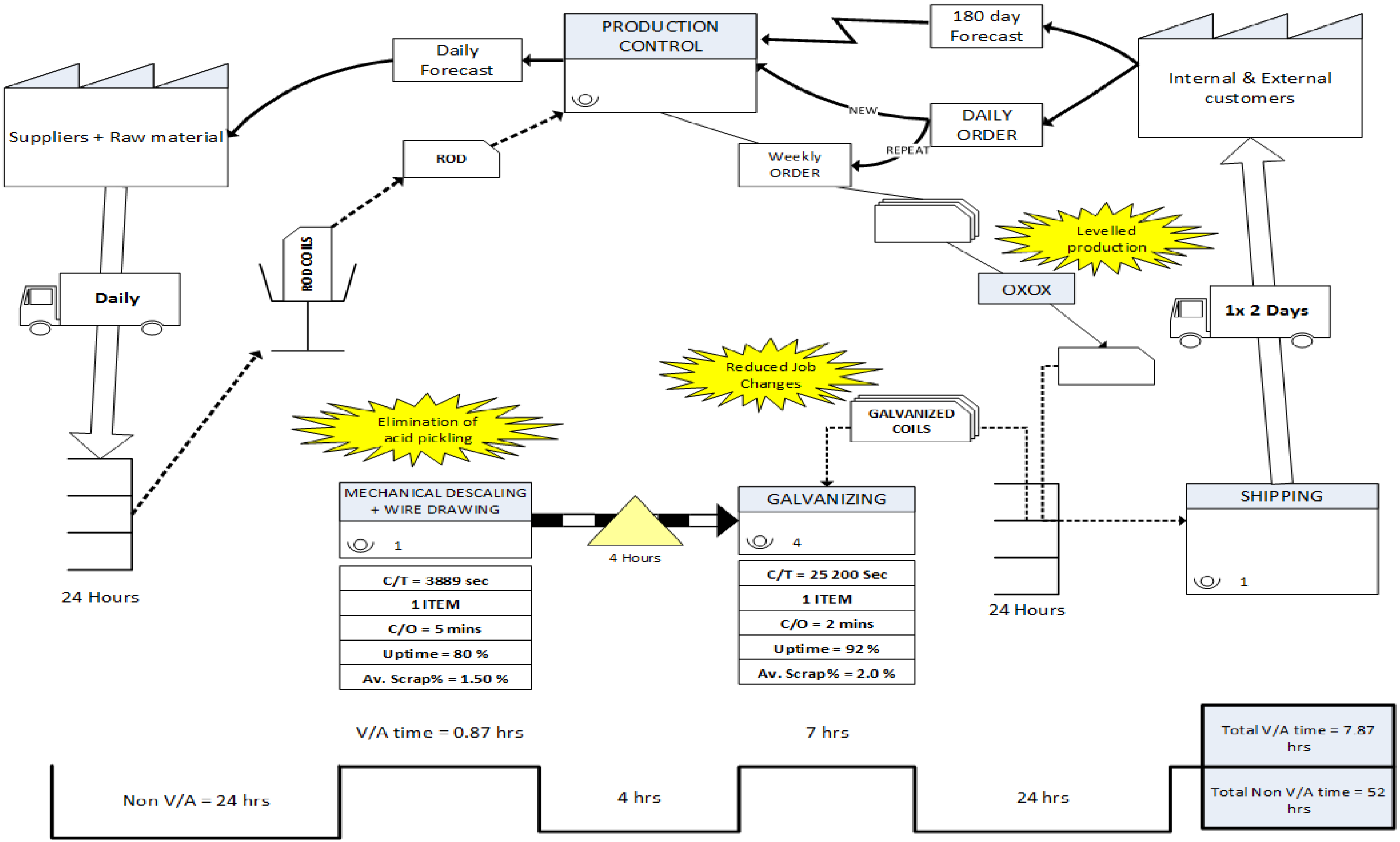

Figure 4.2-3: Ideal future state value stream map

4.3 Measuring the leanness of wire-manufacturing processes

The findings that emerged from Phase 3 of the research method (see Chapter 3) are presented in Figure 4.3-1. The objective of Phase 3 was to determine under which performance region on the EFV metric scale the current wire-manufacturing process falls.

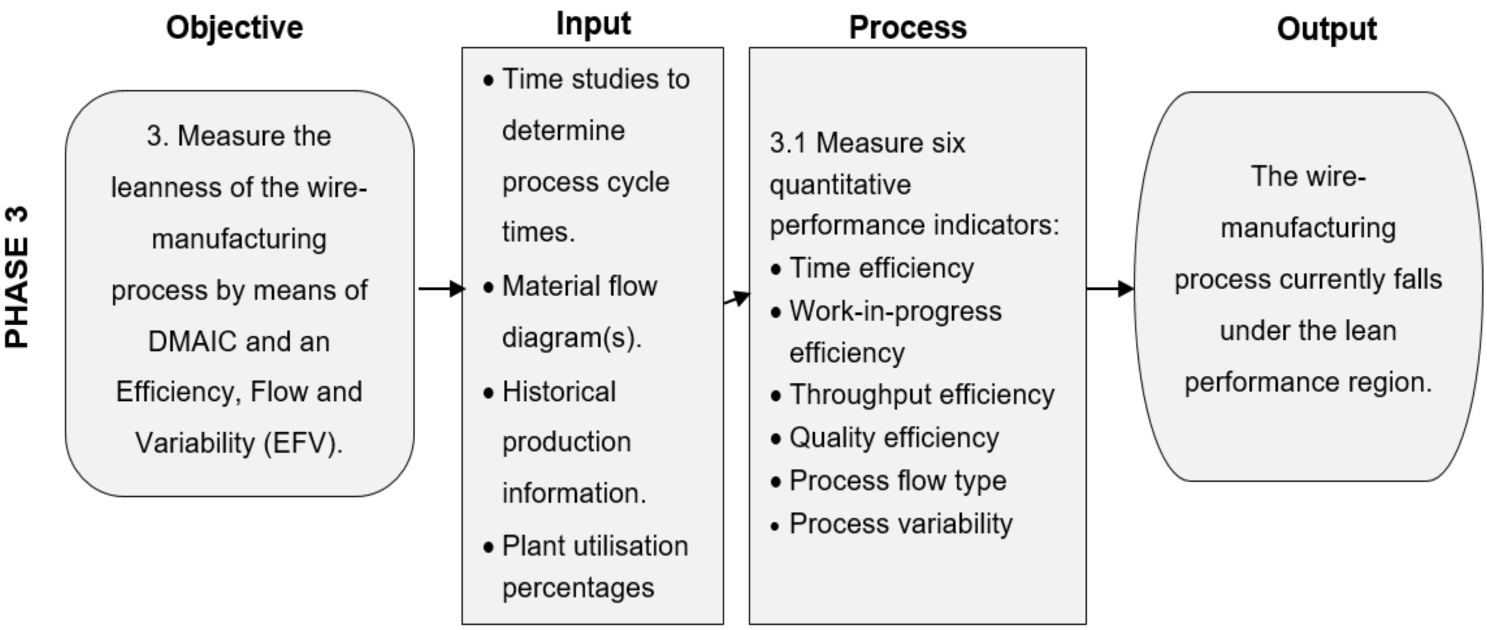

Figure 4.3-1: Phase 3: Flow diagram

The results of the EFV metric introduced by Deif et al. (2015) are presented in Sections 4.3.1 to 4.3.6. Using equation 1 and the daily quantity highlighted in Figure 4.2-2, the Takt time for the current wire-manufacturing process was computed as 7.21 min. Based on this Takt time, the “leanness” of wire manufacturing process was calculated using process data from the galvanizing plant (which was observed as the bottleneck due to the longest processing time). The total weighted efficiency for each metric is presented in Equation 13 below.

$$\text{Weighted Efficiency} = 0.25 * \text{Time efficiency } (E_t) + 0.25 * \text{Work in progress efficiency } \left(E_{wip}\right) +$$

$$0.25 * \text{Throughput efficiency } (E_{th}) + 0.25 * \text{Quality efficiency } \left(E_q\right) \qquad [13]$$

4.3.1 Time efficiency

The results of the time efficiency calculations are summarised in Table 4.3-1.

Table 4.3-1: Time efficiency results

Description	Denotation	Measured results (min)	Ref. equation number	Elements used (see Table 8.2-4)
Idle machine-waste time	$\sum_{i=1}^{12} I_m$	13,80 min	[8]	1+2+3+4
Idle worker-waste time	$\sum_{i=1}^{1}\sum_{j=1}^{12} I_w$	0	[8]	N/A
Total idle-waste time	$T_i = \sum_{i=1}^{12} I_m + \sum_{i=1}^{1}\sum_{j=1}^{12} I_w$	13,80 min	[8]	1+2+3+4
Worker motion-waste time	$\sum_{i=1}^{12} M_w$	14.62 min	[9]	3+8
Transportation motion waste time	$\sum_{i=1}^{12} M_t$	4.33 min	[9]	7+12
Total motion waste time	$T_m = \sum_{=1}^{12} M_w + \sum_{i=1}^{12} M_t$	18.95 min	[9]	3+7+8+12
Total waste time	$\sum W_t = (T_i + T_m)$	34.89 min.	[7]	1+2+3+4+7+8+12
Total value-added time	$\sum V_t$	420 min	[6]	5+6+9+10+11
Time efficiency (E_t)	$\frac{\sum V_t}{\sum W_t + \sum V_t}$	$\frac{420}{34.89 + 420} = 0.92$	[6]	1 to 12

4.3.1 Work-in-progress efficiency

The results of the work-in-progress (WIP) efficiency calculations are shown in Table 4.3-2, and it can be observed that the WIP efficiency was calculated as 0.19.

Table 4.3-2: Work-in-progress calculations

Description	Denotation	Measured result	Ref. equation number
Average throughput	$= \sum_{i=1}^{1}\sum_{i=1}^{12} \mathrm{TH}$	4.7 Coils/hour	[10]
Value-added time	$= \sum_{i=1}^{1}\sum_{i=1}^{12} \mathrm{V}_t$	7 hours	[10]
Work in progress	$= \sum_{i=1}^{1}\sum_{i=1}^{12} \mathrm{WIP}$	173 coils	[10]
Work-in-progress efficiency ($\mathbf{E_{wip}}$)	$= \frac{\sum_{i=1}^{1}\sum_{i=1}^{12} \mathrm{TH} \times \sum_{i=1}^{1}\sum_{i=1}^{12} \mathrm{V}_t}{\sum_{i=1}^{1}\sum_{i=1}^{12} \mathrm{WIP}}$	0.19	[10]

4.3.2 Throughput efficiency

The throughput efficiency was measured by using historical line utilisation information, as shown in Table 4.3-3. From the results listed in this Table 4.3-3, it can be seen that the minimum and maximum efficiencies over the period in which the data was collected ranged between 63% and 75% respectively

Table 4.3-3: Monthly utilisations over the research period

Month	Process utilisation percentages (%)			
	Shift 1	Shift 2	Shift 3	Average
January	73	66	68	69
February	66	64	59	63
March	67	65	71	68
April	69	66	63	66
May	69	70	67	69
June	78	72	70	73
July	72	68	65	68
August	71	67	65	68
Average	**70%**	**67%**	**66%**	**68%**

$$\text{Throughput Efficiency}_{(\text{Eth})} = \frac{\text{min \{Throughput\}}}{\text{max\{Throughput\}}} = \frac{63\%}{73\%} = 0.86 \qquad [11]$$

4.3.3 Quality efficiency

The quality efficiency was determined by computing the relative measure of non-defective parts over the total summation of all parts produced (Deif et al., 2015:49). The number of non-conforming product[8] holds was analysed, and these holds were measured over the period as shown in Figure 4.3-2. The quality efficiency was found to be 0.88 over the period analysed below.

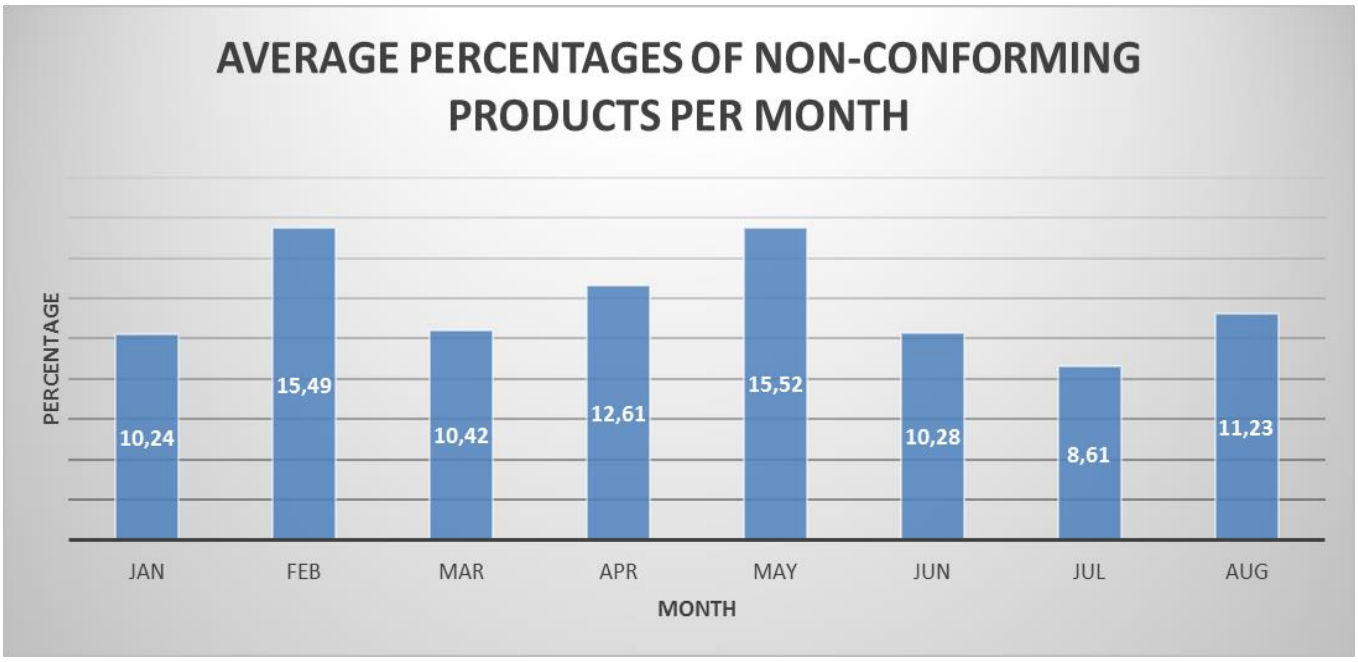

Figure 4.3-2: Percentage holds per department

Note: The average percentage of defective parts over the measure period was computed as 11.80%.

$$\text{Efficiency}_{\text{quality}} = \frac{\sum_{i=1}^{m} \text{parts with no defects}}{\sum_{i=1}^{m} \text{parts with no defects} + \sum_{i=1}^{m} \text{parts with defects}} \qquad 12]$$

$$\therefore \text{Efficiency}_{\text{quality}} = \frac{100\% - 11.80\%}{100\%} = 0.88$$

for the galvanisation process analysed.

4.3.4 Weighted efficiency

Referring to Equation 13 and based on the results obtained in Equations 6 to 12, the weighted efficiency for the measured wire-manufacturing process is:

$$\text{Weighted efficiency} = \frac{E_t + E_{wip} + E_{th} + E_q}{4} \qquad [13]$$

---

[8] Non-conforming products are viewed as any materials that do not meet the minimum quality requirements for a specific product, but that can be re-graded or re-worked into another product range.

Where:

$$\text{Weighted efficiency} = \frac{0.92 + 0.19 + 0.86 + 0.88}{4} = 0.71$$

4.3.5 Process flow types

This section presents the System/Process Flow type, which is the second component of the EFV metric introduced in Equation 4 in Section 2.5.2. The process flow type was modelled based on the principle of push, pull and continuous flow. A 12-step homogenous process was observed for all products that require galvanizing and the nature of each intermediate process was broken down to either a push, pull and/or continuous process. The push, pull or continuous processes were further denoted by a magnitude of 0, 0.5 and 1 respectively. According to Deif et al. (2015:48), the value of a system's flow will always range from 0 to 1. This was evident as a process flow of 0.50 was computed from the process flow diagram represented in Figure 4.3-3.

$$\frac{\sum_{i=1}^{m-1} F_i}{m-1} = \frac{F_{1\_2} + F_{2\_3} + F_{3\_4} + F_{4\_5} + F_{5\_6} + F_{6\_7} + F_{7\_8} + F_{8\_9} + F_{9\_10} + F_{10\_11} + F_{11\_12}}{11} \qquad [14]$$

$$= \frac{0.5 + 0 + 0 + 1 + 1 + 1 + 0 + 0 + 1 + 1 + 0}{11}$$

$$= 0.50$$

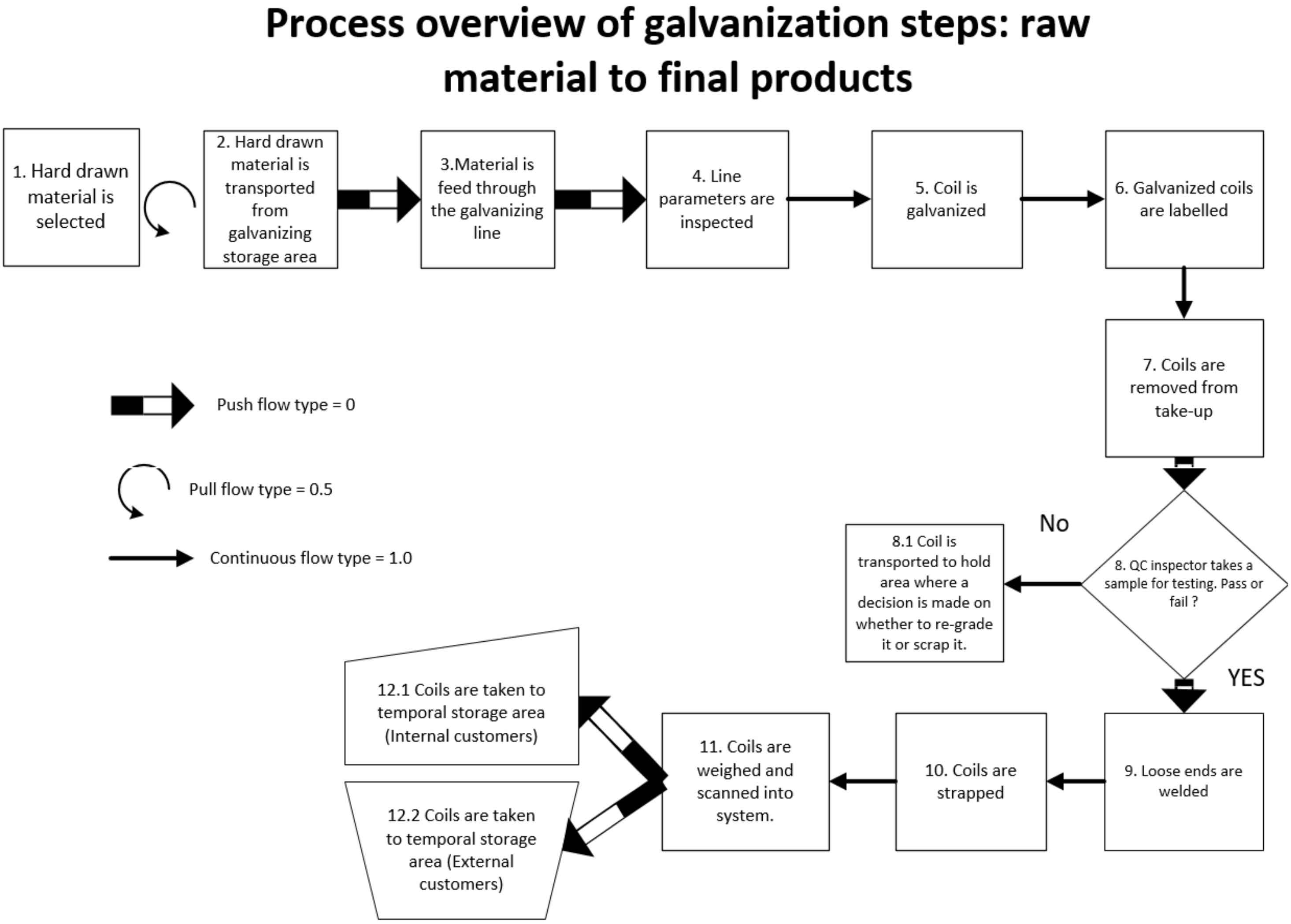

Figure 4.3-3: Process flow diagram of galvanizing steps: Raw material to final products

4.3.6 Process variability

The total process variability was measured to determine the process variability level of the different stages used during the manufacturing process. It was observed that the galvanizing process is driven by both machine and man, with the results of both the mean and standard deviation from each sub-process shown in Figure 4.3-3. The overall process variability was measured using Equation 15 as follows:

$$\text{Overall process variability} = \sum_{i=1}^{m} CV_i \qquad [15]$$

Where CV represents the coefficient of variation $=\frac{\sigma}{\mu}$, σ represents the standard deviation and μ represents the mean cycle time. The process variability was calculated as 0.71, with each component of the equation below computed as follows.

$$\sum_{i=1}^{m} CV_i = \frac{0.82}{20} + \frac{3.56}{127} + \frac{32.66}{550} + \frac{16.27}{131} + \frac{3.56}{24983} + \frac{4.50}{20} + \frac{2.94}{111} + \frac{19.07}{327} + \frac{5.31}{98} + \frac{0.82}{59} + \frac{4.32}{99} + \frac{6.60}{149} = 0.71$$

Additional data for the input that was used for the process variability calculated above can be obtained in Section 8.2 (see Appendix A of this study).

$$\boldsymbol{\sum_{i=1}^{1}\sum_{j=1}^{12} E_{ij} = 0.71}$$

$$\boldsymbol{\sum_{i=1}^{12-1} F_i = 0.50}$$

$$\boldsymbol{\sum_{i=1}^{12} CV_i = 0.71}$$

Based on the parameters of the findings in this sub-section, the leanness that quantifies the efficiency of the wire-manufacturing process was calculated to be as follows:

$$\text{EFV} = \sum_{i=1}^{1}\sum_{j=1}^{12} E_{ij} + \sum_{i=1}^{11} F_i - \sum_{i=1}^{12} CV_i = 0.50 \qquad [4]$$

Based on the EFV computed in Equation 4, the current wire-manufacturing process falls under the “potential improvement” region (see Table 3.4-1). It should also be noted from equation 4 that a relatively high process variability acts against the measured leanness of any manufacturing process.

