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A framework for the successful implementation of Lean Six Sigma in the capital equipment manufacturing environment

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A research project submitted to the Gordon Institute of Business Science, University of Pretoria, in partial fulfilment of the requirements for the degree of Master of Business Administration.

10 November 2014

Abstract

After events like the global financial crisis and the advent of globalisation, companies have experienced increased competition and pressure to improve performance in the new environments in which business is conducted. This has impacted the world of manufacturing, among others, and has necessitated companies in this industry to adopt improvement methodologies to assist in growing the business. This study looks into the implementation of Lean Six Sigma (LSS) as one of these procedures and highlights that most articles and studies on this process concentrate on the high-volume, low-mix manufacturing environment. On account of this, a gap is left in the application of these techniques in the low-volume, high-mix environment. The literature highlights the differences in the two disciplines that have now evolved into one toolkit that is applied as LSS and how that is achieved.

The cases highlighted do not, however, cover the low-volume, high-variety manufacturers, and this paper seeks to use the expertise of LSS practitioners in this environment to get information and derive a framework for successful implementation of LSS in the capital equipment environment.

The main contributor to the study is a company that manufactures capital equipment for the mines, with other respondents being practitioners in similar companies and customers in the mines. Respondents were sent a survey to get their opinion on the implementation of LSS in their environment. The survey attempted to gather information through five key questions on how LSS was being applied and its impact on the cost, cycle-time and on-time delivery of the organisation.

A quantitative study design was adopted to develop a framework for the successful implementation of LSS in the capital equipment industry. A total of 38 respondents gave feedback, which was analysed, and this showed what - according to the professionals involved in this study - are the vital aspects of this implementation to ensure success.

Keywords
Lean manufacturing, Six sigma, Lean six sigma, Cost, Cycle-time, On-time delivery

Declaration

I declare that this research project is my own work. I have submitted it in partial fulfilment of the degree of Master of Business Administration at the Gordon Institute of Business Science, University of Pretoria. It has not been submitted before for any degree or examination at any other university. I further declare that I have the necessary authorisation and consent to carry out this research.

Name: Kgomotso Duiker

Signed:

Acknowledgements

I would like to thank my wife, Mrs Nosipho Duiker, and my two children, Keneilwe and Iviwe Duiker, for their continued strength and support throughout this journey.

My sincerest gratitude goes to my knowledgeable and patient supervisor, Mr Mahendra Dedasaniya, who provided me with support and was always available to assist through the challenges. I feel I have come into my own in terms of 'out-of-the-box' thinking and project management through the guidance and support of Mr Dedasaniya.

I would like to thank my parents and brother for their support as well as encouragement and inspiration that carried me through. To my employer, Joy Global: thank you for allowing me to go on this course and agreeing to give me the time off to attend my studies.

My sincerest gratitude and thanks goes to the Gordon Institute of Business Science for their sterling MBA programme that tests one's character beyond anything one had ever expected.

Lastly, but not least, I would like to thank the Lord God for giving me the strength, knowledge and tenacity to continue and complete this course.

I dedicate this research report to the memory of my older brother, K Sello Duiker.

Table of Contents

Table of figures

List of tables

1 Introduction

Lean Six Sigma (LSS) has been used in the business environment for over 20 years. As shown in figure 1 below, there has been a gradual development of improvement techniques in the business environment and this has culminated in the current LSS.

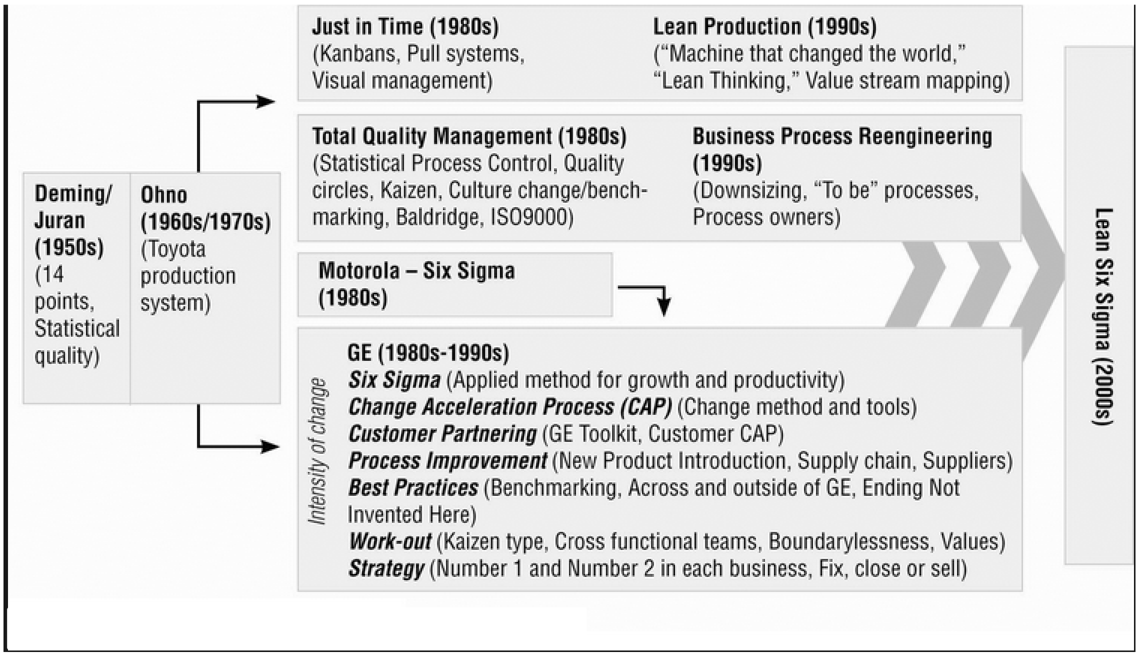

Figure 1- LSS builds on the practical lessons learned from previous eras of operational improvement (Byrne, Lubowe, & Blitz, 2007)

LSS as a discipline is primarily made up of lean manufacturing and six sigma. The diagram indicates that the origins of these techniques were originally from Deming and Juran in the 1950s. The concepts of Deming and Juran's statistical methods were further adapted and improved by Ohno in the 1960s and 70s. These improvements were then applied within Toyota and the program was named Toyota Production Systems.

In the 1980s and 90s came the development of techniques such as Just In Time(JIT), Total Quality Management (TQM), Business Process Reengineering and Six Sigma (SS).

In the 2000s all these tools are included in the program of LSS which has come about as a result of finding the synergies within all these different improvement techniques and consolidating them in a program called lean six sigma (LSS).

LSS has brought about great success for large corporations as this methodology combines two time-tested programmes for achieving operational excellence in major US companies. This process is helping leaders discover innovation opportunities and promote a company-wide culture with a trend towards innovation(Byrne, Lubowe, & Blitz, 2007). This technique might have started gaining traction in the US; however. It has now spread to other areas of the globe assisted by the fact that most corporations are multinationals that implement global roll-out of the LSS programmes. This research paper is focused on an organisation in the capital equipment manufacturing industry that produces original equipment, to order, for the mines. The organisation has implemented LSS and is still embarking on training the workforce to embrace this new way of doing business. The challenge of training the workforce on this new paradigm shift has proven to be challenging, even from the basic actions e.g. housekeeping.

There is, however, a differing view on LSS. Although its popularity endures, the notion of the concept as a corporate cure-all is subsiding (Hindo & Grow, 2007) as there are thoughts around the changing needs of the customer, who is forcing organisations to think more around innovation and customer relationships as the salient value proposition. The customer is consistently demanding better performance from his supplier and is always testing the market for what competitors may offer. It is therefore vital for the organisation to stay ahead of the competition through better performance in all areas of the business when compared to these competitors.

1.1 Definition of problem and purpose

The competitive environment of the current manufacturing sector is characterised by tight budgets and frequent product innovations resulting in managers and engineers striving for innovative and efficient methods of manufacturing at lowest cost with high quality. The purpose of this research paper is to develop a framework for the successful implementation of LSS in the capital equipment manufacturing environment so that it can become a tool management and engineers can use to achieve their goals. The success of the implementation of LSS can be measured through the monitoring of the key measures of manufacturing costs, cycle-time of product and on-time delivery of products to the customer. These metrics are normally used to drive the business to ensure optimum performance. Managing costs is a way of ensuring that the company is doing all that is in its power to maintain lowest cost processes during manufacturing and the goal is to continuously improve on the prior year’s performance. Cycle-time metric is monitored for improvement as the better the cycle-time the more efficient the process is becoming through introducing some improvements. The final metric of on-time delivery is also vital to gauging company performance as there are commitments made to the customer in terms of delivery times and the more reliable a company is the more likely it is to receive repeat business going forward.

There has been a growing demand for minerals and coal production as Sub-Saharan Africa has doubled its production in the period from 2000 to 2011 (Farooki, 2012), resulting in an increasing demand for mining equipment to support this growth. This increase in demand is good for the industry and also indicates how vital this sector is to the growth of the country. Local manufacturers, however, have to perform well in a specialised environment with few major players and high competition. Skills shortages were said to be particularly acute at managerial, engineering, artisanal and technical levels - such as welders and boilermaker (Kaplan, 2012). This is also an indication of a need for change in the current practices within this environment as there is a need for marked improvement in developing skills.

LSS is a problem-solving toolkit that has many approaches, depending on the issues being addressed, and can be applied to multiple disciplines. The tools used can be mostly from the six sigma side as lead and then bringing in the lean manufacturing tools when needed or vice versa, which is why they are used together under the program label called lean six sigma. This research proposes a framework that can be applied in a project manufacturing environment, job-shop - such as that of the capital equipment manufacturer - to bring about the required performance to survive in the current global market environment. There has been several success stories published from both manufacturing companies as well as service companies on the benefits of LSS with the noticeable ones being from companies is the telecommunications industry as well as the airlines industry e.g. Southwest Airlines. It is therefore evident that LSS can be applied across multiple industries and sectors however the approach will not be the same across the board.

The research is conducted in a certain manufacturing company where there is access to information on the implementation of lean six sigma within this organisation. The use of LSS is not widely documented in this environment of capital equipment manufacturing, with most journals focused on automotive industry (Vinodh, Gautham, & Ramiya R., 2011) (Vinodh, Kumar, & Vimal, 2014). There is therefore a gap in knowledge in the use of LSS in the capital equipment manufacturing environment in South Africa, which has its own unique challenges. The relevance of this study will be in assisting stakeholders in the industry to understand how to apply LSS in the capital equipment manufacturing environment and to ensure that the organisation is put onto a continuous improvement path and that the improvements are sustained. The final output will therefore be a framework derived from the insights of the research paper that can be applied in any organisation that is in the industry of low volume and high variety production.

2 Theory and literature review

2.1 Lean manufacturing

The following section of the research will be an explanation into the core concepts of lean manufacturing and how they came about.
While it stems from the roots of mass production concepts developed in the US by pioneers such as Samuel Colt and Henry Ford (Browning & Heath, 2009), the Toyota Production System (TPS) provides the basis for what is now known as 'lean thinking', as popularised by Womack and Jones (1996) cited in Pepper and Spedding (2010). The concept began shortly after the Second World War, pioneered by Taiichi Ohno and associates, while employed by the Toyota motor company. The main focus adopted by Ohno was to reduce cost by eliminating waste.

2.1.1 Background of lean manufacturing

This emphasis on waste reduction drove practices such as inventory reduction, process simplification, as well as the identification and elimination of non-value-adding tasks (Browning & Heath, 2009). Tasks can be divided into three types:

1. Those that add value,
2. Those that do not add value but are necessary with current methods of production, and
3. Those that do not add value and are not necessary.

This was mainly developed through observation of the Ford mass production system, which to Mr Ohno looked wasteful in many ways (Dahlgaard & Dahlgaard-Park, 2006). As stated previously, lean thinking is based on the main concept of elimination of waste. Seven forms of waste were identified:

1. Overproduction,
2. Defects,
3. Unnecessary inventory,
4. Inappropriate processing,
5. Excessive transportation,
6. Waiting, and
7. Unnecessary motion.

(Dahlgaard & Dahlgaard-Park, 2006)

Recently, two more wastes - under the titles ‘underutilisation of creativity of people’ and ‘environmental wastes’ – have also been included in the list Dahlgaard and Dahlgaard-Park (2006) cited in Vinodh *et al.* (2014). The techniques and tools most frequently adopted to eliminate wastes through the application of the Lean Manufacturing paradigm are: 5s, mistake proofing, cellular manufacturing, pull production, value stream mapping, kaizen, Kanban, total productive maintenance, set-up time reduction and visual management (Vinodh *et al.*, 2014). These techniques can be applied in different combinations depending on the project being tackled.

The first step in a lean transition is to identify value-added and non-value-adding processes within the organisation. Value stream mapping (VSM) emerged as a tool to carry out this process (Rother and Shook, 1999 cited in Pepper & Spedding, 2010), and continues to provide reliable qualitative analysis. As various tools and techniques exist to work towards the lean goal, it is necessary to plan carefully and keep track of the lean efforts. VSM results in the construction of a lean roadmap (Cottyn, Van Landeghem, Stockman, & Derammelaere, 2011) and is also used to provide the scope of the project by defining the current state and desired future state of the system. The future state map is then used to develop lean improvement strategies, for example parallel working and flexibility through multi-skilling employees (Pepper & Spedding, 2010). To implement lean, it is necessary to adapt the techniques to the characteristics of the organisation, clients and suppliers (Drohomeretski, Gouvea da Costa, Pinheiro de Lima, & Garbuio, 2014).

This Japanese philosophy of doing business has changed the philosophy that prevailed in the west. The traditional western belief had been that the only way to make a profit is to add it to the manufacturing costs to come up with the desired selling price. In contrast, the Japanese approach believes that customers are the generator of the selling price (Chauhan & Singh, 2012), which translates into the customer paying for more quality or service being built into the product. The difference between the cost of that particular product and the price then becomes the profit.

In more recent years, lean implementations have also targeted low-volume, high-variety companies that are frequently have make-to-order or engineer-to-order production. Although lean transformation is more challenging in these environments, and not all lean techniques are adopted, other aspects - such as streamlining processes, set-up time reduction and flexibility – come to the fore so as to reduce lot size, 5s and operator involvement (Portioli-Staudacher & Tantardini, 2012).

2.1.2 Lean metrics

Lean metrics are a set of performance measures for Lean Manufacturing and examples of these are process throughput, total manufacturing lead time, labour productivity and overall equipment effectiveness (Cottyn *et al.*, 2011). An extensive review of the lean literature shows that lean is a combination of synergistic and mutually reinforcing practices, which have generally been grouped into four complementary subsystems or bundles: just in time (JIT) manufacturing, quality management (QM), total preventative maintenance (TPM) and human resources practices (Longoni, Pagell, Johnston, & Veltri, 2013).

According to a Sriparavatsu and Gupta (1997), when 600 companies were surveyed, it was fond that the manufacturing units implementing JIT and TQM practices have significant increases in quality and productivity levels, employee involvement, management commitment, supplier participation and cost reduction when compared to manufacturing units that do not implement such practices (Furlan, Vinelli, & Pont, 2011). As lean became increasingly understood, it grew - from a focus on JIT and other specific practices performed in the Toyota production system - into what has become an overarching philosophy or paradigm of world-class operations (Browning & Heath, 2009) that constitutes a competitive advantage. [‘Competitive advantage’ is measured by unit cost, quality, delivery, flexibility and the overall performance of the plant relative to global competition (Taj & Morosan, 2011).] This improvement has thus resulted in the researcher focusing on a particular organisation in the equipment manufacturing environment and developing the correct combination of the techniques to be used so that a framework for this type of environment can be developed.

LSS has five key principles (Drohomeretski *et al.*, 2014), which are presented in figure 2.

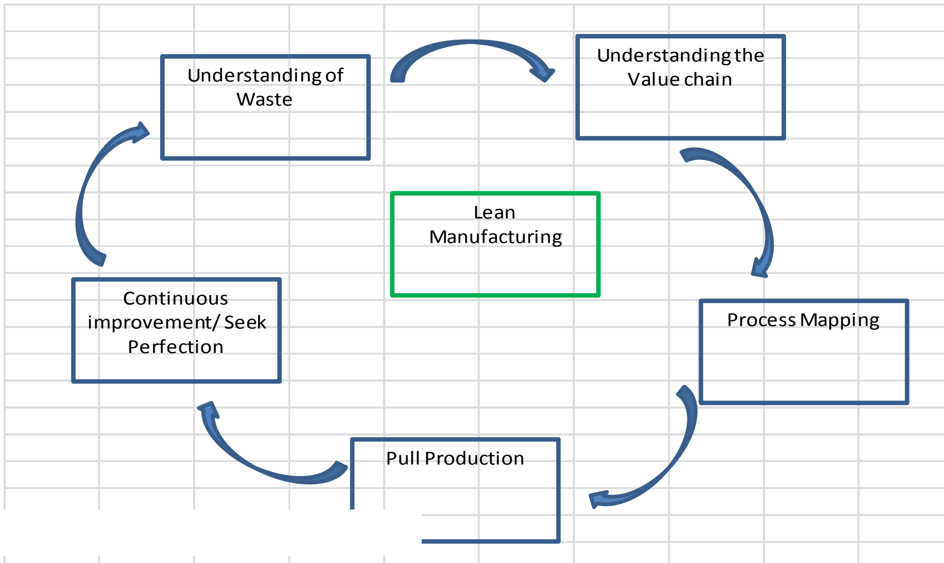

Figure 2 - Characteristics of Lean Manufacturing (Drohomeretski, Gouvea da Costa, Pinheiro de Lima, & Garbuio, 2014)

These principles are also referred to as the five principles for reducing waste and building a lean enterprise (Dahlgaard & Dahlgaard-Park, 2006). Lean production requires a change in attitudes and behaviour, not only for managers but also by employees (Bamber & Dale, 2000).

2.1.3 Implementation of lean manufacturing

Although many variables may affect the success of Lean Manufacturing implementation, many researchers agree anecdotally that commitment by top management is vital (Worley & Doolen, 2006). Managers need to start working with the employees and consider their improvement suggestions. Partnerships are needed in all internal customer-supplier relations, external supplier relations, external customer relations and between managers and their subordinates (Dahlgaard & Dahlgaard-Park, 2006). It is therefore vital to ensure these interactions between line workers and management are held regularly to foster teamwork. The literature refers to team structures being setup under various names, e.g. continuous improvement activity groups (CIAGs) and integrated production teams (IPTs) (Bamber & Dale, 2000; Dahlgaard & Dahlgaard-Park, 2006).

