DEVELOPMENT OF INTEGRATED LEAN SIX SIGMA MODEL FOR SMALL AND MEDIUM ENTERPRISE

by

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LIST OF ABBREVIATIONS

BOM	Bill of materials
BPR	Business process reengineering
CED	Cause and effect diagram
DMAIC	Define, Measure, Analyze, Improve, Control
DOE	Design of experiment
DPMO	Defects per million of opportunities
FIFO	First in, first out
FMEA	Failure mode and effect analysis
GDP	Gross domestic product
GR & R	Gage repeatability and reproducibility
GT	Group technology
ILSSD	Integrated Lean and Six Sigma tools in DMAIC
IT	Information Technology
ISO	International organization for standardization
JIT	Just in time
LSS	Lean Six Sigma
MRP	Material resource planning
NVA	Non-value added
OEM	Original equipment manufacturer
PCB	Printed circuit board
PFA	Production flow analysis
QCD	Quality, cost and delivery
QFD	Quality function deployment

SD	Standard deviation
SIPOC	Supplier-input-process-output-customer
SME	Small and medium enterprise
SMED	Single minute exchange die
SOP	Standard operating procedure
SPC	Statistical process control
TPM	Total productive maintenance
TQC	Total Quality Control
TQM	Total Quality Management
VA	Value added
VOC	Voice of customer
VSM	Value Stream Map
WIP	Work in process

LIST OF SYMBOLS

C	Customer demand
P	Product characteristic
p_j	Part mix fraction of part j
Q	Quality
R_p	Production rate
t	Processing time
T_w	Waiting time
WL_i	Workload of a station i
WL_{n+1}	Workload of part handling

PEMBANGUNAN MODEL BERSEPADU *LEAN SIX SIGMA* UNTUK PERUSAHAAN KECIL DAN SEDERHANA

ABSTRAK

Sistem pengurusan telah dibangunkan untuk membimbing pengilang untuk penambahbaikan berterusan dalam aspek kualiti, kos dan penghantaran. Pembangunan sistem pengurusan yang terkini, *Lean Six Sigma (LSS)* ialah integrasi di antara *Lean Manufacturing* dan *Six Sigma*. Pelbagai model *LSS* telah dibangunkan dan dilaksanakan dalam pelbagai industri dengan bukti yang positif dan kukuh. Walau bagaimanapun, literatur dalam pembangunan dan pelaksanaan model *LSS* di Perusahaan Kecil dan Sederhana (*SME*) adalah terhad disebabkan oleh kekangan saiz pengurusan dan sumber. Kajian ini membangun model *LSS* yang bernama Model Persepaduan alat *Lean* dan *Six Sigma* dalam *DMAIC* (*ILSSD*) yang mengambil kira kekangan ini dalam pemilihan teknik dan alat untuk penambahbaikan berterusan. Model ini memperoleh matlamat pernambahbaikan berterusan daripada misi dan visi sesebuah syarikat. Model *ILSSD* terdiri daripada metodologi *DMAIC* dan mencadangkan kolaborasi penggunaan alat-alat *Lean* dan *Six Sigma* yang tidak memerlukan analisis statistik yang mendalam, misalnya, *Value Stream Map (VSM)*, analisis Pareto, rajah sebab dan akibat, rajah perhubungan dan rajah pokok. Pelbagai teknik pengumpulan data juga diperkenalkan. Struktur model *ILSSD* adalah berpacuan data supaya ia memberi sistem sokongan keputusan dengan analisis yang wajar. Kegunaan *ILSSD* telah disahkan di sebuah syarikat *SME* pencetakan label dan sebuah syarikat *SME* semikonduktor di Pulau Pinang. Keputusan pelaksanaan adalah pengurangan masa persediaan sebanyak 18.42% di syarikat pencetakan label dan pengurangan masa tunggu sebanyak 92.8% di syarikat semikonduktor. Kajian ini telah mencapai objektifnya.