4.4 Root Cause Analysis (RCA) and Pareto analysis

The findings that emerged from Phase 4 of the research method introduced in Chapter 3 are presented in Table 4.1-1. The aim in Phase 4 was to determine the root causes within the wire-manufacturing process that are considered to lead to slow lean optimisation initiatives by performing a root cause analysis (RCA). The findings from the RCA were tabulated in a cause-and-effect (C&E) matrix, which provided data for the Pareto analysis that was conducted in this phase of the study.

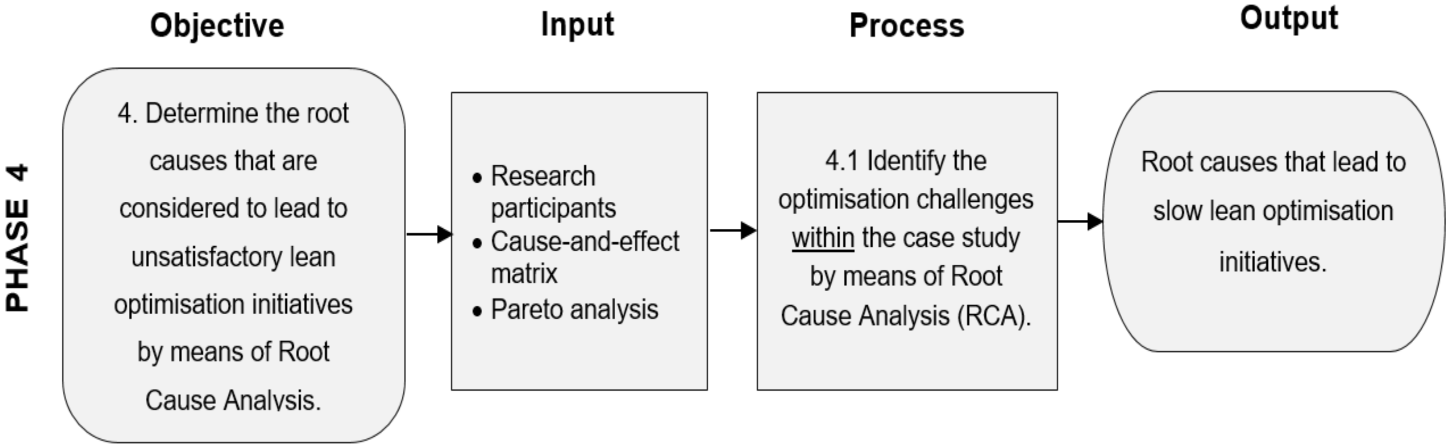

Figure 4.4-1: Phase 4 – Flow diagram

4.4.1 Root Cause Analysis

In the previous sub-section, the findings from the EFV metric that were used to measure the leanness of the wire-manufacturing process were reviewed. Furthermore, the EFV was observed to fall within the "potential for improvement" region. In this section, a review of the findings that emerged from the RCA is presented by the fishbone diagram in shown in Figure 4.4-2. The root causes for each affinity displayed in Figure 4.4-2 were gathered from the purposefully chosen research participants and further quantified in Table 4.4-1. These input variables were analysed by using a Cause-and-Effect (C&E) Matrix, and the Pareto diagram illustrated in Figure 4.4-3 was subsequently used to analyse the inputs that were considered to have the greatest impact on the wire-manufacturing process (the 80/20 principle).

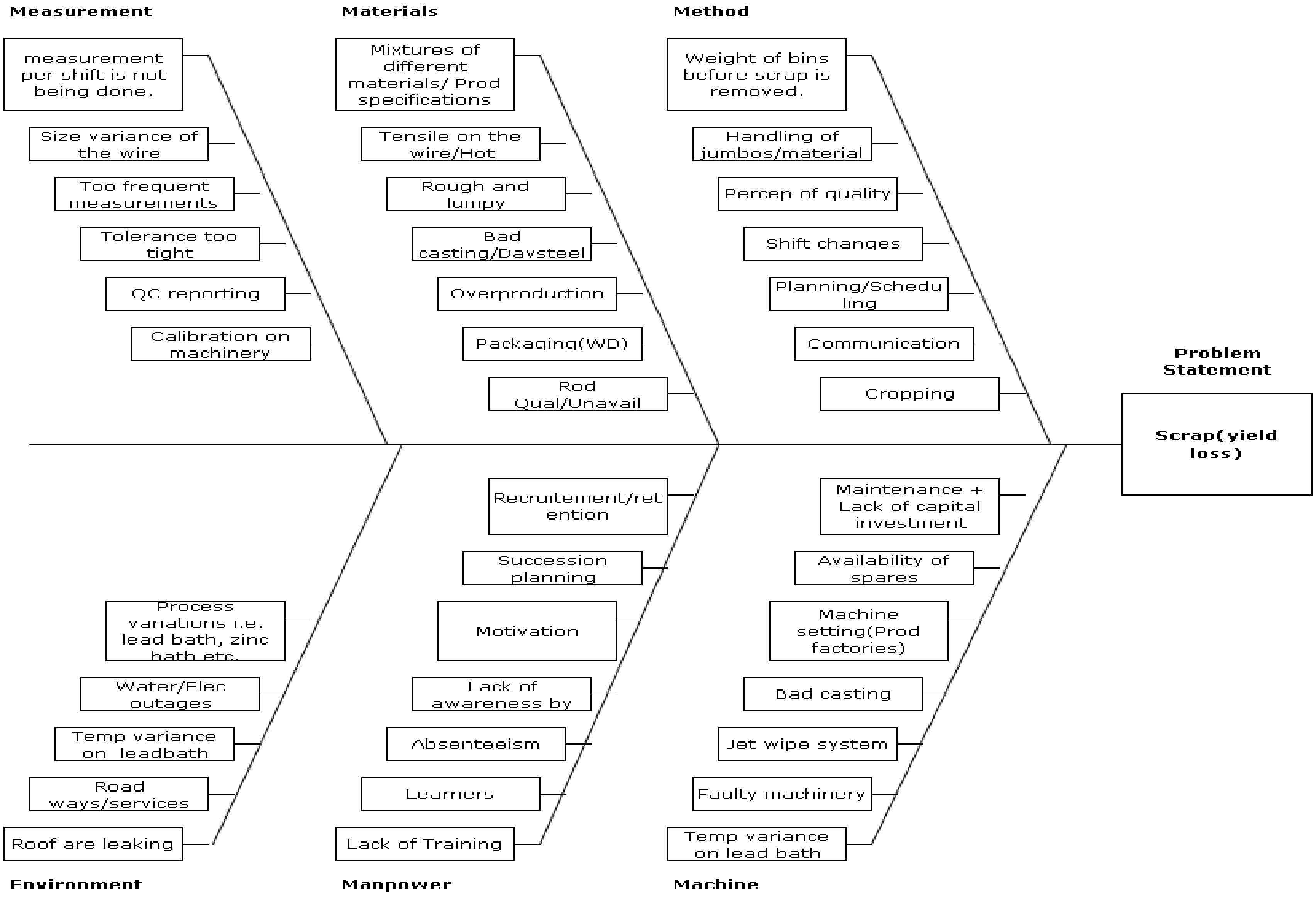

Figure 4.4-2: Primary affinities and their observed root cause

Table 4.4-1: Cause-and-effect matrix – Input variables and the net percentage effect by input

Process Cause & Effect Matrix = Pickling Plant to Product Factories																		
Goal: Reduction of scrap and non-value-added waste		Choose rating from: 1 (not important) - 10 (very important) 1 = Least impact / 10 = Most impact																
		Pickling Plant				Wire Drawing				Galvanizing				Product Factories				
Weighted by Importance		0.5		0.5		0.5		0.5		0.5		0.5		0.5		0.5		
Item #	Process Input	Output		Output		Output		Output		Output		Output		Output		Output		Overall ranking
1	**Measurement**	Scrap		NC holds		Scrap		NC holds		Scrap		NC holds		Scrap		NC holds		
1.1	No measurement per shift	1	**1**	1	**1**	1	**1**	1	**1**	8	**4**	10	**5**	8	**4**	4	**2**	**17**
1.2	Size variance of the wire	1	**1**	6	**3**	1	**1**	6	**3**	5	**3**	1	**1**	4	**2**	1	**1**	**13**
1.3	Too frequent measurements	1	**1**	0	**0**	1	**1**	0	**0**	2	**1**	1	**1**	1	**1**	1	**1**	**4**
1.4	Tolerance too tight	1	**1**	1	**1**	1	**1**	1	**1**	6	**3**	1	**1**	1	**1**	1	**1**	**7**
1.5	QC Reporting	1	**1**	3	**2**	1	**1**	3	**2**	5	**3**	6	**3**	1	**1**	1	**1**	**11**
1.6	Calibration on machinery	1	**1**	6	**3**	1	**1**	6	**3**	5	**3**	7	**4**	6	**3**	1	**1**	**17**
		Pickling Plant				Wire Drawing				Galvanizing				Product Factories				
2	**Materials**	Scrap		NC holds		Scrap		NC holds		Scrap		NC holds		Scrap		NC holds		
2.1	Mixtures of different materials/product specifications	10	**5**	6	**3**	4	**2**	4	**2**	8	**4**	5	**3**	8	**4**	5	**3**	**25**
2.2	Tensile on the wire/hot	1	**1**	5	**3**	7	**4**	8	**4**	10	**5**	6	**3**	10	**5**	6	**3**	**27**
2.3	Rough and lumpy	1	**1**	0	**0**	0	**0**	0	**0**	8	**4**	8	**4**	8	**4**	8	**4**	**17**
2.4	Bad casting	8	**4**	7	**4**	7	**4**	7	**4**	10	**5**	7	**4**	10	**5**	7	**4**	**32**
2.5	Overproduction	1	**1**	1	**1**	1	**1**	5	**3**	7	**4**	8	**4**	7	**4**	8	**4**	**19**
2.6	Packaging/ Wrong labels	10	**5**	10	**5**	9	**5**	0	**0**	9	**5**	4	**2**	9	**5**	4	**2**	**28**
2.7	Rod quality/Unavailability	8	**4**	8	**4**	8	**4**	2	**1**	10	**5**	6	**3**	10	**5**	6	**3**	**29**
		Pickling Plant				Wire Drawing				Galvanizing				Product Factories				
3	**Method**	Scrap		NC holds		Scrap		NC holds		Scrap		NC holds		Scrap		NC holds		
3.1	Weight of bins before scrap is removed	1	**1**	0	**0**	3	**2**	1	**1**	10	**5**	1	**1**	1	**1**	1	**1**	**9**
3.2	Handling of Jumbos/materials	5	**3**	5	**3**	7	**4**	2	**1**	10	**5**	5	**3**	1	**1**	1	**1**	**18**
3.3	Perception of quality inspection	4	**2**	4	**2**	6	**3**	6	**3**	5	**3**	8	**4**	1	**1**	1	**1**	**18**

Table 4.4-2: Cause-and-effect matrix – Input variables and the net percentage effect by input (-continued)

3.4	Shift changes	2	1	2	1	6	3	6	3	6	3	8	4	1	1	1	1	16
3.5	Planning/Scheduling	1	1	1	1	5	3	3	2	10	5	8	4	3	2	1	1	16
3.6	Communication	2	1	2	1	6	3	8	4	7	3	7	4	1	1	1	1	17
3.7	Cropping	2	1	8	4	7	4	0	0	1	1	1	1	1	1	1	1	11
		Pickling Plant				**Wire Drawing**				**Galvanizing**				**Product Factories**				
4	**Environment**	**Scrap**		**NC holds**		**Scrap**		**NC holds**		**Scrap**		**NC holds**		**Scrap**		**NC holds**		
4.1	Roofs leaking	6	3	8	4	5	3	0	0	4	2	1	1	5	3	1	1	15
4.2	Road ways/services	8	4	1	1	7	4	2	1	4	2	1	1	5	3	1	1	15
4.3	Temperature variance with lead baths	1	1	1	1	1	1	2	1	8	4	8	4	1	1	1	1	12
4.4	Water/Electricity outages	10	5	10	5	6	3	0	0	3	2	10	5	1	1	1	1	21
4.5	Process variations	7	4	6	3	6	3	2	1	3	2	8	4	5	3	1	1	19
		Pickling Plant				**Wire Drawing**				**Galvanizing**				**Product Factories**				
5	**Man**	**Scrap**		**NC holds**		**Scrap**		**NC holds**		**Scrap**		**NC holds**		**Scrap**		**NC holds**		
5.1	Lack of training	4	2.0	4	2.0	5	2.5	5	2.5	6	3.0	5	2.5	1	0.5	1	1	16
5.2	Learners	2	1.0	2	1.0	6	3.0	4	2.0	4	2.0	8	4.0	2	1.0	1	1	15
5.3	Absenteeism	6	3.0	6	3.0	6	3.0	4	2.0	6	3.0	10	5.0	3	1.5	1	1	21
5.4	Lack of awareness of operators with respect to scrap accountability	1	0.5	1	0.5	6	3.0	8	4.0	6	3.0	10	5.0	6	3.0	1	1	20
5.5	Motivation	2	1.0	2	1.0	6	3.0	6	3.0	2	1.0	5	2.5	6	3.0	1	1	15
5.6	Succession planning	3	1.5	2	1.0	7	3.5	7	3.5	2	1.0	5	2.5	3	1.5	1	1	15
5.7	Recruitment /retention	3	1.5	5	2.5	8	4.0	8	4.0	1	0.5	5	2.5	2	1.0	1	1	17
		Pickling Plant				**Wire Drawing**				**Galvanizing**				**Product Factories**				
6	**Machine**	**Scrap**		**NC holds**		**Scrap**		**NC holds**		**Scrap**		**NC holds**		**Scrap**		**NC holds**		
6.1	Temperature variance with lead baths	1	0.50	1	0.50	1	0.50	2	1.00	5	2.50	10	5	1	1	1	1	11
6.2	Faulty machinery	2	1.00	2	1.00	7	3.50	4	2.00	5	2.50	7	4	4	2	1	1	16
6.3	Bad casting	8	4.00	8	4.00	7	3.50	4	2.00	5	2.50	8	4	1	1	1	1	21
6.4	Machine settings	6	3.00	6	3.00	7	3.50	4	2.00	5	2.50	5	3	4	2	1	1	19
6.5	Availability of spares	5	2.50	4	2.00	3	1.50	0	0.00	5	2.50	4	2	5	3	1	1	14
6.6	Maintenance + Lack of capital	4	2.00	4	2.00	7	3.50	3	1.50	5	2.50	5	3	5	3	1	1	17
6.7	Jet wipe system	0	0.00	0	0.00	0	0.00	0	0.00	5	2.50	6	3	1	1	1	1	7

4.4.2 Pareto Analysis

The results and findings from the research method described in Section 3.5.2 are provided in this subsection. The C&E matrix introduced in Table 4.4-1 provided the input data for the Pareto diagram that is presented in Figure 4.4-3 of this sub-section.

From this Pareto diagram, it was observed that bad casting was considered by the research participants to be the most dominant cause of undesired scrap and waste yields. Furthermore, rod quality and packaging concerns were considered to contribute negatively to the strategic goals and objectives of the wire-manufacturing process. However, it could be observed from Figure 4.4-3 that the relatively straight (linear) cumulative line indicates that the contribution of each successive root cause thereafter is even. This can be interpreted using the Pareto principle (80/20) as having a wire-manufacturing process with too many process variations that are considered to be problematic as a whole. The linear correlation between the identified root causes also presents a challenge in distinguishing the critical-to-quality (CTQ) components from the identified root causes (see Section 2.5.1). An overall discussion of Chapter 4’s findings is presented in Section 4.5.