The development of a Lean Manufacturing implementation that is in line with operational group objectives is very important (Green, Lee, & Kozman, 2010) as this will ensure that lean initiatives are linked to business unit objectives and will thus lead to operational group objectives that everybody works towards.

Once these teams are setup and are working well together, there will be an improvement in productivity results (Drohomeretski *et al.*, 2014). This team will encourage team members to make improvements to meet targets to satisfy output, with a typical key performance indicator for supervisors being the number of suggestions generated in their area (Bamber & Dale, 2000).

This positive view of lean is not universal; however, many researchers outside the operations and supply chain management fields strongly question the potentially negative impact of lean on worker health and safety. This is a conversation which is also ongoing in the practitioner community (Longoni *et al.*, 2013) and would indicate that there needs to be awareness given to the human factor ensuring employees are not exploited in the pursuit of operational excellence. Convincing managers as well as employees can prove to be quite a challenge as they feel they are being requested to think and act in ways that are foreign to them. Employees may resist the tools of Lean Manufacturing or experience difficulty thinking in new terms such as customer value and waste (Worley & Doolen, 2006).

Some programmes experience early failures as they are viewed as not being effective. The key indicator used in determining the success of the programmes is profit (Meade, Kumar, & White, 2009). The question raised on Lean Manufacturing is therefore sought to be answered based on the known successes documented about the Lean Manufacturing advantages juxtaposed with the negative cases reported:

- Are the key aspects of successful Lean Manufacturing implementation well understood within the organisation?

2.2 Six sigma

The Six Sigma (SS) programme is credited to Dr Mike Harry, a statistician who is the main founder of Six Sigma Academy in Scottsdale, Arizona (Mehrjerdi, 2011). The Six Sigma Improvement Methodology was developed by Bill Smith of the Motorola Corporation (Keely, van Waveren, & Chan, 2013) in the 1980s and today, SS has become widely used as an improvement technique in many different industries. Over time, it has evolved into a comprehensive approach for improving business performance. Table 1 below indicates the five core elements of SS which need to be present to have a successful implementation.

Core Element	Description
Customer orientation	Deming (2000) and other quality gurus have consistently emphasized the importance of understanding customer requirements. At the project level, Six Sigma project teams are strongly encouraged to listen to the "voice of the customer" and define benefits from the customer's perspective. At the organizational level, customer orientation is used as a principle to select and prioritize projects by the project selection committee (Eckes 2000; Harry and Schroeder 2000; Pande, Neuman, and Cavanagh 2000).
Leadership engagement	The success of a process improvement program requires strong top management support. Six Sigma puts a systematic mechanism in place to ensure that the leadership team is engaged and Six Sigma stays on the organization's dashboard. In Six Sigma, senior executives act as champions, and they are directly involved in projects. This ensures that the right projects are selected and receive buy-in from the organization. Black Belts (full-time improvement project leaders) are selected not only because of their technical knowledge but also for their leadership skills (Schroeder et al. 2008).
Dedicated improvement organization	Six Sigma differs from traditional TQM programs in that it requires organizations to use Black Belts and set up a dedicated organizational structure for improvement, that is, what Schroeder et al. (2008) called "parallel-meso." The structure includes roles such as Green Belt, Black Belt, Master Black Belt, and Champion. It is a convention in Six Sigma to select some of the organization's best employees to fill the Black Belt positions (Eckes 2000; Harry and Schroeder 2000; Pande, Neuman, and Cavanagh 2000). This dedication leads to effective improvement and also makes the effort easy to measure.
Structured method	In comparison to past quality programs, Six Sigma is highly prescriptive in demanding that each project must strictly follow the DMAIC structured method. The method supports structured exploration of root causes and structured control of the process to produce the desired output. The emphasis of adhering to a standard method helps create a common language across the whole organization, which benefits knowledge creation and dissemination (Choo, Linderman, and Schroeder 2007a; 2007b).
Metric focus	Six Sigma emphasizes metrics in either customer or financial terms. It also emphasizes rigorous tracking of the metrics to ensure that benefits are obtained from improvement projects. All Six Sigma projects must have clearly defined goals, expressed in metrics such as critical-to-quality (Linderman, Schroeder, and Choo 2003). Each project is carefully audited on its intended and realized benefits, usually in financial terms and certified by the organization's finance department or even the CFO (Eckes 2000; Pande, Neuman, and Cavanagh 2000; Schroeder et al. 2008).

Table 1 - The five core elements of SS (Zhang, Hill, & Gilbreath, 2011)

2.2.1 Background to SS

The SS methodology has been used successfully as a quality-control methodology in many organisations, and has also been successful when applied as a continuous improvement methodology. The SS denomination, 6s, symbolises a specific number, 3.4 defects per million opportunities (DPMO), where “opportunity” is understood as any possible source of error in products, process or services, which refers to key issues for the customer (Gutiérrez, Lloréns-Montes, & Sánchez, 2009). The methodology was named Six Sigma because it has been derived from the definition of a normal distribution by Carl Friedrich Gauss and the standard deviation (s) shows the deviation (rate of defects) from the statistical mean (Heckl, Moormann, & Rosemann, 2010). The normal distribution curve below, in figure 3, highlights this point in that it shows with a standard deviation 1s, only 68.27% of all outcomes would be produced with acceptable limits.

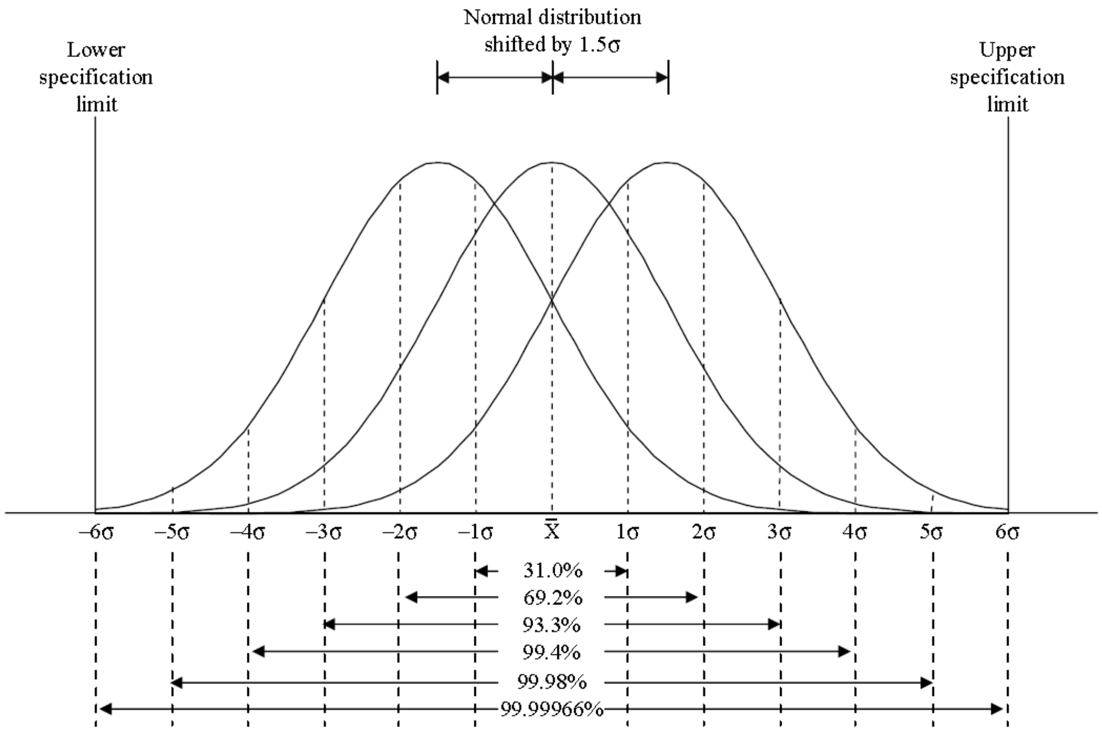

Figure 3 - Shifted normal distribution and corresponding quality levels (Heckl, D., Moormann, J., & Rosemann, M, 2010)

The central theme of SS is that product and process quality can be improved dramatically by understanding the relationships between the inputs to a product or process, and the metrics that define the quality level of the product or process

(Mehrjerdi, 2011). SS has been defined as an organised, parallel-meso structure to reduce variation in organisational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives (Easton & Rosenzweig, 2012). The term 'parallel-meso structure' means the SS structure is parallel to the typical organisational structure and interacts with different levels of the organisation depending on the project focus. This can be through the use of teams, improvement specialists (like Blackbelt or Greenbelts), steering committees, champions, sponsors and other support structures. There are different types of training for the different levels of Blackbelt or Greenbelt as can be seen in table 2 below:

	Green belts	Black belts	Champions
Profile	Technical background Respected by peers Proficiency in basic and advanced tools	Technical degree Respected by peers and management Master of basic and advanced tools	Senior manager Respected leader and mentor of business issues Strong proponent of six sigma who asks the right questions
Role	Leads important process improvement teams Leads, trains and coaches on tools and analysis Assists black belts Typically part-time on a project	Leads strategic, high impact process improvement projects Change agent Teaches and mentors cross-functional team members Full-time project leader Cover gains into £	Provides resources and strong leadership for projects Inspires a shared vision Establishes plan and creates infrastructure Develops metrics Converts gain into £
Training	Two three-day sessions with one month in-between to apply Project review in second session	Four one-week sessions with three weeks in-between to apply Project review in sessions two, three and four	One week champion training Six sigma develop and implementation plan
Numbers	One per 20 employees (5 per cent)	One per 50 to 100 employees (1-2 per cent)	One per business group or major manufacturing site

Table 2 - Comparison of role, profile and training in SS Belt system (Laureani & Antony, 2012)

2.2.2 SS disciplined method

In SS projects, the team brings in different knowledge domains and the cross-functional team facilitates the flow of information and knowledge across functional boundaries (Arumugam, Antony, & Kumar, 2013). This means that this structured approach very much depends on the team expertise to get the results. To combat defects, companies have adopted methodologies to make a linear map of the process.

Two common methodologies are DMAIC (define, measure, analyse, improve, control) and DMEDI (define, measure, explore, develop, implement) (Gillett, Fink, & Bevington, 2010). The DMAIC cycle can be practically useful for knowledge management as follows:

- Define – fact finding,
- Measure – data gathering,
- Analyse – information creation and capturing,
- Improve – knowledge-sharing and utilisation, and
- Control – knowledge-maintaining and evaluation.

(Kumar, Antony, Madu, Montgomery, & Park, 2008)

Examples of SS tools include Pareto analysis, root cause analysis, process mapping or process flow chart, Gantt chart, affinity diagrams, run charts, histograms, quality function deployment (QFD), Kano model and brainstorming (Aboelmaged, 2010). The different stages are run as a project over a set period, which is usually around 180 days. The model below, in table 3, highlights the typical tool used per stage in the project.

DMAIC steps	Steps to be taken	Tools to be used	Deliverable
Define	Define customers and requirements (CTQs) Develop problem statement, goals and benefits Identify champion, process owner and team Define resources Evaluate key organizational support Develop project plan and milestones Develop high level process map	Project charter Process flowchart SIPOC diagram Stakeholder analysis DMAIC work breakdown structure CTQ definitions VOC	Fully trained team is formed, supported and committed to work on improvement project Customers identified and high impact Characteristics (CTQs) defined, team charter developed, business process mapped
Measure	Define defect, opportunity, unit and metrics Detailed process map of appropriate areas Develop data collection plan Validate the measurement system Collect the data Begin developing Y — f(x) relationship Determine process capability and sigma baseline	Process flowchart Data-collection-plan/example Benchmarking Measurement-system analysis VOC Process sigma calculation	Key measures identified, data collection planned and executed, process variation displayed and communicated, performance base lined, sigma level calculated
Analyze	Define performance objectives Identify value/non-value-added process steps Identify sources of variation Determine root cause(s) Determine vital few x's, Y — f(x) relationship	Histogram Pareto chart Time series/run chart Scatter plot Regression analysis Cause and effect diagram Whys Statistical analysis Non-normal data analysis	Data and process analysis, root cause analysis, quantifying the gap/opportunity
Improve	Perform design of experiments Develop potential solutions Define operating tolerances of potential system Assess failure modes of potential solutions Validate potential improvement by pilot studies Correct/re-evaluate potential solution	Brainstorming Mistake proofing Design of experiments Pugh matrix House of quality FMEA Simulation software	Generate (and test) possible solutions, select the best solutions, design implementation plan
Control	Define and validate monitoring and control system Develop standards and procedures Implement statistical process control Determine process capability Develop transfer plan, handoff to process owner Verify benefits, cost savings/avoidance, profit growth Close project, finalize documentation Communicate to business, celebrate	Process sigma calculation Control charts (variable and attribute) Cost savings calculation	Documented and implemented monitoring plan, standardized process, documented procedures, response plan established and deployed, transfer of ownership

Table 3 - DMAIC steps to be taken, tools to be used and the deliverables (Mehrjerdi, 2011)

A company can start with SS deployment by identifying a manageable number of critical projects that are top priority for the organisation and can be successfully completed within a few months (Kumar *et al.*, 2008). Many companies have defined the mastery of SS with the terminology used in martial arts and use Greenbelts, Blackbelts and Master Blackbelts. Blackbelts work on projects full time and have Greenbelts assisting them with the data collection and analysis. Master Blackbelts are teachers of the techniques and are also on hand to guide the Blackbelts when required.
SS can assist people in organisations in tackling cross-functional problems where the solutions are unknown and require multi-disciplinary team formation (Gijo, Antony, Kumar, McAdam, & Hernandez, 2014).

The evaluation grid below, in table 4, indicates the areas that require SS project intervention. When the solution is apparent, the “just do it” approach applies.

		Solution	
		Known	Unknown
Business Impact	High	Lean project (third priority bucket)	Six Sigma project (first priority bucket)
	Low	Quick kill	Six Sigma project (second priority bucket)

Table 4 - Evaluation grid for SS projects (Sunder, 2013)

2.2.3 SS implementation

It is, however, vital that the implementation is performed correctly. If SS is only considered as implementation of statistical tools and techniques to solve complex problems in the organisation, it is doomed to fail because of its very weak linkage to strategic business objectives (Kumar, Antony, & Tiwari, 2011). The use of SS in the capital equipment manufacturing environment will benefit this industry tremendously if it is implemented correctly; however, the deployment has to be driven from top leadership as the team can work on projects that make a minimal contribution to the company objectives.

SS projects will have different objectives, e.g. cycle-time reduction, cost reduction, efficiency improvement, process capability enhancement in terms of sigma-level improvement, customer satisfaction improvement, and rejection level reduction (Arumugam *et al.*, 2013). These are all critical areas to the success of a manufacturing organisation. It is said that in its large-scale application there are cases of misuse, incorrect interpretations, differences between theory and practice and between what is said and what is done (Grima, Marco-Almagro, Santiago, & Tort-Martorell, 2013). The correct support structure is therefore vital when implementing the SS programme within the organisation: there needs to be support for the programme from the top leadership who shows interest in projects progress and has regular reviews with the team to show the importance of the initiative. The leadership should also concentrate on ensuring the right corporate culture for a successful SS implementation (Grima *et al.*, 2013).

As there will be a significant amount of investment made in training of Greenbelts and Blackbelts, it is vital for the organisation to ensure the alignment of the correct skills with the correct culture. The three Human Resources Management practices - employee involvement, employee training, and employee performance and recognition - should support the sustainable use of SS methodology (Xingxing & Fredendall, 2009). The first - employee involvement - will lead to better ownership of new initiatives. The second - training - assists with communicating and spreading the message of how SS brings about improvements in quality. The third - employee performance and recognition - ensures that the company and employee are aligned and working towards the same organisational goals.

The implementation of SS within an organisation is not a decision that is taken lightly as it requires a significant amount of resources. With this process, the company is looking to make noticeable changes in the financial performance of the company as this is one of the widely advertised on the benefits of the program (Venkateswarlu, 2012). The literature related to the impact of SS on corporate performance is largely anecdotal in nature and tends to cite, overwhelmingly, the benefits of the programme on corporate performance.

Freiesleben (2006) suggested that the successful application of SS quality is positively correlated with better financial performance and profit generation (Aboelmaged, 2011). These are the many references there are which attest to the benefits of successful SS implementation. However, there are also contradicting reports, such as Chakravorty (2010) who cites research suggesting that almost 60% of SS initiatives at corporations do not generate the desired results (Shafer & Moeller, 2012). This study will look to investigate the key factors that need to be considered to ensure success in the implementation of SS within the organisation. The research question to answer with regards to SS would be:

- What are the core elements of successful SS implementation within the mining equipment manufacturing environment?

The results of this study will assist in identifying the critical factors for the successful implementation of SS in the said environment, through a questionnaire.

2.3 Lean SS

The phrase "Lean SS" is used to describe the integration of lean and SS philosophies. SS complements lean philosophy as it provides the tools and know-how to tackle specific problems that are identified along the journey (Pepper & Spedding, 2010). In other words, Lean SS integrates SS and Lean Management processes, where lean talks to cycle-time and waste elimination while SS seeks to eliminate defects and reduce variation (Psychogios & Tsironis, 2012). While both lean and SS have been used for many years, they were not integrated until the late 1990s and early 2000s, and today LSS is recognised as business strategy and methodology that increases process performance (Laureani & Antony, 2012).

2.3.1 LSS background

The use of LSS is therefore an evolution of two separate methods being brought into one toolset because of their complementary features. To adopt LSS as a rigid data-driven approach to achieve higher-quality performance in the long term, it has been suggested that a company must develop a unique combination of resources and competencies that 'bring home' the benefits of SS (Hilton & Sohal, 2012). This perspective is based on the premise that the company needs to have the assets, resources as well as skills to allow them to follow the required systematic approach.

