

Implementing lean manufacturing and six sigma in a manufacturing environment

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Abstract

The application of Lean Six Sigma in the manufacturing environment is not new, yet so many companies don't make use of it. This study focuses on the literature of Lean Manufacturing and Six Sigma and then looking at Lean Six Sigma as a combination of the two methods. The methods discussed in theory are then tested on a 70mm quick coupling pipe manufacturing process. These Lean Six Sigma methods are applied to the manufacturing process. From the results obtained it could be seen that Lean Six Sigma as a continuous improvement method delivered higher production as well as higher quality. In this study it could be seen that by implementing a Lean Six Sigma transformation, production went up to almost three times it was before the transformation with almost no extra cost.

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1 CHAPTER 1: NATURE AND SCOPE OF THE STUDY

According to Kanji (2008:577) modern organisations operate in a complex environment where low cost opportunities, rapidly expanding global markets, operational efficiencies and customer-centric services determine the success of a business. The operational side stands out. The first factor combines the controlling of costs and efficiency; these two factors cannot be considered separately because combined they have a huge influence on business. The second factor that can be identified is customer-centric service. Customer satisfaction is crucial in any business; no business can grow or even exist without customers and therefore customer satisfaction plays a critical role in everyday business.

These two factors namely, controlling efficiency (while controlling costs) and customer-centric service, are important for any business, the business we are looking at is no exception to the rule, needs to focus on these two business factors for success. By considering best practices in business methods, it can gain advantages from methods that have been tested by leading companies.

1.1 BACKGROUND

1.1.1 Six Sigma

Almost all organisations claim to be customer focused, yet while there is no system of measurement in place to gauge customer satisfaction, an organisation cannot really claim that its customers are its top priority. According to Harry and Schroeder (2000:5) organisations that do not measure what they profess to value, do not know much about what they value. More importantly, because they do not measure, they cannot control the outcomes of what they value. To Jack Welch, General Electric (GE) is not about numbers; it is about values. These values include employee satisfaction, customer satisfaction, and cash flow. GE knows that employee satisfaction translates into productivity; that high customer satisfaction means strong market share; and that cash flow means that employees have maintained the company's customer-focused vision, its passion for excellence, and its desire

to push forward with energy and enthusiasm. GE backs up its values with performance-based metrics, complete with goals linked to executive incentive wages.

Six Sigma is a management system that focuses on customer satisfaction; the main goal being to increase the 'bottom line' or financial results.

A Six Sigma culture starts with a clear understanding of who the customers are and what is required for complete customer satisfaction. Data systems must be established to measure and monitor customer satisfaction. Improvement goals must be set and programs must be initiated to achieve the goals. Everyone must know his role in achieving complete customer satisfaction and success for the enterprise (Larson, 2003:1).

Six Sigma offers a more prescriptive and systematic approach to process improvement than Total Quality Management (TQM), placing a higher emphasis on accountability and 'bottom-line' results. Many companies all over the world are using Six Sigma management to improve efficiency, cut costs, eliminate defects, and reduce product variation. (Levine, Stephan, Kriehbiel & Berenson, 2008:219).

By using Six Sigma as a continuous improvement process, a company can focus on what the customer perceives as value, then supplying what they want. The complete process is changed based on data and facts, delivering a repeatable and specific product. This is also linked to 'bottom line' results. Giving the customer what he wants is very important, nevertheless only one side of the coin. The question is whether or not the processes that they use to deliver the quality product are efficient.

1.1.2 'Lean' Manufacturing

'Lean' manufacturing, 'lean' enterprise, or 'lean' production, often simply called 'lean', is a production practice that considers the expenditure of resources for any reason other than the creation of value for the end customer, as waste. The main drive in 'lean' manufacturing is the elimination of waste in whatever form it exists. Working from the perspective of the customer who buys a product or service, 'value' is defined as any action or process that a customer would be willing to pay for. The focus on value for the customer is very similar to Six Sigma, but in the case of 'lean' manufacturing, the implementation is focused on

eliminating waste. Anything which is done which the customer is not willing to pay for is waste and must be eliminated. A number of tools and methods are used when implementing 'lean' manufacturing. The goal of 'lean' then becomes the creation and maintenance of a production system which runs repetitively, day after day, week after week in a manner identical to the previous time period.

1.1.3 'Lean' Six Sigma

It can be seen that 'lean' manufacturing and Six Sigma have a lot in common. Both are focused on value for the customer, but they are implementing different strategies which can be successfully combined together. 'Lean' focuses on the potential to eliminate non-value adding activities from the process (controlling operating efficiency and costs), while Six Sigma attempts to improve the activities that must be done and their quality based on value for customers (focusing on customer satisfaction) on a daily basis. Both are data-driven approaches, which respond to the requirements of the customer, however, it is only relatively recently that the combination of the two approaches has been considered (Hammond & O'Donnell, 2008:9).

In a study done by Cavallini (2008:70), the competitive advantage of companies using 'lean' Six Sigma was measured. It was concluded that 'lean' companies obtain higher returns on invested capital (ROIC) when compared to mass counterparts, competitors and non-competitors. He found that on average a 'lean' company will yield 10% higher ROIC than a mass manufacturer.

1.1.4 The company and product oversight

The company we are looking at is an agricultural machinery manufacturer that specialises in the manufacturing of irrigation equipment, tractors and related implements. The irrigation product line, which is the largest part of the business includes centre pivots and linear irrigators, sprayers, PVC pipes, valves, pumps, motors and quick-coupling pipes. Quick-coupling pipes are galvanised steel pipes which are used by land owners for irrigation or water transportation. These quick-coupling pipes comprise six metres of steel pipe, having a male head on one end and a female head on the other end. Various pipes can be joined together at the ends to create a pipeline. Sprayers can be connected to the pipeline at

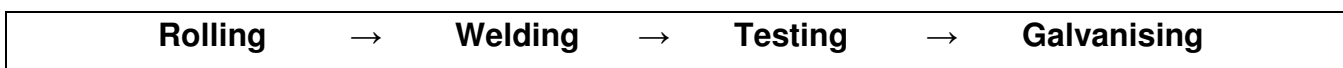
intervals to irrigate a piece of land. These pipelines can be moved between locations to irrigate different parts of a field.

These pipes are used mostly to irrigate small fields, which size does not support the use of centre pivots or linear irrigators. Farmers wanting to irrigate a field but do not want to incur a large capital expense, can use quick-coupling pipes. These pipes are also often used to build temporary pipelines, in some cases even for permanent pipelines. The fact that it is a steel pipe makes it ideal to withstand a high suction force, also making it ideal to use at rivers and dams on the suction side of pumps. The main use for the quick-coupling pipes is to transport water from one spot to another; but there are many other uses for these pipes.

1.1.5 The manufacturing process

Quick-coupling pipes are manufactured by the company's factory. Steel coils are bought from a supplier. A male and a female head are bought from another company factory where they are manufactured. The coil is rolled into tubes. A male and a female head are welded each onto one end of the tube. The pipe is then tested and galvanized before it is shipped to the branches where it is sold to customers.

The quick-coupling manufacturing line is a production line consisting mainly of four value-adding operations:



- **Rolling**

In the rolling process, steel coils are rolled into six meter tubes. This operation is undertaken by a pipe mill running on its own, but needing adjustment by an operator from time to time. The production of the pipe mill is largely a fluctuating production. There is no way of telling how many pipes will be rolled in one day. The limitations on the machine are the running speed of the pipe mill and the downtime because of breakages. When pipes are not rolled properly, any leakages will be picked up at the testing bench down the production line.

- **Welding**

After rolling the coils into pipes, a male and a female head are welded onto each end of the pipe. The pipe is placed on rollers where it is welded, helping ensure an even continuous welding. There are two welding machines available, one on each end of the pipe. The welding can thus be done by one welder which first welds one side and then the other side, or by two welders welding simultaneously. When the pipe is not welded correctly the leakages will be seen on the testing bench before the galvanising process starts.

- **Testing**

After welding, the pipes are tested for any leakages as a result of bad rolling or bad welding. Both ends are coupled in the same manner as would they be connected when used by customers and are then put under pressure to ensure that all the welded seams can withstand the necessary pressure. If any leakages are found they are marked and re-welded. Pipes that withstand the pressure test, showing no leaks, are moved into the galvanising area through an opening in the wall.

- **Galvanising**

Lastly, the completed quick-coupling pipe is galvanised to protect it from rusting in the normal working environment. The pipes are hot-dipped galvanised meaning that it is dipped in a molten zinc bath. After these pipes have been extracted from the bath it will be completely covered by a layer of zinc. The galvanising process is complicated. The quick-coupling pipes are a small part of the total number of parts that are galvanised every day.

1.2 PROBLEM STATEMENT

The quick-coupling pipe production system experiences problems such as low production rate, quality problems and late deliveries, on a daily basis. There are a number of reasons for these problems including breakdowns, operating problems, damaged parts and bad management, to name only some. Production fluctuates from day to day. On days when supervision is strict, production is sometimes more than double the normal production as when there is little supervision. The manufacturing process seems smooth and sorted out

when it is observed on the surface, but when studied closely, much inefficiency can be identified, all collectively adding to the problems named above.

From a 'lean' Six Sigma point of view, many of these problems of the production process can be corrected by changing the process. A close look at the process reveals that almost all of the seven kinds of wastes that 'lean' manufacturing tries to eliminate, are present in the process. It is thus an ideal project for a 'lean' Six Sigma transformation.

The quick-coupling pipe manufacturing process is not a very complicated process, operating completely isolated from the other departments, except for the galvanising part of the process. The quick-coupling pipe manufacturing process can thus be changed easily with no effect on other departments. As mentioned, the only part of the process where it is connected to other processes, is the galvanising process; this part of the production process could be kept unchanged.

1.3 OBJECTIVES OF THE STUDY

1.3.1 Primary objectives

- Creating and implementing a Lean Six Sigma transformation plan on the 70mm quick-coupling pipe manufacturing process.

1.3.2 Secondary objectives

- 'Lean' Six Sigma, as a management system, must be researched and ascertained to determine whether it will benefit in using it to enhance the production process.
- The waste in the manufacturing process must be identified.
- The improvement after the 'lean' Six Sigma transformation has been completed, must be measured.

1.4 SCOPE OF THE STUDY

This study will focus on the subject of operations. The production process of the 70mm quick-coupling pipe will be studied. The production process will then be used to undertake a 'lean' Six Sigma transformation. The transformation will be done on the complete manufacturing process, barring the galvanising process, because of its complexity and the fact that it is

could not be isolated from other production lines. The part of the manufacturing process that will be transformed is the complete process from supplier to customer; there will be no transformation undertaken on the galvanising process, but it will be included in the study.

1.5 RESEARCH METHODOLOGY

This study was conducted in three phases. The first phase was a literature study. The second phase was a practical study of the current manufacturing process and a practical implementation of a 'lean' Six Sigma transformation plan on the process. The third phase consisted of a comparison between the before and after results. A conclusion was drawn and recommendations were made.

1.5.1 Phase 1

- A literature study was conducted to understand the Six Sigma management process;
- The literature study was performed to comprehend the 'lean' manufacturing management process;
- It was also done to understand 'lean' Six Sigma as a combination of the first two management processes.