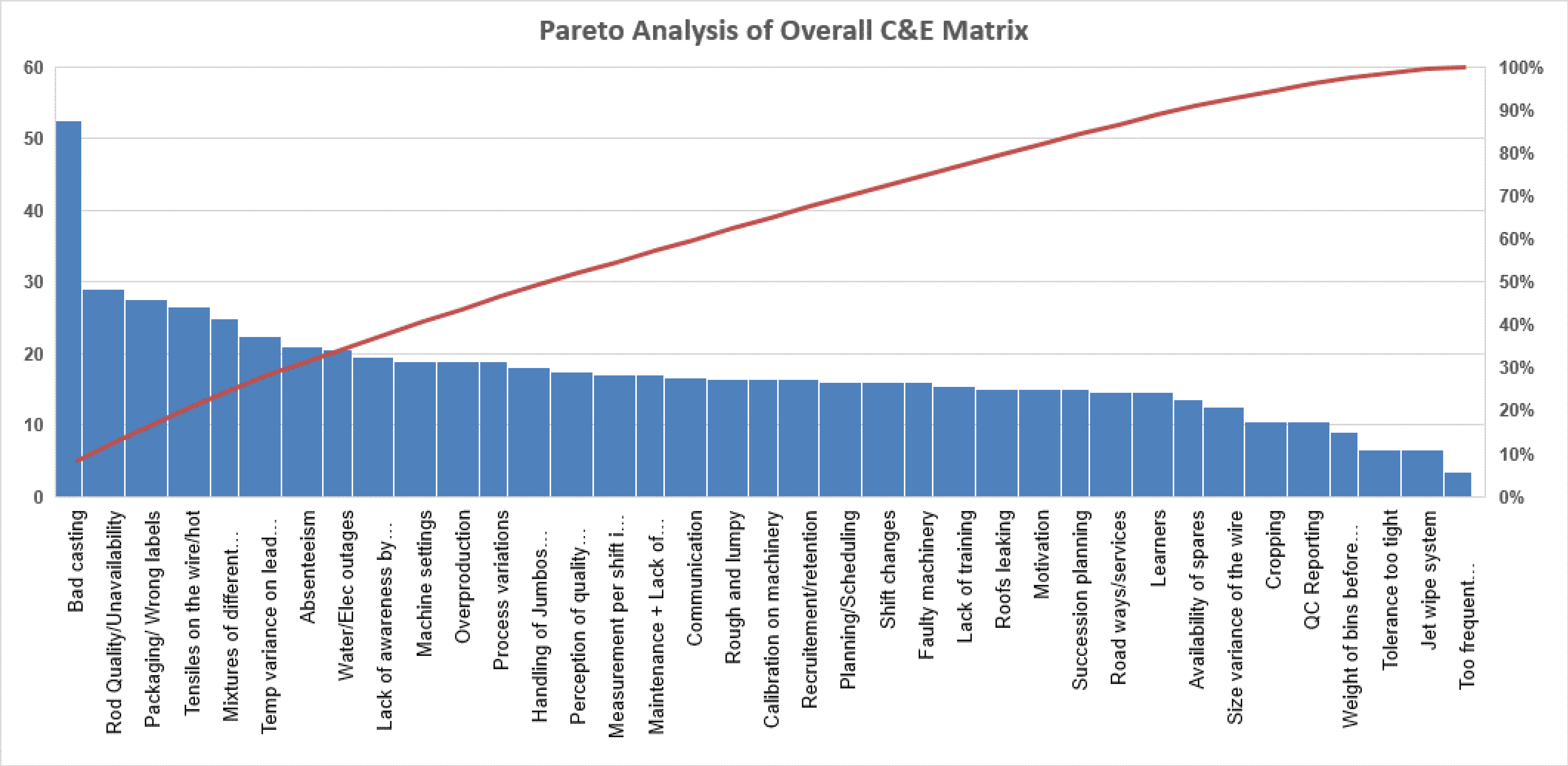

Figure 4.4-3: Pareto analysis of the cause-and-effect matrix

4.5 Discussion of Chapter 4's results

A 5-step research method was introduced in section 3.2 with the aim of achieving this study's first objective (see section 1.4). The findings from phase 1, which are summarised in Table 4.1-1, argue that process-related challenges constitute the most noteworthy barrier during lean transformation in continuous manufacturing environments. The targeted literature review conducted in this study also contends that most continuous manufacturing environments can be defined as high-variety, low-volume manufacturing events. This high-variety, low-volume customer-driven nature of continuous manufacturing organisations present the following key challenges for adopting lean manufacturing in this sector:

- The first pillar of the TPS, the Just-in-time (JIT) principle, involves the ability of a manufacturing process to operate on a pull-replenishment basis. This pull-replenishment system has been observed to be achieved in conjunction with another lean principle – Heijunka. The findings of the study in hand underline the difficulty of implementing Heijunka (levelling production) in continuous manufacturing industries due to the high-variety, low-volume nature of these production environments.
- The second pillar of the TPS, Jidoka, is heavily reliant on the lean principle of Andons, which requires production processes to be stopped when abnormalities are detected. The findings of this study indicate that continuous manufacturing processes do not start and stop in the same manner as their discrete counterparts. Since production processes cannot simply be stopped when abnormalities are detected, the practical use of Andons is restricted.

The value proposition of the case study as a continuous manufacturing process was established by using the value stream mapping techniques introduced by Rother and Shook (1999) (see Chapter 2). From the current-state VSM presented in Section 4.2.1, it can be seen that a push system is the primary component of the case study. Furthermore, it is evident that the current manufacturing process consists of a large component of non-value-added work. Even though the future-state value stream map presented in this study proposes that a 36.6% production lead time reduction may be achieved through kaizen activities, limited evidence was offered to support that this [reduction] would address the intrinsic challenges presented by the problem statement of this study. Furthermore, it was observed that the performance of the wire-manufacturing process could not be benchmarked or compared against any metric through the sole use of value stream mapping. The ambiguity and uncertainty of value stream mapping was subsequently addressed by adopting a quantitative approach to measure the current performance (leanness) of wire manufacturing. The quantitative approach introduced in this study also helped to identify which focus areas may have the greatest impact on achieving any suggested process improvements.

As highlighted in Chapter 4, the findings that emerged from the quantitative leanness measurements indicate that the wire-manufacturing process falls within the "potential for improvement" region on the

Efficiency, Flow and Variation (EFV) metric scale. Further analysis of the empirical approach used to measure the leanness also suggests that for the wire-manufacturing process to reach an optimum “good performance” zone, greater focus is required on reducing the coefficient of variation between intermediate processes. In the context of this study, it was also observed that the coefficient of variation may be reduced by decreasing the standard deviation between measured cycle times of processes.

It was however evident that a number of challenges remain in addressing the findings of the empirical approach that was used to measure the leanness of the case study. Quantitative lean assessment tools (LATs) analogous to the EFV metric highlighted in the previous paragraph have been argued to present a degree of imprecision and vagueness, due to subjective human judgement. Additional studies conducted on quantitative LATs further argue that the vagueness of subjective human judgement can be mitigated through fuzzy logic-based assessment approaches (Vinodh & Vimal, 2012:1185; Susilawati et al., 2015:1), which incorporate qualitative assessments. These fuzzy logic-based LATs extend the findings of Pakdil and Leonard (2014) who contend that incorporating a qualitative approach into a LAT may be beneficial, due to weighing the “opinions” of key stakeholders. The primarily quantitative nature of LATs used in this study was observed to be the principal limitation of the EFV metric used to measure the leanness of the wire-manufacturing process.

The last major component of data collection used in this study involved a root cause analysis (RCA). The root cause analysis was driven mainly by the need to bridge the quantitative shortcomings of the EFV metric that was used to measure the leanness of the wire-manufacturing process. The findings that were obtained from the RCA further suggest that the chartered team with knowledge on the subject matter considered bad casting, unavailability of raw material and packing concerns as significant contributors towards (root causes of) the current performance in the manufacturing process. However (and as underlined in Section 4.4.2), the weighted effect of the other identified root causes is still considered to have a sufficiently negative impact on addressing the organisational goals of this study. Analysis of the root causes using the Pareto principle shows that the current wire-manufacturing process has too many variations, and application of the 80/20 principle may not yield desired waste reductions.

CHAPTER 5: OPTIMISATION PLAN

5.1 Optimisation plan

In this section, a lean optimisation plan is presented based on the findings in Chapter 4.

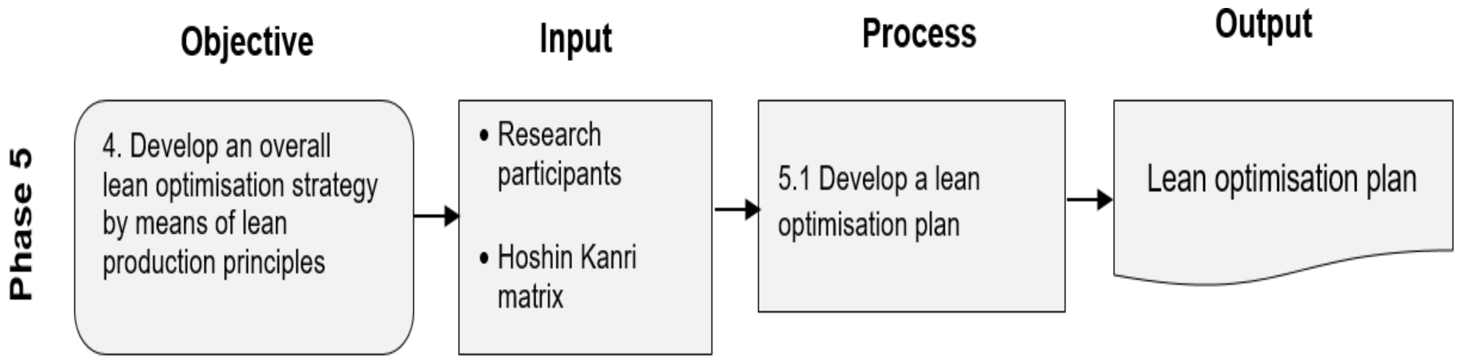

Figure 5.1-1: Phase 1 – Flow diagram

5.1.1 Hoshin Kanri matrix

The sequence of hierarchical objectives that are presented in this section were derived mainly from the findings that emerged in Chapter 4. Table 5.1-1 summarises the research objectives introduced in Chapter 1 (note that the Hoshin objective presented in that chapter was to develop a lean optimisation plan for a wire-manufacturing process).

Table 5.1-1: Summary of the findings obtained in Phases 1 to 4

	Objective	Finding(s)	3-to 5-year breakthrough objectives
Phase 1	**1.1)** Determine the differences between the application of lean in discrete and continuous events.	**4.1)** Lean applications in discrete and continuous events	Ensure that Lean Manufacturing (LM) is understood, and that the philosophy is adopted from a managerial level down to the shop floor level.
Phase 2	**1.2)** Determine the value-added time of the wire-manufacturing process by means of value stream mapping (VSM).	**4.2)** V/A time = 8.62 hours Non-V/A time = 82 hours	Decrease production lead time by 36.6%.
Phase 3	**1.3)** Measure the leanness of the wire-manufacturing process by means of DMAIC and an Efficiency, Flow and Variability (EFV) metric.	**4.3)** Leanness = 0.5 (**falling in the "potential for improvement" region according to the EFV metric scale**)	Achieve a leanness greater than or equal to 1.00 **(good performance region).**
Phase 4	**1.4)** Determine the root causes of unsatisfactory lean and optimisation initiatives by performing a Root Cause Analysis (RCA).	**4.4)** Process has too many variations that are negatively impacting the manufacturing process	Decrease process variations by enforcing the Just-in-time (JIT) and Jidoka principles.

The Hoshin Planning Matrix in Figure 5.1-2 shows the annual stretch goals, top-level improvement opportunities, targets to improve (TTI) and the primary/secondary responsibilities of each metric. The first 3- to 5- year objective displayed in Figure 5.1-2 was derived with the aim of addressing the findings from the "manpower" affinity of fishbone diagram presented in Section 4.4.1.

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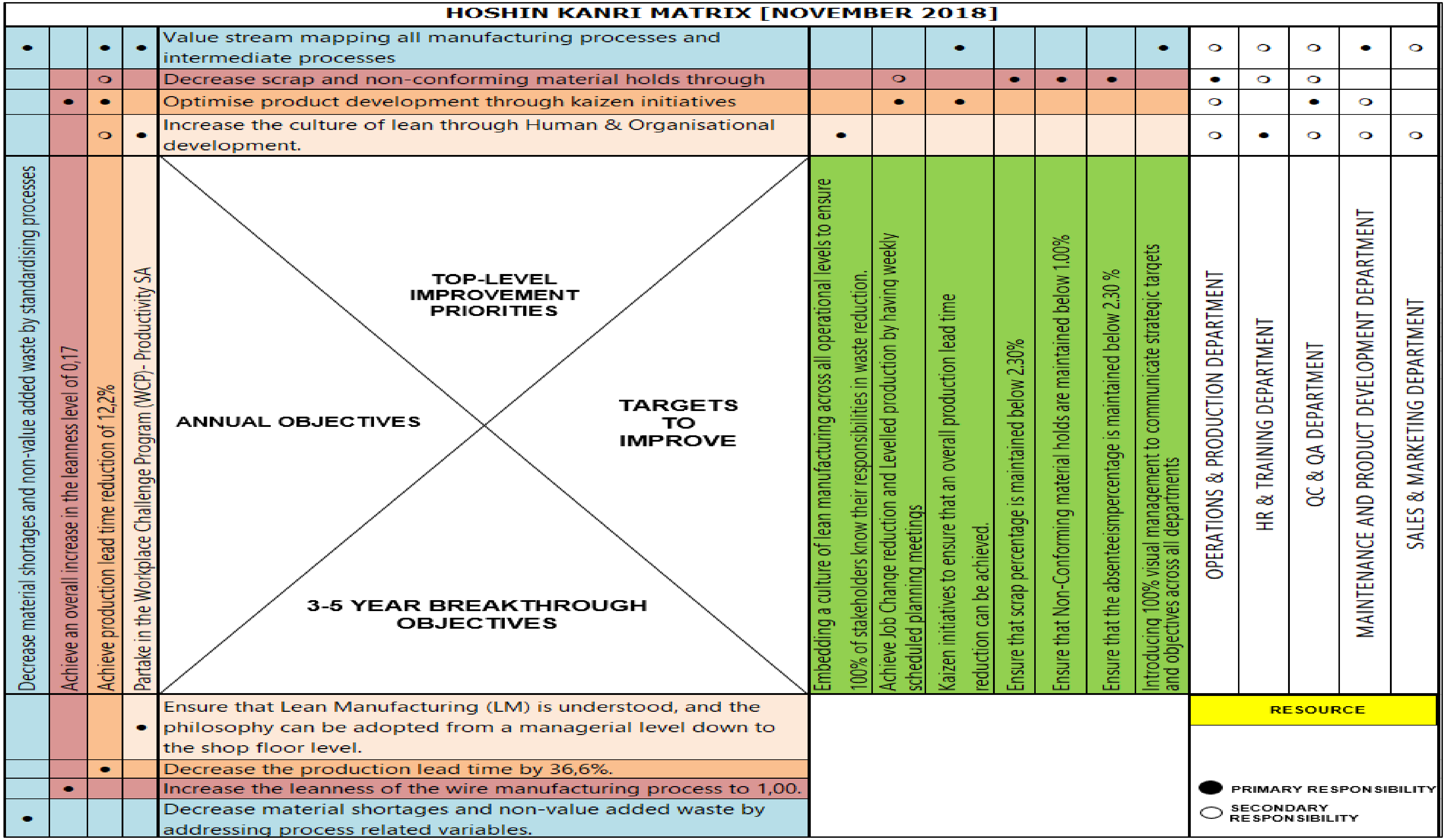

HOSHIN KANRI MATRIX [NOVEMBER 2018]

Decrease material shortages and non-value added waste by standardising processes	Achieve an overall increase in the leanness level of 0,17	Achieve production lead time reduction of 12,2%	Partake in the Workplace Challenge Program (WCP)- Productivity SA	TOP-LEVEL IMPROVEMENT PRIORITIES	Embedding a culture of lean manufacturing across all operational levels to ensure 100% of stakeholders know their responsibilities in waste reduction.	Achieve Job Change reduction and Levelled production by having weekly scheduled planning meetings	Kaizen initiatives to ensure that an overall production lead time reduction can be achieved.	Ensure that scrap percentage is maintained below 2.30%	Ensure that Non-Conforming material holds are maintained below 1.00%	Ensure that the absenteeismpercentage is maintained below 2.30 %	Introducing 100% visual management to communicate strategic targets and objectives across all departments	OPERATIONS & PRODUCTION DEPARTMENT	HR & TRAINING DEPARTMENT	QC & QA DEPARTMENT	MAINTENANCE AND PRODUCT DEVELOPMENT DEPARTMENT	SALES & MARKETING DEPARTMENT
●		●	●	Value stream mapping all manufacturing processes and intermediate processes			●				●	○	○	○	●	○
		○		Decrease scrap and non-conforming material holds through		○		●	●	●		●	○	○		
	●	●		Optimise product development through kaizen initiatives		●	●					○		●	○	
		○	●	Increase the culture of lean through Human & Organisational development.	●							○	●	○	○	○

ANNUAL OBJECTIVES

TARGETS TO IMPROVE

Decrease material shortages and non-value added waste by standardising processes	Achieve an overall increase in the leanness level of 0,17	Achieve production lead time reduction of 12,2%	Partake in the Workplace Challenge Program (WCP)- Productivity SA	3-5 YEAR BREAKTHROUGH OBJECTIVES
			●	Ensure that Lean Manufacturing (LM) is understood, and the philosophy can be adopted from a managerial level down to the shop floor level.
		●		Decrease the production lead time by 36,6%.
	●			Increase the leanness of the wire manufacturing process to 1,00.
●				Decrease material shortages and non-value added waste by addressing process related variables.

RESOURCE

● PRIMARY RESPONSIBILITY

○ SECONDARY RESPONSIBILITY

Figure 5.1-2: Hoshin planning matrix used to summarise the optimisation plan for this case study

5.1.2 Bowling chart and action plan

In support of the overall goal of the Hoshin Kanri matrix presented in Section 5.1.1, a bowling chart and action plan are discussed for each of the 3- to 5-year objectives presented in Table 5.1-1. The bowling charts presented in this section form part of the visual management that may be used in conjunction to the Hoshin Kanri Matrix to monitor key milestones. The action plans are presented the Table 5.1-3 to

Table 5.1-6.

Table 5.1-2: Global tier of Hoshin Kanri objectives

<table>
<tr><th>Entity</th><th>Function</th><th>Plan Owner</th><th>Created on</th><th>Last Revised</th></tr>
<tr><td>Wire manufacturing process</td><td>Optimisation plan</td><td>Case Study</td><td>Sep-17</td><td>Nov-18</td></tr>
<tr><th colspan="5">Business Situation</th></tr>
<tr><td colspan="5"></td></tr>
<tr><th>Objective
(Owner)</th><th>#</th><th colspan="2">Strategy
(Owner)</th><th>Performance Metrics</th></tr>
<tr><td rowspan="2"></td><td>1.1</td><td colspan="2">Be a leading wire manufacturing lean practitioner in South Africa</td><td>Partake in the Workplace Challenge Program (WCP)- Productivity SA</td></tr>
<tr><td>1.2</td><td colspan="2">Decrease the production lead time by 36,6%</td><td>Achieve annual production lead time reduction of 12,2 hrs</td></tr>
<tr><th>Performance Metrics (Targets)</th><td>1.3</td><td colspan="2">Increase the leanness of the wire manufacturing process by 1,00</td><td>Achieve an annual leanness increase of 0,12</td></tr>
<tr><td></td><td>1.4</td><td colspan="2">Decrease bad casting related concerns and the number of process variables.</td><td>Maintain non-conforming holds, absenteeism, scrap percentage < 1%</td></tr>
</table>

Table 5.1-3: Second tier of Hoshin Kanri objectives corresponding to Tier 1.1

Entity	**Function**						**Plan Owner**		**Updated on**	
Wire Manufacturing process	Optimisation plan						Case Study		Jun-18	
Business Situation										
The proposed targets to improve (TTI) that are required to bridge the gap between the current performance and the desired performance are shown below.										
Objective (Owner)	Tactic **(Owner)**	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9
1.1: Be a leading wire manufacturing lean practitioner in South Africa	1.1.1 Establishment of management system framework	■	■							
	1.1.2 Establishment of HKM goal alignment framework			■	■					
Performance Metrics (Targets)	1.1.3 Cleaning and organising (5s)				■	■	■			
Partake in the Workplace Challenge Program (WCP)- Productivity SA	1.1.4 Teamwork and assigning of tasks						■	■		
	1.1.5 Leadership training							■	■	
	1.1.6 Green productivity training									■

Table 5.1-4: Second tier of Hoshin Kanri objectives corresponding to Tier 1.2

Entity	**Function**	**Plan Owner**	**Updated**
Wire Manufacturing	Optimisation plan	Case Study	Nov-18

Business Situation
In chapter 4's future state VSM, it was observed that the non-value added time can be reduced by 30 hrs (or 36,6%). A number of bottleneck areas were identified as shown in the future state VSM. The Targets to improve (TTI) are shown below.

Objective (Owner)	Tactic **(Owner)**	Month 10	Month 11	Month 12	Month 13	Month 14	Month 15	Month 16	Month 17	Month 18
1.2: Decrease the production lead time by 36,6%	1.2.1 Standardise work methods and tools	▬	▬							
	1.2.2 Implement heijunka and level loading principles			▬	▬					
Performance Metrics (Targets)	1.2.3 Technological change through Kaizen initiative			▬	▬	▬	▬	▬	▬	▬
Achieve annual production lead time reduction of 12,2%	1.1.4 Improve the wire manufacturing's layout for flow		▬	▬	▬	▬	▬	▬		

Table 5.1-5: Second tier of Hoshin Kanri objectives corresponding to Tier 1.3

Entity	**Function**	**Plan Owner**	**Updated**
Wire Manufacturing	Optimisation plan	Case Study	Nov-18

Business Situation

The leanness (Efficiency) of the wire manufacturing process was observed to be 0,50. An increase in the leanness of 0,50 is required for this metric to fall under the "Good Performance" region. The Targets to improve (TTI) are shown below.