In addition to the many ideas regarding the compatibility of the two concepts, there are also many different theories as to how LSS could be implemented (Assarlind, Gremyr, & Bäckman, 2013). The different views are either to have SS lead and bring in lean principles in the analysis phase, while another view is to have lean as the standard and to use SS to eliminate variation from this standard. There are tools associated with each discipline and also an overlap with a few of the tools as per figure 4 below. Examining the philosophy, practices and techniques of lean and SS suggests striking similarities and some important differences between the two approaches (Shah, Chandrasekaran, & Linderman, 2008).

The benefits of LSS in the industrial world (both manufacturing and service) include:

- Ensuring services/products conform to what the customer needs (voice of the customer (VOC),
- Removing non-value-adding activities (waste),

- Reducing the incidence of defective products/transactions,
- Shortening cycle-time, and
- Delivering the correct product/service at the right time in the right place.

(Laureani & Antony, 2010)

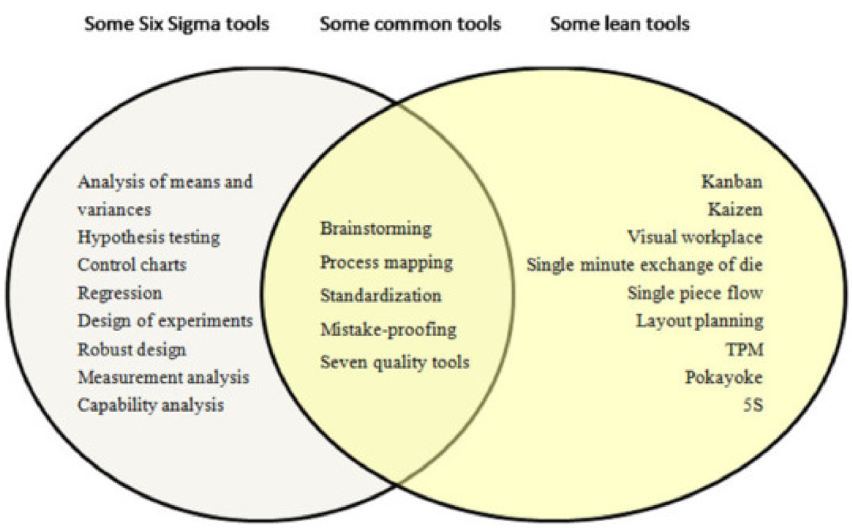

Figure 4 – Common SS and lean tools (Drohomeretski, Gouvea da Costa, Pinheiro de Lima, & Garbuio, 2014)

The integration of lean and SS aims to target every type of opportunity for improvement within an organisation (Pepper & Spedding, 2010). SS has normally been implemented by a few individuals within the company in the form of Blackbelts and Greenbelts whereas Lean Manufacturing can be implemented by anyone in the organisation who can identify and eliminate non-value-adding activities. With the integration of the two techniques, the employees of the company are given an opportunity to contribute towards continuous improvement. The skills level of the LSS programme facilitator and the Blackbelts who lead the projects are also critical to success (Hilton & Sohal, 2012).

2.3.2 Implementation of LSS

Although the barriers to LSS implementation are rather disparate, one common denominator is that many of the discussed barriers are not related to application of tools and methods but rather to organisational issues such as change resistance (Assarlind *et al.*, 2013). There have been several journals written on the success of implementation of LSS in various industries (Psychogios & Tsironis, 2012). There is a vast amount of literature on the implementation of LSS in the low-variety, high-volume facilities as the techniques had their origins in this type of environment, e.g. Telecommunications (Manville, Greatbanks, Krishnasamy, & Parker, 2012). However, little work has been done on the high-variety, low-volume environment, also known as job-shops. There are some key challenges to consider in this regard as job shops face the toughest obstacle when trying to map and analyse the flow of 100 – 2 000+ product routes through their facility (Pepper & Spedding, 2010).

As markets grow, supply networks expand, and international realities present themselves, the number and scope of various risks faced by global organisations will increase substantially (Maleyeff, Arnheiter, & Venkateswaran, 2012). There are therefore some questions around the correct approach to implementing LSS in this environment, which challenges the theory. A framework for the implementation of LSS in the capital equipment industry, which is a job-shop environment, will contribute towards answering this gap in knowledge. Companies like Caterpillar - who is also a job-shop - have written about their implementation of LSS and how it made a tremendous difference to their performance (Byrne *et al.*, 2007). Unfortunately, there is limited literature on the framework applied to achieve this success.

2.4 Impact on cost

The derived benefits from the implementation of tools and techniques - such as LSS - are wide spread and one of the areas is cost. LSS identifies improvement opportunities in all areas the business, limited only by the scope of the improvement team.

The impact on cost can be categorised into two main categories: direct and indirect savings. Direct savings are reflected on the bottom line of the financial statements and are also known as hard savings. These types of savings can be monitored once implemented and can be claimed as project savings for a given period. The other category consists of indirect savings or soft savings, such as cost avoidance through finding a different way of doing things and not incurring a certain cost.
LSS has been marketed as a new organisational change and improvement method, particularly a cost-reduction mechanism (Jayaraman, Teo, & Keng, 2012) and lean methods are used to eliminate waste from processes (Manville *et al.*, 2012). The

reduction in waste will bring about savings that can be realised as soon as these are implemented.

SS concentrates on reducing process variation (Gupta, Acharya, & Patwardhan, 2012). This is done by following a structured project approach and the impact on cost is only realised once the project is complete. As George (2002) argues, LSS is a continuous business-improvement methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital (Psychogios & Tsironis, 2012). The Psychogios & Tsironis reference also alludes to the fact that cost savings need to be measured in relation to spend or invested capital. Elimination of waste will reduce production cost in terms of materials, time savings in workflow while improved quality encourages consumption, enhances sales volume and organisational share of market (Enoch, 2013).

In the article *The continuing evolution of Lean Six Sigma*, it is stated that successful companies will pay attention to agility while continuing to focus on quality, cost and efficiency (Maleyeff *et al.*, 2012). Even though there are new measures that have been highlighted as significant in the current environment, the measure of cost optimisation remains a key factor to success of an organisation. The research question with regards to cost is therefore:

- What has been the effect on cost since the implementation of LSS?

This seeks to obtain some evidence that LSS implementation does have a positive effect on cost optimisation.

2.5 Impact on cycle-time

Cycle-time is another important measure within the manufacturing industry. It is measured as the time it takes to convert raw material into finished goods within the manufacturing cycle. It should be underlined that cycle-time is not total flow time elapsed through the whole process for a part but the elapsed time between two consecutive parts produced in the process (Atmaca & Girenes, 2011). There are targets set by the organisation on the promised cycle-time, which is mainly based on the lead-time of each stage of the value chain. Achieving this cycle-time on a consistent basis is the goal of LSS as SS focuses on quality rather than speed and this lack of speed gained by SS is resolved by lean management (Atmaca & Girenes, 2011). Lean manufacturing is better at improving speed and process flow rather than improvement in quality. Lean focuses on reducing process time by removing non-value-adding steps and waste.(Gupta *et al.*, 2012)

Cycle-time is an important measure within the organisation as it is used as a way to benchmark different locations and get a sense of a better-performing production facility. Having a reliable cycle-time over a sustained period results in better performance, however in the job-shop environment this has proven to be a real challenge because of process variation and dependent events. Therefore, the research question will be:

- What is the effect of LSS on the cycle-time of a product?

The focus of this question will be to validate that the implementation of LSS has a positive impact on the cycle-time performance of the factory.

2.6 Impact on on-time delivery

On-time delivery (OTD) is also an important indicator in the capital equipment manufacturing industry as the mine sites make plans for mining their minerals. It is critical for a machine to be commissioned according to that schedule. The organisation therefore has targets set for on-time delivery which factors in the entire value chain from receipt of order right up until delivery of final product. These targets are measured on a monthly basis and there needs to be improvement actions made in the areas where the target of >95% on-time delivery is not met.

There is evidence of delivery time being reduced because of improvements brought about by LSS (Drohomeretski *et al.*, 2014). This is done through experimenting with a combination of techniques from the LSS toolset. Focusing on waste and cost reduction by reducing the number of non-value-adding steps in critical business processes, through systematic elimination, leads to faster delivery of service (Manville *et al.*, 2012). This is, however, successful when driven from top management and the employees are empowered to bring about change in the areas they see opportunity.

LSS seeks to find out why targeted on-time delivery is not met on a sustainable basis:

- What is the effect of LSS on the on-time delivery of a product?

The response to this question will validate whether the implementation of LSS does have a positive impact on the on-time delivery performance of the factor.

2.7 Summary of Literature review

The literature review has provided a good background to the two disciplines of lean manufacturing and six sigma. It has also shown how the two tools evolved into what is today known as lean six sigma which encompasses both programs. There also seems to be two schools of thought on the derived benefits with some being positive and some being negative. This seems to be primarily based on the implementation success of the program as if not correctly executed then the benefits may not be realised leaving a negative impression on the workforce with regards to the program as a whole.

3 Research questions

3.1 Introduction

This research paper has been conducted to answer some key questions with regards to the implementation of LSS in the capital equipment manufacturing environment. The literature that was surveyed deals with the evolution of LSS since its origins from lean manufacturing and six sigma, and the great successes that have been reported by the different companies who've implemented this methodology. This literature, however, concentrates more on the high-volume, low-variety type industries such as automotive, telecommunications and services. Unfortunately, there are limited examples of the successful implementation of LSS methods within the low-volume, high-variety environment and this paper seeks to explore this area by developing a framework for the successful implementation of LSS in this arena.

3.2 Problem statement

The current LSS literature does not have examples of the successful implementation of LSS in the low-volume, high-variety environment of capital equipment manufacturing. This, then, leads to some challenges in the implementation of LSS in these environments, which are said to be more complex and present a different set of challenges.

3.3 Objectives of research

- To develop a framework for the successful implementation of LSS in the capital equipment manufacturing environment, and
- To determine the correlation of LSS implementation, through the framework which will be developed, with the company performance in terms of cost, cycle-time and delivery.

3.4 Research questions

3.4.1 Research question one

a) **Are the key aspects of successful Lean Manufacturing implementation well understood within the organisation?**

This question was designed to ascertain, from the perspective of the respondents, whether there is a common understanding of the characteristics of Lean Manufacturing. Once this has been ascertained, the more prominent characteristics need to be highlighted in terms of importance in the framework.

3.4.2 Research question two

b) What are the core elements of successful SS implementation within mining equipment manufacturing environment?

The response to this question will assist to determine what type of support is needed to make SS implementation within an organisation successful as well as sustainable.

3.4.3 Question three

c) What has been the effect on cost since the implementation of LSS?

The reason for this question is to get a response with regards to the impact of LSS on costs. The literature supports the case for significant savings being realised and this needs to be validated within the given context.

3.4.4 Research question four

d) What is the effect of LSS on cycle-time of a product?

Cycle-time is an important metric within the capital equipment manufacturing environment as it is linked to productivity. LSS is supported to introduce consistency and reliability to a process that will result in a stable cycle-time, assuming all else remains equal. It is desirous to confirm that the implementation of LSS has a positive effect on the process cycle-times. This will translate into savings for the organisation which is the ultimate goal of focusing on this metric.

3.4.5 Research question five

e) What is the effect of LSS on the On-time delivery of a product?

The literature states that the various methods of waste reduction and process optimisation will have a positive effect on on-time delivery performance of an organisation and this is what this question seeks to validate.

4 Proposed research methodology and design

4.1 Research design

As the research problem has been formulated in clear-cut terms, the researcher will be required to prepare a research design, i.e. it will be necessary to state the conceptual structure within which research will be conducted (Kothari, 2006). The research philosophy that was used is that of realism, which is a research philosophy that stresses that objects exist independently of our knowledge of their existence (Saunders & Lewis, 2012). This philosophy can be classified as direct realism as the data will be collected and conclusions will be drawn on the impact of LSS.

The capital equipment manufacturing environment can be characterised as a job-shop environment. The factory will have a group of engineers of the required discipline of electrical, mechanical and industrial engineering who will be responsible for designing the machines. These designs are then transferred to the manufacturing floor through an engineering change request (ECR) for manufacture by the artisans of various disciplines on the floor. The skills of the artisans range from boilermaker and electrician, to fitter and turner as these are all required skills to manufacture the products. Against this backdrop there has been a LSS programme launched in the organisation under the name of Operational Excellence (Opex). There have been three SS Blackbelts appointed who utilise the existing resources to execute improvement projects. The programme is supported by the leadership team however there is no regular meeting or forum setup to review the LSS project progress.

Deduction was the research approach used as LSS theories were tested and their results analysed. A research questionnaire was developed that sought to answer the research questions as defined in the literature review. The five sequential stages in deductive research are as follows (Saunders & Lewis, 2012):

1. Defining research questions from the general theory that exists,
2. Operationalising these questions, i.e. specifying the way in which the questions may be answered,
3. Seeking answers to the questions defined in stage 1,
4. Analysing the results of the inquiry to determine whether it supports the theory or suggests the need for its modification, and
5. Confirming the initial general theory or modifying it in the light of the findings. (In

the event of step 5 resulting in a modified theory, the five sequential stages are repeated to test the new theory.)

The literature review resulted in some research questions which were the ones that were tested. A questionnaire was used to answer the research questions. The study was therefore of a quantitative and descriptive nature and as the name implies, the major purpose of descriptive research is to describe characteristics of objects, people, groups, organisations, or environments (Zikmund, W., Babin, B., Carr, J., & Griffin, 2012). A five-point Likert Scale method of analysis was used to elicit responses to a questionnaire which was designed to answer the research questions raised. This gave an indication of how strongly people feel about the implementation of LSS, whether it be positive or negative. The survey was conducted electronically and a sample of approximately 50 candidates was contacted allowing for the minimum required sample of 30 to be achieved. The data analysis was completed using a statistical programme, Minitab, which is a very powerful program for statistical data analysis.

4.2 Population, sample and sampling method

The universe for this research project consists of the organisations that manufacture, preferably capital equipment, in the heavy engineering industry. This type of environment is usually a job-shop environment. The targeted population in this universe consist of the organisations that manufacture Original Equipment (OE) and do not assemble ship-in kits from sister plants overseas. The organisations in the targeted universe also need to have implemented LSS within the organisation. Therefore, the unit of measurement is the analyses conducted of LSS projects.

A non-probability sampling technique was used to collect the data as the sampling frame of the complete list of LSS organisations is not well defined. A snowball sampling technique has been selected as most appropriate as it is used when it is difficult to identify members of one’s population. Snowball sampling is a type of non-probability sampling in which, after the first sample member, subsequent members are identified by earlier sample members (Saunders & Lewis, 2012). This questionnaire can be completed at virtually no cost as it will be an on-line questionnaire and will allow the researcher to ask pointed questions around the implementation of LSS.

A pre-test was first completed to ensure there were no errors or misunderstandings emanating from the survey and the respondents were clear what was expected of them. The researcher used his team of Greenbelts and Blackbelts to assist on this initial questionnaire test as they had a deeper understanding on the topic and the company. The employees who were targeted for this research were the various stakeholders who are involved with LSS projects and can provide evidence as either a champion or a team member of a cross-functional team.

4.3 The research instrument

The research design was based on a survey questionnaire with responses from 38 people within the industry who are involved with LSS. The respondents were given a Rensis five-point Likert Rating Scale questionnaire and they needed to complete the document with their best match to the questions. The responses were then coded to facilitate interpretation in the analysis of the data.

4.3.1 Survey questionnaire design

The questionnaire posed 10 questions, which included 46 statements that were identified from the literature. The first section, Part(A), was concerned with the demographics of each respondent. Part (B) follows, firstly posing some general statements relating to LSS in statements one to five of section (1). Statements six to 12 of section 2 pose some statements relating to the implementation of Lean Manufacturing within a facility. The statements attempt to highlight the inputs to successful Lean Manufacturing implementation as per prescribed practices.

Statements 13 to 18 of section 3 follow, which pose statements that aim to determine the critical factors of successful SS programme implementation within the manufacturing environment. This section postulates statements that were guided by the literature review as being essential in successful implementation of SS as they were documented success stories coming from this type of roll-out. Statements 19 to 28 of section 4 are statements that are aimed at uncovering an understanding of the types of tools commonly used in the capital equipment environment when implementing LSS.

Statements 29 to 34 of section 5 aim at getting data on the effect of LSS on cost within the organisation. What is attempted to be ascertained is whether the experience of the respondents is positive or negative in this regard. Statements 35 to 40 of section 6 pose some statements regarding the effect of LSS on the cycle-time achieved within the facility. This section again aims to ascertain the experience of the respondents on whether the effect on cycle-time was positive or negatively perceived. Lastly, statements 41 to 46 are made up of assertions aimed at getting feedback on what respondents experienced in terms of the effect of LSS on on-time delivery of the organisation. Was it a negative or positive effect?

The responses are based on the Rensis five-point Likert Rating Scale on a scale of one to five, where option one is “strongly agree” and option five is “strongly disagree” for the statements posed. The exception is for the demographics section in the beginning of the survey. Respondents in the capital equipment industry were targeted and they are also involved in the LSS discipline and roll-out within their organisation. These environments are typically job-shop-like and commonly share the same trait of being high-variety, low-volume in nature. This requires a new mindset from the traditional origins of LSS, which have been that of high-volume, low-variety where the main focus is to setup a capable process for long runs.

4.3.2 Survey tool and pre-testing

The data was collected in two phases, which were made up of a pre-test phase and the main study. The pre-test captured responses from a small sample of employees to test the reliability of the data-gathering tool and processes, as well as to ensure the statements are well understood. The respondents were contacted by e-mail with a cover note that clearly communicates the objectives of the research and assured respondents that their details will remain confidential.

The pre-test was conducted with LSS respondents from within the organisation who came from different departments to get a variety of responses on the survey. Any improvements suggested were then incorporated into the final updated survey which was sent out.

The survey was completed using a piece of online software called Survey Monkey, which is a very convenient way of getting respondents to complete the survey through an e-mail link.

4.3.3 Survey questionnaire – accuracy, reliability and validity

The researcher will ensure that the principal factors that threaten the validity of research findings and conclusions are guarded against through the process of data collection and analysis. To control these factors, the researcher will seek the help of an independent researcher, who works within the same field, to verify the results. The researcher responsible for the authoring of this current research report will also have his data-collection plan verified by the statistical subject lecturer support offered by the Gordon Institute of Business Science (GIBS).