1.5.2 Phase 2

- The 70mm quick-coupling pipe production process was studied by using a current state value-stream map;
- A Lean Six Sigma transformation was suggested for implementation - future state value-stream map was used;
- The future state value-stream was implemented.

1.5.3 Phase 3

- The improvements after the implementation was measured;
- A comparison was drawn between the before and after results;
- A conclusion was reached and recommendations were made.

1.6 LIMITATIONS OF THE STUDY

The Lean Six Sigma transformation was not done on the galvanising part of the 70mm quick-coupling pipe production process.

After having collected the information, more limitations may appear.

1.7 CHAPTER DIVISION

Chapter 1: Introduction and problem statement.

Chapter 2: Literature study.

Chapter 3: Practical study and implementation.

Chapter 4: Conclusions and recommendations.

2 CHAPTER 2: LITERATURE STUDY

Companies exist to make a profit for their shareholders. Profitable companies provide jobs and pay taxes benefiting the community, state, and country where they manufacture their products or provide their services. Making a profit is dependent on having customers who require your product or service. Requiring your product or service is just the beginning (Eckes, 2003:2). Giving the customer what he wants and the way he wants it, goes much further than just the beginning. Customers are vital for the existence of any business; business processes therefore must be focused on customer needs.

2.1 SIX SIGMA

One method which focuses on what the customer wants and how to deliver this to him is Six Sigma, that focuses specifically on the quality expectations of customers. According to De Mast (2006:455), organizations that implement Six Sigma, choose to invest in the systematic exploration of opportunities for quality improvement, cost reduction and improvement of efficiency. Traditionally, Six Sigma is classed among initiatives for quality improvement, such as Total Quality Management. Quality improvement initiatives exploit their potential to increase customer satisfaction by improving product quality, while reducing production costs by lowering costs associated with poor quality.

2.1.1 Definition of Six Sigma

Six Sigma is difficult to define as there is no single definition or theory available to define it. To find a definition, conceptual development can be done by using field observations, the literature, and/or pure thought (Schroeder, Linderman, Liedtke & Choo, 2008:537). There are many books and articles on Six Sigma written by practitioners and consultants, but only a few academic articles published in scholarly journals (Linderman, Schroeder, Zaheer, Liedtke & Choo, 2004:590).

The following definitions for Six Sigma were found in the literature:

A vague definition is given by Sanders and Hild (2000:604), who called it a management strategy that requires a cultural change in the organisation.

Quality Progress described Six Sigma as a high-performance, data-driven approach to analysing the root causes of business problems and solving them (Blakeslee, 1999:78).

According to Harry and Schroeder (2000:vii) Six Sigma is a business process allowing companies to drastically improve their 'bottom line', by designing and monitoring everyday business activities in ways that minimize waste and resources, while increasing customer satisfaction.

Hahn, Doganaksov and Hoerl (2000:317) defined Six Sigma as a disciplined and statistically-based approach for improving product and process quality.

Bill Smith, a former employee of Motorola, is sometimes referred to as the father of Six Sigma: he defined Six Sigma as organized common sense (Larson, 2003:7).

It can therefore be seen that there is no clear definition for Six Sigma from either the practitioners or the academic literature. This is also confirmed by Hahn, Hill, Hoerl and Zinkaraf (1999:210).

Schroeder *et al.* (2008:537) created a definition after perusing the available literature, combining various definitions into one: "Six Sigma is an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method, and performance metrics with the aim of achieving strategic objectives".

This definition is the best descriptive explanation of the business process Six Sigma, containing all the main aspects of the Six Sigma process:

- Parallel-meso structure;
- Reducing variation;
- Using improvement specialists;
- Structured method;
- Achieving strategic objectives.

These elements and their importance will be discussed later.

2.1.2 History of Six Sigma

In the mid-1980s Motorola was losing ground in every market they served. Customer dissatisfaction and frustration with Motorola were epidemic. Throughout its customer base, Motorola had the reputation of being arrogant. Operating costs were too high, which led to dismal profits. Motorola was losing market share to Japanese competitors. A group of senior managers and executives were sent on a benchmarking tour to Japan to study operating methods and product quality levels. From the Japanese they learned that including all of your employees in the company's brain trust was an effective means of increasing efficiency and morale. They also learned that simpler designs result in higher levels of quality and reliability.

From their own customers they learned to focus on customer satisfaction. Motorola's leaders pulled all this together to establish a vision and set a framework for Six Sigma. From this vision and framework, Six Sigma was launched by Motorola in 1987 (Larson, 2003:7).

A highly-skilled, confident, and trained engineer who understood statistics, Mikel Harry, began to study the variations in the various processes within Motorola. He soon began to realise that too much variation in a process resulted in poor customer satisfaction and ineffectiveness in meeting the customer's requirements (Eckes, 2003:6). This laid the cornerstone for one of the fundamentals of Six Sigma, the management of variation.

Bill Smith was a high-level quality leader, credited with developing the mathematics of Six Sigma. The arithmetic of Six Sigma was created as a way of 'levelling the playing field' throughout Motorola. The concept of opportunities for error was developed to account for differing complexities. An opportunity for error is something that must be performed correctly in order to deliver conforming products or service. Bill Smith was far more than the developer of Six Sigma algorithms; he was the heart and soul of its deployment throughout Motorola (Larson, 2003:11). By putting these two together, Six Sigma was created: variation must be measured first, and from there it could be compared with other processes by using opportunities for error as a comparable metric.

Jacobs, Chase and Aquilano (2009:313) state that Six Sigma refers to the philosophy and methods companies such as General Electric and Motorola used to eliminate defects in their products and processes. A defect is simply any component that does not fall within the

customer's specification limits. Six Sigma advocates that one should view variation as the enemy of quality, therefore the theory underlying Six Sigma involve fighting variation.

This philosophy or method cannot be sustained merely by good intentions; it must be supported by, or based on something substantial. This is one of the aspects that distinguish Six Sigma from other quality improvement methods. Everything must be based on data and facts.

It is thus not surprising that the main focus of Six Sigma is to put the customer first and to use facts and data to drive for better solutions to improve customer satisfaction. By doing so, better profits are retained. Three main areas are targeted by Six Sigma efforts:

- Improving customer satisfaction;
- Reducing cycle time;
- Reducing defects.

Pande and Holpp (2002:3) state that improvement in these three areas usually represents dramatic cost savings to businesses, as well as opportunities to retain customers, capture new markets, and build a reputation for top performing products and services.

2.1.3 Elements of the definition of Six Sigma

Once there is clarity on the meaning of the term Six Sigma, the various elements contained in the definition may be discussed. The essence of Six Sigma can be understood by focusing on the definition given above:

- **Parallel-meso structure**

Parallel structures are “external creations that operate outside of, and do not directly alter an organization’s normal way of operating” (Lawler, 1996:132). Meso theory concerns the integration of both the micro- and macro-levels of analysis. Scholars have recognized Six Sigma as an example of a meso approach to work design (Sinha & Van de Ven, 2005:402). It is thus a structure that is outside the normal organisational structure and works through all levels of analysis and business.

- **Reducing variation**

Variation that is not planned in a process or outcome is any company's enemy. The more variation exists, the less accurate any prediction of quality, throughput, delivery time, etc. will be. Variation in the processes mentioned may have a serious negative effect on business and 'bottom line' results. Variation must therefore be limited as far as possible. There will always be some variation, but this must be controlled within the necessary specifications which differ from process to process.

- **Using improvement specialists**

Six Sigma makes use of Black Belts (BB) and Master Black Belts (MBB) that are specialists in the improvement process. These employees have extensive training in relevant fields; their work focuses solely on improvement projects. These BBs and MBBs are supported by Green Belts (GB) that have less training. They work in improvement teams supporting the BBs and MBBs.

- **Structured method**

The DEMAIC (Define, Measure, Analyze, Improve and Control) process is used in all Six Sigma projects. By following the DEMAIC process and the various tools associated with each step, this Six Sigma meta-routine promotes rational decision-making in a stepwise order. It gives a practical guide for knowing what to do next.

- **Achieving strategic objectives**

Six Sigma does not focus on projects for the sake of quality alone. In every Six Sigma project the results must be based on the improvement of financial returns. These include long- and short-term improvement of financial results, depending on the project.

These elements will resurface throughout the study.

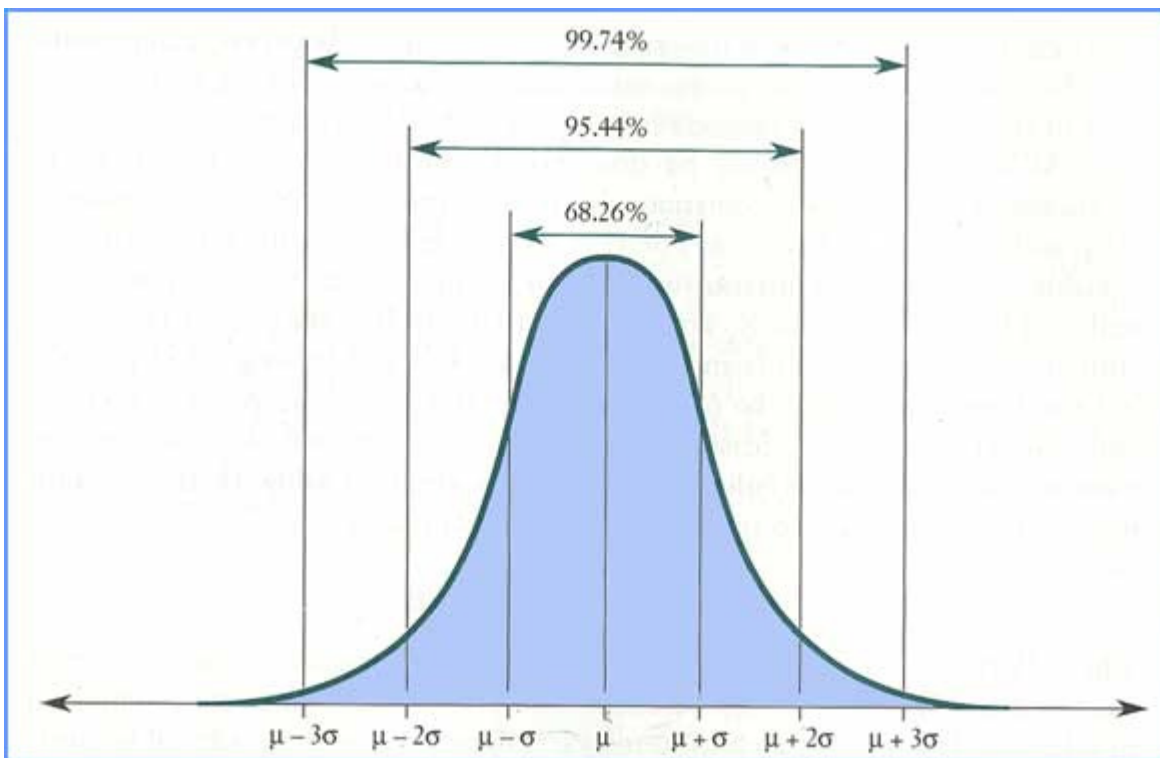
2.1.4 The statistical side of Six Sigma

The concept of Six Sigma springs from a strong statistical foundation. Comprehending the basic statistical concepts is essential to help understanding Six Sigma.