Objective (Owner)	Tactic **(Owner)**	Month 20	Month 21	Month 22	Month 23	Month 24	Month 25	Month 26	Month 27	Month 28
1.3: Increase the leanness of the wire manufacturing process by 0,50.	1.3.1 Conduct a Rattlesnake hunt	■	■							
	1.3.2 Goal alignment review			■	■					
Performance Metrics (Targets)	1.3.3 Cleaning and organising				■	■	■			
Achieve an annual leanness increase of 0,17	1.3.4 Teamwork toolkit						■	■		
	1.3.5 Leadership toolkit							■	■	
	1.3.6 Green productivity toolkit									■

Table 5.1-6: Second tier of Hoshin Kanri objectives corresponding to Tier 1.4

Entity	**Function**							**Plan Owner**		**Updated**
Wire Manufacturing process	Optimisation plan							Case Study		Nov-18
Business Situation										
Decrease process variations by focusing on identified root causes that are leading to non-value added waste										
Objective	Tactic	Month 25	Month 21	Month 22	Month 23	Month 24	Month 25	Month 26	Month 27	Month 28
1.4:Decrease process waste that is related to the high frequency of process variations observed in the RCA	1.4.1 Updated visual stream maps	■	■							
	1.4.2 Gemba leadership review			■	■					
Performance Metrics (Targets)	1.4.3 Cleaning and organising (5s) review				■	■	■			
Achieve an annual leanness increase of 0,17	1.4.4 Elimination of manufacturing silos						■	■		
	1.5.5 Updated assessment of leanness of the wire manufacturing process							■	■	

CHAPTER 6: VERIFICATION

6.1 Verification of Hoshin Kanri matrix

This chapter presents a comprehensive overview of the findings of the verification process that was conducted. The findings are divided into two sub-sections, which review Round 1 and Round 2 of the Delphi technique respectively.

6.1.1 Round 1 of the Delphi Technique

In this round of the iteration, and according to Lawshe (1975), only items that were marked as “essential” by more than half of the research participants were considered to have some degree of content validity. Furthermore, a minimum one-tailed test p-value of 0.49 was required for the average CVI to satisfy the 95% confidence interval required for convergence from 15 participants. In the first round of the iteration, all items that were considered “essential” by less than half of the participants (i.e. less than 7) were discarded from the initial 24-item questionnaire, and this facilitated the next round of the verification of the Hoshin Kanri matrix using the Delphi technique.

The Hoshin Kanri Matrix that was distributed with round 1’s questionnaire is presented in Figure 6.1-1[9]. The 24-item based questionnaire that was distributed in this round of the iteration can be found in Annexure B of this study. Furthermore, the feedback received was also analysed to establish the degree of consensus after each iteration (see Table 6.1-1).

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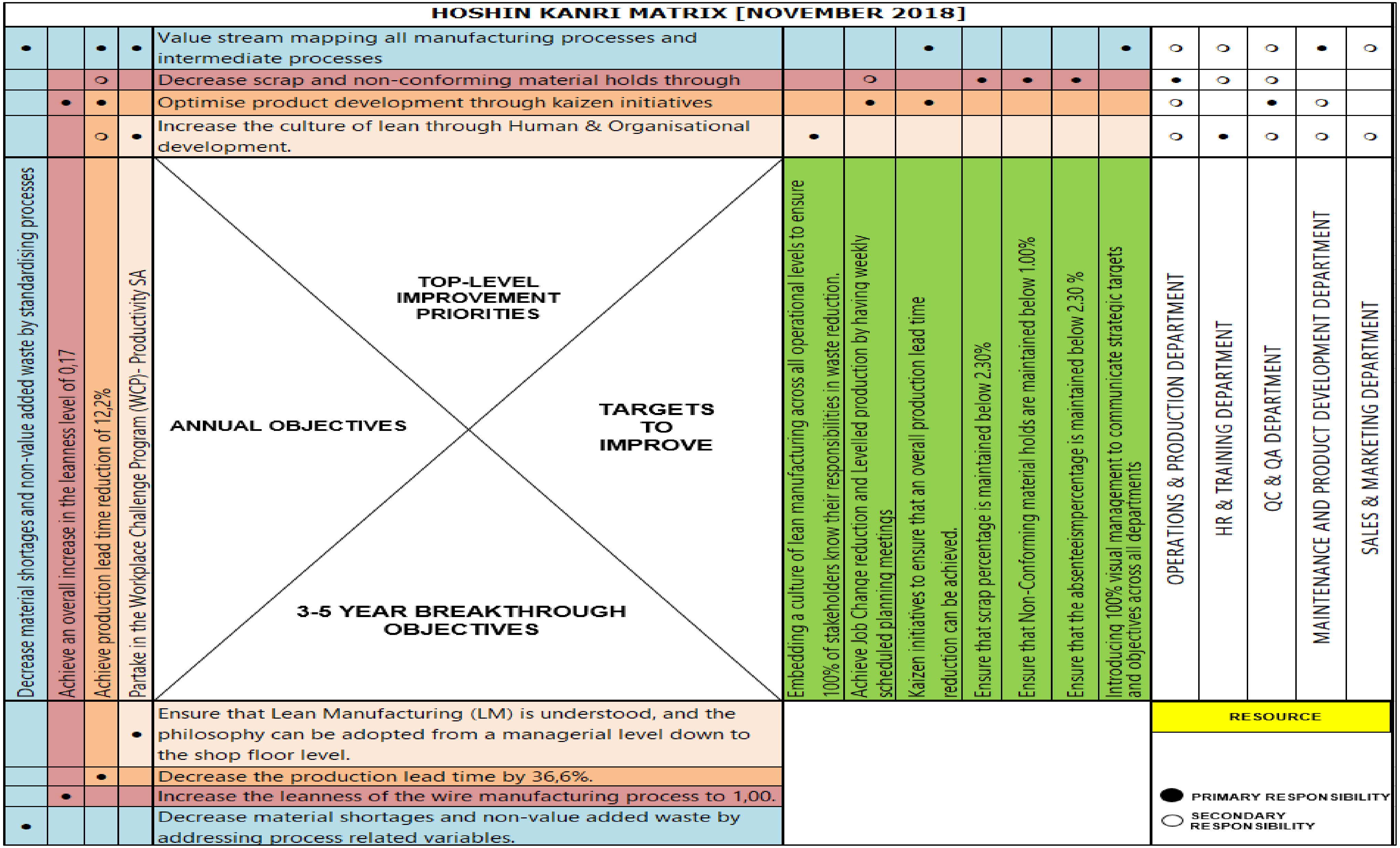
[9] Note: Figure 6.1-1 is a duplicate of the original Hoshin Kanri Matrix presented in Figure 5.1-2 but has been included in this section for simplicity for the reader.



HOSHIN KANRI MATRIX [NOVEMBER 2018]

Decrease material shortages and non-value added waste by standardising processes	Achieve an overall increase in the leanness level of 0,17	Achieve production lead time reduction of 12,2%	Partake in the Workplace Challenge Program (WCP)- Productivity SA	ANNUAL OBJECTIVES	Embedding a culture of lean manufacturing across all operational levels to ensure 100% of stakeholders know their responsibilities in waste reduction.	Achieve Job Change reduction and Leveled production by having weekly scheduled planning meetings	Kaizen initiatives to ensure that an overall production lead time reduction can be achieved.	Ensure that scrap percentage is maintained below 2.30%	Ensure that Non-Conforming material holds are maintained below 1.00%	Ensure that the absenteeismpercentage is maintained below 2.30 %	Introducing 100% visual management to communicate strategic targets and objectives across all departments	OPERATIONS & PRODUCTION DEPARTMENT	HR & TRAINING DEPARTMENT	QC & QA DEPARTMENT	MAINTENANCE AND PRODUCT DEVELOPMENT DEPARTMENT	SALES & MARKETING DEPARTMENT
●		●	●	Value stream mapping all manufacturing processes and intermediate processes			●				●	○	○	○	●	○
		○		Decrease scrap and non-conforming material holds through		○		●	●	●		●	○	○		
	●	●		Optimise product development through kaizen initiatives		●	●					○		●	○	
		○	●	Increase the culture of lean through Human & Organisational development.	●							○	●	○	○	○

Decrease material shortages and non-value added waste by standardising processes	Achieve an overall increase in the leanness level of 0,17	Achieve production lead time reduction of 12,2%	Partake in the Workplace Challenge Program (WCP)- Productivity SA	3-5 YEAR BREAKTHROUGH OBJECTIVES
			●	Ensure that Lean Manufacturing (LM) is understood, and the philosophy can be adopted from a managerial level down to the shop floor level.
		●		Decrease the production lead time by 36,6%.
	●			Increase the leanness of the wire manufacturing process to 1,00.
●				Decrease material shortages and non-value added waste by addressing process related variables.

● PRIMARY RESPONSIBILITY
○ SECONDARY RESPONSIBILITY

Figure 6.1-1: Summary of the Hoshin Kanri matrix distributed with the research questionnaire in Round 1

The feedback from round 1 of the Delphi technique is presented in Table 6.1-1. It can be seen from Table 6.1-1 that the items that converged after this round of the iteration (i.e. had a CVR greater than 0.49 for 15 participants) were the following:

- Item 1 – Policy deployment
- Item 2 – Management system
- Item 4 – Continuous improvement
- Item 23 – Synchronisation
- Item 24 – Visual Performance feedback

However, it should also be observed that the items that were considered by less than half of the 15 participants to be "essential" were discarded and only items that converged or were considered to be "essential" by more than half of the research participants were retained after Round 1 of the iteration. Using Lawshe (1975)'s Content validity ratio (CVR) as a guideline, the Hoshin Kanri matrix was not considered as an effective medium for addressing following lean and management principles:

- Item 3 – Leadership standard work
- Item 9 – Employee development
- Item 13 – Management of Raw material
- Item14 – Management of finished goods
- Item 19 – 5S

The content validity index (CVI), which is the average of all the items' content validity ratios, was calculated as 0.14 for round 1 of the iteration. Furthermore and from the additional open response feedback from round 1 of the iteration, the 3- to 5- year objectives displayed in Figure 6.1-1 were modified because they were considered too "low-level" to be 3- to 5-year objectives. A second round of the Delphi technique was conducted and the findings from this iteration are discussed in Section 6.1.2.

Table 6.1-1: Feedback from Round 1 of the Delphi probe

Feedback from Round 1																								
Content evaluation panel (Participants)	1. Policy Deployment	2. Management System	3. Leader Standard Work	4. Continuous Improvement	5. Scrap	6. Respect for Team Members	7. Morale	8. Problem Solving	9. Employee Development	10. Suppliers	11. 8 Waste Reduction	12. Quality	13. Raw Material	14. Finished Goods	15. Material Handling	16. Pull Systems	17. Level Loading	18. Value Streams	19. 5S	20. Layout for Flow	21. Cross-Training	22. Quality Results	23. Synchronisation	24. Visual Performance Feedback
	Marked "Essential"																							
1	X	X	X			X				X	X		X				X				X		X	X
2	X	X		X		X	X			X	X	X				X		X	X	X	X	X	X	X
3	X			X			X			X		X			X	X	X	X				x	x	
4	X			X				x			X										X	X	X	
5	X			X			X					X										X	X	
6	X	X	X		X	X	X		X	X	X			X	X	X	X		X	X	X	X	X	X
7	X	X		X	X	X		X	X	X	X			X	X		X		X	X	X		X	X
8	X	X		X	X	X	X	X	X	X	X							X					X	X
9	X	X		X	X		X	X	X			X	X	X	X	X		X	X				X	X
10	X	X	X	X	X															X				X
11	X	X		X	X	X	X	X			X	X	X		X	X	X	X	X	X		X	X	X
12	X	X	X	X	X		X			X	X		X	X	X	X	X	X	X		X		X	X
13	X	X			X	X	X	X	X	X	X	X			X		X			X	X		X	X
14	X	X	X	X	X			X		X	X	X			X	X	X	X	X	X				X
15	X	X		X	X	X	X				X		X	X		X	X	X		X		X		X
Total No. Essential	15	12	5	12	10	8	10	7	5	9	11	7	5	5	8	8	9	8	6	8	7	7	12	12
CVR	**1,00**	**0,60**	**-0,33**	**0,60**	**0,33**	**0,07**	**0,33**	**-0,07**	**-0,33**	**0,20**	**0,47**	**-0,07**	**-0,33**	**-0,33**	**0,07**	**0,07**	**0,20**	**0,07**	**-0,20**	**0,07**	**-0,07**	**-0,07**	**0,60**	**0,60**

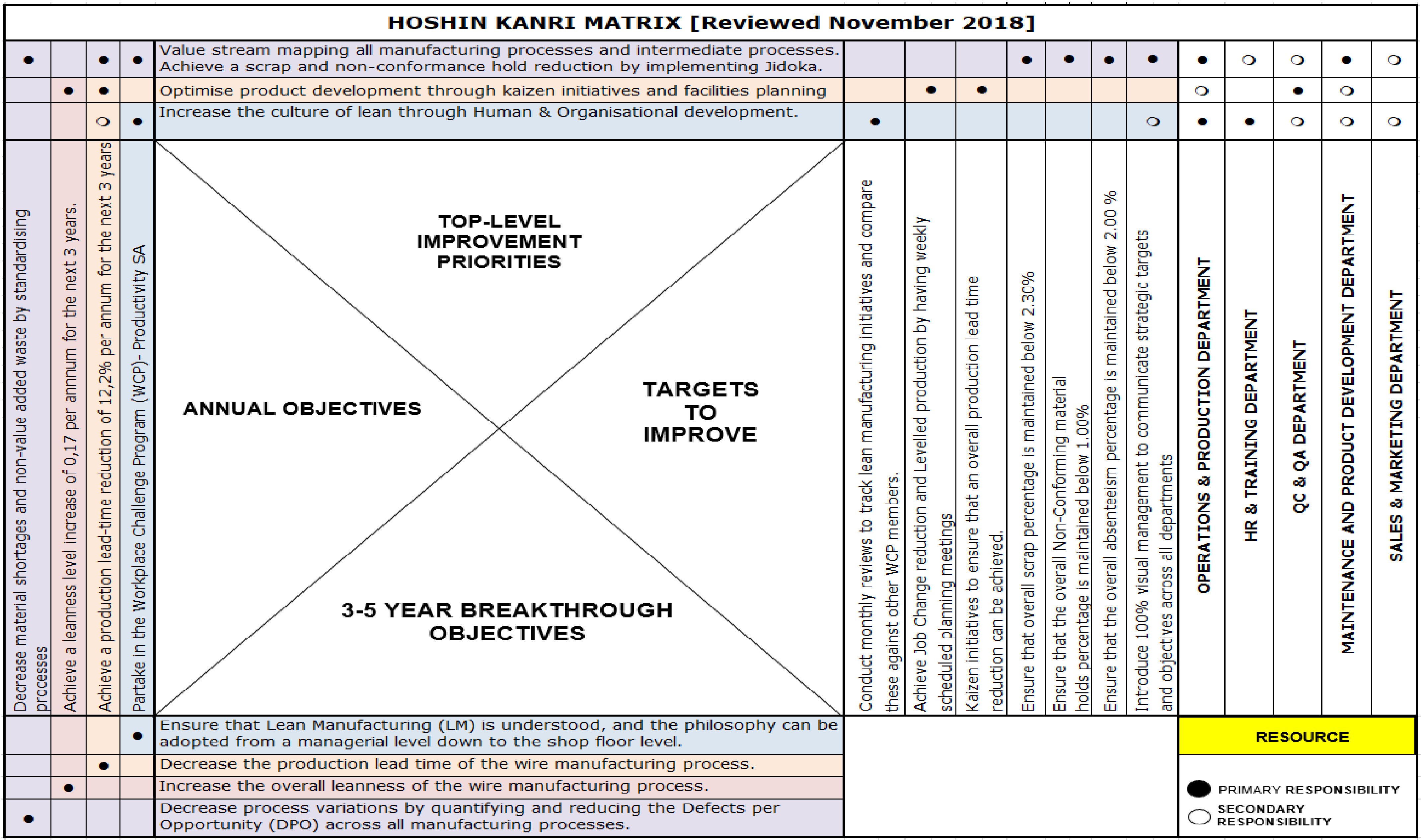
CVI Av
0,14

6.1.2 Round 2 of the Delphi Technique

In a second round, the research questionnaire was sent to the same research panel that participated in verifying the initial Hoshin Kanri matrix distributed during Round 1. A relatively low response rate of 47% (i.e. 7 participants) was achieved within the requested time-frame for the information required to complete Round 2 of the iteration. A follow-up email was sent to the participants whose feedback was still outstanding and the information gathered from Round 2 of the iteration was collected from the remaining 8 participants and summarised in Table 6.1-2**.**

The content validity index (CVI) of 0.50 that was computed using the feedback captured in Table 6.1-2 highlights that this average is above the minimum value deemed necessary for consensus for 15 participants. This feedback was then translated as consensus being reached by the judgement panel (i.e. participants) regarding the Hoshin Kanri matrix's ability to be used as a final deliverable of this study. It was however observed that even though a majority of items were considered to have some degree of content validity (due to the fact that they were considered "essential" by more than half of the research participants), some items still did not meet the 0.49 minimum value established in Table 3.7-1. These items were the following:

- Item 5 – Respect for team members
- Item 7 – Problem solving
- Item 8 – Suppliers support and development
- Item 11 – Material handling
- Item 15 – Layout for flow
- Item 16 – Cross-training



HOSHIN KANRI MATRIX [Reviewed November 2018]

TOP-LEVEL IMPROVEMENT PRIORITIES

ANNUAL OBJECTIVES

TARGETS TO IMPROVE

3-5 YEAR BREAKTHROUGH OBJECTIVES

TOP-LEVEL IMPROVEMENT PRIORITIES	Decrease material shortages and non-value added waste by standardising processes	Achieve a leanness level increase of 0,17 per annum for the next 3 years.	Achieve a production lead-time reduction of 12,2% per annum for the next 3 years	Partake in the Workplace Challenge Program (WCP)- Productivity SA	Conduct monthly reviews to track lean manufacturing initiatives and compare these against other WCP members.	Achieve Job Change reduction and Levelled production by having weekly scheduled planning meetings	Kaizen initiatives to ensure that an overall production lead time reduction can be achieved.	Ensure that overall scrap percentage is maintained below 2.30%	Ensure that the overall Non-Conforming material holds percentage is maintained below 1.00%	Ensure that the overall absenteeism percentage is maintained below 2.00 %	Introduce 100% visual management to communicate strategic targets and objectives across all departments	OPERATIONS & PRODUCTION DEPARTMENT	HR & TRAINING DEPARTMENT	QC & QA DEPARTMENT	MAINTENANCE AND PRODUCT DEVELOPMENT DEPARTMENT	SALES & MARKETING DEPARTMENT
Value stream mapping all manufacturing processes and intermediate processes. Achieve a scrap and non-conformance hold reduction by implementing Jidoka.	●		●	●				●	●	●	●	●	○	○	●	○
Optimise product development through kaizen initiatives and facilities planning		●	●			●	●					○		●	○	
Increase the culture of lean through Human & Organisational development.			○	●	●						○	●	●	○	○	○

ANNUAL OBJECTIVES	Decrease material shortages and non-value added waste by standardising processes	Achieve a leanness level increase of 0,17 per annum for the next 3 years.	Achieve a production lead-time reduction of 12,2% per annum for the next 3 years	Partake in the Workplace Challenge Program (WCP)- Productivity SA
Ensure that Lean Manufacturing (LM) is understood, and the philosophy can be adopted from a managerial level down to the shop floor level.				●
Decrease the production lead time of the wire manufacturing process.			●	
Increase the overall leanness of the wire manufacturing process.		●		
Decrease process variations by quantifying and reducing the Defects per Opportunity (DPO) across all manufacturing processes.	●			

RESOURCE

● PRIMARY RESPONSIBILITY

○ SECONDARY RESPONSIBILITY

Figure 6.1-2: Summary of the Hoshin Kanri matrix distributed with the research questionnaire in Round 1