4.4 Data analysis and interpretation

The data used was cross sectional, as the responses from the questionnaire represented a snapshot in time, and then these were analysed. The researcher then used statistical software, SPSS, to complete the analysis using techniques such as descriptive statistics and the other analysis techniques required e.g. Pareto charts, correlation, hypothesis testing.

4.4.1 Data collection

Quantitative data was collected for the study using a survey questionnaire that was sent out using a web-based program. There were 48 questionnaires sent out and within three weeks, 40 respondents were received. This constituted a 83% response rate.

This current research project is targeted at individuals involved in the LSS program implementation, in some way, to gain insights based on the practical application of the tools and their results. The various respondents were selected from several companies within the mining industry, which have implemented LSS.

4.4.2 Data reduction

All responses (a total of 40) were collected on Survey Monkey. Out of these 40 responses, only 38 were completely filled out. Of the remaining two questionnaires, only section one of the questionnaire was completely filled out. The analysis in section two was therefore carried out using the 38 completed questionnaires.

4.4.3 Data display

As stated previously, data was collected using Survey Monkey and was displayed in graph format that this application offers. It was also possible, using this programme, to have the data displayed using tables and figures.

4.4.4 Conclusion/verification

The research was checked for biases that might have affected the research project. To measure the internal consistency (reliability), the Alpha Test developed by Cronbach was conducted for each of the constructs. The Cronbach Alpha was found to be acceptable for all the constructs. The correlation coefficients for all the constructs of LSS - against the independent variables of cost, cycle-time and on-time delivery - were also completed.

4.5 Limitation of study

For this study, it’s necessary to obtain feedback from all the people, from other organisations, on their implementation of LSS. Currently, the researcher is only certain of the access to the employees employed by his current employer as he has obtained agreement from the leadership team. However, because of confidentiality issues, other organisations – which are in competition with Joy Global – may not cooperate. This will mean that the current research study will focus on the views of global employees, however these individuals will be from one organisation.

4.6 Assumptions

The following assumptions were made as a baseline for the study:

1. It is assumed that LSS is well understood by the respondents selected for the questionnaire.
2. It is also assumed that the respondents are honest and truthful with their responses to the questionnaire.
3. A sample size greater than, or equal to, 30 is an acceptable sample.
4. Respondents were able to understand the questions and were clear in their responses.

5 Results

5.1 Introduction

This chapter of the research paper is aimed at providing an overview of the results as well a summary of the findings of the survey with reference to the research questions stated in chapter 3. The data was analysed using the program SSPS, which gave the descriptive statistics tested for reliability and validity using the Cronbach Test. Correlation studies were run to determine the inputs that were most relevant to improving cost, cycle-time and on-time delivery within a LSS implementation.

5.2 Response rate

There were 48 survey questionnaires sent out and a total of 40 responses were received. Out of these 40, there were two that needed to be discarded in the analysis section two as these were incomplete. There were 38 respondents that were valid responses which equates to a 79% response rate used for the study.

5.3 Demographics

The following section gives some insight into the make-up of the sample of respondents. The survey was specifically aimed at employees who had been exposed to LSS to a certain degree.

5.3.1 Role of respondents

Figure 5 shows the role that the respondents play in their organisations. This was a snowball-sampling technique aimed at employees who are involved in the LSS programme in some capacity in their current environments. It was important to obtain responses from the different levels within the organisation to get the various perspectives on the success of the program roll-out.

The largest proportion of the respondents came from the department managers (42.5%), followed by the directors (15%), the engineer (12.5%), project leader (12.5%), SS Blackbelt (7.5%), SS Greenbelt (7.5%) and lastly the project team members (2.5%).

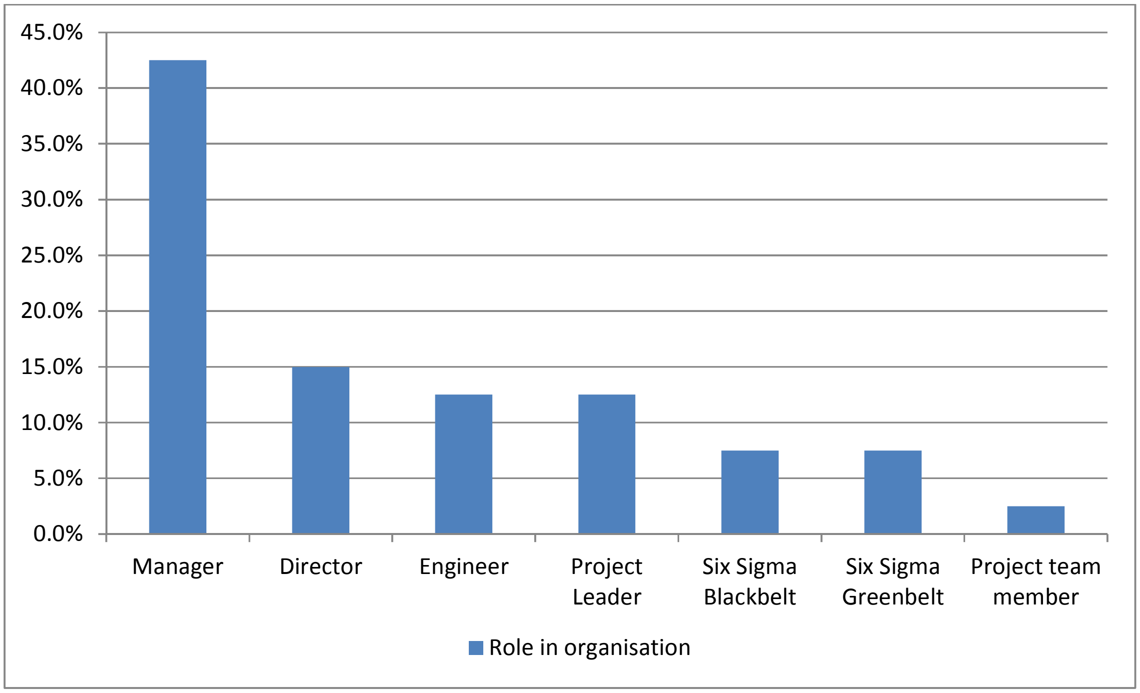

Figure 5 - Role in organisation

It was interesting to see that most of the respondents are managers, however the reasoning is that LSS can be deployed to any department within the organisation and one would obviously seek approval and buy-in from the managers who are affected first. The other respondents were split amongst the other roles.

5.3.2 Work experience in total

The work experience, in total, was measured to get an understanding of the experience of the respondent. This will give more weight to their opinions.

Figure 6 below details the experience of the respondents. Only 2.6% has experience between 0 and five years, 23.1% has between five and ten years' experience, 25.6% has ten to 15 years' experience, 23.1% has 15 – 20 years' experience and 25.6% has over 20 years' experience. The majority of respondents have at least ten years' working experience.One can assume that these respondents are subject-matter experts in their field.

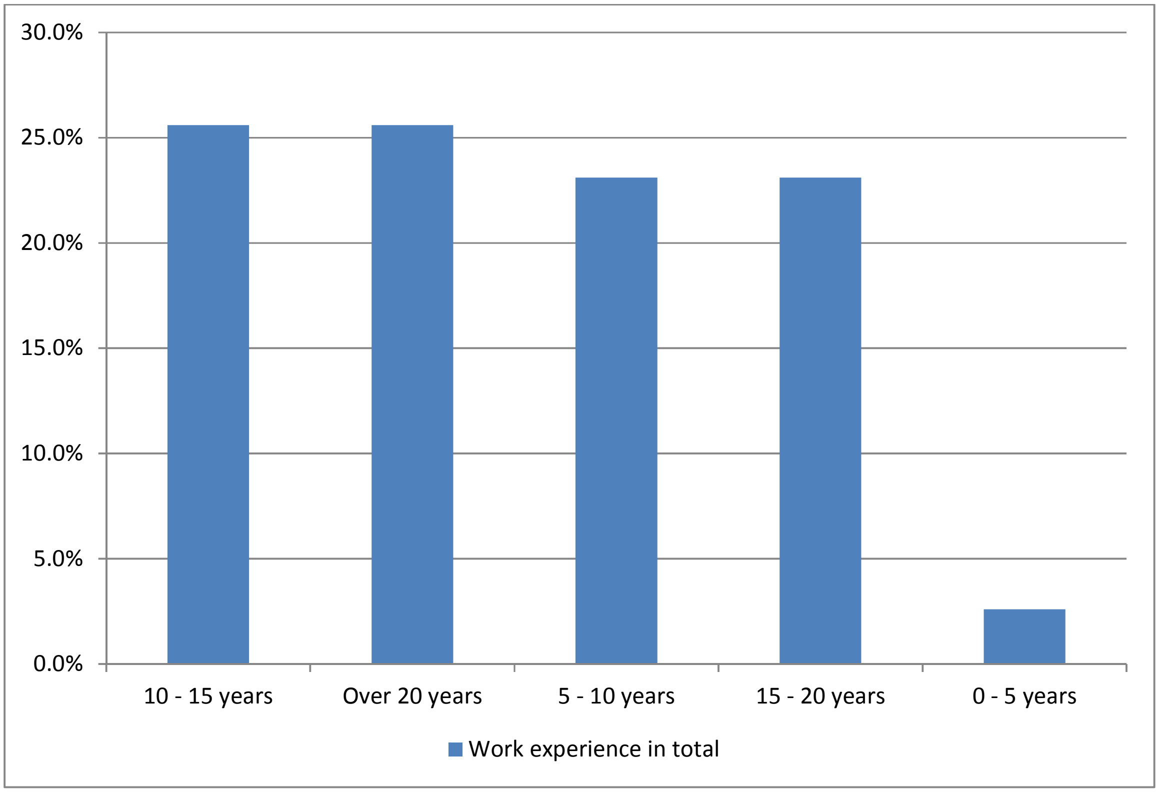

Figure 6 - Total work experience

5.3.3 Work experience in LSS

The work experience of the respondent, in LSS, is split in the following way for the different sections: 48.7% - between 0 and five years' experience, 33.3% - between five and ten years' experience, 7.7% - between ten and 15 years' experience, 5.1% - between 15 and 20 years' experience, 5.1% - over 20 years' experience. The graph in figure 7 clearly details that the majority of the respondents, nearly half, have between 0 and five years' experience.

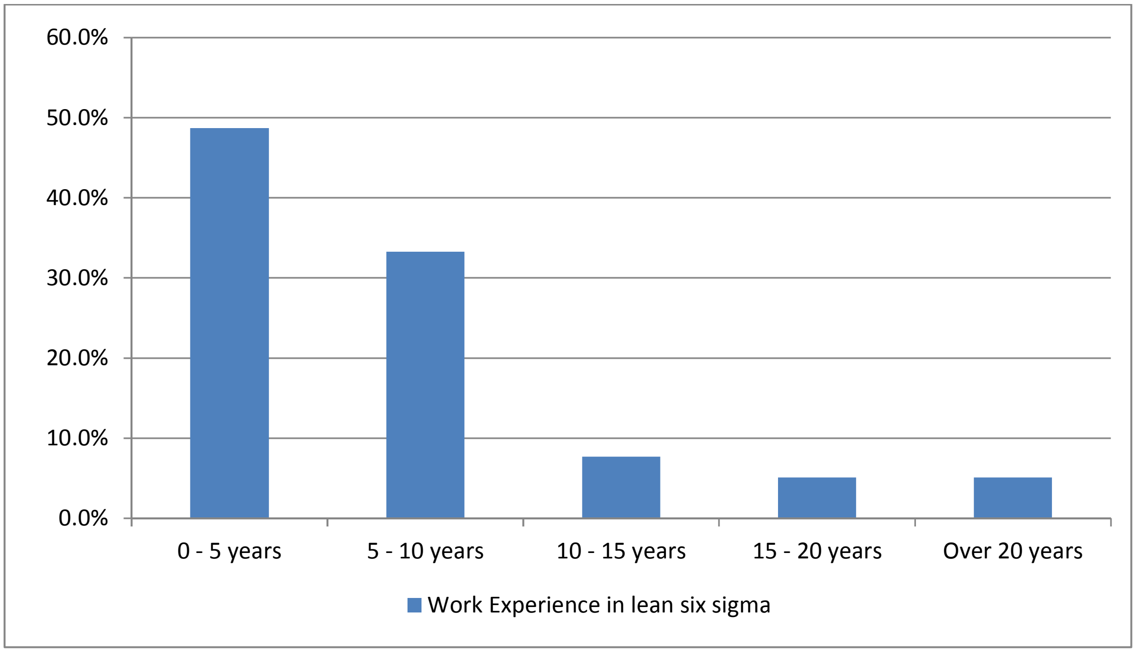

Figure 7 - Work experience in LSS

The graph above clearly shows that respondents do not have much experience: only 5.1% have over 20 years' experience, which indicates that about 82% have 10 years or less work experience.

5.3.4 Maturity of LSS programme implementation within the organisation

The maturity of the LSS programme within the organisation was between 0 and 25% (representing 50% of the responses). There was a 25 - 50% maturity for 36.8% of the responses, between a 50 – 75% maturity for 10.5% of the responses, and lastly between a 75 and 100% maturity for 2.6% of the responses.

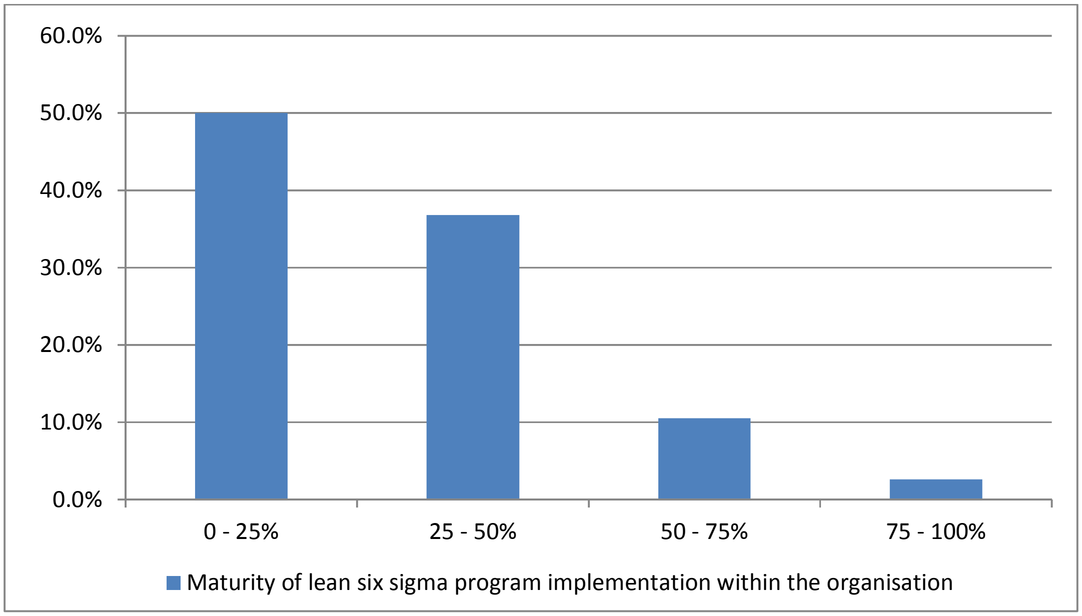

Figure 8- Maturity of LSS programme implementation within the organisation

The maturity of the programme was only between 0 and 25% for half of the respondents and up to a 50% maturity was represented by 36.8% of the respondents. This means that only 13.1% had an above 50% maturity of implementation.

5.4 LSS within the organisation and its success

The LSS questions that followed in this section were gathered to get feedback from the employees on their general understanding and opinion of LSS as a continuous improvement process. The questions are aimed at employees who have had experience of LSS implementation within their organisation and have been involved in improvement projects.

Table 5 below gives some descriptive statistics on the feedback from the questions posed. It can be clearly seen that the majority of respondents strongly agreed with these statements (mainly agreed or strongly agreed) as the median – for these questions – was between four and five.

Statistics

		LSS is a tool used to improve manufacturing process capability	The LSS programme has to be supported by senior leadership to be successful	The techniques used in LSS can be used in any department, from operations, engineering and Supply Chain Management to HR	It is essential to ensure that the LSS projects are aligned to the organisations strategic goals	There needs to be a cost-saving target related to a LSS project
N	Valid	40	40	40	40	40
	Missing	1	1	1	1	1
Mean		4.25	4.78	4.65	4.88	3.98
Median		4.00	5.00	5.00	5.00	4.00
Mode		5	5	5	5	4[a]
Std. Deviation		.899	.577	.700	.335	1.074
Variance		.808	.333	.490	.112	1.153
Minimum		1	2	2	4	1
Maximum		5	5	5	5	5

a. Multiple modes exist. The smallest value is shown

Table 5 - Descriptive statistics on general questions

5.5 Test for normality

A normality test is used on all the 46 questions to determine if a data set is well modelled by a normal distribution and to compute how likely it is for a random variable underlying the data set to be distributed normally. It is important to perform this test as the point of departure as it sets the direction on which methods to use when analysing the data set. Therefore, a test for normality on the completed questions, from the 38 respondents, was run.

The results from SPSS indicated that the data was non-parametric, which means the statistics related to this data were not based on parameterised families of probability distributions. Unlike parametric statistics, non-parametric statistics make no assumptions about the probability distributions of variables being assessed. The studies to follow will therefore be based on the appropriate non-parametric tests.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Lean Six Sigma (LSS) is a tool used to improve manufacturing process capability.	.262	38	.000	.744	38	.000
This Lean Six Sigma program has to be supported by senior leadership to be successful.	.472	38	.000	.453	38	.000
The techniques used in Lean Six Sigma can be used in any department from Operations, Engineering, SCM to HR etc.	.434	38	.000	.582	38	.000
It is essential to ensure that the Lean Six Sigma projects are aligned to the organizations strategic goals.	.518	38	.000	.400	38	.000
There needs to be a cost saving target related to a Lean Six Sigma project.	.246	38	.000	.825	38	.000

Table 6 - Kolmogorov-Smirnov and Shapiro-Wilk normality test results

An assessment of the normality of data is a prerequisite for many statistical tests because normal data is an underlying assumption in parametric tests. The normality test in the analysis is assessed numerically using SPSS and the significance is zero. Since this is below 0.05, it means the data is non-parametric.