DEVELOPMENT OF INTEGRATED LEAN SIX SIGMA MODEL FOR SMALL AND MEDIUM ENTERPRISE

ABSTRACT

Management systems have been developed to guide manufacturers to continuously improve performance in the aspects of quality, cost and delivery. The latest developed management system, Lean Six Sigma (LSS) is an integration of Lean Manufacturing and Six Sigma. Various LSS models have been developed and implemented in different industries with positive and strong evidences. However, literature on developing and implementing LSS models in Small and Medium Enterprise (SME) is scant due to size-related management and resource constraints. This research develop a LSS model named Integrated Lean and Six Sigma tools in DMAIC (ILSSD) model to take into consideration these constraints in the selection of techniques and tools for continuous improvement. The model derives continuous improvement goals from a company's mission and vision. The ILSSD model consist of DMAIC methodology and proposed collaborated usage of Lean and Six Sigma tools which is not heavy in statistical analysis namely Value Stream Map, Pareto Analysis, Cause and Effect Diagram, Interrelationship Diagram and Tree Diagram. Various data collection techniques were also introduced. The ILSSD model was structured to be data driven so that it provides a decision support system with sound analysis. The practicality of ILSSD was validated in an SME label printing company and SME semiconductor company in Penang. The results of implementation are 18.42% reduction in setup time in label printing company and 92.8% reduction in waiting time in semiconductor company. The research has achieved its objectives.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter, consisting of four sections, introduces the development of a management system model based on the principles of Lean Manufacturing and Six Sigma to improve performance such as quality, cost and delivery in Small and Medium Enterprise (SME) manufacturing industries. The first section provides the background of management systems in this research field. The second section highlights contemporary issues related to management systems to support the problem statement in the present study. The third section presents the research aims and objectives and the fourth section presents the scope of study. The final section is an outline of the whole thesis.

1.1 Research background

Manufacturers recognize the need to improve performances to meet customer demands in connection to product quality, cost and delivery (QCD) (George, 2002). A quality product has to fulfil customer expectations and the requirements including serving the utility. A case in point is a car manufacturer's duty includes the securance of its product to safely transport passengers and goods within specific load and without breakdown. In addition to timely delivery of their products, product cost should be kept at a level for reaching an acceptable gain when the product is sold. It is a common knowledge that customer expectation on product quality, cost and delivery is bound to the fundamental law of competition and evolving market.

Manufacturers therefore have to constantly improve to maintain competitive edges over their competitors.

For this reason, several management systems such as Total Quality Control (TQC), Total Quality Management (TQM), Deming's system of profound knowledge, business process reengineering (BPR), Lean Manufacturing and Six Sigma have been developed and implemented (Chiarini, 2011). Of these systems, Lean Manufacturing and Six Sigma have prevailed in recent years (Tan et al., 2012). Large companies such as Toyota, Danaher Corporation, General Electric, Motorola and Honeywell have been in the forefront to implement Lean Manufacturing and Six Sigma, with significant attributable production improvements reported (Kumar et al., 2006).

Six Sigma follows a structured methodology led by improvement specialists to lessen process variation (Schroeder et al., 2008), ultimately to achieve the goal of 3.4 defects per million opportunities (Linderman et al., 2003). This results in a very well controlled and stable process which will be continuously and rigorously monitored. On the other hand, Lean Manufacturing is an all embracing management philosophy to streamline process with a human system to continuously remove wastes in the value chain (Wong et al., 2009). Lean Manufacturing relies on various tools to remove what is generally regarded as the seven Lean wastes of defects, over-processing, travelling, waiting, inventory, motion and over-production (Ohno, 1988). The direct implications are increasing flow of work-in-process (WIP) throughout the production and on-time delivery.