Table 6.1-2: Feedback from Round 2 of the Delphi probe

Feedback from Round 2																			
Content evaluation panel (Participants)	1. Policy Deployment	2. Management System	3. Continuous Improvement	4. Scrap	5. Respect for Team Members	6. Morale	7. Problem Solving	8. Suppliers	9. 8 Waste Reduction	10. Quality	11. Material Handling	12. Pull Systems	13. Level Loading	14. Value Streams	15. Layout for Flow	16. Cross-Training	17. Quality Results	18. Synchronisation	19. Visual Performance Feedback
	Marked "Essential"																		
1	X	X			X	X		X	X	X		X	X	X	X	X		X	X
2	X	X	X	X		X	X		X		X	X		X			X	X	X
3	X	X	X	X		X		X	X	X	X	X	X	X	X		X	X	X
4	X	X	X	X		X	x		X	X		X	X			X	X	X	X
5	X		X	X	X	X				X			X	X			X	X	
6	X		X	X		X		X	X	X	X	X	X	X	X	X	X	X	X
7	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X					X			X	X	X
9	X	X	X	X		X	X		X	X	X	X	X	X	X	X		X	X
10	X	X	X	X				X	X	X		X		X	X		X		X
11	X	X	X		X	X	X		X	X		X	X		X	X	X	X	X
12	X	X	X	X		X		X	X	X	X	X	X	X			X	X	X
13	X	X		X	X	X			X	X	X		X		X	X	X	X	X
14	X	X	X	X			X	X	X	X	X	X	X	X	X		X		X
15	X	X	X	X	X	X	X		X			X	X	X			X		X
Total No. Essential	15	13	13	13	7	12	8	8	14	12	8	12	12	12	9	7	13	12	14
CVR	**1.00**	**0.73**	**0.73**	**0.73**	**-0.07**	**0.60**	**0.07**	**0.07**	**0.87**	**0.60**	**0.07**	**0.60**	**0.60**	**0.60**	**0.20**	**-0.07**	**0.73**	**0.60**	**0.87**

CVI AV

0.50

6.1.3 Summary of verification

As underlined in chapter 1, the final deliverable of this study is presented and summarised using the Hoshin Kanri matrix as shown in Figure 6.1-2. The final deliverable of this study was further verified using a 24-item based questionnaire that was adapted from the Association of Manufacturing Excellence (AME)'s 60-item based questionnaire. The research questionnaire was distributed to a total of 15 research participants that were identified using a knowledge resource nomination worksheet (KRNW), and Lawshe (1975)'s content validity ratio (CVR) was additionally used to evaluate the degree of consensus of each item on the questionnaire. An overall content validity index (CVI), which in the context of this study, refers to the average of all the measured CVRs, was computed as 0.50. In Section 4.1.2, Liker (2004)'s "4Ps of lean transformation" were used to summarise the key differences between the application of lean in discrete and continuous manufacturing environments. Although a degree of consensus was reached on the Hoshin Kanri matrix's ability to be used as an optimisation plan after two iterations, a comparison of the items that were discarded with the findings of Section 4.1.2 is shown in Table 6.1-3 as follows:

Table 6.1-3: A comparison of Phase 6's findings to Phase 2's findings

Discarded items (i.e. items with CVRs lower than 0.49)	Category under Liker (2004)'s 4P dimensions of lean transformation
Item 3 – Leadership standard work	Philosophy
Item 5 – Respect for team members	Philosophy
Item 5 – Problem solving	Problem solving
Item 8 – Suppliers	People and Partners
Item 9 – Employee development	Philosophy / People and partners
Item 16 – Cross training	Philosophy

Table 6.1-3 underlines that even though Figure 6.1-2 is considered as an effective tool to address process related challenges within the case study; the research participants do not consider it as an effective tool for addressing the other 3Ps of lean transformation. A conclusion of the overall study presented in this dissertation is provided in Chapter 7.

CHAPTER 7: CONCLUSION

7.1 Summary

A literature review was conducted as the preamble to this study to establish the difference(s) between the application of lean in discrete and continuous manufacturing environments. Analysis of the literature reviewed underlined that challenges are still encountered during the application of lean in continuous manufacturing environments similar to the manufacturing process in this case study. It can be argued that the practical and effective implementation of lean principles in continuous manufacturing environments is mainly restricted by the high variety, low volume mix of customer driven products in this manufacturing sector. However, the literature review conducted as part of this study also underlines that every continuous manufacturing process does eventually have a discrete component or process - and it is by means of these discrete processes that lean principles can be applied effectively.

The future state value stream map (FSVSM) that was drawn using the results from the current state value stream map (CSVSM) proposes that a 36.6% reduction in the process lead time can be achieved through kaizen initiatives. The measured Takt time of the CSVSM was however used to identify which area of the wire manufacturing should be considered a bottleneck, and subsequently used as a basis for measuring the leanness of the entire value stream. Overall, the empirical findings obtained from the efficiency, flow and variation EFV metric suggest that a decrease in process variations within the wire-manufacturing process is required to bridge any gap between the current performance and the desired strategic and operational goals. Moreover, the EFV metric used to measure the leanness of the wire-manufacturing process proposes that this may be achieved through incremental annual increases of 0.17 in the measured leanness level of the manufacturing process (over a period of three years).

The findings from the Root Cause Analysis (RCA) conducted in this study suggest that bad casting is considered by the research participants with knowledge on the subject matter as a leading cause of scrap and non-value added waste. However, analysis of the RCA using the Pareto principle underlines that a relatively straight (linear) cumulative line between the weighted root causes indicates that the contribution of each successive root cause is even. The relatively linear successive root causes was interpreted using the 80/20 principle as having a wire-manufacturing process with too many process variations that are considered to contribute negatively towards the organisation’s operational goals and targets.

A Hoshin Kanri matrix was used to summarise the findings from this study and to present an optimisation roadmap for the wire-manufacturing process. The Matrix cascaded the findings of this study into 3- to 5-year breakthrough objectives and the targets-to-improve (TTI) that are required to achieve the research aim and objectives introduced in Chapter 1. Even though this study’s Hoshin Kanri matrix provided a powerful and concise approach towards incorporating lean principles into the wire-manufacturing process, the degree of practicality and effectiveness of this approach also had to be established in this study. This was achieved in Chapter 6 when the final deliverable of this study, the Hoshin Kanri matrix, was verified by distributing a 24-item questionnaire to 15 research participants using an iterative Delphi technique. The degree of consensus (agreement) on the items presented in the research questionnaire was further established by using Lawshe (1975)’s content validity ratio (CVR), with a minimum CVR of 0.49 required for the 15 participants. Consensus was reached about the ability of the final deliverable of the current study to address the minimum required number of items on the questionnaire after two iterations.

7.2 Limitations

Limitations are evident both in the research approach adopted in this study and its final deliverable. Firstly, the ideal future state value stream map that is presented in this study does not comprehensively provide sufficient information on the resources that are required to achieve the suggested kaizen improvements. Secondly, based on the feedback received during the verification of the Hoshin Kanri matrix, it became evident that even though the Matrix is seen as an effective optimisation deployment strategy, the research participants did not consider it an effective medium to address the other 3 dimensions of lean transformation (see Table 6.1-3). This limitation parallels the ongoing debate that a change in organisational culture, or more specifically, emphasis on the dimension of people/partners and lean as a management philosophy, is often omitted when organisations implement lean manufacturing in various settings (Corbett, 2007:96; Hines et al., 2004; Panwar et al., 2015; Coetzee et al., 2016:79). Lastly, the effectiveness of the Hoshin Kanri matrix as an optimisation roadmap was not validated in this study because implementation of the study’s findings did not form part of the research aim and objectives introduced in Chapter 1.

7.3 Contribution

Even with the limitations that are presented in Section 7.2, this study still offers a practical and comprehensive guideline for any lean, would-be lean practitioners and organisations who are challenged by the fundamental question of - “How do we do it?” The 5-step research method introduced in this study can be adapted to suit any manufacturing environment, with the Hoshin Kanri matrix also providing a powerful strategy deployment tool to summarise the optimisation goals and targets of any organisation.

7.4 Future research

Future studies should include follow-up work that has been designed to evaluate whether the lean principles and quality management tools used in this study actually meet the objectives of differing and specialised manufacturing environments. This can be achieved by ensuring that future research is adapted from this study to include a Hoshin Kanri Matrix as an optimisation roadmap with 3-5 year objectives established using this study’s research method. Furthermore, scheduled tollgate reviews can however be incorporated into future research to establish if all the dimensions of lean transformation (4-P) are being addressed using this study’s research approach.

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ANNEXURE A

8.1 Ethics and study verification information

Annexure A contains additional information that was either obtained from various sources or was used throughout this study to achieve the objectives introduced in chapter 1. The various ethical considerations that were considered prior to this study being conducted are presented in Table 8.1-1.

Table 8.1-1: Ethical issues in qualitative, quantitative and mixed methods research

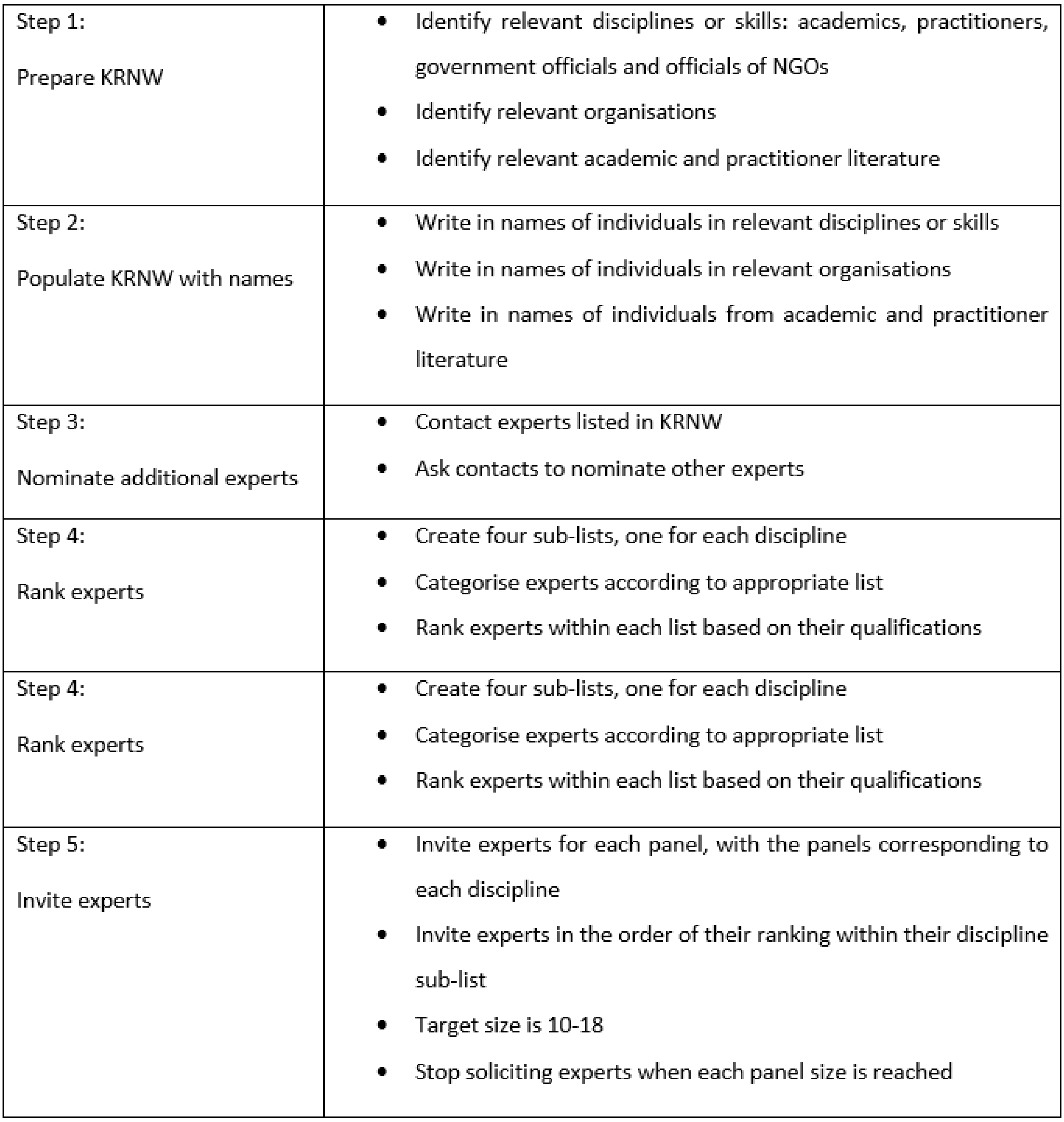
Where in the research process the ethical issue occurs	Type of ethical issue	How to address the issue
Prior to conducting the study	• Examine professional association standards. • Seek college/university approval on campus through an institutional review board (IRB). • Gain local permission from site and participants. • Select a site without a vested interest in outcome of study. • Negotiate authorship for publication.	• Consult the code of ethics for professional association in your area. • Submit proposal for IRB approval. • Identify and go through local approvals; find gatekeepers or key personnel to help. • Select sites that will not raise power issues with researchers. • Give credit for work done on the project; decide on author order in future publication.
Beginning the study	• Identify a research problem that will benefit participants. • Disclose purpose of the study. • Do not pressure participants into signing consent forms. • Respect norms and charters of indigenous societies. • Be sensitive to needs of vulnerable populations (e.g. children).	• Conduct a needs assessment or informal conversation with participants about their needs. • Contact participants and inform them of the general purpose of the study. • Tell participants that they do not have to sign form. • Find out about cultural, religious, gender and other differences that need to be respected. • Obtain appropriate consent (e.g. parents, as well as children).
Collecting data	• Respect the site and disrupt as little as possible.	• Build trust and convey the extent of anticipated disruption in gaining data.
	• Make certain that all participants receive the same treatment.	• Put into place waitlist provisions for treatment for controls.
	• Avoid deceiving participants.	• Discuss purpose of the study and how data will be used.

	• Respect potential power imbalances and exploitation of participants (e.g. interviewing, observing).	• Avoid leading questions. Withhold sharing personal impressions.
	• Do not “use” participants by gathering data and leaving site.	• Avoid disclosing sensitive information. Involve participants as collaborators.
	• Avoid collecting harmful information.	• Provide rewards for participating.
		• Stay with questions stated in an interview protocol.
Analysing data	• Avoid siding with participants (going native).	• Report multiple perspectives.
	• Avoid disclosing only positive results.	• Report contrary findings.
	• Respect the privacy and anonymity of participants.	• Assign fictitious names or aliases; develop composite profiles of participants.
		• Report honestly.
Reporting, sharing and storing data	• Avoid falsifying authorship, evidence, data, findings and conclusions.	• See APA (2010) guidelines for permissions needed to reprint or adapt work of others.
	• Avoid disclosing information that would harm participants.	• Use composite stories so that individuals cannot be identified.
	• Communicate in clear, straightforward and appropriate language	• Use unbiased language appropriate for audiences of the research.
	• Share data with others.	• Provide copies of report to participants and stakeholders. Share results with other researchers. Consider website distribution.
	• Keep raw data and other materials (e.g. details of procedures, instruments).	

Source: Creswell (2014)

In Table 8.1-2, the steps that were used to identify this study’s research participants are summarised in the knowledge resource nomination worksheet (KRNW) as follows:

Table 8.1-2: Knowledge resource nomination worksheet steps



Step 1: Prepare KRNW	• Identify relevant disciplines or skills: academics, practitioners, government officials and officials of NGOs • Identify relevant organisations • Identify relevant academic and practitioner literature
Step 2: Populate KRNW with names	• Write in names of individuals in relevant disciplines or skills • Write in names of individuals in relevant organisations • Write in names of individuals from academic and practitioner literature
Step 3: Nominate additional experts	• Contact experts listed in KRNW • Ask contacts to nominate other experts
Step 4: Rank experts	• Create four sub-lists, one for each discipline • Categorise experts according to appropriate list • Rank experts within each list based on their qualifications
Step 4: Rank experts	• Create four sub-lists, one for each discipline • Categorise experts according to appropriate list • Rank experts within each list based on their qualifications
Step 5: Invite experts	• Invite experts for each panel, with the panels corresponding to each discipline • Invite experts in the order of their ranking within their discipline sub-list • Target size is 10-18 • Stop soliciting experts when each panel size is reached

Source: Okoli & Pawlowski (2003)

8.2 Value stream mapping information and data

A suppliers-input-process-output-customers (SIPOC) analysis of the wire-manufacturing process is presented in Figure 8.2-1. This SIPOC diagram illustrates the wire-manufacturing process' products order-to-delivery cycle, and creates a baseline for the value-stream mapping that was conducted in this study.

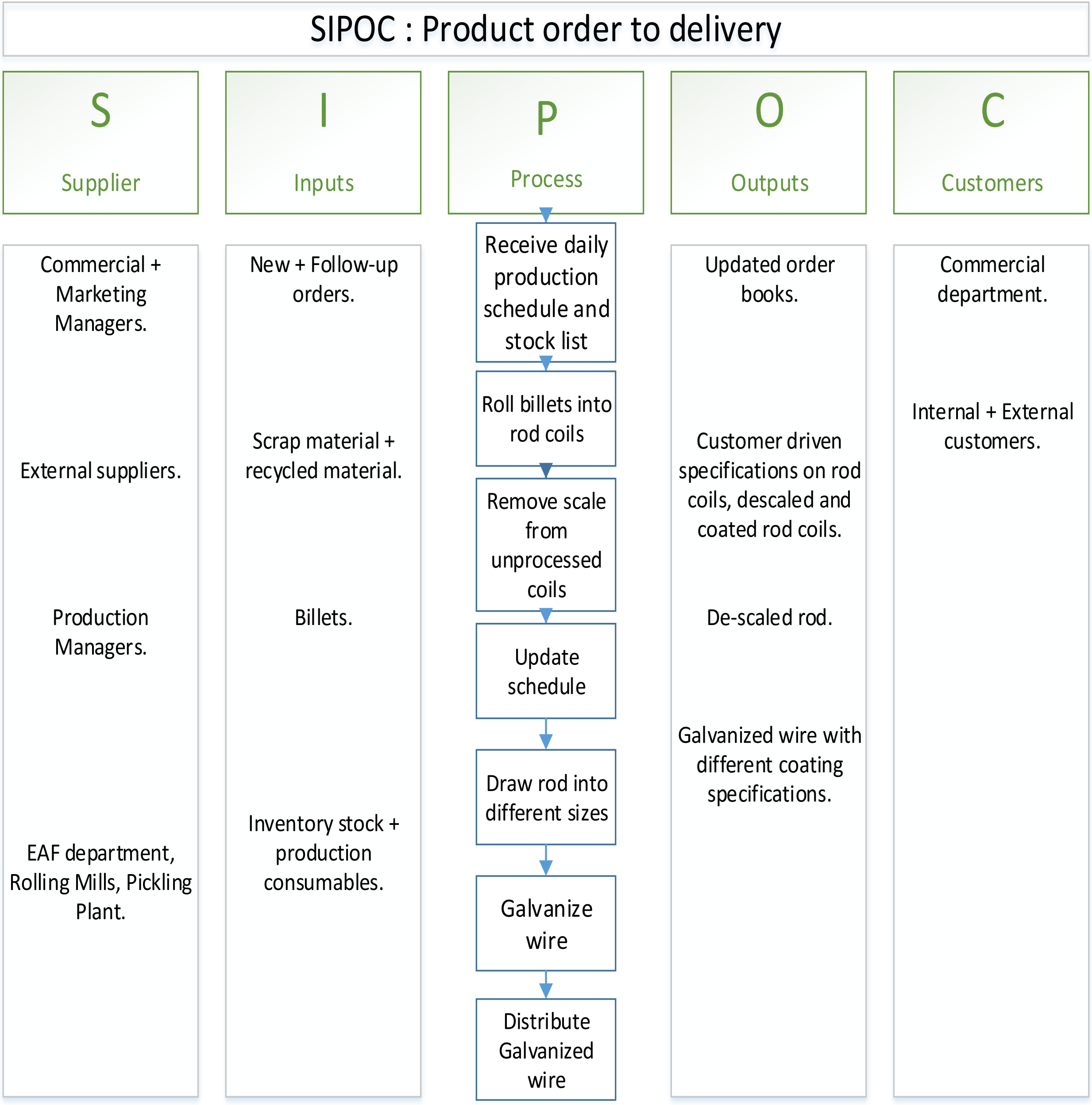


Figure 8.2-1: SIPOC diagram of the wire-manufacturing process used in this study.