5.6 Reliability of the constructs

The reliability of the data was tested using the main constructs of the research questions. The idea behind reliability is that any significant results must be more than once-off finding and be inherently repeatable. Reliability is a necessary ingredient for determining the overall validity of a scientific experiment and enhancing the strengths of the results.

The four constructs that were tested were derived from the literature review section. For Lean Manufacturing, the constructs were drawn from figure 2, i.e. understanding of waste as well as continuous improvement, which had questions that sought to obtain feedback on understanding the value chain, process mapping, pull production and continuous improvement/seek-perfection culture.

The other constructs that were used to assist in answering the SS research question were that of internal and external support and also that of a disciplined method, i.e. the main constructs derived from table 1. In addition, reliability was tested in other constructs, i.e. those that had an output concerned with cost or cycle-time or on-time delivery as these were to be analysed for the correlation relationships with LSS.

The first output is the Cronbach Alpha of the first construct of understanding waste.

Reliability statistics

Cronbach Alpha	N of Items
.734	5

Table 7 - Cronbach Alpha for understanding waste

Cronbach's alpha is a coefficient of internal consistency. A commonly accepted rule for describing internal consistency using the Cronbach Alpha is as per table 8.

Cronbach Alpha	Internal consistency
α ≥ 0.9	Excellent (high-stakes testing)
0.7 ≤ α < 0.9	Good (low-stakes testing)
0.6 ≤ α < 0.7	Acceptable
0.5 ≤ α < 0.6	Poor
α < 0.5	Unacceptable

Table 8 - Cronbach Alpha guidelines

Table 9 below summarises the Cronbach Alpha results for the other constructs that were analysed.

Item	Cronbach Alpha	No. of item	Result
Continuous improvement	0.816	10	Accept
Internal and external support	0.809	3	Accept
Disciplined method	0.773	6	Accept
Cost	0.613	6	Accept
Cycle-time	0.908	6	Accept
On-time felivery	0.852	6	Accept

Table 9 – Cronbach Alpha for the 6 other constructs.

The Cronbach Alpha Test, used to check the reliability of the data, found it this was all acceptable for use.

5.7 Suitability of factor analysis - KMO and Bartlett Test Results

Table 1- below shows two tests that indicate the suitability of the data for structure detection of all the 46 questions. The Kaiser-Meyer-Olkin Measure (KMO) of sampling adequacy is a statistic that indicates the proportion of variance in the variables that might be caused by underlying factors. High values (close to 1.0) generally indicate that a factor analysis may be useful with the data.

The Bartlett Test of Sphericity tests the hypothesis that one's correlation matrix is an identity matrix. Small values (less than 0.05) of significance level indicate that a factor analysis may be useful with the data. The suitability factor analysis using KMO of sampling adequacy was tested and this was found to be 0.681. This suggests that a factor analysis may be useful to derive insights. The test of sphericity showed a significant result of zero, which also indicates that the factor analysis is useful with this type of data.

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.681
Bartlett's Test of Sphericity	Approx. Chi-Square	85.978
	df	21
	Sig.	.000

Table 10 - KMO and Bartlett test results

In most academic and business studies, KMO and the Bartlett test play an important role for accepting the sample adequacy. While the KMO ranges from 0 to 1, the world-over-accepted index is over 0.6. The result of the KMO for this research paper was found to be 0.681, which made the sample adequate. Also, the Bartlett Test of Sphericity relates to the significance of the study and thereby shows the validity and suitability of the responses collected to the problem being addressed through the study. For factor analysis to be recommended as suitable, the Bartlett test must be less than 0.05. In this research report, it was found to be zero, which shows that the responses were valid and suitable.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	12.187	25.390	25.390	12.187	25.390	25.390
2	6.736	14.034	39.425	6.736	14.034	39.425
3	4.376	9.117	48.541	4.376	9.117	48.541
4	3.734	7.780	56.321	3.734	7.780	56.321
5	2.736	5.699	62.021	2.736	5.699	62.021
6	2.141	4.461	66.482	2.141	4.461	66.482
7	1.896	3.950	70.432	1.896	3.950	70.432
8	1.503	3.131	73.562	1.503	3.131	73.562
9	1.421	2.960	76.522	1.421	2.960	76.522
10	1.362	2.838	79.361	1.362	2.838	79.361
11	1.239	2.582	81.943	1.239	2.582	81.943
12	1.068	2.225	84.168	1.068	2.225	84.168
13	.921	1.920	86.087			
14	.825	1.718	87.806			
15	.772	1.609	89.415			
16	.712	1.484	90.899			
17	.681	1.420	92.318			
18	.521	1.085	93.403			
19	.481	1.003	94.406			
20	.410	.855	95.260			
21	.349	.728	95.988			
22	.308	.641	96.630			
23	.298	.620	97.250			
24	.258	.538	97.788			
25	.208	.434	98.222			
26	.177	.368	98.590			
27	.148	.309	98.898			
28	.134	.279	99.177			
29	.101	.211	99.388			
30	.079	.164	99.552			
31	.068	.142	99.694			
32	.051	.107	99.801			
33	.030	.063	99.864			
34	.021	.045	99.909			
35	.019	.040	99.949			
36	.015	.031	99.980			
37	.009	.020	100.000			
38	1.898E-15	3.953E-15	100.000			
39	1.224E-15	2.551E-15	100.000			
40	8.725E-16	1.818E-15	100.000			
41	6.054E-16	1.261E-15	100.000			
42	4.283E-16	8.922E-16	100.000			
43	3.438E-16	7.162E-16	100.000			
44	6.070E-17	1.264E-16	100.000			
45	-1.318E-16	-2.746E-16	100.000			
46	-2.766E-16	-5.763E-16	100.000			

Extraction Method: Principal Component Analysis.

Table 11 - Suitability of factor-analysis results (Eigenvalues)

Only 12 factors were extracted as components with eigenvalues of greater than one. In factor analysis, eigenvalues are used to condense the variance in a correlation matrix. The factor with the largest eigenvalue has the most variance, and so on, down to factors with small or negative eigenvalues that are usually omitted from solutions. From the analysts' perspective, only variables with eigenvalues of 1.00 or higher are traditionally considered worth analysing.

5.8 Analysis of the constructs

The frequency distribution charts for the constructs are displayed below in figure 8. The first one - of understanding waste - looks high in terms of importance when running a Lean Manufacturing programme.

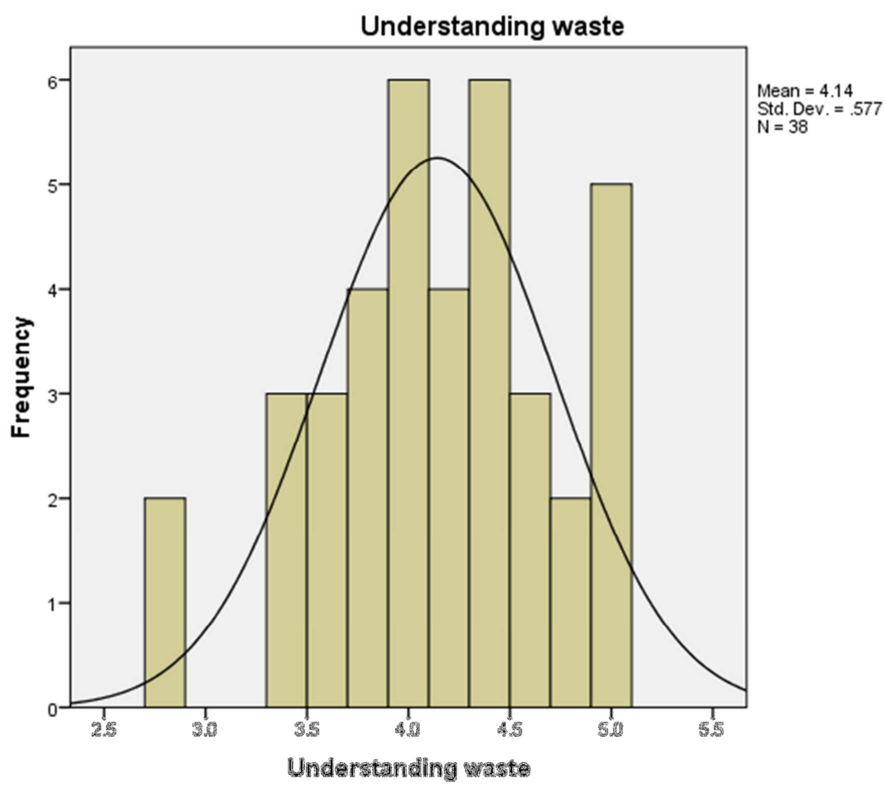

Figure 9 - Understanding waste construct

The construct of continuous improvement (with a mean score of 4.24) is also of high importance from the respondents' point of view.

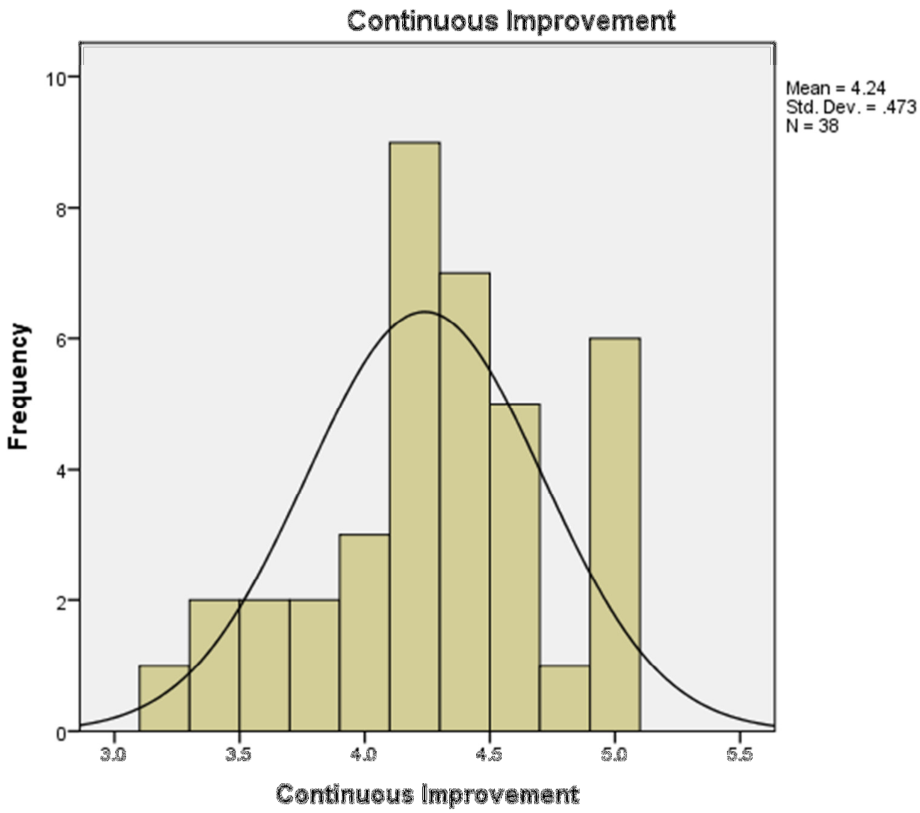

Figure 10 - Continuous improvement

The construct of internal and external support, when implementing SS, also seems to be high in respondents' scoring with a mean score of 4.09.

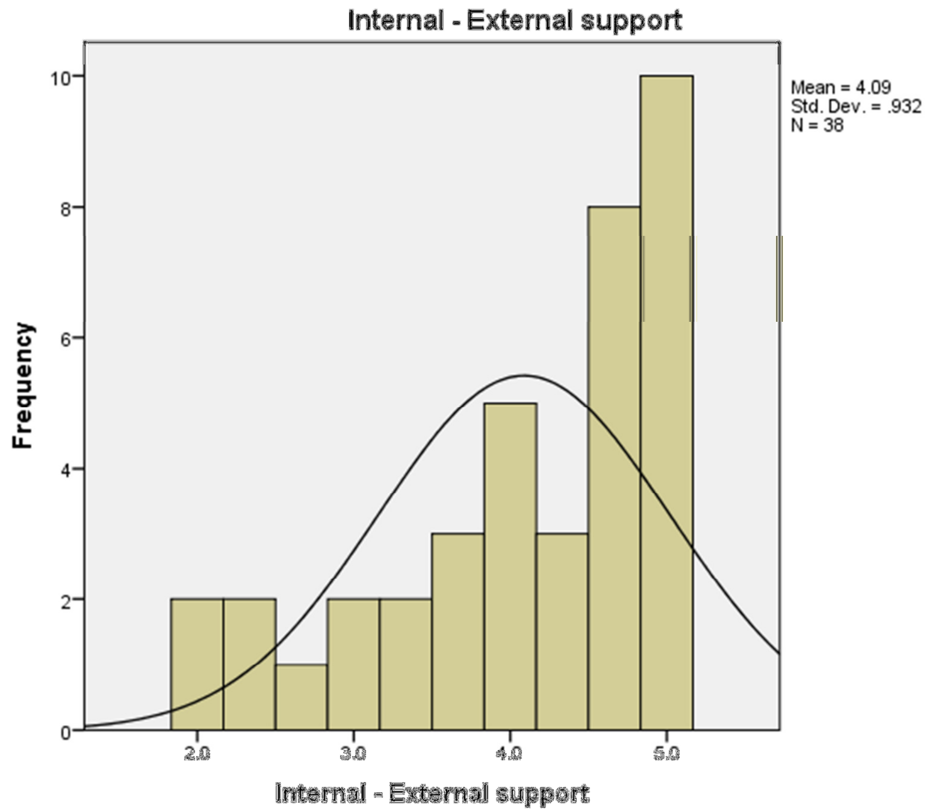

Figure 11 - Internal and external support

The construct of a disciplined method also seems to be high in importance, according to respondents' feedback. This has with a mean of 4.13.

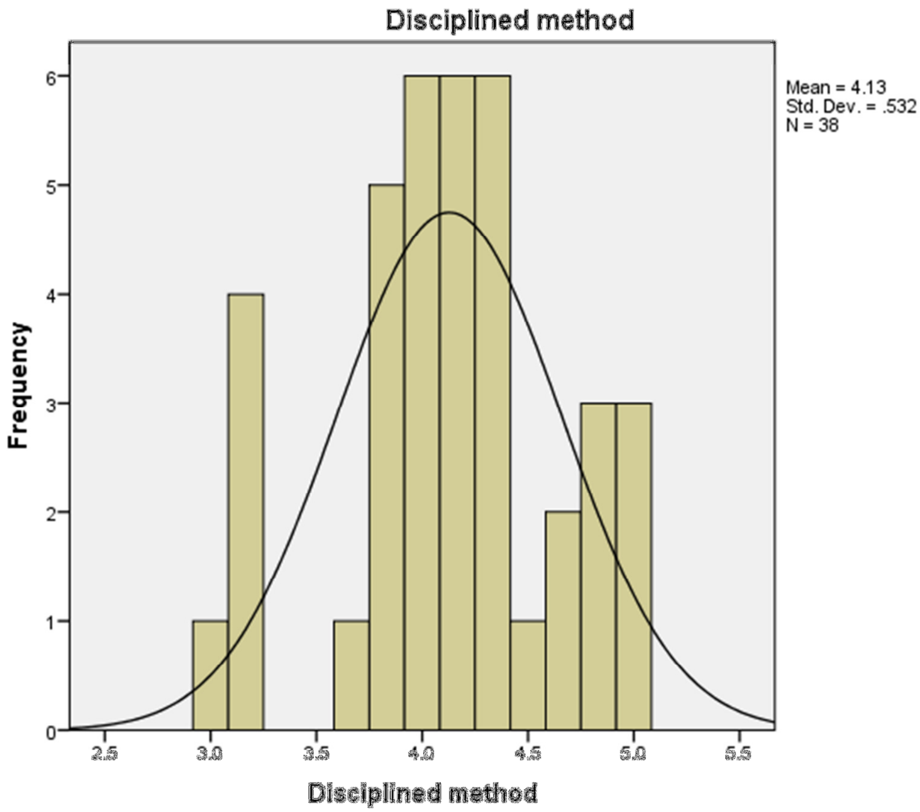

Figure 12 - Disciplined method

The constructs of cost indicate a higher-than-average impact on cost as the mean calculated was 3.6.

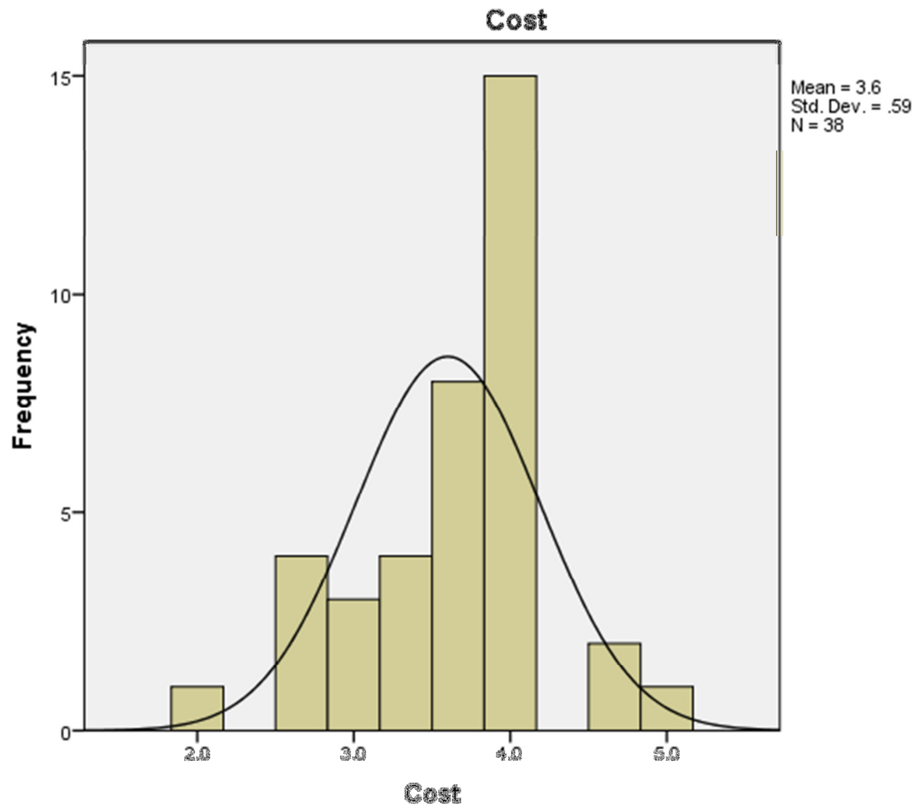

Figure 13 - Cost

The cycle-time construct seems to indicate a higher-than-average impact according to the respondents. The mean calculated for this construct was 3.35.