A normal distribution (sometimes referred to as the Gaussian distribution) is the most common continuous distribution used in statistics. In practice, many variables have distributions that closely resemble the theoretical properties of the normal distribution (Levine *et al.*, 2008:219).

Figure 2.1 below is an illustration of a normal distribution and its standard deviations (George, 2005).

Figure 2.1: Normal Distribution



Source: George (2005)

The lower case Greek letters mu (μ) and sigma (σ) stands for the average and the standard deviation of a normal distribution respectively. According to Levine *et al.*, (2008:107) the sample standard deviation (S) is the square root of the sum of the squares differences around the mean divided by the sample size minus one.

The equation is written as follows:

$$\sigma = S = \sqrt{S^2} = \sqrt{\frac{\sum_{i=1}^n (X_i - \bar{X})^2}{n-1}}$$

Where:

σ, S = Standard deviation

\bar{X} = Mean value

N = Sample size

X_i = i^{th} value of the variable X

Standard deviation is a statistical way of describing how much variation exists in a set of data, a group of items, or in a process. The smaller the standard deviation the less variation there is in the process. According to statistics, 68.26% of the data points of a normal distribution would fall inside one standard deviation ($\mu \pm \sigma$) from the mean. For two standard deviations, 95.44% would fall inside ($\mu \pm 2\sigma$) and for three standard deviations, 99.74% would fall inside ($\mu \pm 3\sigma$)(Figure 2.1).

The first step in calculating sigma or in understanding its significance is to grasp what your customers expect. In the language of Six Sigma, customers' requirements and expectations are called CTQs (Critical to quality). One of the keys of Six Sigma is to better understand and therefore to assess how well a process performs on all CTQs, not just one or two.

In normal processes there are certain CTQ tolerances or specifications within which one may work. These tolerances or specifications dictate whether or not the part, process or service conforms. If it does not conform to the specifications it is considered defective. These tolerances or specifications are essential to a Six Sigma process and must be dictated by customers' requirements and budget constraints. By viewing quality through the eyes of customers, value from the customers' point of view can be determined before defining specifications and tolerances.

Once these CTQ specifications or tolerances based on customer preference are clear, they must be implemented to change the process or service accordingly. It is worked back up into the process through each step off the process. Each of these steps is independently inspected, counting how many opportunities there are for a defect to occur. The total opportunities for defects that occur through a process are then added for the end part, product or service. These opportunities for defects are used to calculate a metric namely, Defect per Million Opportunities (DPMO).

Stated by Jacobs *et al.*, (2009:314) the benefit of Six Sigma is that the performance of any process may be described and compared with other processes using a common metric DPMO. This calculation of DPMO uses three units of data:

- Unit: The item produced or being serviced;
- Defect: Any item or event that does not meet the customer's requirements;
- Opportunity: A chance for a defect to occur.

The calculation to determine the DPMO is:

$$DPMO = \frac{\text{Number of defects}}{\text{Number of opportunities for error per unit} \times \text{Number units}} \times 10^6$$

This is where the standard deviation (σ) proves valuable again. The name Six Sigma describes the variation that is tolerated. In a Six Sigma process six standard deviations must fall inside the tolerance or specification. This implies that 99.9997% of the defect opportunities in a Six Sigma process will conform to the specifications or tolerances.

Corresponding DPMO numbers for the various sigma levels are shown in table 2.1.

Table 2.1: Corresponding DPMO numbers for the various sigma levels

Sigma Level (σ)	Defects per Million Opportunities (DPMO)
6	3.4
5	233
4	6,210
3	66,807
2	308,537
1	690,000

Larsen (2003:12) states that above all one should think of Sigma-scale as an optional element of the Six Sigma system. Several businesses including some units of General Electric, express their overall measures as defect rate, and only occasionally translate them to the Sigma scale. This emphasizes the importance of the metric DPMO and the ease of using it.

2.1.5 Six Sigma methodology

Six Sigma methods include many of the statistical tools that were employed in other quality processes. Here they are employed in a systematic project-orientated fashion through the Define, Measure, Analyse, Improve, and Control (DMAIC) cycle (Jacobs *et al.*, 2009:314). The DMAIC cycle is a more detailed version of the Deming PDCA cycle, which consists of the four steps Plan, Do, Check, and Act (PDCA) that underlie continuous improvement (also called kaizen).

This DMAIC cycle was developed by General Electric (GE) and contained the following steps:

1. Define

- Identify customers and their priorities;
- Identifies a project suitable for Six Sigma efforts based on business objectives as well as customer needs and feedback;

- Identify CTQs (Critical to quality characteristics) which the customer considers to have the most impact on quality.

2. Measure

- Determine how to measure the process and how it is performing;
- Identifies the key internal process that influences CTQs and measure the defects currently generated relative to those processes.

3. Analyse

- Determine the most likely causes of defects;
- Understand why defects are generated, by identifying the key variables that are most likely to create process variation.

4. Improve

- Identify means of removing the causes of defects;
- Confirm the key variables and quality of their effects on the CTQs;
- Identify the maximum acceptance ranges of the key variables and a system for measuring deviations of the variables;
- Modify the process - keeping it within an acceptable range.

5. Control

1. Determines how to maintain the improvements;
2. Put tools in place to ensure that key variables remain within the maximum acceptance ranges under the modified process.

2.1.6 The Six Sigma Team

According to Gowen (2002:28) the Six Sigma programme design usually starts with selecting high potential executives as the Black Belts (BB). These chosen executives receive about four months of intensive statistical and managerial training, covering statistical analysis, the Six Sigma DMAIC process, team building, leadership and project management, before being assigned to a process improvement team project. These extensive training programmes distinguish Six Sigma from other quality initiatives.

After having completed several successful projects, BBs are certified as Master Black Belts (MBB) status; they then supervise BB activities. Other workers receive about four days of training to become Green Belts (GB), before being assigned to assist BB project teams. Projects improvement programmes are usually assigned to the teams by a middle-level manager called a managerial champion. Because of the extensive training, the cost of implementing Six Sigma can be high. If it is not correctly implemented it could have the reverse effect of what was planned. If it is correctly implemented, the results could be the improvement of profitability, customer satisfaction and a better market position amongst other factors (Antony & Desai, 2009:413).

2.1.7 Six Sigma Tools

Once the DEMIAC process and the team structure are understood, the analytic tools used during the different stages of the DEMIAC process may be discussed. Analytic tools were used for quality improvement for a long time. What makes their application to Six Sigma unique is the integration of these tools in a corporate wide management system (Jacobs *et al.*, 2009:316). The following tools are used for analysis; they may also be used during the DMAIC stages:

Define:

- Flow charts;
- Run charts.

Measure:

- Pareto charts;
- Check sheets.

Analyse:

- Cause and effect charts.

Improve:

- Opportunity flow diagram.

Control:

- Control charts.

These analytic tools are used to better understand and analyse the various stages and their corresponding information. Six Sigma is clearly not a process that can be adopted by one employee alone. It is a company decision which must be taken as a strategic step to accomplish something bigger than merely installing the Six Sigma system.

2.1.8 Strategic components of Six Sigma

The companies benefiting most from benchmarking and best-practice initiatives, re-engineering, TQM, and Six Sigma, are companies that view such programmes not as ends in themselves, but as tools by means of which company strategy may be more effectively implemented and executed. Business process re-engineering aims at onetime quantum improvement, while continuous improvement programmes like TQM and Six Sigma aim at ongoing incremental improvements. All these initiatives need to be seen and used as part of a 'bigger-picture' effort to execute strategy proficiently, according to Thompson, Strickland and Gamble (2010:368).

Unlike other quality initiatives preceding it, Six Sigma is a management philosophy. Management must become actively involved in its application. Senior Management must be resolved to do whatever it takes to make the new culture work. Managers must be willing and able to modify their own behaviour to model the new rules and norms (Larson, 2003:23). The essence of a Six Sigma culture is one that focuses on the voice of the customer. All decisions, programmes and operating systems will be geared to total customer satisfaction (Larson, 2003:32).

The vehicle for this involvement is the strategy of Six Sigma called Business Process Management. The first step in creating a business process management system, is to clarify and communicate the strategic business objectives of the organization. With these objectives clarified, management must identify the key processes of the organization that are connected to these objectives. These key processes must then be measured in terms of effectiveness and efficiency. From there the highest impact lowest performing process should be chosen for a Six Sigma project (Eckes, 2003:26). By applying that, the largest return may be gained

with least effort. From there on processes must be decided on according to the above criteria.

According to Pande and Holpp (2002:7) the Six Sigma measure was developed to help:

- Focus measures on the paying customers of a business. Many of the measures, such as labour hours, costs, and sales volume traditionally used by companies, evaluated aspects unrelated to what the customer really cares about;
- Provide a consistent way of measuring and comparing different processes. The performance of any two processes can be compared by using the sigma scale.

These are the tools normally used in the Six Sigma process, however, any metric or tool may be used as long as it is factual and statistically based.

2.1.9 Six Sigma compared with Total Quality Management (TQM)

Understanding Six Sigma requires identifying what is new about it compared to other quality management approaches. Differences between TQM and Six Sigma are widely debated. Some say that Six Sigma is something new, while others say it is just another jacket for TQM. Schroeder *et al.*, (2008:548) provided a summary of differences between TQM and Six Sigma by comparing the various definitions and processes:

- The financial focus in a Six Sigma project is on the project level, while in TQM it is on the organisational level;
- The degree of insistence on following the structured method, the intense training of full-time specialists and the full integration of statistical and non-statistical tools are unique to Six Sigma;
- The metrics that are used to measure performance such as DPMO, critical to quality and process, are new in Six Sigma. These measures encourage improvement goals.
- The use of full-time improvement specialists by Six Sigma is new;
- A clear commitment to make decisions on the basis of verifiable data, rather than assumptions and guesswork, is more prominent in Six Sigma.

Anbari (2002) states that Six Sigma and its positioning could be explained more comprehensively by using an equation:

Six Sigma = TQM + Stronger Customer Focus + Additional Data Analysis Tools + Financial Results + Project Management.

He explains that Six Sigma methods include measured and reported financial results; it uses more advanced data analysis tools in addition; it focuses on customer concerns, and it uses project management tools and methodology.

By exploring the differences mentioned above, it can be perceived that Six Sigma has much in common with older quality processes such as TQM, but it is better structured and formalized. It also brings in new metrics for measuring performance and improvement.

2.2 'LEAN' MANUFACTURING

2.2.1 The history of 'Lean' Manufacturing

The origin of 'lean' manufacturing dates back to 1950 when a young Japanese engineer named Eiji Toyoda spent three months studying Ford's Rouge plant in Detroit. Mr Toyoda studied Ford's methods and considered ways in which to improve them. He did that by keeping a keen eye open for waste, or muda, as any kind of wasted motion, effort, or materials is known in Japanese (Henderson & Larco, 2000:20). A basic tenet of the Toyoda method, and therefore of 'lean' manufacturing, is to eliminate activities that do not add value for the end user of a product or service. Another is to look for and improve the process continually.