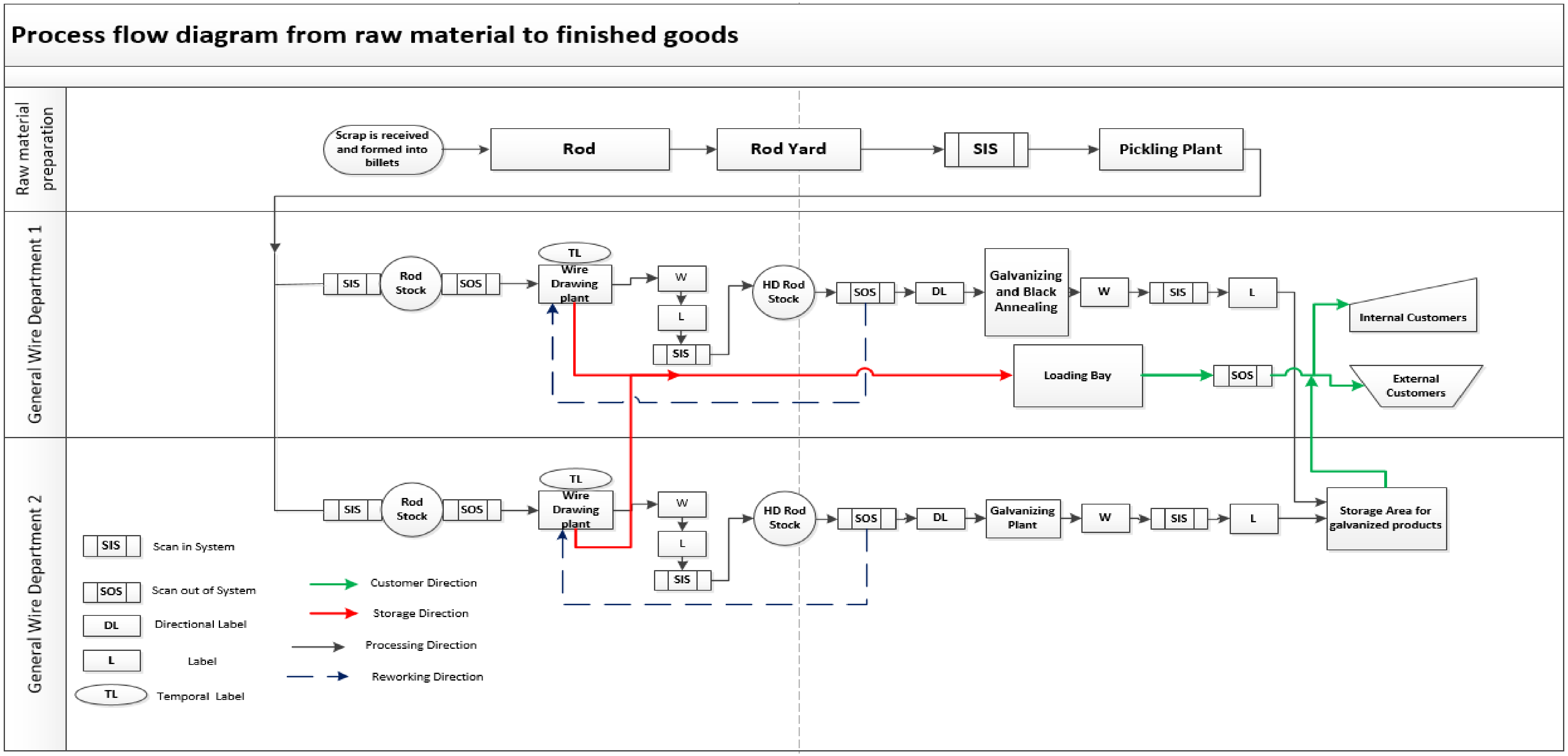


Figure 8.2-2: Process flow diagram for the organisation used as a case study

The Historical production figures are presented in Table 8.2-1 for the various wire sizes and their respective production tonnages that were produced on the galvanizing lines over this study's research period.

Table 8.2-1: The various wire sizes and their respective production tonnages over the research period.

Wire Diameter vs Production yield over research period							
Process line 1		**Process line 2**		**Process line 3**		**Process line 4**	
Size (mm)	Tons	Size (mm)	Tons	Size (mm)	Tons	Size (mm)	Tons
0.95	1	1.25	2	0.69	203	1.57	1860
1.60	52	1.60	3295	0.71	1	1.60	20
1.75	233	1.70	800	0.85	126	1.7	19
1.80	47	1.75	2397	0.90	719	1.75	1
1.90	47	1.80	2944	0.95	30	1.78	370
1.93	267	1.90	20	1.25	6591	1.80	98
1.96	23	1.93	289	1.40	832	1.90	75
2.00	6082	2.00	3947	1.45	11	1.96	782
2.20	860	2.20	768	1.52	66	2.00	3229
2.40	27	2.22	51	1.55	6	2.11	2
2.42	832	2.25	474	1.57	154	2.12	39
2.46	155	2.40	35	1.60	2863	2.22	25
2.50	8893	2.42	180	1.70	15	2.24	9503
2.70	387	2.46	20	1.75	996	2.28	1552
2.74	23	2.50	665	1.80	323	2.32	3
2.75	12	2.60	698	1.93	24	2.40	36
2.80	926	2.70	1	2.00	291	2.42	51
2.90	41	3.15	253	2.20	389	2.46	165
3.00	131			2.24	901	2.50	49
3.05	0			2.42	16	2.51	46
3.06	25			2.46	11	2.65	96
3.15	5565			2.50	425	2.70	37
3.25	31			2.60	25	2.80	602
3.40	52			2.70	1342	3.06	111
3.55	131			2.74	165	3.15	108
3.60	25			2.92	5	3.35	494
3.63	22			3.00	3670	3.55	66
3.65	9			3.15	101	3.65	8

3.90	11			3.40	148	3.80	72
3.96	6			3.60	25	4.00	999
4.00	2713			3.65	320		
4.40	17			3.96	1916		
4.60	25			4.00	40		
4.62	0						
5.00	74						
5.60	344						

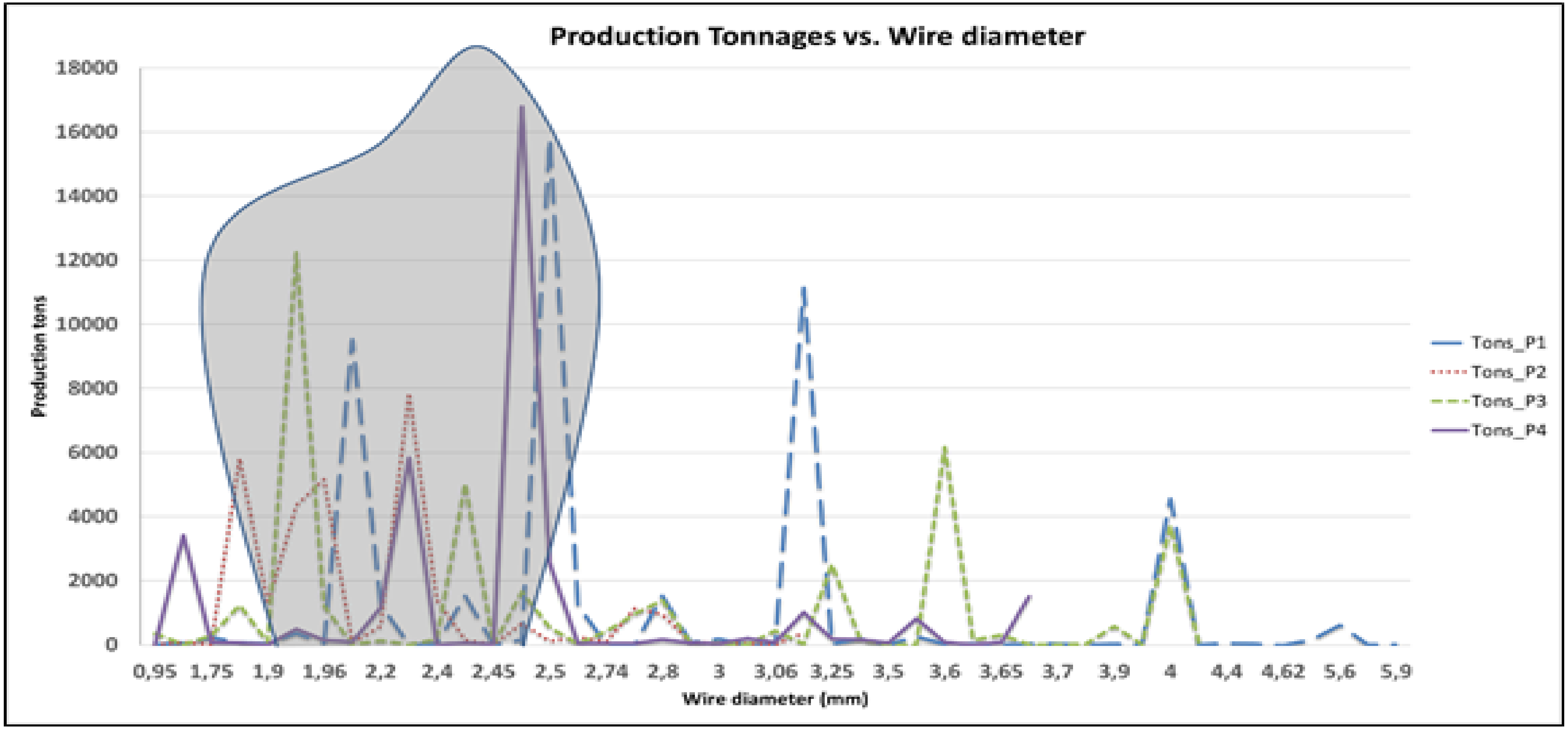


Figure 8.2-3: A graphical representation of the information presented in Table 8.2 1 highlights that the wire sizes range mostly between 1.90 mm and 2.50 mm. A median range of 2.20 mm was used as this study's product family

In Figure 8.2-4, a summary of the generic value stream mapping symbols and their descriptions (meaning) is presented. Rother & Shook (1999)'s value stream mapping technique was introduced in chapter 2, and Figure 8.2-4's symbols were used to map both the current and future-state maps presented under this study's findings.

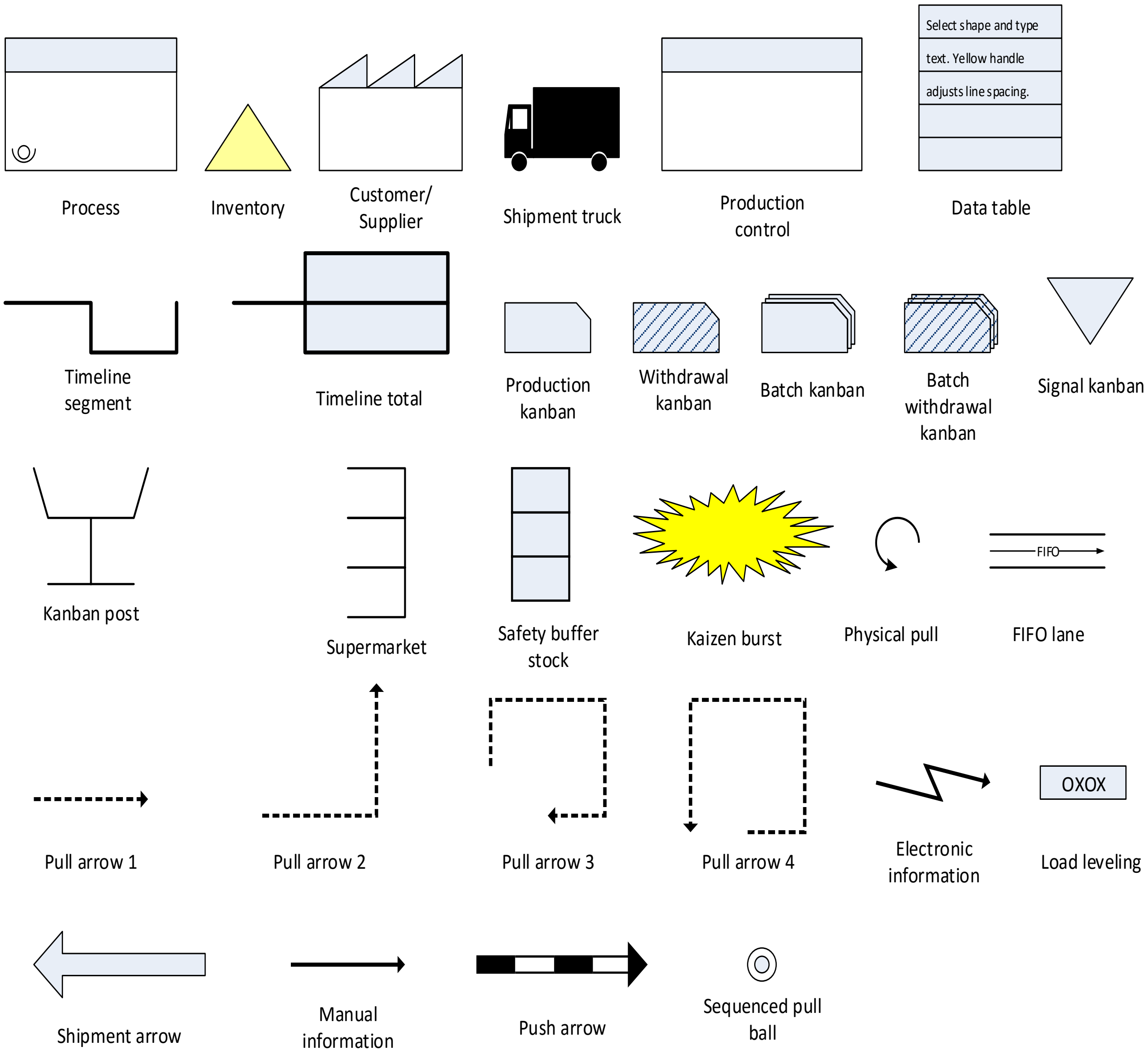
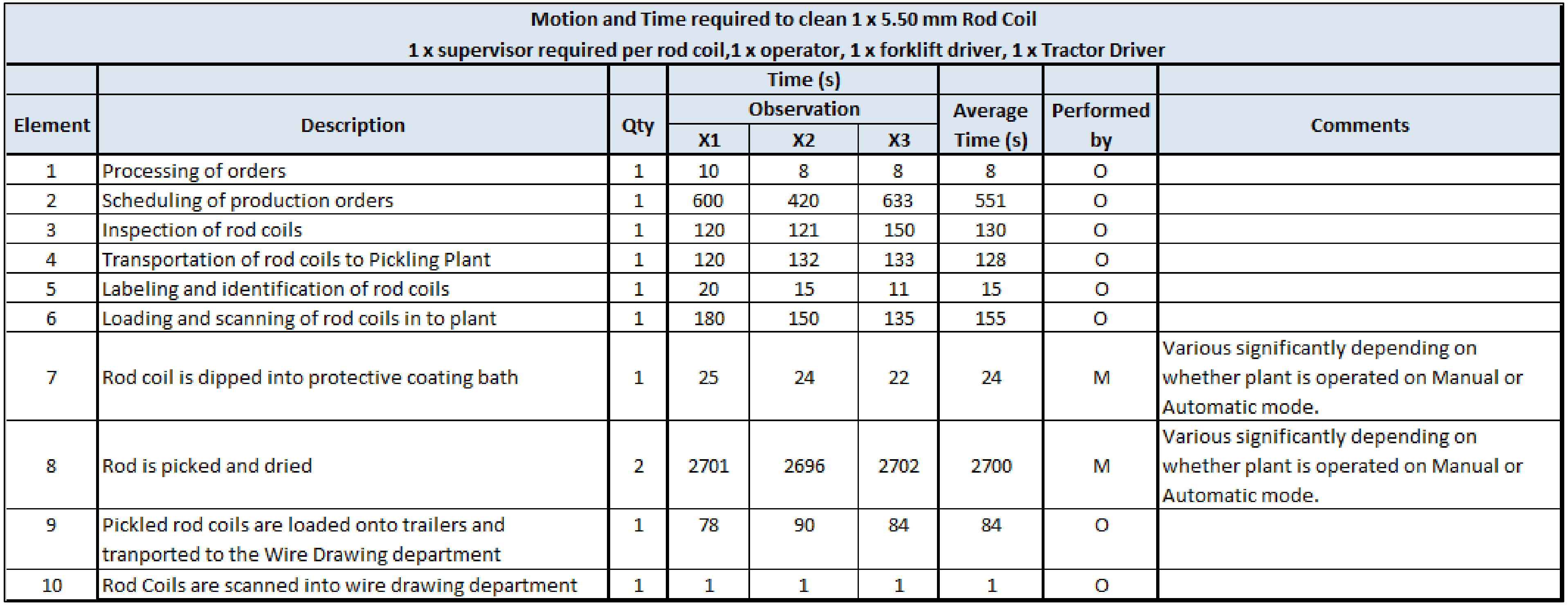


Figure 8.2-4: Generic Value Stream Mapping symbols

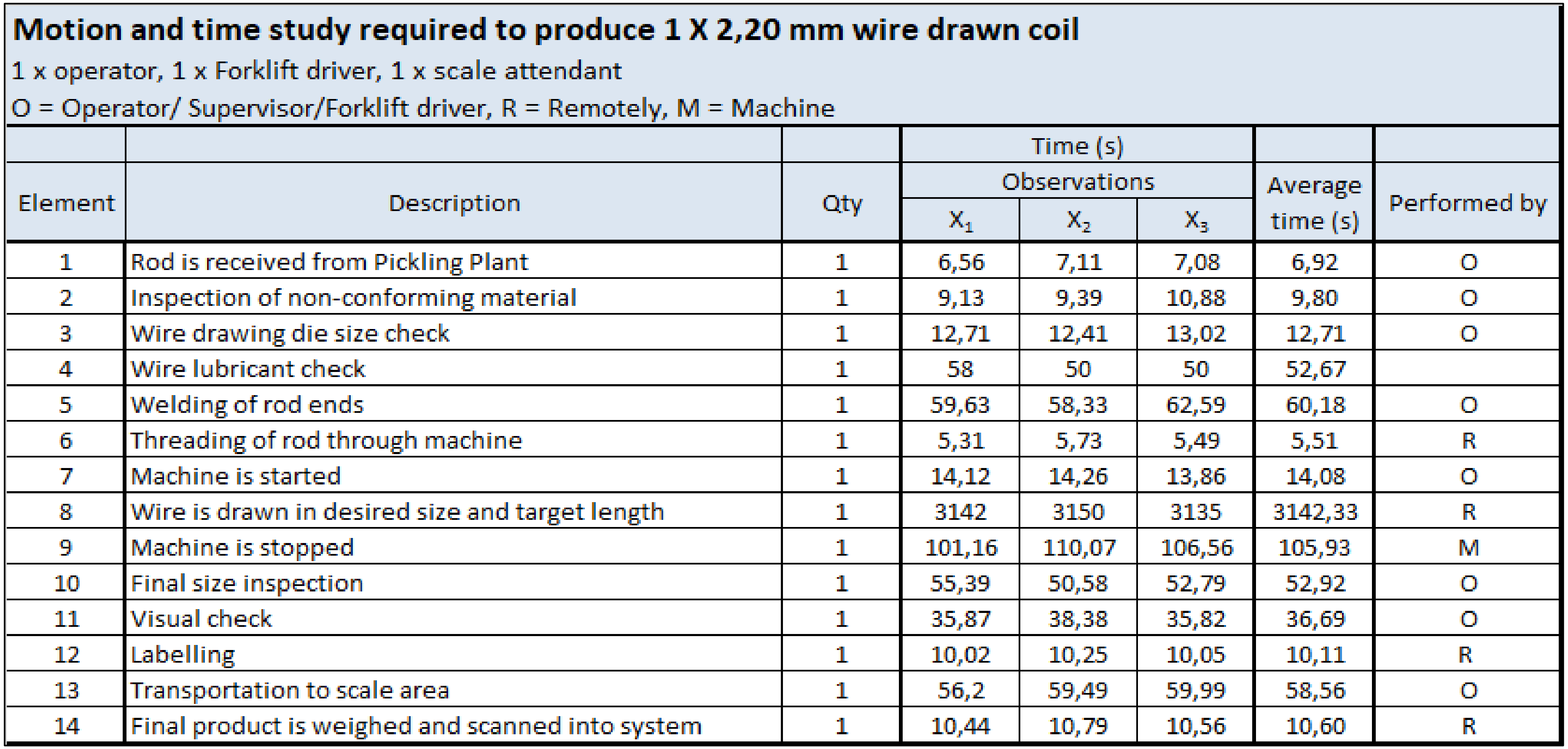
A summary of the motion and time studies that were conducted in this study are summarised in Table 8.2-2 to Table 8.2-4. From the tables provided below, it should be observed that three observations were conducted for each element that was measured.