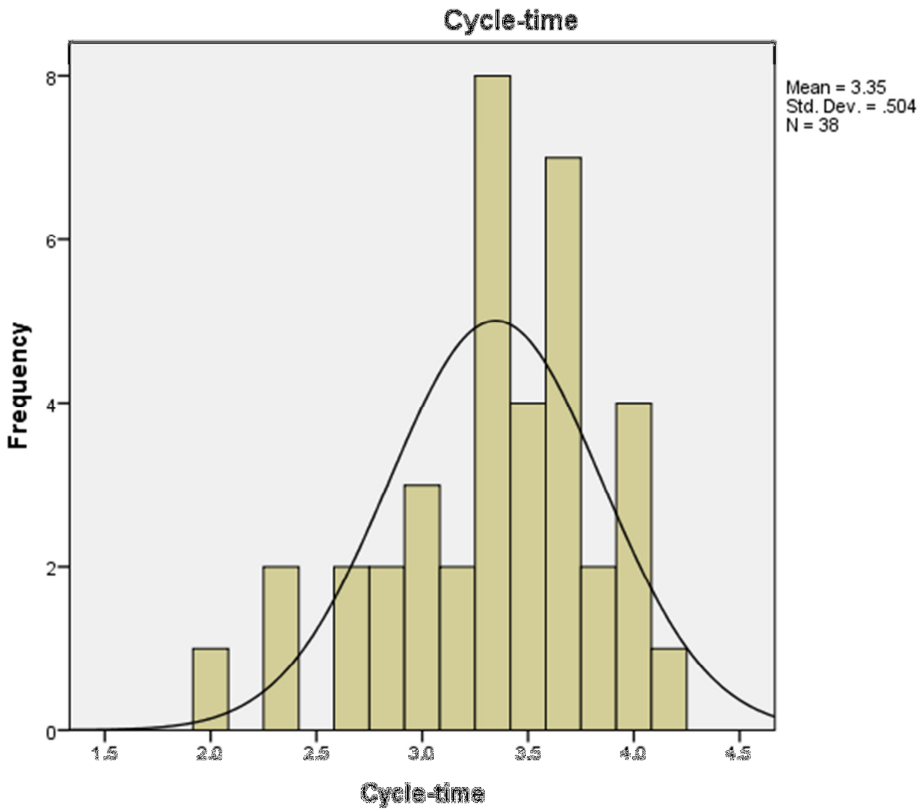

Figure 14 - Cycle-time

The construct of on-time delivery indicates a mean calculated of 3.61, which is above average according to the feedback of the respondents.

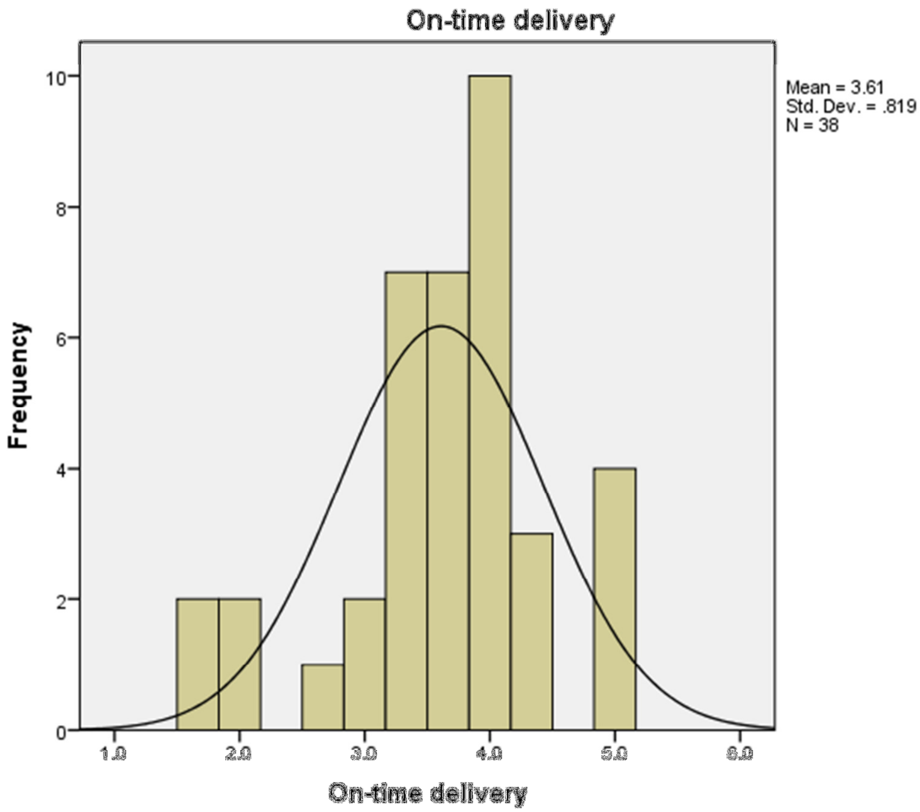

Figure 15 - On-time delivery

5.9 Correlation table

The Spearman Correlation Table was used as non-parametric data is being dealt with.

Correlations

			Understanding waste	Continuous Improvement	Internal - External support	Disciplined method	Cost	Cycle-time	On-time delivery
Spearman's rho	Understanding waste	Correlation Coefficient	1.000	.842**	.331*	.499**	.264	.183	.212
		Sig. (1-tailed)	.	.000	.021	.001	.055	.136	.101
		N	38	38	38	38	38	38	38
	Continuous Improvement	Correlation Coefficient	.842**	1.000	.375*	.672**	.168	.097	.122
		Sig. (1-tailed)	.000	.	.010	.000	.156	.281	.234
		N	38	38	38	38	38	38	38
	Internal - External support	Correlation Coefficient	.331*	.375*	1.000	.640**	.264	.213	.293*
		Sig. (1-tailed)	.021	.010	.	.000	.055	.100	.037
		N	38	38	38	38	38	38	38
	Disciplined method	Correlation Coefficient	.499**	.672**	.640**	1.000	.236	.219	.328*
		Sig. (1-tailed)	.001	.000	.000	.	.077	.094	.022
		N	38	38	38	38	38	38	38
	Cost	Correlation Coefficient	.264	.168	.264	.236	1.000	.533**	.649**
		Sig. (1-tailed)	.055	.156	.055	.077	.	.000	.000
		N	38	38	38	38	38	38	38
	Cycle-time	Correlation Coefficient	.183	.097	.213	.219	.533**	1.000	.530**
		Sig. (1-tailed)	.136	.281	.100	.094	.000	.	.000
		N	38	38	38	38	38	38	38
	On-time delivery	Correlation Coefficient	.212	.122	.293*	.328*	.649**	.530**	1.000
		Sig. (1-tailed)	.101	.234	.037	.022	.000	.000	.
		N	38	38	38	38	38	38	38

**. Correlation is significant at the 0.01 level (1-tailed).

*. Correlation is significant at the 0.05 level (1-tailed).

Table 12 Spearman Correlation Table

In processes, there is often a direct relationship between two variables. If a strong relationship between a process input variable correlates with a key process output variable, the input variable could then be considered a key process input variable (Forrest & Breyfogle, 2003).

In this study the input variables are the constructs which represent LSS implementation, which are split into understanding waste, continuous improvement for Lean Manufacturing and internal-external support and disciplined method for SS. The correlation coefficients in the table therefore give the result on the strength of the relationship between these input variables and the resultant output variables of cost, cycle-time and on-time delivery of the organisation.

6 Discussion of results

6.1 Introduction

The main reason for this research is to derive a framework for successful LSS implementation within the capital equipment manufacturing space. This will be done by confirming successful implementation of LSS within an organisation and then to test its effects on cost, cycle-time and on-time delivery of the organisation.

This study is based on perception analysis of 38 respondents who are experiencing LSS methodologies. The implementation of LSS was tested through descriptive analysis and frequency graphs to identify the perceptions, from the respondents, of the questionnaire. The questionnaire was designed to draw out questions meant to test the existence of the core elements of Lean Manufacturing as well as SS, thereby resulting in LSS being utilised. The questionnaire also posed questions aimed at getting the respondents feedback on the effect on cost, cycle-time and on-time delivery after successful implementation of the improvement programme.

The results of the analysis of the questionnaire will be compared with the concepts that were outlined in the literature review, chapter 2, on LSS implementation. These results, stated in chapter 5, were analysed using factor analysis, descriptive statistics and then correlation analysis was used to test their relationship with the key output metrics of cost, cycle-time and on-time delivery. The results of the analysis will then be used to answer the research questions for Lean Manufacturing, SS as well as their statistical relationship to cost, cycle-time and on-time delivery. It is, however, important to note that the questionnaire was targeted at employees in the LSS programme in some way or another, ranging from project team member to director of a department. A total of 42.5% of the sample consists of managers in their organisations and about 15% are SS Blackbelts or Greenbelts. The respondents are in the capital equipment industry and therefore represent the perspective the study is interested in.

6.2 Discussion of results

The following results will be presented in terms of the tests conducted to answer the five research questions. The first section is a report-back on the general question that ascertained viewpoints regarding the improvements brought about by using LSS. The second section gives detailed results about the research questions.

6.3 General questions

The responses to the general questions, posed on LSS, indicate the respondents had positive feedback on their experience with the programme. The mean figures ranged from 3.98 to 4.88, which indicate agreement, to strong agreement, to the questions from the respondents.

6.4 Factor analysis results

Factor analysis is a commonly used data/variable-reduction technique. This methodology was used to analyse this data and there were twelve factors that had eigenvalues higher than one. This indicates that the questionnaire can be reduced to 12 factors. The eigenvalue for a given factor measures the variance which is accounted for by the factor.

6.5 Research question one

a) Are the key aspects of successful Lean Manufacturing implementation well understood within the organisation?

This question was design to get feedback from the respondents on whether they understood the drivers of successful Lean Manufacturing implementation within their organisation. Once this has been confirmed, it is then possible to test the implementation of Lean Manufacturing against its effect on the output metrics of interest, i.e. cost, cycle-time and on-time delivery.

The questions were therefore structured into constructs which test for the characteristics of Lean Manufacturing, as depicted in figure 2 of chapter 2. The first construct was that of understanding waste. The results given by the respondents indicate a mean of 4.14 and a standard deviation of 0.577. The mean indicates that the characteristics of understanding waste are vital to Lean Manufacturing from the perspective of the respondents. The respondents were in agreement with this construct, with some even strongly agreeing.
The standard deviation measures the amount of variation or dispersion from the average. A low standard deviation indicates that the data points tend to be very close to the mean. The results in this research report indicate a low standard deviation on this research question, indicating that the data points are close to the mean. This is a

strong indication that the respondents have the same perceptions on the characteristics of understanding waste. It was also stated, in the literature, that an emphasis on waste drove the correct behaviour in that it influenced inventory reduction, process simplification and the identification and elimination of non-value-adding tasks(Browning & Heath, 2009).

The second construct of continuous improvement was also structured to test the characteristics of Lean Manufacturing as it posed questions to test the understanding of the value chain, process mapping, pull production and a continuous improvement culture that seeks perfection. The mean result for this construct was 4.24 and the standard deviation was 0.473. The mean indicated that there was a significant amount of agreement, even strong agreement, with the characteristics of Lean Manufacturing in the second construct. A low standard deviation also indicated that the data points were close to the mean. The tools and techniques in this construct are stated as being the ones most frequently adopted to eliminate waste through the application of Lean Manufacturing paradigm like 5s, mistake proofing, cellular manufacturing, pull production, value stream mapping, kaizen, Kanban, total productive maintenance, set-up time reduction and visual management (Vinodh *et al.*, 2014).

6.6 Research question 2

b) What are the core elements of successful SS implementation within the mining equipment manufacturing environment?

This question was designed to elicit what the core elements of SS are, according to respondents based on their experience. These elements were tested using the SS constructs depicted in table 1.

The first construct was that of internal and external support for the programme. This is broken down into customer orientation and leadership engagement. Once it has been established that the core elements of SS are in place, it is possible to test their effect on cost, cycle-time and on-time delivery. The mean result for this construct was 4.09 and the standard deviation was 0.932. The mean result indicates that respondents mostly agreed that there needs to be support from leadership as well as an external customer focus. The standard deviation is also low, which shows measurements are close around the mean. These results indicate an agreement on this construct, which supports the literature which spoke of the leadership having to concentrate on ensuring the right corporate culture to have successful SS implementation (Grima *et al.*, 2013).

The second construct to test SS core elements is that of a disciplined method. This was made of the elements of dedicated improvement organisation, structured method and metric focus. The mean was found to be 4.13 and the standard deviation was 0.532. The mean indicated an agreement, mostly from the respondents to the disciplined methods. The DMAIC acronym (define, measure, analyse, improve and control) is the most popular structure indicated. The standard deviation is also low, at 0.532, which indicates a low dispersion from the average. This is well supported by the literature, which defined the disciplined method as an organised, parallel-meso structure to reduce variation in organisational processes by using improvements specialists, a structured method, and performance metrics with the aim of achieving strategic objectives (Easton & Rosenzweig, 2012).

The results displayed by this analysis indicate that there is agreement on the elements that make up SS. The perceptions of the respondents were then tested on how they saw the effects of SS on cost, cycle-time and on-time delivery.

6.7 Research question 3

c) What has been the effect on cost since the implementation of LSS?

This question has been chosen to test the effect of implementation of LSS on the cost metric. This research question will be analysed in two ways: through analysing the descriptive statistics of the constructs and checking the correlation relationships with LSS and the independent variables of cost.

The mean displayed by the results was found to be 3.6, which was towards agreement in terms of the questionnaire, but also had a healthy sum of respondents being neutral. This is an indication that although quite a few respondents felt that they agreed with the effect of LSS on cost, there were some individuals who were neutral. This is an indication that there is not always a clear measure of the effect on cost and that this metric is not well monitored or understood. It is said, in the literature, that LSS has been marked as a new organisational change and improvement method, particularly as a cost-reduction mechanism (Jayaraman *et al.*, 2012). It is, however, difficult to build on this statement and show the positive impact of LSS if the improvement metric of cost is not measured.

The standard deviation is 0.59, which means that most of the numbers are very close to the average.

The improvement to cost is often punted as being the biggest benefit of implementing LSS within the organisation. This is mentioned in the literature as a continuous business improvement method that maximises shareholder value (Psychogios & Tsironis, 2012) but is not measured well within this environment. In the results, this came through as there were a significant number of respondents who were neutral on this construct.

6.7.1 Correlation coefficients for cost

The correlation coefficients for the different constructs of LSS, against the output variables of cost, are as follows:

- Understanding waste versus cost had a correlation coefficient (r) of 0.264. This indicates a mild positive correlation between understanding waste and cost. The mild relationship gives an indication that the improvement is not so clearly visible for it to warrant a strong positive correlation result from the respondents. This will have to be addressed in the formulation of the framework in terms of ensuring that the metric of cost is clearly measured and tracked to monitor improvements in waste reduction.
- The next input variable is continuous improvement versus cost. The correlation coefficient is 0.168, which shows a mild positive correlation between the continuous improvement construct and cost. This indicates that although there are improvements realised in this construct for Lean Manufacturing, which includes using the tools, there is no clear link made between the improvements that resulted in the output metric of cost.

  It is, therefore, an area to improve on in terms of any improvements made in the process using Lean Manufacturing techniques. The cost benefit has to be clearly stated and measured to monitor for improvement. The literature does indicate that there is empirical evidence that companies using Lean Manufacturing techniques do end up, for example, improving their cost reductions (Furlan *et al.*, 2011).
- The third input variable is internal and external support and the correlation coefficient for this versus cost is 0.264. This is a mild positive correlation and

indicates that although there is a relationship between these two variables, it is not very strong. There needs to be more emphasis on the benefits brought about by SS, supported by the leadership team, so that both the internal and external team members can clearly see the fruits of their efforts.

- The final construct of disciplined method versus cost had a correlation coefficient of 0.236. This is a mild positive correlation indicating there is a relationship between the variables. It is said, in the literature, that there are varying objectives for SS projects, with cost reduction being one of them (Arumugam *et al.*, 2013)

Therefore, there needs to be a savings or cost-reduction target set when completing a SS project to ensure that the team is focused on the key objective and do not allow for scope creep. The literature indicates that the successful implementation of SS is positively correlated with better financial performance and profit generation (Aboelmaged, 2011).

6.7.2 Summary of cost

There is a mild positive relationship between the four different constructs of LSS and cost. This indicates that although there is a correlation between these two variables tested - using one construct at a time - this relationship does not appear to be strong. In the experience gained thus far - in running projects within this environment - one can find it quite challenging to track the cost impact throughout the project as it is not the focus in most scenarios. It is, however, vital firstly to get a baseline of the cost at the beginning of the project and then to continue tracking the trend from this baseline. The benefits of measuring in this way are that one can monitor the trend and decide whether to change strategy, if necessary, and also the positive impact on cost will serve as a motivator for the team as a whole.

6.8 Research question 4

d) What is the effect of LSS on cycle-time of a product?

This research questioned is designed to find out if LSS implementation has a positive effect on cycle-time through the factory. It is measured through analysing the descriptive statistics after which there will be an analysis of the correlation between LSS and cycle-time conducted.

The mean result of the analysis was 3.35 and the standard deviation was 0.504. This mean indicates that the respondents are more neutral on this construct. In the job-shop environment, cycle-time is dependent on many factors and is often not measured accurately. Operation times are known but are difficult to maintain in sequence as these are very dependent on other variables in between operations like queue time in machine shop, waiting for parts, quality support or engineering support. The cycle-time construct, therefore, indicates that most of the respondents do not agree that LSS positively affected cycle-time, however they also do not disagree in any way. They are rather neutral, which indicates they are not able to confirm that there is a cycle-time impact on the total manufacture of the product.