In a 1990's best seller *The Machine That Changed the World: The Story of Lean Production*, the term 'lean thinking' was used. The book takes the reader through the stages of an automobile manufacturer that moved from craft production to mass production and then to 'lean' production. It tells the story of how Henry Ford standardized automobile parts and assembly techniques, so that low-skilled workers and specialized machines could build cheap cars for the masses. The book furthermore explains that mass production provided cheaper cars than did craft production, but resulted in an explosion of indirect labour: production planning, engineering, and management. The book also describes how a small

company set its sights on manufacturing cars for Japan, but could neither afford the enormous investment in single-purpose machines that seemed to be required nor the inventory or large amount of indirect labour that seemed necessary for mass production. It therefore invented a better way of operating, using very low inventory and moving decision making to production workers. This company eventually grew into a large company and the Toyota production system has become known as 'lean production' (Poppendick, 2002:1).

2.2.2 What is 'lean' manufacturing?

'Lean' production is an integrated set of practices (Poka Yoke, standardised work, FIFO, root-cause problem solving, cell production, quality systems, work teams etc.) designed to achieve production using minimal inventories of raw materials, work-in-process, and finished goods. Parts must arrive at the next work station 'Just-in-time' (JIT) and are completed and moved through the process quickly. JIT could be traced back as far as Henry Ford, when he used JIT concepts in the manufacturing of automobiles to streamline his moving assembly lines. In the 1970s JIT was fully refined when Taiichi Ohno of Toyota Motors used JIT to take Toyota's cars to the forefront concerning delivery time and quality (Jacobs *et al.*, 2009:404). According to Melton (2005:662), Taiichi Ohno had started work on the Toyota production system in the 1940s and continued its development into the late 1980s, unhindered by the advancements in computers which had allowed mass production to be further 'enhanced' by MRP (Material Requirement Planning) Systems. By the 1970s Toyota's own supply base was 'lean'; by the 1980s their distribution base was 'lean' as well.

'Lean', as it is often termed, represents a fundamental break with western manufacturing traditions. According to De Koning, Verver, Van den Heuvel, Bisgaard and Does (2006:5), and stated somewhat simplistically, the traditional mass-manufacturing concept of the west was based on the following assumptions:

- A separation of 'thinking' from 'doing' is most effective;
- Defects are unavoidable;
- Organizations should be designed as a hierarchical chain of command;
- Inventories are necessary and are used to buffer production from fluctuations in market demand. Toyota and other Japanese companies on the other hand, developed 'lean' thinking as an alternative paradigm.

'Lean' manufacturing starts with customer and value. In a customer, manufacturer relationship value is what the customer is willing to pay for. Any process for which the customer does not want to pay is not value adding but is waste, and must be, according to 'lean' principles, eliminated as far as possible.

2.2.3 Waste

Lean production's most distinguishing principle is the relentless pursuit of waste - everything that does not add value to the product (Ahlstrom 1998:327). George (2003:29) states that in service processes at least 50% of the work is non-value-adding.

Not all waste can simply be eliminated. Sometimes the waste is a necessary part of the process, adding value to the company - compare financial controls. Thus in some cases waste is useful and necessary for the company but as far as possible waste must be eliminated. According to Melton (2005:664) the seven types of waste are:

- Overproduction (product made for no specific customer);
- Waiting (people, equipment, or products waiting to be processed add no value);
- Transport (moving the product to several locations);
- Inventory (storage of products, intermediates, raw material);
- Over processing (when a particular process step does not add value to the product);
- Motion (the excessive movement of people who operate the manufacturing facility);
- Defects (errors during the process either requiring rework or additional work.

The Example Consulting Group (2010) adds another eighth waste, namely that of intellect. This refers to the failure to fully utilize the time and talents of people. This eighth waste differs from the rest in that all the others can be measured and quantified, whereas intellect cannot be measured exactly. One of the major themes of the Lean Six Sigma is measurability, which is taken very seriously by the Six Sigma system. Intellect cannot be quantified accurately; therefore this eighth waste will be omitted from this study.

The most important source of waste is inventory. Inventory is especially wasteful in the form of work-in-progress - hiding problems as it does; preventing their solution. Because inventory exists for a reason, the causes behind the existence of inventory must first be removed.

Important ways of reducing the need for inventory are: reducing set-up times, using preventive maintenance to reduce machine downtime, and changing layouts, thereby reducing transportation distances for parts (Ahlstrom 1998:329).

2.2.4 'Lean' fundamentals

'Lean' manufacturing is built on certain fundamentals. By focusing on these fundamentals, a manufacturing company can start transforming itself into a 'lean' manufacturer. Henderson and Larco (2000:46) name six fundamentals of 'lean' manufacturing:

- Workplace safety, order, cleanliness (a 'lean' organisation will be exceptionally safe, neat and clean, even if it is considered a messy business);
- JIT production (in a 'lean' organisation, products are built just in time (JIT), and only to customer demand);
- Six Sigma quality (Six Sigma quality forms part of the product design of the 'lean' producer and is built into its manufacturing process);
- Empowered teams (when a problem is spotted, the team decides how to fix it - there is no need to call in management);
- Visual management (Visual management is used to track performance and to view five workers' feedback on how they are doing);
- Pursuit of perfection (There is a relentless pursuit of perfection).

These are the fundamentals of 'lean' manufacturing - by combining and implementing all these principles manufacturing companies can gain financially by 'lean' manufacturing.

2.2.5 'Lean' implementation

'Lean' manufacturing is a stepwise implementation; it may be divided into 4 steps according to Henderson and Larco (2000:99):

1. Map the assembly process for the area to be transformed:
 - Clean and organise all areas to be changed, ensuring that nothing unnecessary remains;
 - Start drawing a value-stream map;
 - Identify value from the perspective of the end customer by product family.
2. Install continuous flow;

3. Install a Kanban 'pull' scheduling system between the order entry function and final assembly, linking production to customer 'takt' time;
4. Start working progressively backwards in the production process. Reduce progressively set-up times, batch sizes and defects.

The goal is to have perfect parts flowing from suppliers through the manufacturing plant to the customer at the takt time the customer demand. This method must be done continuously to ensure that the best value is delivered with the least cost and effort.

The core thrust of lean production is that these practices can work synergistically to create a streamlined, high-quality system that produces finished products at the pace of customer demand with little or no waste (Shah & Ward 2003:129).

In a study done by Shah and Ward (2003:145) it was found that organizational context significantly affects the likelihood of implementing 'lean' practices. The influence of plant size in particular, appears to be substantial across a wide mix of practices. The influence of unionization and plant age however, appear to be less pervasive than conventional wisdom suggests. There is thus no reason why companies cannot implement 'lean' manufacturing; it is a matter of choice.

2.3 'LEAN' SIX SIGMA

'Lean' investigates the potential to remove non value-adding activities from the process, while Six Sigma attempts to improve the activities that must be done. They are both data-driven approaches, responding to the requirements of the 'customer', however, it is only relatively recently that the combination of the two approaches has been considered (Hammond & O'Donnell 2008:9). Businesses become increasingly aware that improving quality with Six Sigma or trying to improve process efficiency with 'lean', is not enough – both systems have to be implemented for maximum 'payback'.

According to De Koning *et al.* (2006:10), 'lean' Six Sigma incorporates the organizational infrastructure and the thorough diagnosis and analysis tools of Six Sigma with lean analysis tools and best practice solutions for problems dealing with waste and unnecessary time consumption. Kaufman (2003:3) further stated that by combining the implementation elements of 'lean' and Six Sigma, and more specifically, by broadening the variety and applicability of improvement tools available to an organisation deployed within a proven implementation structure, sustainable and significant business improvements will be provided – this in nearly 50% less time with significantly greater results than using a single initiative, i.e. either 'lean' or Six Sigma.

In short, what distinguishes 'lean' Six Sigma from its individual components, is the recognition that one cannot decide on either 'just quality' or 'just speed' (George 2003:8). It can also be learned from the above that 'lean' Six Sigma is bigger than the sum of its parts when it is implemented correctly. The synergy that exists between the two systems or processes can deliver great results, as confirmed by the following statements.

By combining Six Sigma with a material management concept such as 'lean' manufacturing, the principals of Six Sigma are combined with a system which strives to achieve high-volume production and minimal waste, through the use of 'just-in-time' inventory methods (Jacobs *et al.*, 2009:404). Six Sigma, when combined with 'lean' manufacturing, allows for easier identification and quicker resolution of quality issues or problems. It reaps quick results while expanding views to new and better possibilities on the floor. Because of less inventory on the

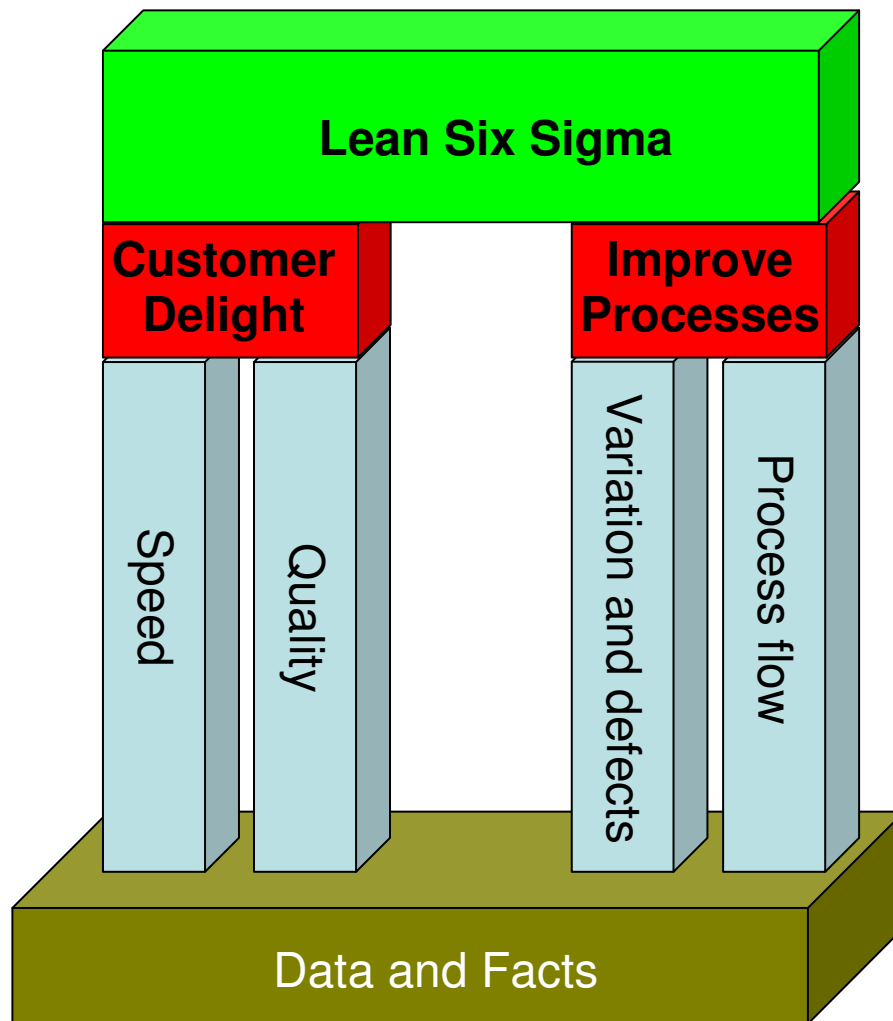
floor, the opportunity for defects running through large batches before being spotted down the line is much lower. This results in less waste.