In many cases, implementing either Lean Manufacturing or Six Sigma is deemed inadequate to address and resolve problems and issues (Corbett, 2011). In reference to this, in 1996, General Electric (GE) CEO Jack Welch heralded Six

Sigma as the most important initiative taken by GE and yet, he drew concern on the consistency in product lead time (George, 2002). Implementing Lean Manufacturing and Six Sigma separately gives varied outcomes as efforts by individual systems are often disjointed.

Therefore, many recent studies have integrated both methods which is coined with a new term called Lean Six Sigma (LSS) (Salah et al., 2010; Cheng and Chang, 2012; Vinodh et al., 2014; Swarnakar and Vinodh, 2016). The integration involves Six Sigma methodology and statistical tools as well as Lean Manufacturing tools and techniques. LSS aims to increase process performances resulting in enhanced customer satisfaction and improved bottom line results (Snee, 2010). This is important not only for large companies but also small and medium enterprises (SMEs). An SME is defined by its sales turnover or number of full-time employees. According to SME Corporation Malaysia (2013), in the manufacturing sector, a Medium enterprise has a sales turnover of RM15 mil-RM50 mil or 75-200 employees while a Small enterprise has a sales turnover of RM300,000-RM15 mil or 5-75 employees. In the services and other sectors, a Medium enterprise has a sales turnover of RM3 mil-RM20 mil or 30-75 employees while a Small enterprise has a turnover of RM300, 000-RM3 mil or 5-30 employees.

From the 1900s onwards, the latest trend seems to be downsizing large firms and outsourcing business to SMEs (Lande et al., 2016). According to the statistics reported by SME Corporation Malaysia (2011), SMEs account for 97.3% of total business establishments in Malaysia for the year 2010 and since then have achieved a Gross Domestic Product (GDP) growth of 6.7% in 2015. The Department of Statistics Malaysia (2014) reported that the contribution of SMEs GDP to the country's economy expanded to 33.1% in 2013. The reported figure confirms that the

SME manufacturing industry is growing in size and economic contribution. Therefore the adoption of management practices by SME is an 'important determinant of success in the global market place' (Kumar et al., 2014, p. 6482).

1.2 Problem statement

Various methods are conceived to integrate Lean Manufacturing and Six Sigma based on contextual issues faced by manufacturers (Antony et al., 2003). For example, when manufacturers are faced with an issue to identify process variables that affect a particular defect, the integration may include tools such as Design of Experiment (DOE). If manufacturers lack the expertise to use DOE, Thomas et al. (2009) simplified the DOE and integrated it into their LSS system. The integration may not necessarily include all the tools and techniques from both Lean Manufacturing and Six Sigma (Assarlind et al., 2013). Most LSS systems are inclined towards incorporating sophisticated statistical tools with little attention given to other decision making tools from Lean Manufacturing and Six Sigma. There is a need to explore a new LSS integration that combines other tools and techniques (Kumar et al., 2006).

Since SME constitutes the bulk of enterprise (Kumar, 2007) and there is growing importance of the supply chain issue together with the pressure from original equipment manufacturers (OEM) to perform, SMEs are compelled to implement management systems such as Six Sigma (Antony et al., 2005). However, the literature shows that SMEs are hesitant to implement management systems. A study conducted by Thomas and Webb (2003) concludes that only approximately 10% of SMEs in Wales have implemented some management systems. In a more recent survey reported by Kumar et al. (2014) only 36% of SMEs in Australia and

26% in the UK have moved beyond ISO 9000 certification to implement management systems because most SMEs consider ISO 9000 as a satisfactory final destination. Therefore, LSS in the context of SMEs should be further explored to encourage implementation as the knowledge in management systems is focused primarily on large organizations (Kumar et al., 2014).