The literature clearly states that the aim of lean is to remove non-value-adding steps and waste (Gupta *et al.*, 2012), which should positively impact on the cycle-time. It is therefore important for project team members to capture cycle-time performance at the start of a project, during the project and also once improvement has been implemented.

There is also very little variation from the average. The standard deviation is low as the data points are close to the mean. This is an indicator that the perspective of the respondents is similar to this construct. It will therefore be important to measure cycle-time improvements better as these will be impacted because cycle-time is not total flow time elapsed through the whole process for a part but the elapsed time between the consecutive two parts produced in the process (Atmaca & Girenes, 2011).

6.8.1 Correlation coefficients for cycle-time

The correlation coefficients for the different constructs of LSS, against the output variables of cycle-time, are as follows:

- Understanding waste versus cycle-time has a correlation coefficient of 0.183. This indicates a mild positive relationship between the two variables. The metric of cycle-time within the low-volume, high-variation environment is difficult to claim as it is dependent on so many other variables. It is also very dependent on the operator and his motivation level. When removing waste from the processes, the natural by-product is that of improved cycle-time but this has to be clearly measured as a baseline then monitored as the implementation of

Lean Manufacturing takes place.

- The second construct of continuous improvement versus cycle-time has a correlation coefficient of 0.97. This is a mild positive correlation, which indicates that this construct does not have a strong relationship with cycle-time. This is a clear indication that although there are improvements made in cycle-time, it is not recorded well enough to show the improvement to all the team members.

  The literature states Lean Manufacturing focuses on reducing process time by removing non-value-adding steps and waste (Gupta *et al.*, 2012). The small improvements in cycle-time, as defined in the literature, should therefore be publicised and celebrated, as well as being held as the new standard of performance. Often in the low-volume, high-variety environment one tends to work on mean time achieved, taken as standard time, and this is based on mediocrity and the world-class performance is seen as a once-off occurrence that occurs when there are no issues.
- The third construct of internal and external support versus cycle-time has a correlation coefficient of 0.213. This is a mild positive relationship which indicates that although there is a relationship between these variables it is not strong. This means that the senior leadership does not support and display the results of LSS in the organisation. The team members are therefore not sure of the benefits to cycle-time. It is said, in the literature, that the three Human Resources Management practices of employee involvement, employee training and employee performance recognition should support the sustainable use of SS methodology (Xingxing & Fredendall, 2009).
- The final construct of discipline method versus cycle-time has a correlation coefficient of 0.219. This was a mild positive correlation between the two variables. There is therefore work to be done in highlighting the positive effect of using the disciplined methods of SS on the metric of cycle-time.

6.8.2 Summary of cycle-time

The results indicate a mild positive relationship between the four constructs of LSS and cycle-time. There is, therefore, a relationship between the variables but this relationship is not strong. Cycle-time in the job-shop environment is challenging to maintain as there are multiple variables that can stop one from achieving the required results. Unlike a high-volume, low-variety environment, where one can setup to a certain model and run hundreds of products, the low-volume and high-variety environment is not as predictable. It is therefore important to measure the baseline cycle-time of the process prior to the implementation of LSS and track its progress during the programme. When removing waste from the process and focusing on implementing the LSS tools and techniques, one will realise a lot of benefits but these will not be clear when considering the value chain. It is therefore important to celebrate the cycle-time gains within the process and quickly adopt them as the new standard.

6.9 Research question five

e) What is the effect of LSS on the on-time delivery of a product?

This research question seeks to find out if the implementation of LSS has an effect on the on-time delivery metric. This is done through analysing the descriptive statistics given by the responses to the questionnaire. There will also be an analysis conducted of the correlation relationships between LSS and on-time delivery from the perspective of the respondents.

The mean result was 3.61 and standard deviation was 0.819. The mean indicates that the respondents are closer to 4, which is agreed based on the construct of questions that tested for the effect of LSS on on-time delivery. This metric is usually tracked within the organisation and quite visible when performing both negatively - i.e. being late - or performing positively - i.e. that becomes the new benchmark. It is therefore best for the organisation to perform at the targeted levels on an ongoing and consistent basis.

The literature mentions in chapter 2 - that there is evidence of delivery time being reduced because of improvements brought about by LSS (Drohomeretski *et al.*, 2014) - this is supported by the data which indicates a significant amount of people that agree on this statement. The focus on waste and cost reduction, through reduction of non-value-adding steps in critical business processes through systematic elimination, leads to faster delivery of service (Manville *et al.*, 2012). This is further supported by the results achieved thus far and indicates that the results are ongoing and there is an element of continuous improvement as one seeks to eliminate non-value-adding activities, wherever possible, on an ongoing basis.

The standard deviation is closer to 1 at 0.819, which shows a wide spread but with the majority of the results around 4, as shown by figure 15 on-time delivery. This result indicates that there is also an instance of respondents who felt that the on-time delivery metric was negatively affected by implementing LSS as well as respondents who strongly agreed with the positive effect of LSS on on-time delivery. However, most were agreement. It is easier to measure this metric, which is the time taken from order received date to the customer selected due date, which is better known as the voice of the customer. The perspectives of the respondents therefore indicates that they felt that there was an improvement in this regard and with the literature indicating that it is a systematic and on-going improvement the improvement is sustainable as it is based on solving the root cause of failure issues.

6.9.1 Correlation coefficient of on-time delivery

The correlation coefficients for the different constructs of LSS, versus the on-time delivery output, are as follows:

- The construct of understanding waste versus on-time delivery resulted in a correlation coefficient of 0.212. This is a mild positive correlation, which indicates that there is a relationship but it is not strong. The on-time delivery metric within the low-volume, high-variety environment is always a very important metric as it is vital to the customer and often difficult to maintain on a sustainable basis. It is therefore important to measure the baseline on-time delivery performance prior to implementing LSS and then measuring the trend during the programme.
  The second construct of continuous improvement versus on-time delivery is 0.122. This indicates a mild positive correlation between the two variables. With a continuous improvement construct, one is able to map the process and analyse it with the intention of removing the non-value-adding steps. This is, however, a challenge as job-shops face the toughest obstacle when trying to map and analyse the flow of 100 – 2 000 + product routes through the facility (Pepper & Spedding, 2010).

It is therefore vital to spend a significant amount of time understanding the product flow and the different lead-times to understand where the constraint that influences the on-time delivery performance is situated. However, it will allow a focus on waste removal and cost reduction through removing the non-value-adding steps within the process, leading to faster delivery time (Manville *et al.*, 2012). With continuous improvement construct, one has to measure the baseline of the on-time delivery metric and continually work to improve on this metric over time and implement controls to sustain the optimum level.

- The third construct, of internal and external support versus on-time delivery, gave a correlation coefficient of 0.293. This is a mild positive result and is an indication that the relationship between the two variables is not very strong. The internal and external support for LSS is vital for the success of the process and it is therefore important to embed in the implementation by ensuring there is a support structure set up by the programme champion. This structure will then ensure there is regular meeting with senior leadership, which is geared at highlighting the successes of the programme and setting plans in place to work on other areas that will have a high impact.
- The final construct is that of disciplined method versus on-time delivery. The correlation coefficient was found to be 0.328. Although this is the strongest relationship of all, it still indicates a mild positive relationship. There was therefore more confidence from the respondents on confirming that using a disciplined method does have an effect on on-time delivery performance. Using this method in the prescribed manner will therefore ensure success of LSS implementation.

6.9.2 Summary of on-time delivery

The results gathered from this study indicate a mild positive correlation between the constructs of LSS and on-time delivery. The correlation coefficient for using a disciplined method followed by internal and external support came out higher, which indicates a stronger relationship on these construct. It is therefore important to ensure that these two constructs are well entrenched when implementing LSS to ensure improvement in on-time delivery performance.

7 Conclusion

7.1 Introduction

This chapter highlights the findings of the research and then puts all the recommendations together into a framework, which is based on the LSS philosophy but is designed for application in the capital equipment environment.

7.2 Major findings

The major finding was with regard to dependent variables of LSS. The most important construct was that of continuous improvement and this highlights the importance of ensuring that understanding the value chain and using pull production is core to the implementation of LSS. The next important construct was that of disciplined methodology, which is made up of the core elements of dedicated improvement organisation, structured methodology and metric focus. Understanding waste was third in order of importance. The last one - which is internal and external support - in terms of their order is an indication that the first priority is to have solid implementation of continuous improvement culture and a clear strategy of using a disciplined method to execute on the plan.

In terms of the independent variables of cost, cycle-time and on-time delivery it was interesting to find that the on-time delivery had the highest mean result followed by the cost and lastly the cycle-time. It confirms that improvements are felt by the different respondents that have experienced SS and these improvements need to be made visible.

Cost had a tight standard deviation of 0.59. The cost improvements are therefore felt and this needs to be closely monitored. The cycle time improvements ranked last in mean result against cost and on-time delivery. This indicates that in the environment of low volume and high variants, it is difficult to identify cycle-time improvements. This is because one product is run at a time with weeks, or sometimes months, until the next build. Accurate records of the cycle time of each job need to be kept and the best cycle time needs to be recorded so that the operator always understands the expectation.

The correlation coefficient results also indicate that the highest correlation results were in disciplined methodology and internal and external support, against the on-time delivery. This further validates that in terms of respondent experience with LSS they find the most prevalent improvement is in on-time delivery metrics. The framework below is a basic system of implementation of LSS and is based on the DMAIC steps of SS with the Lean Manufacturing tools inserted in the necessary areas in the low-volume, high-variety environment.

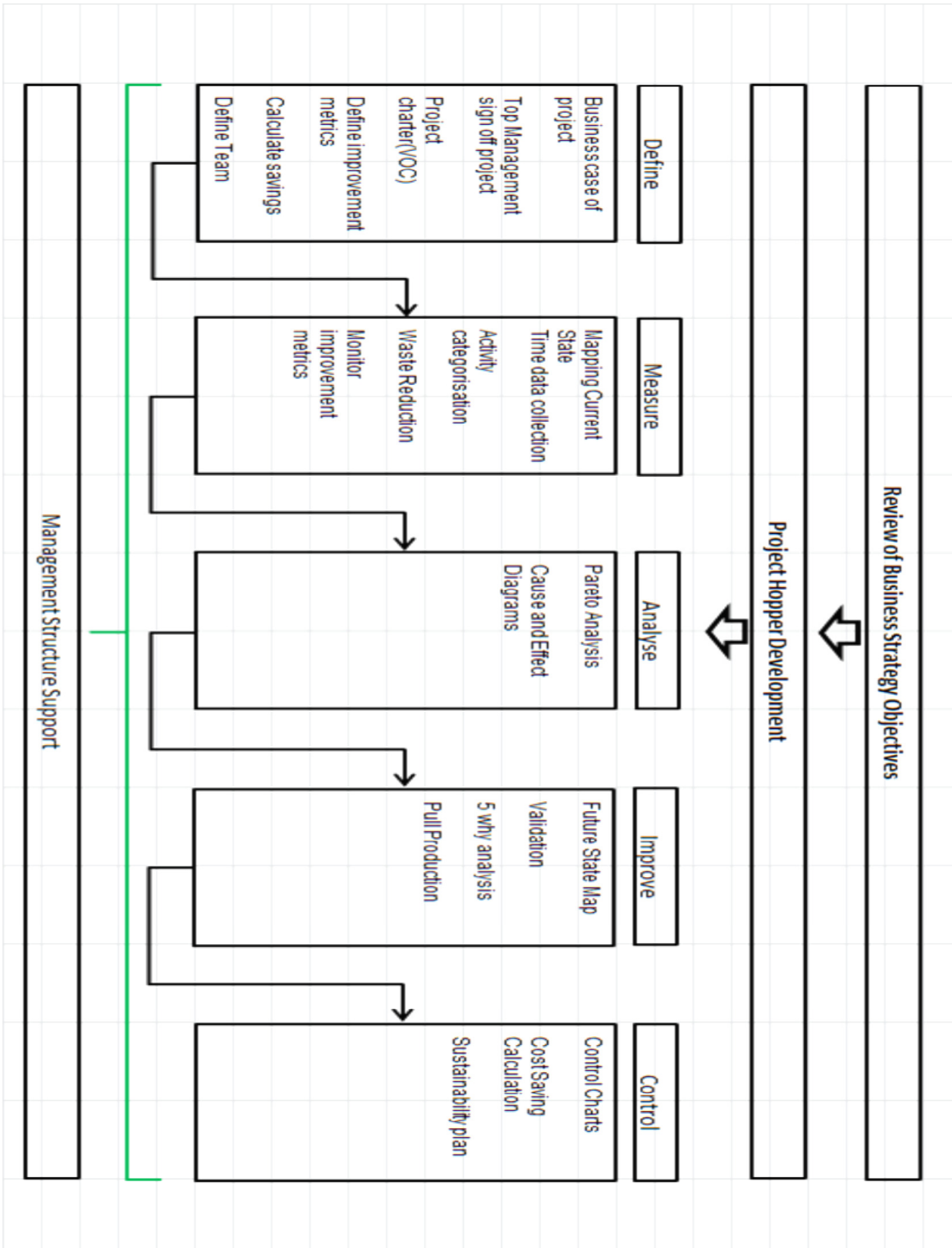

Figure 16 – Framework for LSS

7.3 Use of LSS framework

7.3.1 Review of business strategy objectives

The top level of the framework shows what drives the plan. There needs to be a complete review of the business strategy objectives conducted as this will ensure that the parallel meso structure of LSS is focused on projects that are aligned to the leadership business strategy objective. The benefits of implementing the improvement programme has to be seen by the leadership as assisting the company reach its goals in key areas of the business as per the plan. In mature companies, in LSS implementation the SS team is part of the business strategy development.

7.3.2 Project hopper development

Critical to this framework is to develop a project hopper, which is a repository of all planned projects that are potential beneficial projects for the company. This hopper has to be reviewed regularly and kept up to date. Once projects are launched, these are moved from this hopper into active status. Active status indicates that the project has been launched.

7.3.3 Stages of the project

The next part of the framework indicates the different stages of the project. As per the findings, i.e. that a disciplined method is important, the structure of the SS steps of define, measure, analyse, improve and control will serve this purpose. Each stage needs to be monitored carefully for its duration, which will vary per project depending on the challenges faced. There needs to be regular reviews conducted with leadership to ensure that the team is not stuck on any stage and that barriers are removed.

7.3.4 Define phase actions

The define phase actions are aimed at setting up a strong base to justify the project. This is done by first completing a business case for the project. Once this has been completed and shows positive benefits in terms of net present value then top leadership needs to sign the project off and this gives an indication to start.

The project charter - a contract developed stating the key factors of problem description as well as the what, where, when and how of the project - is then drawn up. The project charter should also represent the voice of the customer (VOC) in terms of the improvement targets.

Critical to the define phase is to be clear on the improvement metric for the project. This is important to establish and monitor as it is necessary to see the results of the project implementation, which acts as a motivator for the team.

To establish the potential savings requirements forecasted from the improvements targeted on the chosen metric. The final critical step of the define phase is to establish a cross-functional team for each project, clearly indicating the responsibility of each individual.

7.3.5 Measure phase actions

The measure phase actions start with mapping of the current process. As stated before, this can be a very challenging task within this environment but is vital to the success of the project. It is recommended that a lot of effort and resources are spent on this action to ensure a proper study is completed. Time data collection is also a critical part of this phase. As there are not many machines and automation within this environment, the real assets that are sold as labour hours. Therefore, any positive gains in cycle-time directly relate to cost saving for the company.

'Activity categorisation' refers to the naming and coding of each activity, linking the rate and skill level to each category. This is important to get in place - especially for the analysis phase. Waste reduction is more than just a phase. It is the constant seeking to reduce waste from the workforce. This has been a key component of LSS, which results in many positive spin-offs, e.g. safety improvement.

The last step of the measure phase in the framework is to implement a measure on the metrics targeted for improvement. This will then be reported on monthly to ensure that improvements are made.

7.3.6 Analyse phase actions

A pareto analysis is the first action within the analysis phase. This can be done on or within business units. As the cycle-time reduction is one of the biggest levers within this environment, it will therefore be logical to review the cycle-time performance against the standard quoted on the routings. By performing this exercise, one will be able to see the processes that are struggling to reach their targeted standard times indicated, thus showing opportunities for improvement. Pareto analysis can be used in multiple ways, including assessing cycle-time performance between artisans to encourage healthy motivation.

The other important tool of the analysis phase is to use the cause-and-effect diagram to come up with possible root causes of the problem.

7.3.7 Improvement phase actions

The first step in the improvement phase actions is to draw the future state map which will include all the improvement actions identified in the analysis phase. This is where the team has to get creative and keep their attention focused on getting optimised processes put in place with no waste. The continuous improvement philosophy is most effective in this stage as tools like Kanban and Kaizen Bursts - result in some significant benefits, such as inventory reduction.

The improvements need to be validated to ensure one is not adversely affecting the process. In the areas where the improvement required is not obvious then the five why analysis tool can be used to get to the root cause. A very important tool to ensure inventories are kept under control is to utilise the pull-production technique, where work is pulled to the floor only when there is an order.

7.3.8 Control phase actions

The control phase is the last phase of the project, which shows that all improvement actions are complete and the project can be closed. The concern of the team will therefore be to ensure that the improvement is sustained. The implementation of control charts for the critical metrics is therefore used in this regard.

The cost savings over the project are also calculated at this stage once all actions are complete. It is vital to make this saving calculation visible to motivate the team and the company about the benefits of LSS.

Lastly, in the control phase is the sustainability plan which clearly indicates the responsible person for that process and his support structure.

7.3.9 Management structure support

This level of the framework indicates the underlining support represented by top leadership. The leadership needs to show interest in the programme and hold regular reviews to provide the support needed for the continuous programme to thrive.

7.3.10 Application of this model

The framework for LSS presented is meant to assist the team to follow the correct process to implement the programme to ensure success within the capital equipment environment. This framework came about after review of the available literature on the subject as well as consolidating the perspectives of respondents utilising these tools in their environments today. The tools used in this framework are more focused towards dealing with environments with low volume and high variability in their production mix. Applying the model in this way will also ensure there is a proper structure set-up which will be required to work through some tough project challenges therefore there needs to be a coherent effort to get to the improvement goals.