2.3.1 The functioning of 'Lean' Six Sigma

When combining 'lean' and Six Sigma, it is important to use the elements of both these systems as well as their tools, in improvement projects. George, Rowlands and Kastle (2004:10) stated that it takes all the elements, working together, to create real solutions. These elements may be described as follows:

Everything must be based on data and facts. On the base of data and facts rest four pillars: quality, variation and defects, speed, and process flow. The elements contained within each pillar must be improved. Improving quality and speed will improve customer delight. Attending to process flow, variation and defects will result in process improvement, leading to quality and speed during production once more. This may all be achieved by implementing 'lean' Six Sigma. Figure 2.2 demonstrates how these building blocks fit into one other (George *et al.*, 2004:10).

Figure 2.2: The building blocks of 'Lean' Six Sigma



According to George (2003:6) a fundamental truth is that by stepping up the pace of production, one can improve quality; improving quality can promote speed of production; reducing complexity improves speed and quality. According to George, this cycle cannot occur in the absence of either 'lean' or Six Sigma. Thus by using 'lean' Six Sigma speed of production and the quality of products delivered to customers may be enhanced.

Johnstone, Pairaudeau and Pettersson (2011:50), stated that there is a genuine and understandable concern that a methodology such as 'Lean' Six Sigma, which includes standardization and the reduction of variation in their guiding principles, will restrict the freedom required for innovative ideas to survive and flourish. They further stated that there are reports to the contrary. They continue by stating that these differences are

understandable because deploying 'lean' thinking does not, as a direct consequence, enhance or drive innovation, nor is it contraindicated. Instead, they believe that the fate of innovation under a continuous improvement drive depends on the choices that are made and the climate that is created during the deployment journey. They firmly believe that there is much in the continuous improvement philosophy that can be interpreted and implemented to support and even enable more innovation.

De Koning *et al.* (2006:10) equated the learning process of 'lean' Six Sigma with the learning process of pianists and painters. Pianists and painters attend conservatories and art schools to receive intensive training in their profession. Innovation, as with artistic performance, can be learned. The combination of Six Sigma and 'lean' with their tools, road maps, and management processes — are essentially a carefully managed process for systematically scheduling and carrying out innovation projects that can be taught, learned, and performed with a high degree of success.

2.3.2 Tools used in Lean Six Sigma

According to Henderson and Larco (2000:46) 'lean' Six Sigma uses tools and methods such as:

- Workplace safety, order, cleanliness (5S);
- JIT production;
- Six Sigma quality
- Empowered Teams;
- Visual Management;
- Pursuit of Perfection;
- Theory of Constraints;
- The 7 Wastes;
- Toyota Production Systems (TPS);
- Demand Flow;
- Value-Stream Mapping;
- Transactional Mapping;
- TQC;
- Re-engineering;

- Root-cause analysis (by asking 5 times 'Why?' when the root cause of a problem could be found (Hammond & O'Donnell 2008:14)).

3 CHAPTER 3: PRACTICAL STUDY AND IMPLEMENTATION

Applying knowledge gained through the literature study, 'Lean Six Sigma' could be tested on real world applications. By implementing 'Lean Six Sigma' step by step the literature could be tested in practice. This process must be repeated often but for this study it will be conducted once only.

By examining Figure 2.2 and by using the building blocks of Lean Six Sigma and the various implementation methods combined, the researcher will undertake a 'Lean Six Sigma' transformation on the factory's 70mm quick-coupling pipe manufacturing line.

3.1 'LEAN' TRANSFORMATION PROCESS

By first doing a 'lean' transformation and after examining all the available data, quality improvements using Six Sigma's DMAIC method can be undertaken.

The four steps of 'lean' implementation, as mentioned earlier are:

1. Map the assembly process for the area to be transformed:
 - Clean and organize all areas to be changed, ensuring that there remains nothing that is not necessary;
 - Start drawing a value-stream map;
 - Identify value from the perspective of the end customer by product family.
2. Install continuous flow;
3. Install a Kanban 'pull' scheduling system between the order entry function and final assembly to link production to customer 'takt' time;
4. Start working progressively backwards in the production process. Progressively reduce set-up times, batch sizes and defects.

By applying these four steps used in 'lean' transformation the 70mm quick-coupling pipe production can be transformed:

3.1.1 Step 1

1. Map the assembly process for the area to be transformed.
 - a) Clean and organise all areas to be changed, ensuring that there remains nothing unnecessary.
 - b) Begin by drawing a value-stream map.
 - c) Identify value form the perspective of the end customer by product family.

The area must first be cleaned and organised. By cleaning the area, everything that is not necessary must be removed. Only parts and tools that are used on a regular basis must be kept in a marked place. By applying 5S, the area may be cleaned and organised.

Once after the area is clean and organised a value-stream map has to be drawn. Rother and Shook (2003:15) described the value-stream mapping process in detail, giving the following advice:

- All value-stream maps have to be drawn in pencil. No drawing must be made on a computer (it must be easy to change and must be made on the manufacturing floor).
- The current state must be represented as accurately as possible by the current state map.
- The current state map has to be drawn first.
- Value must be identified from the customer's view point.

When drawing a value-stream map, 'lean' measurements are taken from the process and are then used to draw the value-stream map. The following measurements are used:

- Cycle time (C/T) - the time in seconds that elapses between one part's coming off the process to the next part coming off;
- Changeover time (C/O) - The time it takes to switch from producing one product type to another;
- Number of People – the number of people required to operate the process (this is indicated by an operator icon);
- Available working time – the time per shift in seconds minus breaks, meetings, and clean-up time);
- Machine uptime – the percentage of time the machine is working;

- Production batch sizes (EPE) – every part, every hour, week or month. This measures the production batch size. If a changeover is made to a particular part every two weeks, the EPE must be two weeks' stock;
- Pack size – parts handled per batch;
- Scrap rate – the rate at which scrap is produced;
- Value-creating time (VCT) – time it take those work elements that transform the product to something that the customer is willing to pay for;
- Lead time (L/T) – the time it takes one piece to move all the way through a process or a value stream, from start to finish.

The last part of step one is to identify the value. The value stream is used to see where the value is created and where the waste is. The value to identify, is the value from the customer's point of view.

3.1.2 Applying Step 1

- To map the boundaries of the project under study, a SIPOC diagram that depicts the boundaries for the project, is drawn (See figure 3.1).

Figure 3.1: The SIPOC diagram marks

70mm Quick-Coupling pipe SIPOC diagram				
Supplier	Input	Process	Output	Customers
Steelrode	Cold rolled steel coils Male and Female steel heads	Rolling Welding Testing Galvanising Dispatching	70mm Quick-Coupling pipes	Distribution Branches

- The area was cleaned and organised to a state where everything is neat and in its place;
- Drawing the current state value-stream map may be started, but before that the production process is discussed in detail in order to better understand the value-stream map that will be drawn thereafter.

3.1.2.1 Production process

- **The product**

The value-stream map will be drawn for the 70mm quick-coupling pipe manufacturing process. These pipes are used to transport water, in most cases by farmers manually irrigating their fields. There are five sizes of quick-coupling pipes manufactured. The 70mm quick-Coupling pipes are the fastest selling pipes from the range of five sizes and for this reason they were chosen. The 70mm pipe comes in only one type. The pipes are rolled by a pipe mill, and then tested for leaks. Thereafter a male and a female head are each welded on either of the two ends of the six metre pipe. After the heads have been welded onto the pipe, the pipe is galvanised before it is sent to the branches from where is sold to the customers.

- **Customer requirement**

The customer requirement has been calculated from five years' historic sales data in Appendix A. There were identified two periods. The first period is the normal production period in which normal sales of 658 pipes per month would take place from November to July. The second period is the high production period where 1571 pipes would be sold per month when sales peak between August and October. These two figures are used to calculate the production rate. Because different sizes of pipe are rolled on the same pipe mill, 70mm quick-coupling pipes are rolled once every two months. During this two-week rolling period, the stock needed for two months must be manufactured, e.g. $658 + 658 = 1316$ pipes must be manufactured in two weeks. Two weeks consists of ten working days. Orders from branches are placed on a MRP system. Currently production is scheduled by manually evaluating the outstanding orders and deciding when to manufacture them.

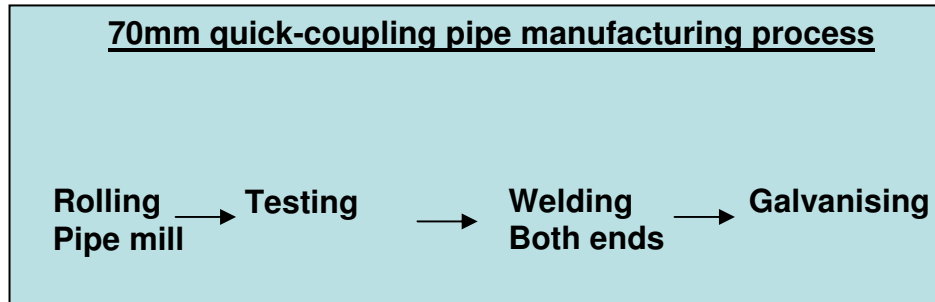
- **Raw Material**

Steel coils of ± 10 tons are normally ordered from Steelrode. Orders are placed manually when manufacturing is scheduled. Orders vary and are dependent on the manufacturing speed and downtime of the pipe mill. Suppliers deliver steel within one week from order date. The coils are stored next to the pipe mill. Sometimes large quantities of steel are ordered which may start to rust before it is used..., thus creating problems when rolling the coils into pipes.

The second raw material part is formed by the male and female heads. Each pipe has a male or a female head on either side. These heads are bought from the other company factory where they are manufactured. They are manufactured in batches of 600 male and female heads, of which 6000 are kept in stock normally. Because of the large amount of stock a large portion of the stock starts to rust before it is used.

Figure 3.2 illustrates a diagram of the production process:

Figure 3.2: Production process



- **Rolling process**

The coils are de-coiled and rolled into pipes with a welded seam, then cut into 6 metre lengths in a continuous process on the pipe mill. Each coil delivers ± 150 pipes normally. The speed of the pipe mill can be adjusted with little effort to between 2m/min and 6m/min. Some manual adjustments by the operator are required, mainly when the coils are started and sometimes while rolling. The machine must stop when a coil is completed and a new coil must be loaded onto the de-coiler and joined to the end of the previous coil strip. The joint is done by cutting both ends square, and then welding them together. After the two coils have been joined, the mill can start up

again. One or more pipes are scrapped every time the pipe mill stop and starts again because of the inconsistent welding of the seam. It can affect more than 20 pipes when something goes wrong in the mill, before the problem is rectified completely. The pipes normally have many defects on the seam when the steel coils are rusty, because of bad welding on the rusted area, therefore steel coils should not be kept in stock long enough to rust. The mill normally runs at 6m/min. The mill is stopped when the stockpile of finished pipes is full (60 pipes), and if there is available space, it is started again. The mill normally stops and starts between five and ten times a day, including coil changes. This creates between twelve and twenty scrap pipes per day.