Table 8.2-2: Motion and time study for the cleaning of 1 x 5.50 mm Rod Coil



Motion and Time required to clean 1 x 5.50 mm Rod Coil 1 x supervisor required per rod coil,1 x operator, 1 x forklift driver, 1 x Tractor Driver								
			Time (s)					
Element	Description	Qty	Observation			Average Time (s)	Performed by	Comments
			X1	X2	X3			
1	Processing of orders	1	10	8	8	8	O	
2	Scheduling of production orders	1	600	420	633	551	O	
3	Inspection of rod coils	1	120	121	150	130	O	
4	Transportation of rod coils to Pickling Plant	1	120	132	133	128	O	
5	Labeling and identification of rod coils	1	20	15	11	15	O	
6	Loading and scanning of rod coils in to plant	1	180	150	135	155	O	
7	Rod coil is dipped into protective coating bath	1	25	24	22	24	M	Various significantly depending on whether plant is operated on Manual or Automatic mode.
8	Rod is picked and dried	2	2701	2696	2702	2700	M	Various significantly depending on whether plant is operated on Manual or Automatic mode.
9	Pickled rod coils are loaded onto trailers and tranported to the Wire Drawing department	1	78	90	84	84	O	
10	Rod Coils are scanned into wire drawing department	1	1	1	1	1	O	

Table 8.2-3: Motion and time study for the production of 1 x 2.20 mm wire drawn coil



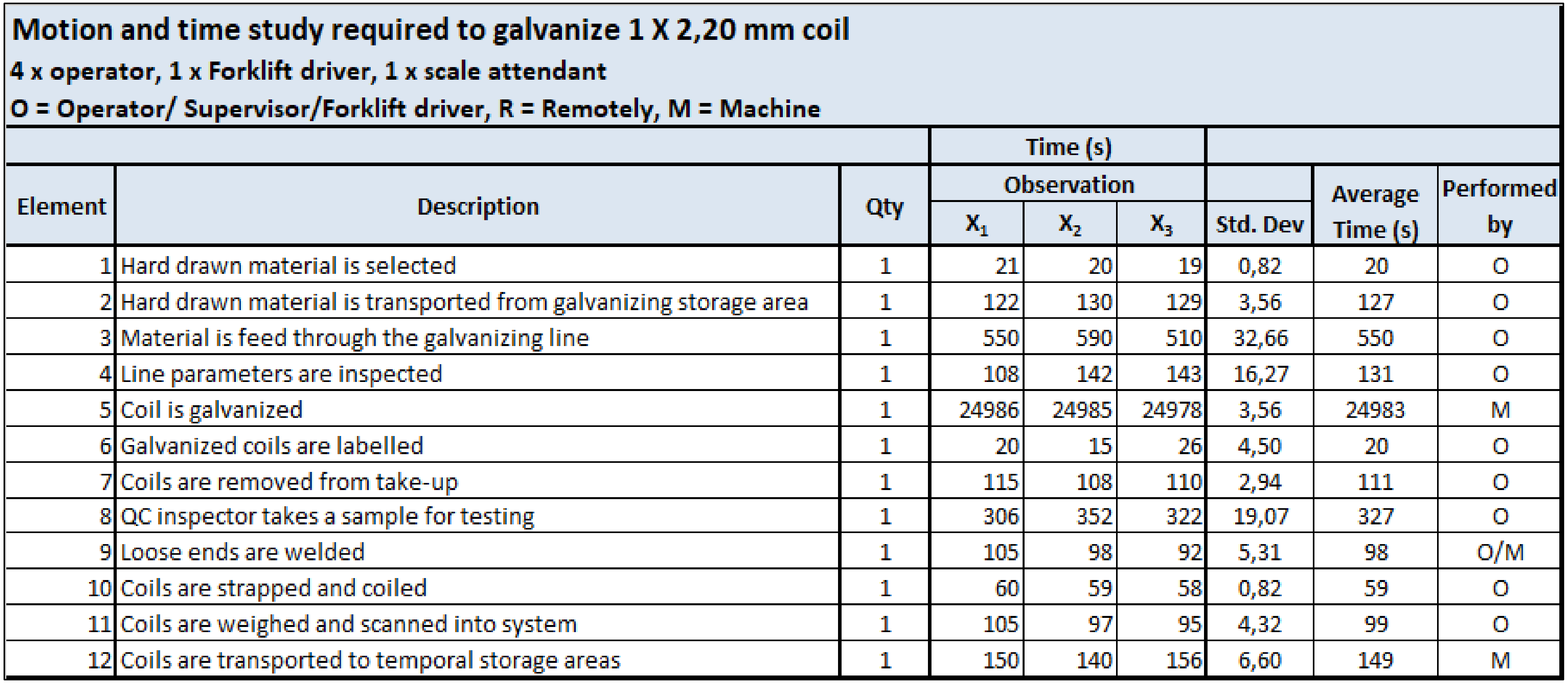
Motion and time study required to produce 1 X 2,20 mm wire drawn coil

1 x operator, 1 x Forklift driver, 1 x scale attendant

O = Operator/ Supervisor/Forklift driver, R = Remotely, M = Machine

			Time (s)				
Element	Description	Qty	Observations			Average time (s)	Performed by
			X_1	X_2	X_3		
1	Rod is received from Pickling Plant	1	6,56	7,11	7,08	6,92	O
2	Inspection of non-conforming material	1	9,13	9,39	10,88	9,80	O
3	Wire drawing die size check	1	12,71	12,41	13,02	12,71	O
4	Wire lubricant check	1	58	50	50	52,67	
5	Welding of rod ends	1	59,63	58,33	62,59	60,18	O
6	Threading of rod through machine	1	5,31	5,73	5,49	5,51	R
7	Machine is started	1	14,12	14,26	13,86	14,08	O
8	Wire is drawn in desired size and target length	1	3142	3150	3135	3142,33	R
9	Machine is stopped	1	101,16	110,07	106,56	105,93	M
10	Final size inspection	1	55,39	50,58	52,79	52,92	O
11	Visual check	1	35,87	38,38	35,82	36,69	O
12	Labelling	1	10,02	10,25	10,05	10,11	R
13	Transportation to scale area	1	56,2	59,49	59,99	58,56	O
14	Final product is weighed and scanned into system	1	10,44	10,79	10,56	10,60	R

Table 8.2-4: Motion and time study for the production of 1 x 2.20 mm galvanized coil



Motion and time study required to galvanize 1 X 2,20 mm coil

4 x operator, 1 x Forklift driver, 1 x scale attendant

O = Operator/ Supervisor/Forklift driver, R = Remotely, M = Machine

			Time (s)					
Element	Description	Qty	Observation X_1	Observation X_2	Observation X_3	Std. Dev	Average Time (s)	Performed by
1	Hard drawn material is selected	1	21	20	19	0,82	20	O
2	Hard drawn material is transported from galvanizing storage area	1	122	130	129	3,56	127	O
3	Material is feed through the galvanizing line	1	550	590	510	32,66	550	O
4	Line parameters are inspected	1	108	142	143	16,27	131	O
5	Coil is galvanized	1	24986	24985	24978	3,56	24983	M
6	Galvanized coils are labelled	1	20	15	26	4,50	20	O
7	Coils are removed from take-up	1	115	108	110	2,94	111	O
8	QC inspector takes a sample for testing	1	306	352	322	19,07	327	O
9	Loose ends are welded	1	105	98	92	5,31	98	O/M
10	Coils are strapped and coiled	1	60	59	58	0,82	59	O
11	Coils are weighed and scanned into system	1	105	97	95	4,32	99	O
12	Coils are transported to temporal storage areas	1	150	140	156	6,60	149	M

ANNEXURE B

9.1 Research Questionnaire – supporting information

Annexure B presents the information used to verify the research method and this study's optimisation plan. The Knowledge resource nomination worksheet (KRNW) that was used is also presented in Table 9.1-1.

Table 9.1-1: Knowledge resource nomination worksheet (KRNW)

	Knowledge resource nomination worksheet			
ID	**Relevant Field/Job description**	**Highest Qualification**	**Rank**	**Years of experience**
EP 1	Business Advisory-Solutions manager	M.Eng Engineering Management	1	>10
EP 2	Capacity and constraints analyst	BSc Applied Industrial Systems	3	>10
EP 3	Lecturer	BEng Industrial	4	<3
EP 4	Process Engineer	BEng Industrial	5	5<years<10
EP 5	Industrial Engineer	NDip Industrial	6	<3
IP 1	Production Manager	MBA	2	>10
IP 2	Production Manager	BSc	7	>10
IP 3	Production Manager	NDip	10	>30
IP 4	Production Manager	BEng	8	<5
IP 5	Quality Manager	BEng	9	<5
IP 6	Process Controller	Matric/Trade Test	12	>25
IP 7	Lab Technician	BTech	11	>10
IP 8	Supervisor	Matric/Trade Test	13	>10
IP 9	Supervisor	Matric/Trade Test	14	5<years<10
IP 10	Supervisor	Matric/Trade Test	15	5<years<10

A Requirements Traceability Matrix (RTM) was used to establish which items from the original AME 60-item questionnaire would be applicable to this study.

Table 9.1-2: Requirements traceability matrix

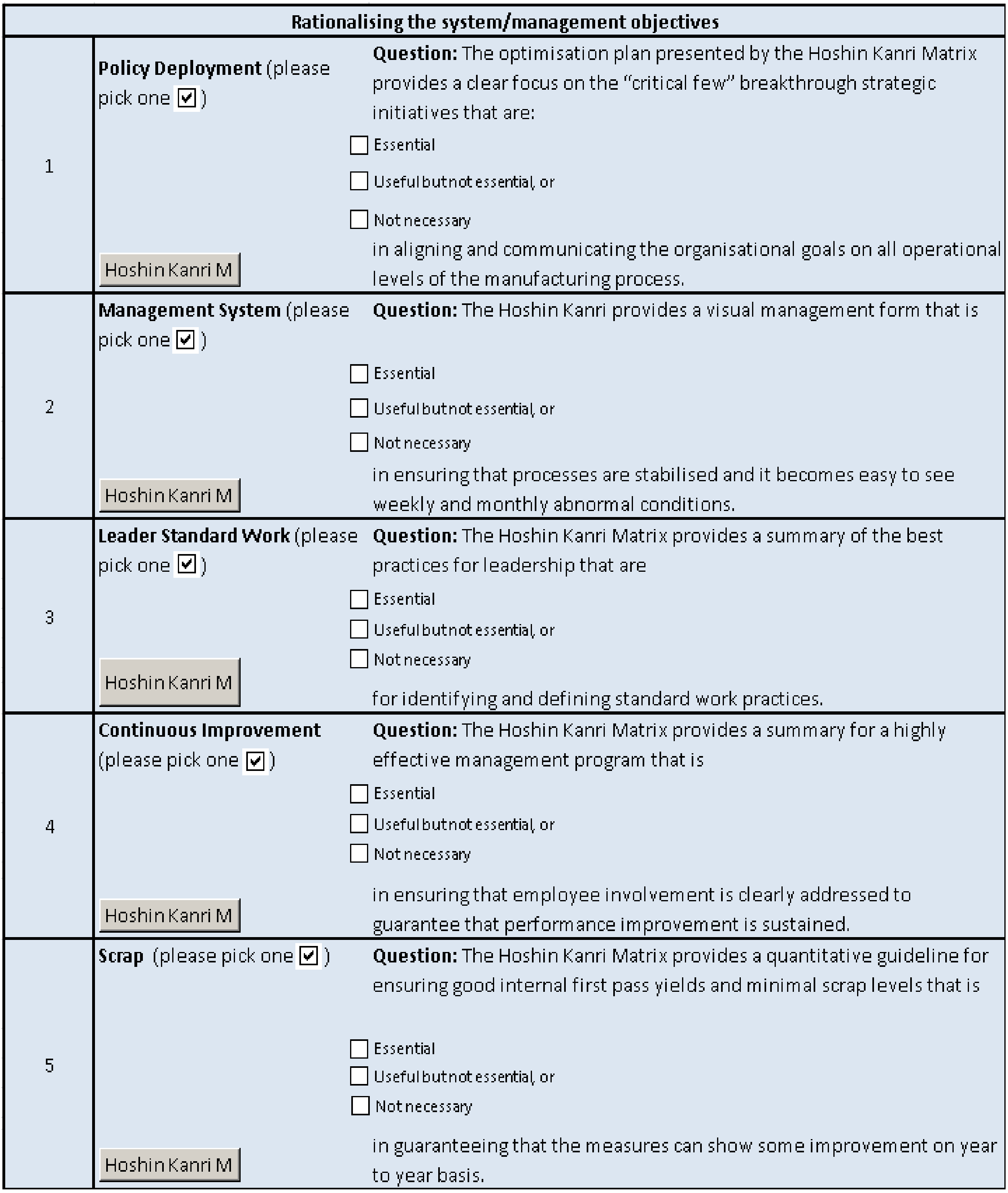
		Benchmark (Are these required for this study?)										
	Kobayashi's 20 Keys to workplace improvement	**Management System**	**Human and Organisational Development**	**Safety and Environmental Health**	**Manufacturing Operations**	**Business Operations**	**Product Development**	**Supplier Development & Procurement**	**Quality**	**Cost**	**Delivery**	**Profitability**
1	Cleaning and organising	O	O	O	O	O		O	O		O	
2	Rationalising the system/management of objectives	O	O		O	O		O	O		O	
3	Improvement team activities	O	O		O	O		O	O		O	
4	Reducing inventory (shortening lead-times)	O	O		O	O		O	O		O	
5	Quick changeover manufacturing	O	O		O	O			O			
6	Manufacturing Value analysis (Methods Improvement)	O	O		O	O		O	O			
7	Zero Monitor Manufacturing	O			O	O			O			
8	Coupled manufacturing	O	O									
9	Maintaining equipment	O			O				O			
10	Time control and commitment	O	O		O	O					O	
11	Quality assurance system	O	O		O			O	O		O	
12	Developing your suppliers	O	O		O	O		O	O		O	
13	Eliminating waste (Treasure Map)	O	O		O	O		O	O		O	
14	Empowering workers to make improvement	O	O		O	O			O		O	
15	Skill versatility and cross-training	O	O		O	O						
16	Production scheduling	O			O	O					O	
17	Efficiency control	O	O		O	O			O		O	
18	Using information systems	O	O	O	O	O		O	O		O	
19	Conversing energy and materials	O			O	O						
20	Leading technology and site technology	O	O		O	O			O		O	
Count		**20**	**16**	**2**	**19**	**17**	**0**	**9**	**15**	**0**	**13**	**0**

It should be noted that Kobayashi's 20 keys to workplace improvement were used in the above RTM. A summary of the RTM is presented in Table 9.1-3.

Table 9.1-3: Summary of requirements traceability matrix (RTM)

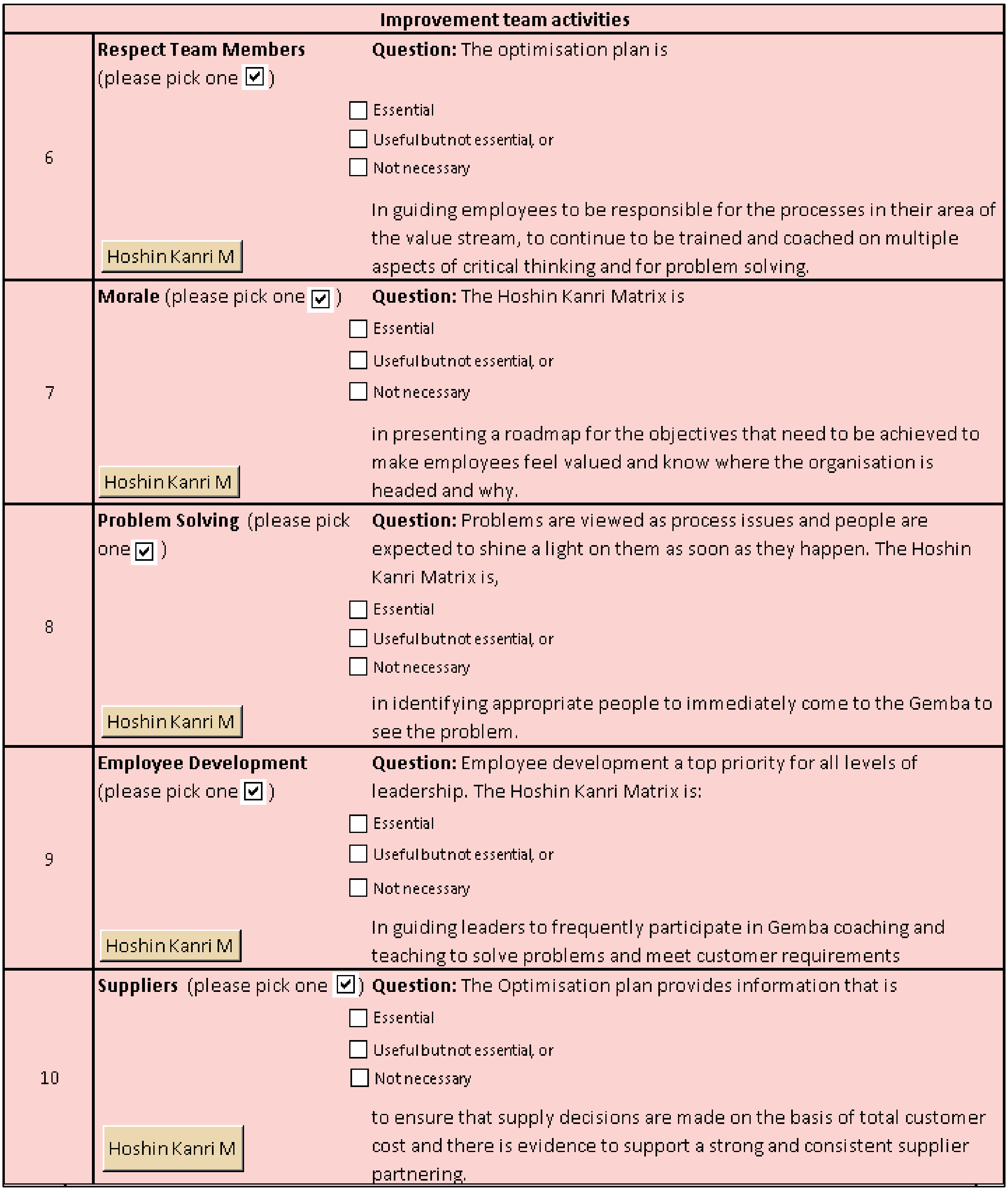
Management System	20
Manufacturing Operations	19
Business Operations	17
Human and Organisational Development	16
Quality	15
Delivery	13
Supplier Development & Procurement	9
Safety and Environmental Health	2
Product Development	0
Cost	0
Profitability	0

A sample of this study's 24-item research questionnaire is presented in Figure 9.1-1 to Figure 9.1-5