7.4 Recommendations for practitioners

The use of this LSS framework will be beneficial to any continuous improvement implementation within the capital equipment industry. This framework depicts the important aspects of the programme to ensure success as it is derived from the literature as well as research through surveying individuals in the industry. An implementation supported by top leadership is key to the programme where the leadership team takes a keen interest in projects and the results they produce.

7.5 Recommendations for academics

Academics should be aware of these improvement techniques that were developed in industry, and try and incorporate them in the course outline. This will make their contribution more impactful from the beginning when working on projects using LSS philosophy.

7.6 Recommendations for future research

This research added value in highlighting the important aspects of LSS implementation within the capital equipment environment, which is markedly different from the traditional environment of automotive or fast moving consumer goods (FMCG).
This is the first paper to concentrate on this area from a technical structure and tools usage point of view. There is, however, further investigation required for this environment, related to the following areas:

- Measuring the correlation between top management support and the success of LSS implementation,
- Human Resources required for successful LSS implementation, and
- The link between the success of a company with LSS implementation against its competitors on market share.

7.7 Conclusion

This study has further enforced the theory that LSS is applicable to most industries but the difference will be in the application of the tools. The framework therefore highlights the important to tools to use within the capital equipment environment. Once this framework is applied, there will be a robust implementation of continuous improvement, which will ensure that the benefits to cost, cycle-time and on time delivery are highlighted at the highest level to provide motivation to the teams working on the project. The research also indicated that there has been experience of bad implementation of LSS and this framework ensures that the correct structure is put in place to ensure the success of the programme.

Even though the research was focused on one industry of capital equipment, the findings can also be used in any other manufacturing environment that has low volume and high variation.

References

Aboelmaged, M. G. (2010). Six Sigma quality: a structured review and implications for future research. *International Journal of Quality & Reliability Management*, *27*(3), 268–317. doi:10.1108/02656711011023294

Aboelmaged, M. G. (2011). Reconstructing Six Sigma barriers in manufacturing and service organizations: The effects of organizational parameters. *International Journal of Quality & Reliability Management*, *28*(5), 519–541. doi:10.1108/02656711111132562

Arumugam, V., Antony, J., & Kumar, M. (2013). Linking learning and knowledge creation to project success in Six Sigma projects: An empirical investigation. *International Journal of Production Economics*, *141*(1), 388–402. doi:10.1016/j.ijpe.2012.09.003

Assarlind, M., Gremyr, I., & Bäckman, K. (2013). Multi-faceted views on a Lean Six Sigma application. *International Journal of Quality & Reliability Management*, *30*(4), 387–402. doi:10.1108/02656711311308385

Atmaca, E., & Girenes, S. S. (2011). Lean Six Sigma methodology and application. *Quality & Quantity*, *47*(4), 2107–2127. doi:10.1007/s11135-011-9645-4

Bamber, L., & Dale, B. G. (2000). Lean production: A study of application in a traditional manufacturing environment. *Production Planning & Control: The Management of Operations*, *11*(3), 291–298. doi:http://dx.doi.org/10.1080/095372800232252

Browning, T. R., & Heath, R. D. (2009). Reconceptualizing the effects of lean on production costs with evidence from the F-22 program. *Journal of Operations Management*, *27*(1), 23–44. doi:10.1016/j.jom.2008.03.009

Byrne, G., Lubowe, D., & Blitz, A. (2007). Using a Lean Six Sigma approach to drive innovation. *Strategy & Leadership*, *35*(2), 5–10. doi:10.1108/10878570710734480

Chauhan, G., & Singh, T. P. (2012). Measuring parameters of lean manufacturing realization. *Measuring Business Excellence*, *16*(3), 57–71. doi:10.1108/13683041211257411

Cottyn, J., Van Landeghem, H., Stockman, K., & Derammelaere, S. (2011). A method to align a manufacturing execution system with Lean objectives. *International Journal of Production Research*, *49*(14), 4397–4413. doi:10.1080/00207543.2010.548409

Dahlgaard, J. J., & Dahlgaard-Park, S. M. (2006). Lean production, six sigma quality, TQM and company culture. *The TQM Magazine*, *18*(3), 263–281. doi:10.1108/09544780610659998

Drohomeretski, E., Gouvea da Costa, S. E., Pinheiro de Lima, E., & Garbuio, P. A. da R. (2014). Lean, Six Sigma and Lean Six Sigma: an analysis based on operations strategy. *International Journal of Production Research*, *52*(3), 804–824. doi:10.1080/00207543.2013.842015

Easton, G. S., & Rosenzweig, E. D. (2012). The role of experience in six sigma project success: An empirical analysis of improvement projects. *Journal of Operations Management*, *30*(7-8), 481–493. doi:10.1016/j.jom.2012.08.002

Enoch, O. (2013). Lean Six Sigma Methodologies and Organizational Profitability: A Review of Manufacturing SMEs in Nigeria. *American Journal of Industrial and Business …*, *2013*(October), 573–582. Retrieved from http://file.scirp.org/Html/38627.html

Farooki, M. (2012). The diversification of the global mining equipment industry – Going new places? *Resources Policy*, *37*(4), 417–424. doi:10.1016/j.resourpol.2012.06.006

Forrest, W., & Breyfogle, I. (2003). *Implementing six sigma* (Second edi.). New Jersey: John Wiley & Sons.

Furlan, A., Vinelli, A., & Pont, G. D. (2011). Complementarity and lean manufacturing bundles: an empirical analysis. *International Journal of Operations & Production Management*, *31*(8), 835–850. doi:10.1108/01443571111153067

Gijo, E. V., Antony, J., Kumar, M., McAdam, R., & Hernandez, J. (2014). An application of Six Sigma methodology for improving the first pass yield of a grinding process. *Journal of Manufacturing Technology Management*, *25*(1), 125–135. doi:10.1108/JMTM-12-2011-0109

Gillett, J., Fink, R., & Bevington, N. (2010). How Caterpillar Uses to Execute Strategy 6 SIGMA. *Strategic Finance*, (April).

Green, J. C., Lee, J., & Kozman, T. a. (2010). Managing lean manufacturing in material handling operations. *International Journal of Production Research*, *48*(10), 2975–2993. doi:10.1080/00207540902791819

Grima, P., Marco-Almagro, L., Santiago, S., & Tort-Martorell, X. (2013). Six Sigma: hints from practice to overcome difficulties. *Total Quality Management & Business Excellence*, *25*(3-4), 198–208. doi:10.1080/14783363.2013.825101

Gupta, V., Acharya, P., & Patwardhan, M. (2012). Monitoring quality goals through lean six sigma insures competitiveness. *International Journal of Productivity and Performance Management*, *61*(2), 194–203. doi:http://dx.doi.org/10.1108/17410401211194680

Gutiérrez, L. J. G., Lloréns-Montes, F. J., & Sánchez, Ó. F. B. (2009). Six sigma: from a goal-theoretic perspective to shared-vision development. *International Journal of Operations & Production Management*, *29*(2), 151–169. doi:10.1108/01443570910932039

Heckl, D., Moormann, J., & Rosemann, M. (2010). Uptake and success factors of Six Sigma in the financial services industry. *Business Process Management Journal*, *16*(3), 436–472. doi:10.1108/14637151011049449

Hilton, R. J., & Sohal, A. (2012). A conceptual model for the successful deployment of Lean Six Sigma. *International Journal of Quality & Reliability Management*, *29*(1), 54–70. doi:10.1108/02656711211190873

Hindo, B., & Grow, B. (2007). Six Sigma: So Yesterday? *Bloomberg Businessweek*.

Jayaraman, K., Teo, L. K., & Keng, L. S. (2012). The perceptions and perspectives of Lean Six Sigma (LSS) practitioners. *TQM Journal*, *24*(5), 433–446. doi:http://dx.doi.org/10.1108/17542731211261584

Kaplan, D. (2012). South African mining equipment and specialist services: Technological capacity, export performance and policy. *Resources Policy*, *37*(4), 425–433. doi:10.1016/j.resourpol.2012.06.001

Keely, A. L., van Waveren, C. C., & Chan, K.-Y. (2013). A longitudinal study of the indicators and factors for successful six sigma deployment in the South African mining industry. *South African Joural of Industrial Engineering*, *24*(1), 167–191.

Kothari, C. R. (2006). *Research Methodology*. New Delhi: New Age International.

Kumar, M., Antony, J., Madu, C. N., Montgomery, D. C., & Park, S. H. (2008). Common myths of Six Sigma demystified. *International Journal of Quality & Reliability Management*, *25*(8), 878–895. doi:10.1108/02656710810898658

Kumar, M., Antony, J., & Tiwari, M. K. (2011). Six Sigma implementation framework for SMEs – a roadmap to manage and sustain the change. *International Journal of Production Research*, *49*(18), 5449–5467. doi:10.1080/00207543.2011.563836

Laureani, A., & Antony, J. (2010). Reducing employees' turnover in transactional services: a Lean Six Sigma case study. *International Journal of Productivity and Performance Management*, *59*(7), 688–700. doi:10.1108/17410401011075666

Laureani, A., & Antony, J. (2012). Standards for Lean Six Sigma certification. *International Journal of Productivity and Performance Management*, *61*(1), 110–120. doi:10.1108/17410401211188560

Longoni, A., Pagell, M., Johnston, D., & Veltri, A. (2013). When does lean hurt? – an exploration of lean practices and worker health and safety outcomes. *International Journal of Production Research*, *51*(11), 3300–3320. doi:10.1080/00207543.2013.765072

Maleyeff, J., Arnheiter, E. a., & Venkateswaran, V. (2012). The continuing evolution of Lean Six Sigma. *The TQM Journal*, *24*(6), 542–555. doi:10.1108/17542731211270106

Manville, G., Greatbanks, R., Krishnasamy, R., & Parker, D. W. (2012). Critical success factors for Lean Six Sigma programmes: a view from middle management. *International Journal of Quality & Reliability Management*, *29*(1), 7–20. doi:10.1108/02656711211190846

Meade, D. J., Kumar, S., & White, B. (2009). Analysing the impact of the implementation of lean manufacturing strategies on profitability. *Journal of the Operational Research Society*, *61*(5), 858–871. doi:10.1057/palgrave.jors.2602657

Mehrjerdi, Y. Z. (2011). Six-Sigma: methodology, tools and its future. *Assembly Automation*, *31*(1), 79–88. doi:10.1108/01445151111104209

Pepper, M. P. J., & Spedding, T. A. (2010). The evolution of lean Six Sigma. *International Journal of Quality & Reliability Management*, *27*(2), 138–155. doi:10.1108/02656711011014276

Portioli-Staudacher, A., & Tantardini, M. (2012). A lean-based ORR system for non-repetitive manufacturing. *International Journal of Production Research*, *50*(12), 3257–3273. doi:10.1080/00207543.2011.564664

Psychogios, A. G., & Tsironis, L. K. (2012). Towards an integrated framework for Lean Six Sigma application: Lessons from the airline industry. *Total Quality Management & Business Excellence*, *23*(3-4), 397–415. doi:10.1080/14783363.2011.637787

Saunders, M., & Lewis, P. (2012). *Doing Research in Business & Management* (First edit.). Edinburgh Gate: Pearson.

Shafer, S. M., & Moeller, S. B. (2012). The effects of Six Sigma on corporate performance : An empirical investigation. *Journal of Operations Management*, *30*(7-8), 521–532. doi:10.1016/j.jom.2012.10.002

Shah, R., Chandrasekaran, A., & Linderman, K. (2008). In pursuit of implementation patterns: the context of Lean and Six Sigma. *International Journal of Production Research*, *46*(23), 6679–6699. doi:10.1080/00207540802230504

Taj, S., & Morosan, C. (2011). The impact of lean operations on the Chinese manufacturing performance. *Journal of Manufacturing Technology Management*, *22*(2), 223–240. doi:10.1108/17410381111102234

Venkateswarlu, P. (2012). Costs and Savings of Six Sigma Programs : An Empirical Study. *The Quality Management Journal*, *19*, 39 – 54.

Vinodh, S., Gautham, S. G., & Ramiya R., A. (2011). Implementing lean sigma framework in an Indian automotive valves manufacturing organisation: a case study. *Production Planning & Control*, *22*(7), 708–722. doi:10.1080/09537287.2010.546980

Vinodh, S., Kumar, S. V., & Vimal, K. E. . (2014). Implementing lean sigma in an Indian rotary switches manufacturing organisation. *Production Planning & Control*, *25*(4), 288–302. doi:10.1080/09537287.2012.684726

Worley, J. M., & Doolen, T. L. (2006). The role of communication and management support in a lean manufacturing implementation. *Management Decision*, *44*(2), 228–245. doi:10.1108/00251740610650210

Xingxing, Z., & Fredendall, L. D. (2009). Enhancing Six Sigma Implementation Through Human Resource Management. In *The Quality Management Journal*.

Zikmund, W., Babin, B., Carr, J., & Griffin, M. (2012). *Business research methods.* Cengage Learning.

Appendices

Appendix A: Cover note of survey questionnaire

Dear Colleagues,

This survey has been conducted in order to give selected individuals who are practicing Lean Six Sigma in their current environment an opportunity to express their views. The study is focused on getting information that will be used to define a framework for successful lean six sigma implementation in the manufacture of capital equipment. Participants are trusted to be open and honest with their feedback in order to derive the benefits of the study. The questionnaire will take about 20-30minutes to complete and post. Your participation is voluntary and you can withdraw at any time without penalty. By completing the survey, you indicate that you voluntarily participated in this research. If there are any queries or concerns please contact either myself or my supervisor. Details to use are below.

Researcher

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Please complete survey and return completed questionnaire on e-mail.

Thank you for your participation.

Sincerely,

Kgomotso Duiker

Appendix B: Survey Questionnaire

Part A: Personal Questions

Please mark the appropriate box with a cross(x) in the space provided.

JOB TITLE

Director	
Manager	
Engineer	
Project Leader	
Six Sigma Blackbelt/Greenbelt	
Project Team Member	

Work Experience

	Total	In LSS
0 – 5yrs		
5 – 10yrs		
10 – 15yrs		
15 – 20yrs		
Over 20 yrs		

Maturity of Lean Six Sigma program implementation within the organisation

Department	% Implementation of program			
	0 – 25%	25 – 50%	50 -75%	75 – 100%
Manufacturing				
Engineering				
Supply Chain				
Finance				
Human Resources				

Part B: Response section

This section is a series of statements that indicate the implementation of Lean Six Sigma (LSS) within the organization and its success. Please indicate with a 'x' under your selected answer on a scale of 1 – 5, where 1 is strongly disagree and 5 is strongly agree. Kindly answer all questions under each section.

#	Question/ Statement	Strongly disagree (1)	Disagree (2)	Neutral (3)	agree (4)	Strongly agree (5)
Section 1 : General Questions						
1	Lean Six Sigma (LSS) is a tool used to improve manufacturing process capability.					
2	This Lean Six Sigma program has to be supported by senior leadership to be successful.					
3	The techniques used in Lean Six Sigma can be used in any department from Operations, Engineering, SCM to HR					

	etc.					
4	It is essential to ensure that the Lean Six Sigma projects are aligned to the organizations strategic goals.					
#	Question/ Statement	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly agree (5)
5	There needs to be a cost saving target related to a Lean Six Sigma project.					
Section 2: Lean Manufacturing implementation within the organization depends on						
6	Lean manufacturing becoming a culture for problem solving within the organization.					
7	A project charter for the objectives of the project as well as the team members.					
8	Several kaizen events completed annually in the organization.					
9	The 7 elements of waste being eliminated and prevented.					
10	The team frequently discussing ideas to improve production processes.					
11	Value stream mapping the process to establish a baseline/current state					
12	Implementing improvements identified on the current state map to achieve the improved future state.					
Section 3: Critical factors of Six Sigma implementation						
13	Six Sigma is supported by senior leadership who review progress on projects on a regular basis.					
14	Training is provided to the organisations selected employees through creditable institute.					
15	DMAIC process of a project is completed in around 6 - 9 months					

16	Project teams include subject matter experts.					
17	It is essential for the project leader/Blackbelt to have capability in the use of Six Sigma tools.					
18	Project achievements are recognized and awarded.					
Section 4: Lean Six Sigma tools used in capital equipment environment are						
19	5S a methodology for creating a self-sustaining culture that perpetuates an organized, clean, safe, and efficient workplace					
20	Value stream mapping the process to understand current process performance					
21	Waste elimination through kaizen events					
#	Question/ Statement	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
22	Pull systems in production, e.g. kan-ban					
23	Fishbone diagrams to get to the root cause of the problem.					
24	Standardized work					
25	Total productive maintenance					
26	Setup reduction or quick change-over					
27	Statistical analysis tools from the six sigma toolbox					
28	Visual management on the process performance.					
Section5: What has been the effect of Lean Six Sigma on cost						
29	Lean six sigma has resulted in significant cost savings due to scrap reduction					
30	Lean six sigma has resulted in significant savings due to productivity improvements					
31	The cost savings in most cases is more than that invested capital into the project.					

32	There is always cost savings realized either direct or indirect costs.					
33	No cost change due to implementation of Lean Six Sigma.					
34	Cost savings are not achieved due to poor implementation.					
Section 6: What is the effect of Lean Six Sigma on cycle-time of the product						
35	Lean Six Sigma has greatly improved the cycle-time it takes to complete a product through the factory					
36	Focusing on eliminating non-value added activities has improved the cycle-time within the organization.					
37	Cycle-time is improved through process changes.					
38	Cycle-time is improved due to quality improvements					
39	Cycle-time is negatively affected due to Lean Six Sigma.					
40	No significant change to cycle-time due to Lean Six sigma projects.					
Section 7: What is the effect of Lean Six Sigma on the on-time delivery of the product						
41	Lean Six Sigma eliminates the causes of not achieving the targeted on-time delivery on sustainable basis					
42	Focusing on eliminating non-value added activities has improved the on-time delivery within the organization.					
43	On-time delivery is set realistically considering lead-time for the value chain.					
44	There is adequate support in terms of systems, procedures and tools to ensure that the overall cycle-time for manufacture meets the					

	customer date.					
45	The On-time delivery metric is continuously being worked on to improve the current performance.					
46	The drivers for successful On-time delivery of cycle-time, work in progress turns and work in progress age are monitored well.					