- **Testing**

Each pipe is tested after it has come out of the pipe mill. The pipe is inserted in a test bench, then pumped full of water, after which it is put under pressure. If leakages appear on the seam of the pipe welded by the pipe mill, it is marked and then taken off the bench for repairs. The repair work is done manually. The pipe is scrapped if there are too many leaks for a proper repair. If the pipe shows no leaks, the water is pumped out and the pipe is disconnected from the bench and put on the pile for the heads to be welded onto it:

- To put the pipe in the test bench takes 5 seconds;
- To pump the pipe full of water takes 62 seconds;
- Putting the pipe under pressure takes 19 seconds;
- Pumping out the water again takes 21 seconds;
- Taking the pipe out of the bench and putting it through the window takes 12 seconds.

- **Welding**

During the welding process a male or a female head is welded onto either end of the six meter pipe. The welding can be done by a single operator welding both sides of the pipe or by two welders, one on each side. The more rusted the steel, the more difficult it becomes to weld the parts together. It takes between one and three minutes to weld the heads onto the pipes, depending on the amount of rust on the steel. The head is placed in the nearby acid bath to remove the rust if it is too rusty. This is a

labour-intensive and time-consuming task. The pipe is put through an opening in the wall into the galvanizing area after the heads have been welded on.

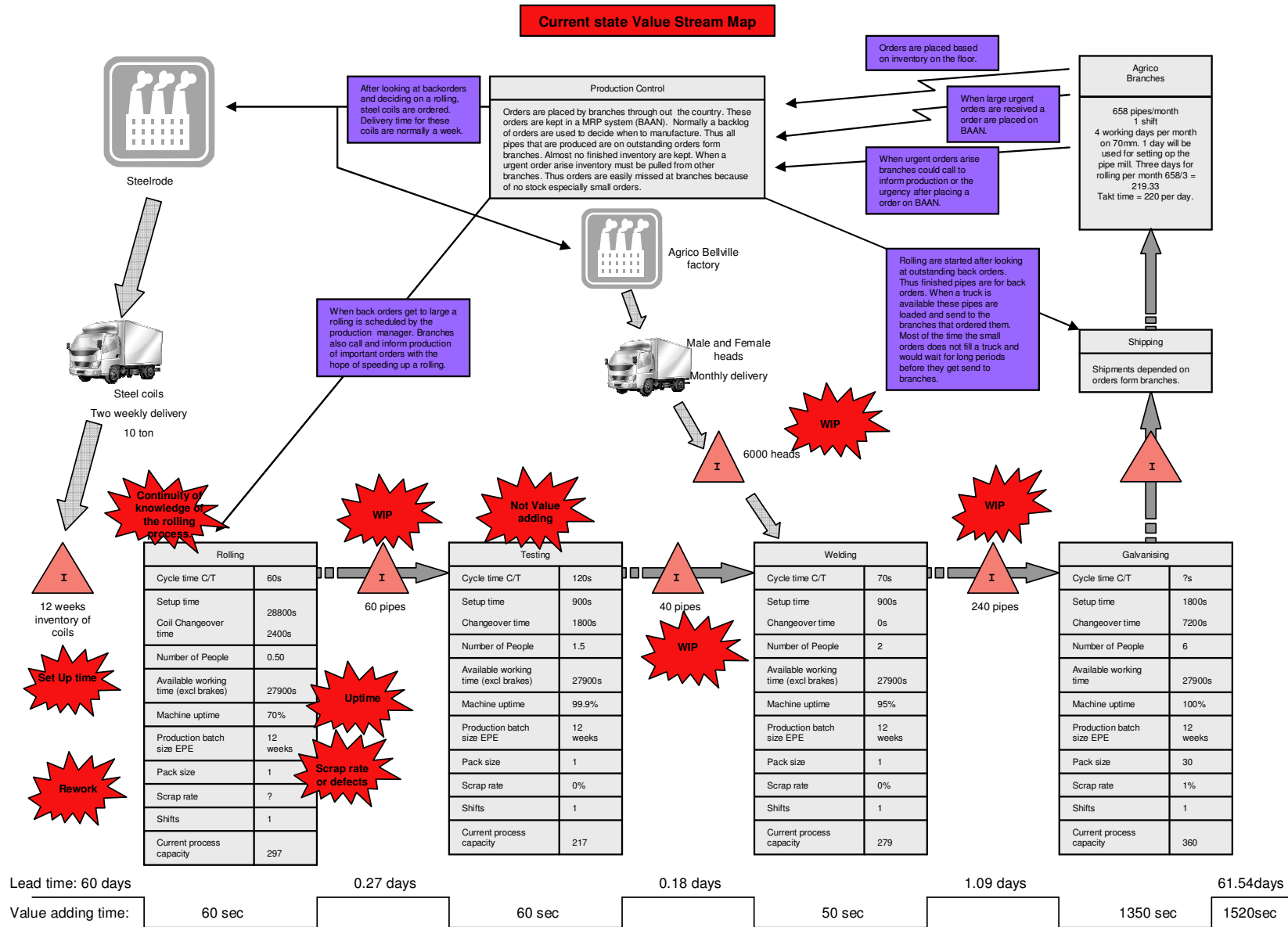
- **Galvanising**

The galvanising bath is used for galvanising quick-coupling pipes as well as centre pivot parts. For a better part flow the quick-coupling pipes are galvanised during the night shift. These pipes have their own jigs for galvanising. All pipes that were manufactured during the day are galvanised during that night shift. Pipes are galvanised in batches of thirty. Jigs taking thirty pipes are used to take the pipes through the process. The process takes 31 minutes per batch.

- **Dispatching**

The galvanised pipes are loaded onto trucks and when the truck is full it is dispatched to the branches. The process data given above is used to draw a traditional value-stream map.

Figure 3.3: Traditional value-stream map



- **Customer's feedback**

From the feedback received by customers, the following complaints were levelled:

- 73% Leaking welds where the heads had been welded on;
- 14% Late delivery (because of slow production or downtime);
- 13% Other complaints.

3.1.3 Applying steps 2 and 3

The current state value-stream map shows what is value adding and what is waste. In the future state value-stream map continuous flow, as well as some other 'lean' principles, are installed in the process. A DMAIC process was also undertaken after scrutinizing customer feedback.

Applying Six Sigma's DMAIC process:

- **Define**

Looking at the customers' complaints, 73% of them are in connection with leaking welding seams on the heads. Heads are welded on after the pipes were tested on the test bench. These welded seams leaks from time to time according to customer complaints. This single problem is responsible for 73% of customer complaints.

- **Measure**

From the pipes welded, 3 out of 150 had leaking welds on one side of the pipe. The DPMO could be calculated for the complete process, but to keep it more specific it is calculated for the welding process alone. Each pipe has two welds, meaning that there are two opportunities for error on each pipe, In other words on 150 pipes there are 300 opportunities for error, thus there are three defects per three hundred opportunities, adding up to 9999.999 or 10 000 defects per 1 million and a rating of about 4 sigma for the welding process.

- **Analyse**

The problem defined is that the welding seam where the heads were welded onto the pipes sometimes leaks as a result of bad welding. There is no test done after the welding of the head has been completed. Pipes are simply pushed through to galvanising from where it is dispatched to the customer. The problems experienced by the customer are communicated back to the manufacturer. It may be weeks or months before this problem can be followed up. The same leaking on welded seams exists on the rolled pipes, but these pipes are pressure tested before the heads are welded on.

By doing the pressure test after the welding of the heads process, all the leakages, including leaks on the pipe as well as leaks on the heads, will be discovered before the pipe is sent for galvanising, and thereafter to the customer. The only problem is that the pipes with heads welded on will not fit in the current test bench. The connections on the test bench had to be changed - it was decided to change the connections of the pressure test bench to the same heads that were welded onto the pipes. The pipes that are now inserted into the test bench are thus connected in the same way as used by customers. The male coupling on one side of the pipe will be coupled to the female head attached to the bench and the female head on the other side of the pipe will be coupled to the male head attached to the bench on the other side. The pipe can thus be pressure tested exactly as it will be used by customers. The welders now have an incentive to get it right the first time, because they know that they will have to re-weld each pipe that leaks. This problem can thus be measured more accurately because of the testing after the process. As a product of continuous improvement this problem could be measured again and if necessary the root problem could be investigated and eliminated by a second and third continuous improvement process.

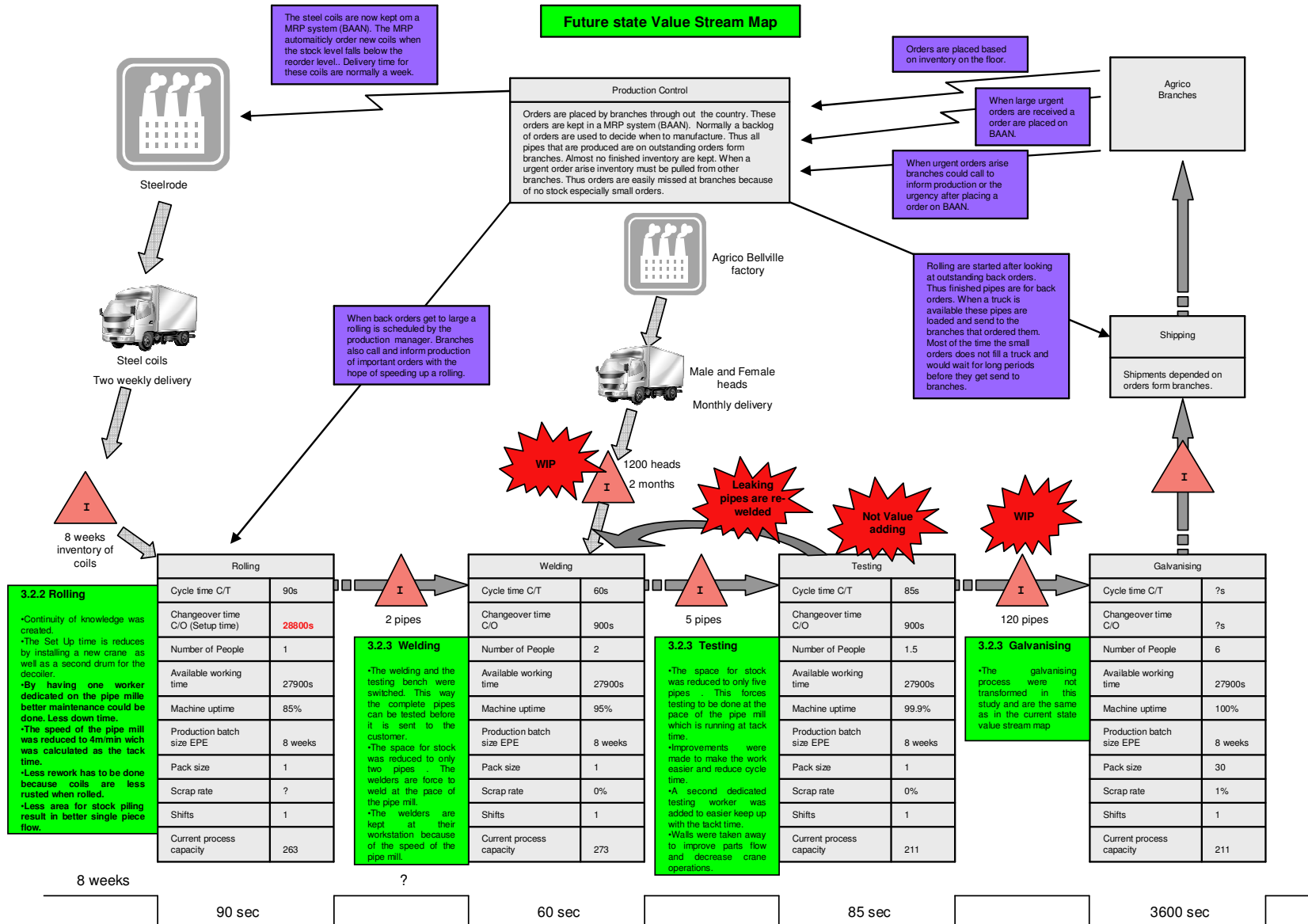
- **Improve**

As mentioned above, turning the manufacturing sequence around and testing the pipes after welding, could eliminate leaking pipes being dispatched to customers. The manufacturing process will be changed in the future state value stream. If anything does not fit, the problem can be discovered before the pipes are sent to the customer.