Several reasons were cited in the literature for the reluctance of SMEs to adopt management systems. A major factor is resource constraint (Achanga et al., 2006, Chen et al., 2010; McAdam et al., 2014) which hinders the allocation of funds for external training and development of employees to adopt systems such as Lean and Six Sigma (Kumar et al., 2014). The survey of SMEs in Australia and the UK by Kumar et al. (2014) revealed the top three impeding factors to adopt management practices to be lack of resources (finance, human and time), knowledge and top management commitment. The constraint of resources is the main challenge especially for micro SMEs (Timans et al., 2016). Limited financial resources have caused companies to use in-house training and self-education, which are relatively inexpensive strategies compared to external consultation. Kumar et al. (2014) suggested that this move has led to 'conceptual confusion' (p. 6488) or lack of understanding of management practices. Therefore the development and application of any management system in SMEs should be feasible and fulfil practical requirements. A LSS model that works in the SME should capitalize on the existing capabilities of its employees, secure commitment from management and work within limited financial resources budgeted for improvement projects.

Few empirical studies have been published in the area of adopting LSS in SME (Albliwi et al., 2015, Timans et al., 2016). Sreedharan and Raju (2016) stressed that the adoption of LSS in SME is not widespread due to the reasons as mentioned.

One of the gaps identified by Albliwi et al. (2015) is the need of a roadmap to implement LSS and a customized LSS toolkit in the SME context.

1.3 Research objectives

This research aims to develop and implement a novel LSS model in the SME manufacturing industry with reference to two selected companies to improve their performance. As a whole, the objectives of this research are:

1. To determine suitable Lean Manufacturing and Six Sigma tools and techniques for the manufacturing SME.
2. To create a LSS model integrating the selected Lean Manufacturing and Six Sigma tools and techniques which are effective for the manufacturing SME.
3. To validate the developed LSS model in two case study companies.

1.4 Research Scope

LSS is the latest management system which integrates Six Sigma methodology, tools and techniques with Lean manufacturing tools and techniques to improve manufacturer's quality, cost and delivery. This research is directed towards the developing a model with suitable tools and techniques in the context of implementing LSS in SMEs. The challenge is on how LSS can be practiced in the SME industry despite its constraints. The developed model in this research will aid the industry to improve in QCD and the results of implementation are used to plan improvement actions.

1.5 Thesis outline

This thesis is divided into seven chapters. Chapter 1 provides the contextual background to this research on LSS, the problem statement and objectives of the research. The chapter prepares readers for what this research is all about and the aims to be achieved. Chapter 2 reviews the available literature on the history of quality management systems and their principles. The chapter also covers research on LSS models as well as their tools and techniques used in these models and implementation approaches.

This is followed by Chapter 3 which discusses the methodology undertaken in this research including steps in the model development process. Chapter 4 describes the developed LSS model with information on each stage of the model and the method to be applied in the two case studies selected. Techniques for data collection and data analysis approaches are detailed out in this chapter.

Subsequently, the step by step process of validating the developed LSS model in two SME companies is described in Chapter 5. A brief background of each company is presented first to provide more information on the case studies. Then, full details and elaborations of the implementation are put forward.

Chapter 6 presents a discussion of the validation results by focussing on the notable points of the model from the conceptual and structural perspectives. Finally, Chapter 7 concludes with the contributions of the study and recommendations for future work to fill the potential gap of knowledge in this field. Articles, journals and books cited in this thesis are numbered and listed down accordingly in the reference section at the end of this thesis.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter reviews the literature on management systems particularly LSS to build the appropriate knowledge foundation. It begins with an introduction and definitions of three fundamental objectives or core competencies for a business organization (Liker, 2004), namely, quality, costs and delivery (QCD). Several management systems are explained next in the chapter followed by the definition and philosophy of Lean Manufacturing and Six Sigma. This includes the tools, techniques and methodologies of these two management systems. Finally LSS as the latest management system developed is explained and a number of LSS models in the recent literature are presented.