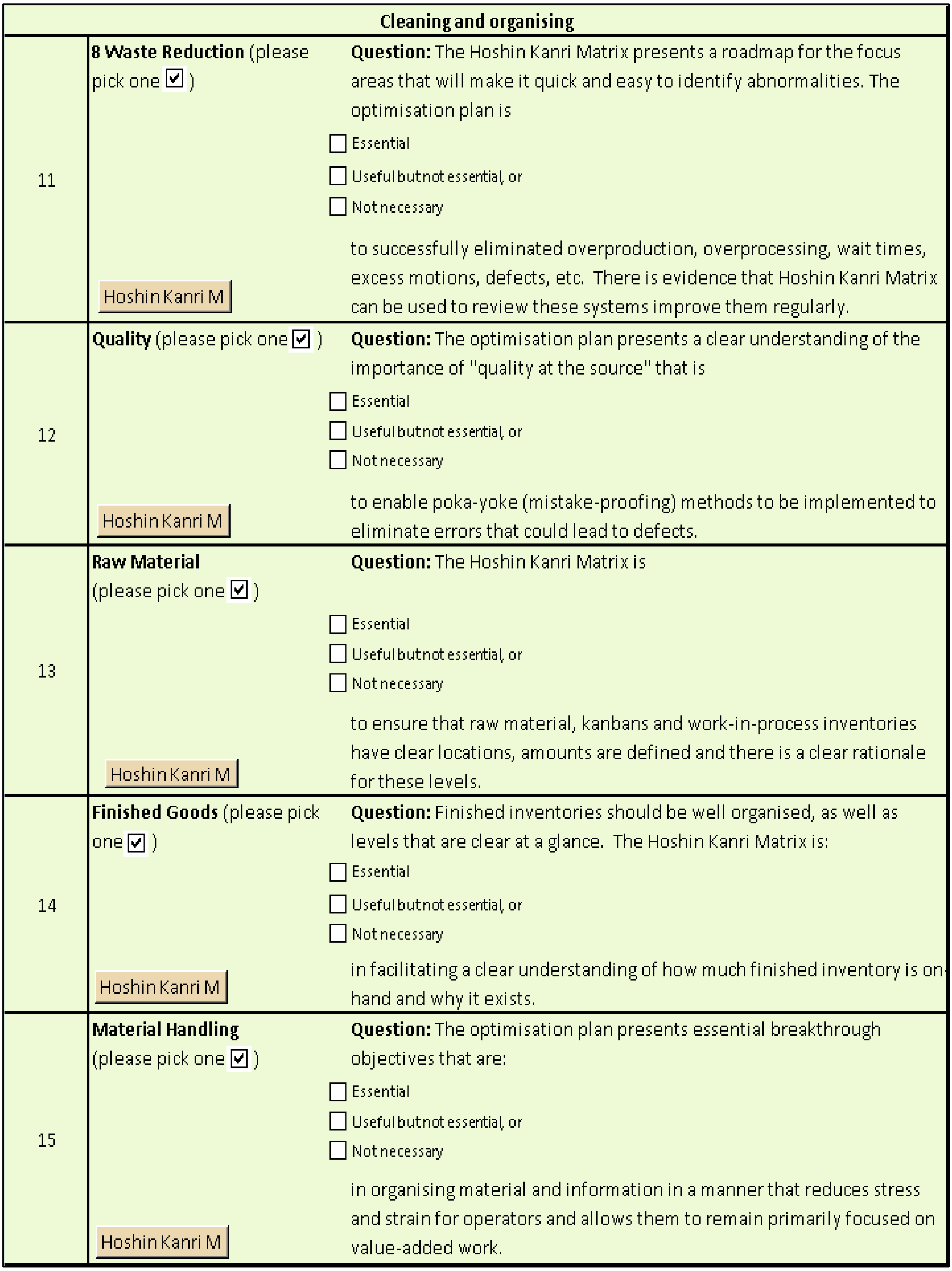
	Rationalising the system/management objectives	
1	**Policy Deployment** (please pick one ☑) Hoshin Kanri M	**Question:** The optimisation plan presented by the Hoshin Kanri Matrix provides a clear focus on the "critical few" breakthrough strategic initiatives that are: ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in aligning and communicating the organisational goals on all operational levels of the manufacturing process.
2	**Management System** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri provides a visual management form that is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in ensuring that processes are stabilised and it becomes easy to see weekly and monthly abnormal conditions.
3	**Leader Standard Work** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri Matrix provides a summary of the best practices for leadership that are ☐ Essential ☐ Useful but not essential, or ☐ Not necessary for identifying and defining standard work practices.
4	**Continuous Improvement** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri Matrix provides a summary for a highly effective management program that is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in ensuring that employee involvement is clearly addressed to guarantee that performance improvement is sustained.
5	**Scrap** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri Matrix provides a quantitative guideline for ensuring good internal first pass yields and minimal scrap levels that is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in guaranteeing that the measures can show some improvement on year to year basis.

Figure 9.1-1: Research questionnaire Items 1 to 5



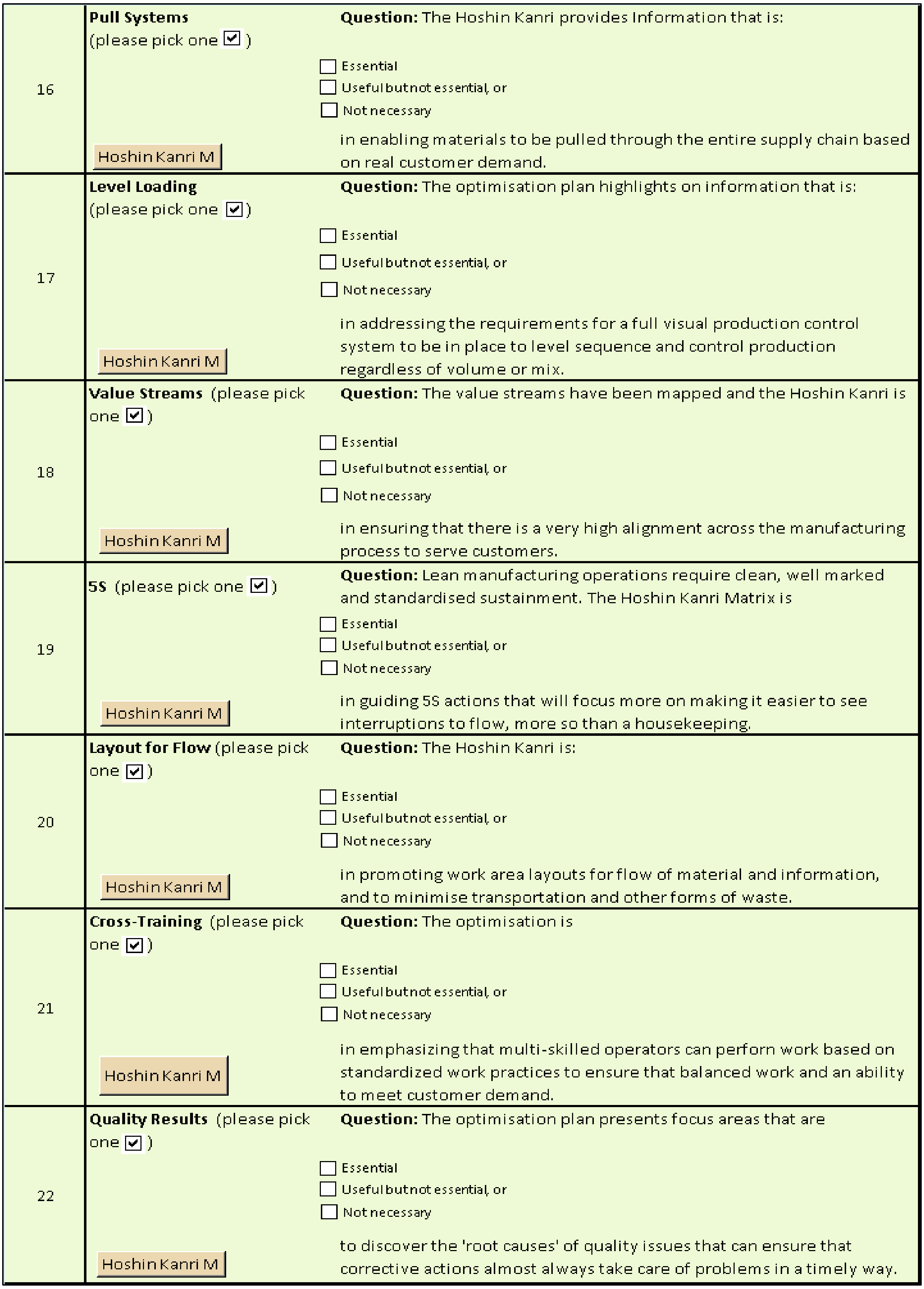
Improvement team activities		
6	**Respect Team Members** (please pick one ☑) Hoshin Kanri M	**Question:** The optimisation plan is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary In guiding employees to be responsible for the processes in their area of the value stream, to continue to be trained and coached on multiple aspects of critical thinking and for problem solving.
7	**Morale** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri Matrix is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in presenting a roadmap for the objectives that need to be achieved to make employees feel valued and know where the organisation is headed and why.
8	**Problem Solving** (please pick one ☑) Hoshin Kanri M	**Question:** Problems are viewed as process issues and people are expected to shine a light on them as soon as they happen. The Hoshin Kanri Matrix is, ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in identifying appropriate people to immediately come to the Gemba to see the problem.
9	**Employee Development** (please pick one ☑) Hoshin Kanri M	**Question:** Employee development a top priority for all levels of leadership. The Hoshin Kanri Matrix is: ☐ Essential ☐ Useful but not essential, or ☐ Not necessary In guiding leaders to frequently participate in Gemba coaching and teaching to solve problems and meet customer requirements
10	**Suppliers** (please pick one ☑) Hoshin Kanri M	**Question:** The Optimisation plan provides information that is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary to ensure that supply decisions are made on the basis of total customer cost and there is evidence to support a strong and consistent supplier partnering.

Figure 9.1-2: Research questionnaire items 6 to 10



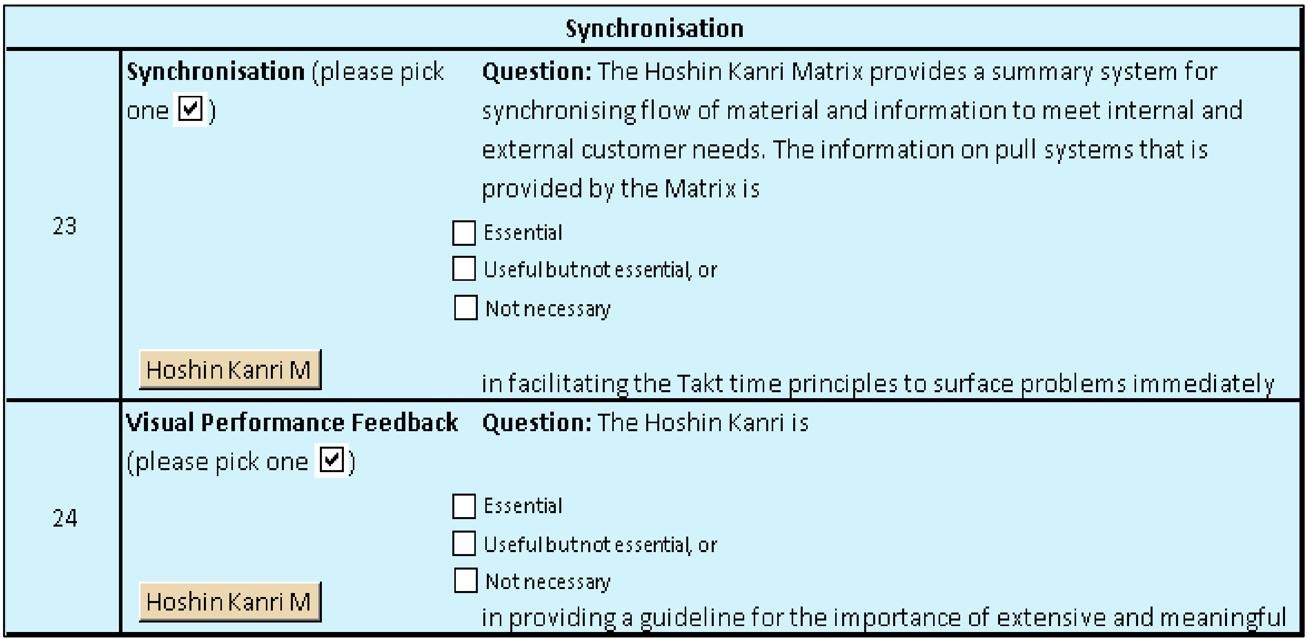
	Cleaning and organising	
11	**8 Waste Reduction** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri Matrix presents a roadmap for the focus areas that will make it quick and easy to identify abnormalities. The optimisation plan is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary to successfully eliminated overproduction, overprocessing, wait times, excess motions, defects, etc. There is evidence that Hoshin Kanri Matrix can be used to review these systems improve them regularly.
12	**Quality** (please pick one ☑) Hoshin Kanri M	**Question:** The optimisation plan presents a clear understanding of the importance of "quality at the source" that is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary to enable poka-yoke (mistake-proofing) methods to be implemented to eliminate errors that could lead to defects.
13	**Raw Material** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri Matrix is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary to ensure that raw material, kanbans and work-in-process inventories have clear locations, amounts are defined and there is a clear rationale for these levels.
14	**Finished Goods** (please pick one ☑) Hoshin Kanri M	**Question:** Finished inventories should be well organised, as well as levels that are clear at a glance. The Hoshin Kanri Matrix is: ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in facilitating a clear understanding of how much finished inventory is on-hand and why it exists.
15	**Material Handling** (please pick one ☑) Hoshin Kanri M	**Question:** The optimisation plan presents essential breakthrough objectives that are: ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in organising material and information in a manner that reduces stress and strain for operators and allows them to remain primarily focused on value-added work.

Figure 9.1-3: Research questionnaire items 11 to 15



16	**Pull Systems** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri provides Information that is: ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in enabling materials to be pulled through the entire supply chain based on real customer demand.
17	**Level Loading** (please pick one ☑) Hoshin Kanri M	**Question:** The optimisation plan highlights on information that is: ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in addressing the requirements for a full visual production control system to be in place to level sequence and control production regardless of volume or mix.
18	**Value Streams** (please pick one ☑) Hoshin Kanri M	**Question:** The value streams have been mapped and the Hoshin Kanri is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in ensuring that there is a very high alignment across the manufacturing process to serve customers.
19	**5S** (please pick one ☑) Hoshin Kanri M	**Question:** Lean manufacturing operations require clean, well marked and standardised sustainment. The Hoshin Kanri Matrix is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in guiding 5S actions that will focus more on making it easier to see interruptions to flow, more so than a housekeeping.
20	**Layout for Flow** (please pick one ☑) Hoshin Kanri M	**Question:** The Hoshin Kanri is: ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in promoting work area layouts for flow of material and information, and to minimise transportation and other forms of waste.
21	**Cross-Training** (please pick one ☑) Hoshin Kanri M	**Question:** The optimisation is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in emphasizing that multi-skilled operators can perform work based on standardized work practices to ensure that balanced work and an ability to meet customer demand.
22	**Quality Results** (please pick one ☑) Hoshin Kanri M	**Question:** The optimisation plan presents focus areas that are ☐ Essential ☐ Useful but not essential, or ☐ Not necessary to discover the 'root causes' of quality issues that can ensure that corrective actions almost always take care of problems in a timely way.

Figure 9.1-4: Research questionnaire Items 16 to 22



	Synchronisation	
23	**Synchronisation** (please pick one ☑)	**Question:** The Hoshin Kanri Matrix provides a summary system for synchronising flow of material and information to meet internal and external customer needs. The information on pull systems that is provided by the Matrix is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in facilitating the Takt time principles to surface problems immediately
24	**Visual Performance Feedback** (please pick one ☑)	**Question:** The Hoshin Kanri is ☐ Essential ☐ Useful but not essential, or ☐ Not necessary in providing a guideline for the importance of extensive and meaningful

Figure 9.1-5: Research questionnaire Items 23 to 24

ANNEXURE C

10.1 Examples of the material commonly referenced in this study

In Annexure B, the generic images shown Figure 10.1-1 to Figure 10.1-3 are used to describe the intermediate products that are common in all wire-manufacturing industries. The terms represented in the pictures have also been used in this study.

Figure 10.1-1: Rod Coil

Source: Alibaba. Image by unknown

Figure 10.1-2: A typical rod yard where coils are temporarily stored

Source: Alibaba. Image by unknown

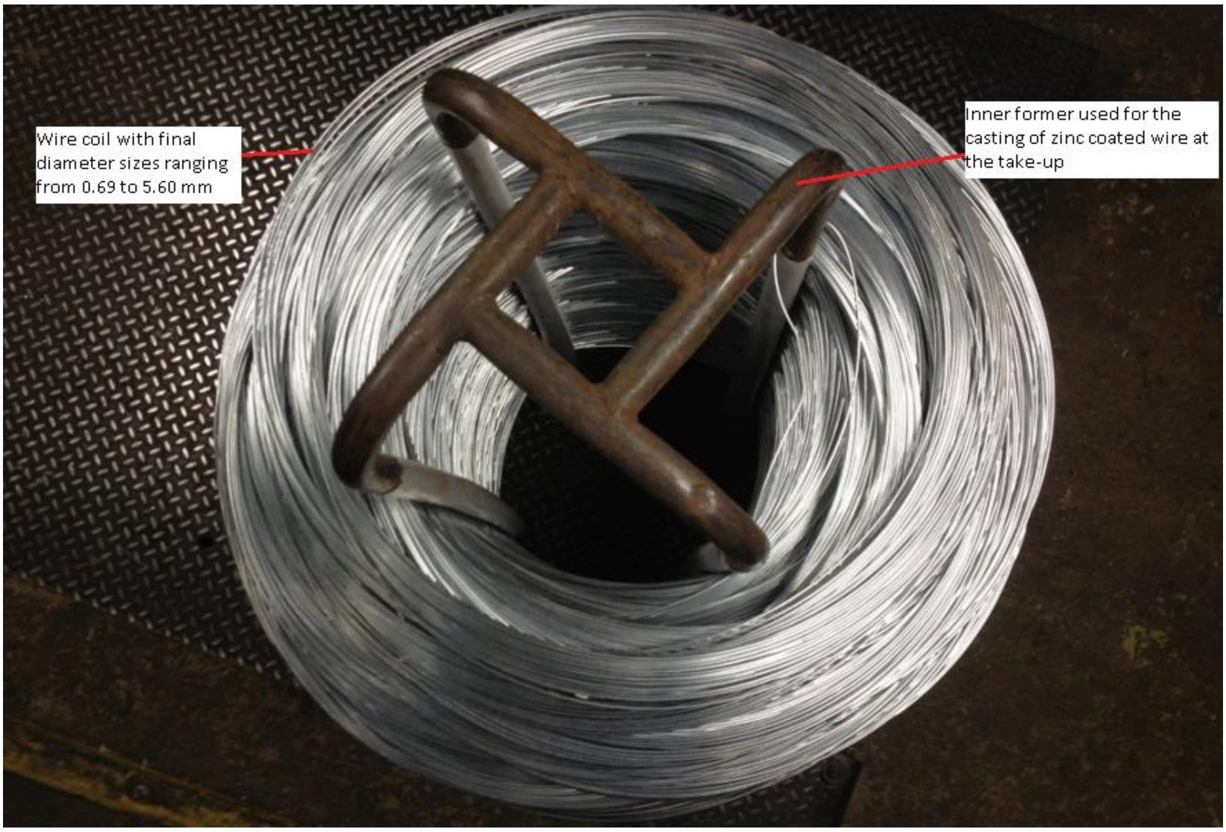


Figure 10.1-3: Galvanized wire coils in a steel structure called a former

Source: Mid-South Wire. Image by unknown

DECLARATION FROM LANGUAGE EDITOR

11.1 Language editor's declaration

ISABEL CLAASSEN

Accredited member of the South African Translators' Institute (No. 1000583)

DECLARATION

I herewith declare that I,

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completed the *language editing** of the research article entitled

Development of a lean optimisation plan for a wire-manufacturing process

which had been submitted to me by

Maqhawe Shongwe
(Student Number: 25751255)

in partial fulfilment of the requirements for the degree

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