- **Control**

By physically moving the testing bench and the welding stations, it will ensure that the new sequence will be followed in the future. This implementation will also be made in the future state value-stream map.

Figure 3.4a: The future state value-stream map



It can be perceived from the future state map that much waste and other factors not value adding had been removed from the process. There is still, however, some waste that can be eliminated. These problems and others that may arise can be attended to on the follow-up continuous improvement processes.

3.2 CHANGES MADE

3.2.1 Raw Material

- Raw coil inventory was reduced from 24 days to 3.2 days. The reduction of inventory resulted in fewer rusted coils because of less time standing on the factory floor. The ordering procedure was changed from a manual order when steel was needed to an electronic MRP system. An optimal ordering batch size was determined. The supplier was asked to keep two weeks of stock on his floor ready at all times. There are thus four weeks of production stock on the factory floor and four weeks of stock on the supplier's floor. The historic sales were used to calculate a long-term trend. The historic sales were also used to estimate sales and the necessary raw material inventory was determined.
- The inventory of male and female heads was reduced from 33 days to 5.4 days of stock. The reduction of inventory results in less rusting because the parts do not stand long before welding. The heads are now ordered on the same MRP system as the raw steel coils with the necessary reorder points.

3.2.2 Rolling

- On the quick-coupling pipes the rolling process on the pipe mill is the most complicated part of the manufacturing process. Before the transformation only one operator could operate the pipe mill. This operator worked on the mill for twenty years, and was the only person who knew the mill, resulting that the mill would stand still when he was on leave or away from work, because no one could run it. This posed a serious threat, not only to production but mainly to the continuity of knowledge of the rolling process. Had he left the company or had something happened to him, it would have a huge negative effect on production. Another person (the son of the old operator) in the department was therefore identified, starting to work together with the operator for two weeks. He had a basic understanding of most things around the mill

because he had been working in that department for some time. The old operator was very eager to teach his son the working of the machine. He had to train himself to handle the pipe mill on his own. After two weeks the old operator was moved away from the department to a similar job situation where his specific skills could be used. The new operator had to operate the mill on his own but always had the opportunity to call the old operator in case of a serious problem. There were some costs involved in the learning curve of the new operator, of which the largest were more scrap pipes in the beginning. A third person in the same department has volunteered, showing willingness to learn the working of the mill. He will also be trained to handle the machine on his own. This ensures the continuity of knowledge for this process.

- A dedicated hoist was installed to load new coils onto the de-coiler as well as a new drum for the de-coiler to enable faster loading of coils. This reduced the time it took to change a coil from an average of 40 min to 15 min. In the past the overhead crane shared by 5 departments would be used which frequently resulted in long waiting periods. Depending on the length of the coils, they must be changed at least once, but mostly twice a day, in which case this results in an one hour's reduction in change over time.
- The operator was also responsible for helping at the testing process in the past. He is now only responsible for making sure the pipe mill is running smoothly with as little scrap as possible. The dedicated operator resulted in less scrap than in the past. Smaller maintenance work can now be done while the machine is working. The operator is also responsible for reworking leaking pipes after they have been pressure tested.
- The mill was set to run as fast as possible previously, which is 6m/min or one pipe per minute. At 6m/min the speed was too high for the welders and the testing process to keep up. For this reason the mill would run at full speed until the area before the welders would be filled with stock and then be stopped to weld and test the pipes till there was enough space to let the mill run again. Reject pipes were produced with every stop and start. By studying at the cycle times on the welding and testing bench, the speed of the pipe mill was reduced to 4m/min at which the two downstream processes could just keep up. By allowing the process to run for some time, the welders and testers came into a rhythm and are currently easily keeping up with the pipe mill. This was done to level the work and keep the mill running at a speed to

which the welders and the testing process could keep up. There were also some alterations done on the welding and testing processes which will be discussed later.

- A better welding seam is a result of the lower stock levels which lead to less rust on the coils. A welding seam that is correct the first time, eliminates the rework.
- To enforce single part flow the area available for stock after the mill and before the welders, was reduced to only holding two pipes.

3.2.3 Welding

- Firstly, the welding and testing processes were reversed. This was done to ensure that no leaking pipes were sent to customers... being a result of the first round of Six Sigma's DEMIAC process that was followed earlier. The reason for leaking welds can be eliminated when a second round of continuous improvement is undertaken by making use of the above DEMIAC process..., but the time frame for this study was limited and may therefore be completed later.
- As mentioned above, the stock-keeping area for rolled pipes from the mill was reduced. The welders are now forced to take each pipe from the mill as it is finished. There is space only for two pipes, one coming out of the mill and one other pipe. This forces the welders to keep up with the mill.
- Two welders were used previously, one welding male heads and the other welding female heads.
- The welders took time in the past to do things that were not necessary. They now have to work at the pace of the pipe mill and are thus forced to be at their workstations.
- The pipe mill operator has some spare time; if either of the two welders needs to go somewhere, he must fill the welder's place until the welder returns. This way the production does not stop unnecessarily.
- The stock of welded pipes that is kept before testing was reduced from 25 to only 5 pipes. The only reason for there being stock between the processes, is to give the pipes time to cool off after welding, because the rubber seals of warm pipes are damaged when tested on the pressure testing bench.

3.2.4 Pressure testing

- The pressure testing is now done after the heads are welded onto the pipes.
- There is space for five pipes before the pressure-testing bench. There may never be fewer than three pipes, because a buffer of at least three pipes is needed for the pipes to cool off after welding, as mentioned above. The testers may thus never take a pipe to test it if there are not at least three pipes at the workstation.
- The frame onto which the welded pipes are placed was modified to make the extraction of the pipes from the frame easier and faster. In the past, the pipes had to be lifted from the frame, now it can slide effortlessly from it onto the test bench. It makes the process easier as well as faster.
- In the past there was only one dedicated person for testing, and the machine operator helped with the testing. Two dedicated testers were introduced helping to speed up the testing process thus enabling the keeping up with the production tact time needed.
- The pipe mill operator has some spare time, therefore if either of the two testers needs to go somewhere he must fill the tester's place till he returns. This assures that the production will not be stopped unnecessarily.
- Valves and pipes were changed to stop leakages, which made pressure testing the pipes more time consuming than previously.
- After testing, each pipe would be put through a window in the wall and placed on a frame waiting for the overhead crane to take it to the jiggling area for galvanizing. It happened that at times that the frame was full of pipes the testers had to wait for the overhead crane to take the pipes to the jiggling area before they could continue testing the pipes. Pipes are moved in bundles of thirty because the galvanising jig handles thirty pipes per dip. To install a better flow of parts, an eight metre section of the wall has been removed to make movement from one side to the other possible. Two trolleys, each taking thirty pipes, were built. The trolleys were put next to the testing bench. After a pipe was tested it is placed on the trolley - when there are thirty pipes on the trolley it is pushed through the opening to the jiggling area to be offloaded. This saves overhead crane movement as well as time.
- The testing bench was moved to be more in line with the pipe mill, thereby employing less movement.

3.2.5 Galvanising

- For this study the focus is not on the galvanising process. The quick-coupling pipes going through the galvanising process are but a small part of the total parts galvanised. It is thus more complicated to make changes in the galvanising process. For this study there will not be a transformation done on the galvanising process, nevertheless this can be undertaken at a later stage. The galvanising process is still part of the production process, therefore included in the value-stream map, but not different from the current value-stream map to the future value stream map.

3.2.6 People

- Before the transformation, four people were working in the production team. One person was added to meet the transformation. The production team now includes five workers This has created a 25% growth in personnel and a 16% growth in wages. The slower growth in wages is because a low wage worker was added.
- The workers are now working at a steady pace repeating the same process over and over. The cycle time is enough to give the welders and the testers a few seconds to rest. The workers appear to be more sure of what to do and they even look relaxed. The welders even manage to take a seat at times while waiting for the next pipe to come out of the pipe mill.

4 CHAPTER 4: RESULTS

4.1 INTRODUCTION

By examining the 'Lean Six Sigma' transformation, the following results can be established. (The final column shows the percentage of change experienced after the transformation.)

Table 4.1: Lean Six Sigma' transformation

	Before	After	Improvement
Lead time (days)	34.54	6.521	-81.12%
Value-adding time (s)	1562	1550	-0.77%
Production workers	4	5	25.00%
Wages (proportional)	1	1.16	16.00%
Factory floor space used (m ²)	236	160	-32.20%
Workers able to operate the pipe mill	1	2	100.00%
Average production of pipes per day	91	252	176.92%
Number of processes having quality check after completion of work	1	2	100.00%
Raw material lead time (days)	7	1	-85.71%
Cycle time rolling process (s)	60	90	50.00%
Cycle time testing process (s)	119	70	-41.18%
Cycle time welding process (s)	123	80	-34.96%
Usage of overhead cranes during production (min/day)	42	0	
Scrap rate	15% to 26%	7%	
Pipe mill speed (m/min)	6	4	
Raw material standing on floor long enough to start rusting	Yes	No	
Production method	Push production	Continuous flow	
Percentages in black show a positive improvement; percentages marked in red show a negative improvement			

The following are some of the more important changes:

- Production rose from an average of 91 pipes per day to 252 pipes per day, mainly as a result of installing continuous flow. Turnover rose by 176%. The increase in net profit cannot yet be measured but is likely to show an even higher percentage increase than turnover, everything has already been paid for - the only extra costs are those of the direct material and consumables.