2.1 Quality

Crosby (1996) defined quality as conformance of a product to requirements while Juran and De Feo (2010) defined quality as fitness of product for its purposes. On the other hand, Feigenbaum (1991) defined quality as the total composite product characteristics of marketing, engineering, manufacture and maintenance through which the product will meet the expectations of the customer. These definitions from literature unanimously agree on quality as the product characteristic that meets customer demands. The quality of a product is determined by the customers only (Feigenbaum, 1991) and is quantified based on the ratio of product characteristic to customer demands (Besterfield, 2004) (equation 2.1),

$$Q = \frac{P}{C} \tag{2.1}$$

where Q = quality

P = product characteristic

C = customer demands

Manufacturers strive to achieve a value of 1 for Q as indicated by equation 2.1 to meet customer demands. Since customer demands are the determinant of quality, quality may change over time and often unpredictably (Knowles, 2011), analogous to a moving target in a competitive market (Feigenbaum, 1991). Therefore, manufacturers need to continuously improve their product. In Kaushik et al. (2012), a SME manufacturing bicycle chains in India undertook a project to improve the diameter tolerance of the bicycle bush. Sigma level was significantly increased, resulting in an estimated monetary savings of Rs 0.288 million per annum.

2.2 Delivery

Delivery refers to the transportation of finished products to customers within the shortest time or at the specific required time. In this case, manufacturers have to minimize lead time and achieve on-time product delivery. Lead time of an activity is defined as the duration to complete the activity from the beginning (Engineer, 2005). In manufacturing, lead time can be distinguished as order lead time or production lead time. Their difference is illustrated in Figure 2.1.

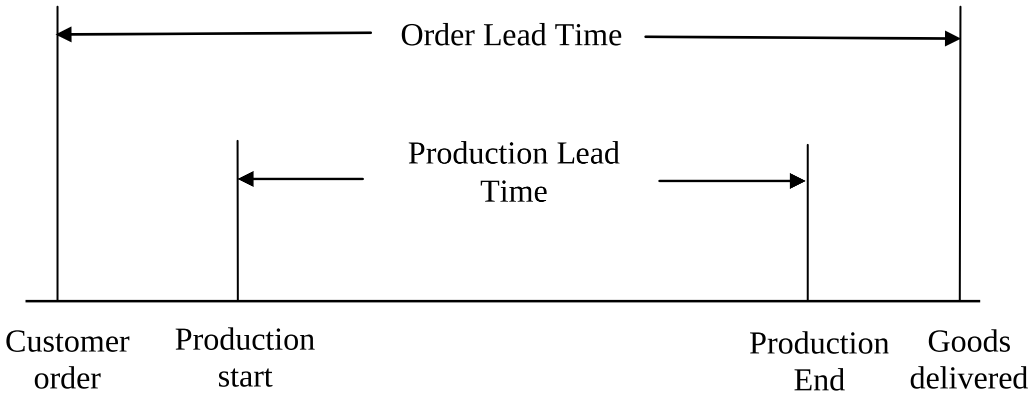

Figure 2.1 Lead time terminology in manufacturing

Order lead time defines the time taken to place an order of a product until the product is received by the customer while production lead time defines the time consumed for one part to go through the entire production (Rother and Shook, 2003). Production lead time includes work-in-process (WIP) waiting time, online setup time and processing time. During the production lead time, a company is exposed to the risk of customer demand change, production disturbances such as machine breakdown and stock spoilage. Franchetti and Barnala (2013) associates 7-12 percent efficiency improvement and annual cost savings amounting to USD 65,000 in a recycling plant in Ohio when reducing production lead time.

2.3 Costs

According to George (2002), quality and delivery are equally important and both affect manufacturing costs. Costs are normally divided into direct materials cost, direct labour cost and manufacturing overhead (Groover, 2008). Direct material costs are cost of raw materials that form the product while direct labour cost is the wages of workers involved in the production. Manufacturing overhead refers to costs incurred in the manufacturing activities such as in the acquisition and maintenance of equipment and utilities. Manufacturing costs cover a wide range of expenses and are contributed by many factors including product quality and delivery time. For example, manufacturing costs increase in tandem to the number of rejected products and penalty incurred for late delivery. Such costs are termed cost of quality (COQ) and categorized as prevention cost, appraisal cost, internal failure cost and external cost (Heizer and Render, 2008). Since product cost should be kept at a level to attract customers with a marketable price, COQ should be kept at a minimum. This is depicted in a case study by Jones (2013) in a Boeing company where implementing Lean Manufacturing brought about USD24 million costs savings through projects to reduce cycle time, labour costs, and time lost due to anomalies and non-conformances.