- Quality control was added on a process responsible for 73% of customer complaints. These complaints must be measured over time and may be used again in the future should a Six Sigma project be selected.
- By reducing the stock levels, the product quality was enhanced. Less cash was tied up in inventory.
- The total production lead time on the pipes was reduced from 34.54 days to 6.521 days. This resulted once again in having less money tied up in the form of inventory, leaving more funds available for other purposes.
- One low-wage worker was added to the production process.
- By incorporating the supplier into the production planning, raw coils can now be 'pulled' from the supplier at any time with a one day lead time, compared with the previous time period of a week.
- By applying minor changes, the overhead cranes are no longer required during production, except for when galvanising and loading takes place. This leaves the overhead cranes available for use by other departments.
- A better production forecast can now be offered.

4.2 CONCLUSION

- A 'Lean' Six Sigma transformation;
- By looking at the results obtained above it can be seen that 'Lean' Six Sigma as a continuous improvement method delivered higher production as well as higher quality;
- Thus by implementing a 'Lean' Six Sigma transformation, production went up to almost three times than before the transformation with almost no extra cost.

4.3 RECOMMENDATIONS

- The complete implementation was the first step in a long process of continuous improvement. In future, customer complaints as well as production data may be used in conducting another 'Lean Six Sigma' project.
- This study showed that the scrap rate on the pipe mill can be reduced. Scrap rate is, however, still very high: this is the direct cause of negative 'bottom line' results. A

study could be undertaken on quality improvement and scrap reduction at the pipe mill.

- Pressure testing is now conducted after welding the heads onto the pipes. Any leakages can now easily be identified. Because the testing is done immediately after the welding, the causes of leaking welds may now more easily be studied. This could also form part of a further continuous improvement project.

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5 Appendix A

Calculating customer requirements

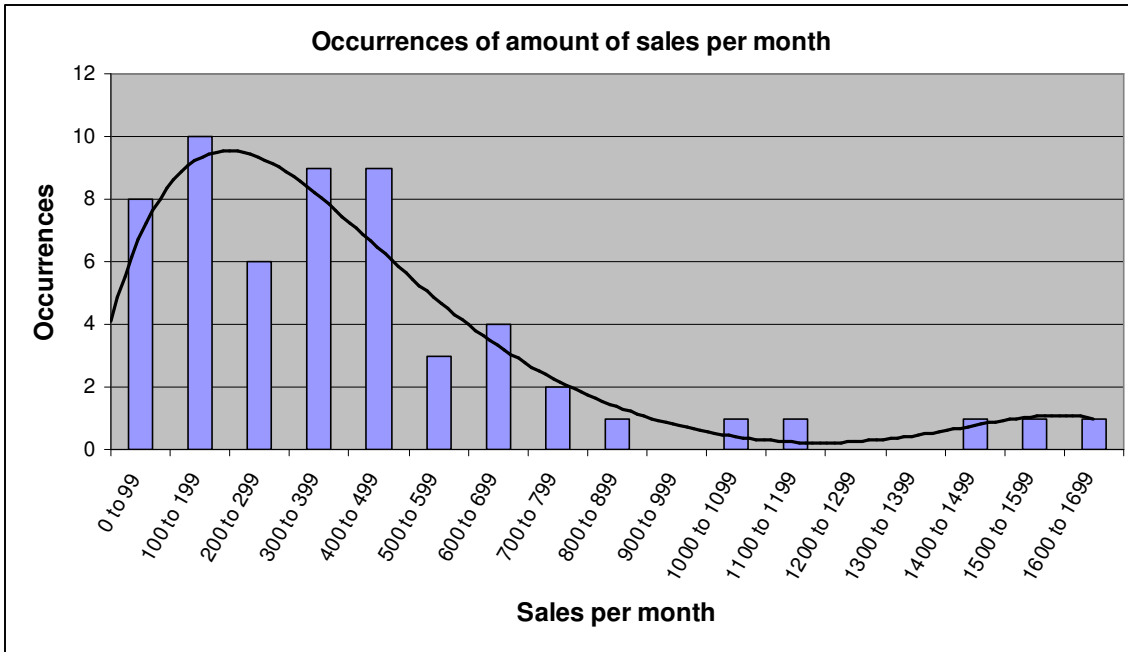
The historic sales of the 70mm quick-coupling pipes for the past 5 years are summed up in a table:

70mm Quick-Coupling pipe Sales for five years						
	2007	2008	2009	2010	2011	Average
Jan	456	208	750	147	166	345
Feb	545	391	608	205	345	419
Mar	656	49	646	331	785	493
Apr	133	126	52	130	32	95
May	289	360	609	470	160	378
Jun	416	356	18	477	329	319
Jul	309	547	339	32	40	253
Aug	189	418	1106	276	40	406
Sep	70	1469	134	1085	1611	874
Oct	1541	428	387	863		805
Nov	461	444	100	437		361
Dec	524	111	228	202		266
Total	5589	4907	4977	4655	3508	415
Average	466	409	415	388	390	Standard
Median	436	376	363	304	166	deviation 367
Skewness	2.195917	2.387987	0.657141	1.294991	2.0231	

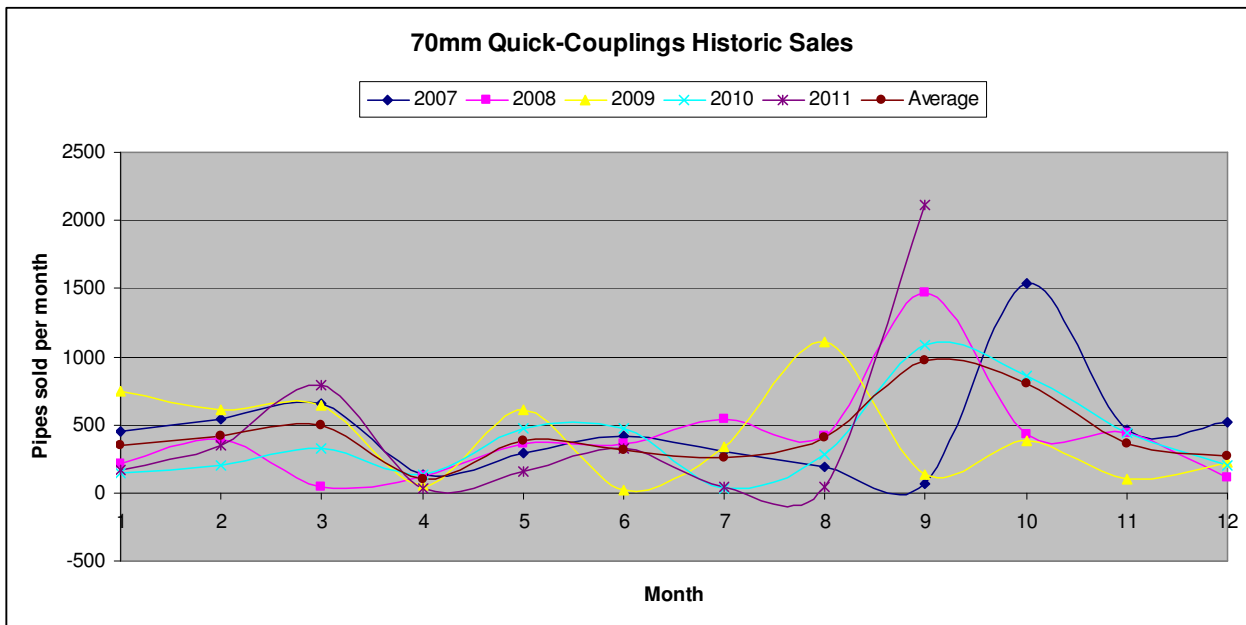
Viewing sales per month over the last five years it may be seen that average sales are always higher than the median. This proves that the distribution of the monthly sales in is not a normal distribution; it is rather skewed to the right. Every years skewness is positive which means it is skewed to the right.

The skewness to the right is as a result of the points falling far from the mean being further away from the mean on the higher side than the points on the lower side. This means that 'shoot-outs' in per month sales are much higher than the mean but not much lower than the mean.

The form of the distribution shows the number of occurrences for a certain range of sales per month plotted against the range. The skewing to the right is clear.



It can thus be seen that the peaks to the far right are responsible for the skewing of the distribution. Because these pipes are used for irrigation, it may be that these peaks are cyclical. To discover whether or not there is a cyclical movement in the pipe sales, the sales per month are plotted against each other for five years.



Plotting the historic sales gives a good view of the cyclical nature of the 70mm quick-coupling pipe sales. It is noted that when farmers start irrigating and working their fields in the spring months of August, September and October, sales tend to peak. For the rest of the year sales

are more or less constant with sales at their lowest in April. The peaks in springtime are responsible for the skewing seen.

For the purpose of calculating customer requirements, the assumption is made that distribution is normal; one can use the mean and standard deviation to calculate customer requirements that can be used as a production schedule.

The data establishes the median for sales for all the months over the last five years were 374 pipes per month. The average of all the sales is 415, which is higher than the median. Some predictions can be made when calculating the production speed and assuming that the distribution is normal. If the production is equal to the mean plus one standard deviation, production would meet sales in 68.26% of months:

Production: $415 + 367 = 782$ pipes per month.

When adding another standard deviation to the mean the production would meet the sales in 95.44 % of the monthly sales:

Production: $415 + (2 \times 367) = 1149$ pipes per month.

It could be perceived that these production numbers are high, which could result in overproduction in most of the months, because included in these figures are the peak months.

To lower the overproduction the production schedule can be divided into two periods: the high production period and the normal production period. Less skewing will be present once production is divided into these two periods. There will be a more normal distribution therefore the results will be more accurate. The following table shows the division into two periods:

70mm Quick-Coupling pipe Sales for five years							
Normal production months		2007	2008	2009	2010	2011	Average
	Jan	456	208	750	147	166	345
	Feb	545	391	608	205	345	419
	Mar	656	49	646	331	785	493
	Apr	133	126	52	130	32	95
	May	289	360	609	470	160	378
	Jun	416	356	18	477	329	319
	Jul	309	547	339	32	40	253
	Nov	461	444	100	437		361
	Dec	524	111	228	202		266
	Total	3789	2592	3350	2431	1857	326
	Average	421	288	372	270	265	Standard Deviation
	Median	456	356	339	205	163	
	Skewness	0	0	0	0		
High production months	Aug	189	418	1106	276	40	406
	Sep	70	1469	134	1085	1611	874
	Oct	1541	428	387	863		805
	Total	1800	2315	1627	2224	1651	687
	Average	600	772	542	741	826	Standard deviation
	Median	189	428	387	863	826	
		Skewness	2	2	1	-1	

It could be seen that during the normal production months the skewness is 0 which means it could be considered as a normal distribution.

The same calculation is made again for the two periods to determine the necessary production speed.

To meet 68.26% of the monthly sales (mean + standard deviation) the production must be:

Normal production months: $236 + 211 = 447$ pipes per month

High production months: $419 + 576 = 995$ pipes per month

To meet 96.44% of the monthly sales (mean + 2 x (standard deviation):

Normal production months: $236 + (2 \times 211) = 658$ pipes per month

High production months: $419 + (2 \times 576) = 1571$ pipes per month

It is clear that these production speeds will result in much less overproduction. By assuming that sales were lost in the past because of shortages of stock and by assuming that the sales could increase in the future as a result of available stock, the production meeting 96.44% of sales would be the better option.

The customer requirement is thus 658 pipes per month during normal production months (November to July) increasing to 1571 pipes per month in high production months (August to October).