A systematic approach is necessary to improve the manufacturer's performance as measured by QCD (Snee, 2010). Management systems have been developed to enhance performance on a continuous basis and these systems are reviewed in the following section.

2.4 Management systems

Several management systems have been developed over the years. These systems include Total Quality Control (TQC), Total Quality Management (TQM), Deming's system of profound knowledge, Business Process Reengineering (BPR), Lean Manufacturing, Six Sigma and Lean Six Sigma. They are oriented towards process improvement and result in continuous improvement, customer satisfaction and, people and management involvement (Chiarini, 2011). The systems differ in their origins and historical paths of implementation as shown in Figure 2.2.

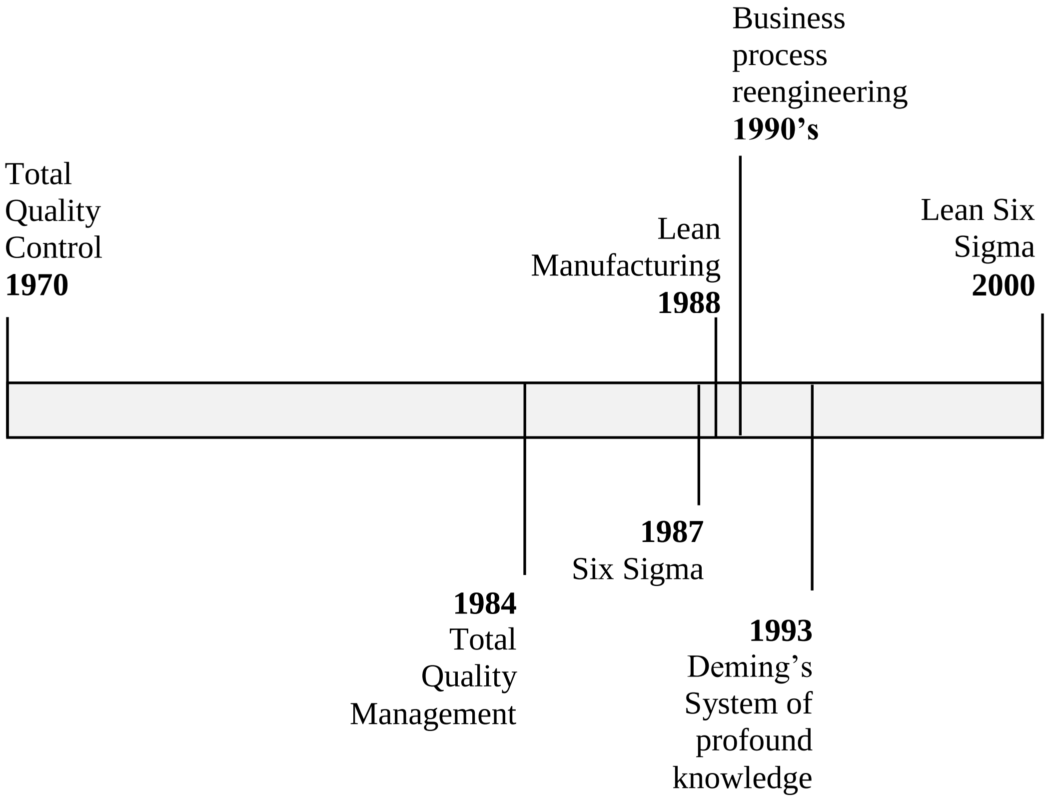

Figure 2.2 Historical timeline on origin of various management systems

TQM shifts its philosophy from TQC to manage quality rather than to control quality and then evolves into Deming's system which stresses on the integral role of employees from different departments to play a part in improvement. Subsequently, the advancement of information technology (IT) was used to enhance management practices which led to the birth of BPR. From then on, Lean Manufacturing and Six Sigma were introduced into the various industries. The approach to integrate Lean Manufacturing and Six Sigma into a unified system has taken place since both systems are largely compatible. The integration aims to increase the scope of improvement. Extensive research was conducted on these management systems (Dahlgaard and Dahlgaard-Park, 2006, Chiarini, 2011) which are reviewed in the following subsections.

2.4.1 Total Quality Control (TQC)

Considered as the oldest management system, TQC links management and procedure to manufacture products with specific quality standards (Feigenbaum, 1991). Through TQC, manufacturers aim to achieve targets such as reducing cost while improving quality, sales and profit (Chiarini, 2011). The early statistical research carried out around 1940's formed the roots of TQC (Deming and Shewhart, 1986). Many statistical tools were used to measure, analyse and control production issues in TQC. These include the seven basic quality control tools of check sheets, Pareto, histogram, stratification, control chart, cause-and-effect diagram, and scatter diagram and management tools like design of experiment, quality function deployment, Taguchi and mistake proofing (also known as poka-yoke). Ishikawa (1985) stresses the need for a quality specialist to lead TQC due to the extensive use of statistical tools. TQC has since evolved from production quality control to a companywide quality control involving employees from all levels (Ishikawa, 1985). Employee involvement in quality management systems moves away from the slow and inflexible top-down management style which gives directives and prescribes solutions. Employee involvement gives room for innovative ideas to enhance customer satisfaction.

2.4.2 Total quality management (TQM)

TQM consists of three interdependent components which are values, techniques and tools (Hellsten and Klefsjö, 2000). It is often interpreted as a form of management philosophy based on a number of core values such as stakeholders' involvement, teamwork, customer focus and continuous improvement of structures and processes (Mosadeghrad, 2014). TQM aims to improve and sustain product quality continuously (Modgil and Sharma, 2016). The idea of quality being controlled changes to the idea of quality being managed (Martínez-Lorente et al., 1998); hence the term 'Control' being substituted with 'Management'. TQM, introduced by Deming and Juran, focuses less on techniques and tools but gives more attention to the human aspect (Ehigie and Akpan, 2004). The important characteristic of TQM is management involvement and participation, management by fact and long term vision (Porter and Parker, 1993). The human aspect identifies problems and improves quality while tools are used to assist the process. Tools assisting problem solving in TQM can be divided into quantitative and non-quantitative tools (Besterfield, 2004). Examples of quantitative tools are statistical process control (SPC), Taguchi's Quality Engineering, Failure Mode and Effect Analysis (FMEA) and Quality Function Deployment (QFD) while non-quantitative tools are International Organization for Standardization (ISO), Total Productive Maintenance (TPM) and Information Technology (IT). Deming who founded TQM also introduced Deming's quality management system (Deming, 1993).

2.4.3 Six Sigma

Motorola developed Six Sigma in 1987 to increase the quality levels from measuring defects per thousand of opportunities to measuring defects per million of opportunities (DPMO) (Barney, 2002). The Six Sigma model assumes that if the process is centred at the target and the nearest specification limit is six standard deviations from the mean, the process will operate at 3.4 DPMO (Montgomery, 2010). The term sigma is a Greek alphabet letter used to describe variability and is applied as a statistical process technology measure in organizations (McAdam and Lafferty, 2004). Six Sigma is described as a system to reduce process variation which focuses on continuous and breakthrough improvements (Andersson et al., 2006). It seeks to identify and eliminate causes of errors or defects by focussing on outputs that are critical to the customer (Snee, 1999). Six Sigma has transformed over the past 20 years and is now a flexible and adaptive business strategy applicable to many aspects of business and organizations (Siddiqui et al., 2016).

The Six Sigma approach is strongly based on facts and data while following the structured methodology called DMAIC (Define, Measure, Analyze, Improve and Control) as shown in Figure 2.3.

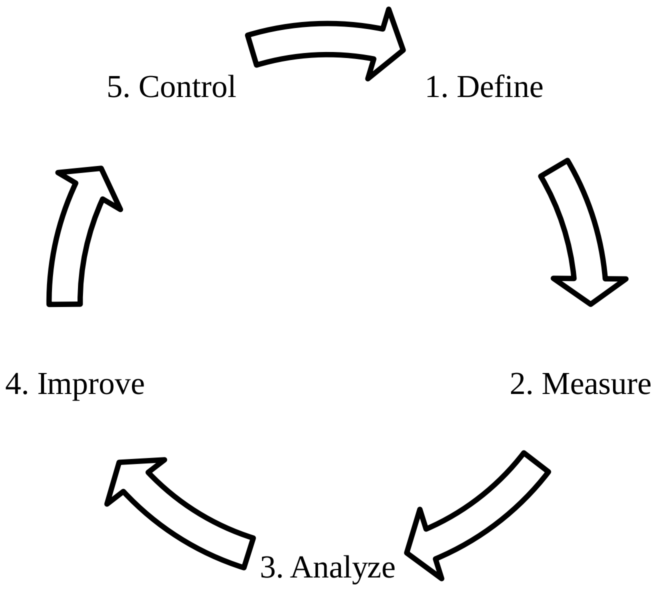

Figure 2.3 The DMAIC methodology of Six Sigma

Pyzdek (2003) provides a detailed description of the DMAIC methodology as presented briefly here. In the Define stage, goals of an improvement project are defined from direct communication with customers, shareholders and employees. An example of a goal is to reduce the defect level of a particular process. In the Measure stage, performance metrics are established to monitor the progress towards the goals defined in the previous stage. For example, the types of defects and their rates of occurrence are measured. In the Analyze stage, the ways to eliminate the current performance to achieve the desired goal is identified. Statistical tools will be used to guide the data analysis process in this stage. The fourth stage is the Improve stage, where improvement teams will have to be creative to find new ways to improve the current system. Statistical methods are used to validate the proposed solution. In the final stage which is the Control stage, the improved system is institutionalized by modifying policies, procedures and operating instructions. Statistical tools such as control chart are used to monitor the stability of the new system. There are various tools often found to be useful within each stage of the methodology. These tools will be elaborated in Section 2.5.

Many organizations train most of their employees assigned to Six Sigma projects (Schroeder et al., 2008). In fact, Linderman et al. (2003) stressed that organizations should train all employees by using an extensive program. Training includes the application of statistical and quality tools. Schroeder et al. (2008) explained that employees who receive two weeks training are called Green Belts while employees that receive four weeks training with hands-on experience are called Black Belts. Both Green and Black Belts must complete two projects apart from the internal training (Krueger et al., 2014). Master Black Belts are those who receive extensive training beyond Black Belt and their main responsibility is to serve as instructors to provide technical assistance and mentoring (Slater, 1999).

2.4.4 Lean Manufacturing

Krafcik (1988) first used the term ‘lean’ to describe the Toyota Production System (TPS) that aims to achieve continuous flow. This is in contrast with the Ford mass production system at that time (Womack et al., 1990). Lean Manufacturing considers inventory as waste, which opposes traditional manufacturing that builds inventory (Gupta and Jain, 2013). In order to be lean, manufacturers focus on making the product flow through processes without interruption (Liker, 2004) by eliminating non-value added activities referred to as wastes (Ohno, 1988). Therefore, Lean Manufacturing is defined as a system whose main objective is to eliminate waste (Shah and Ward, 2007) so that products can be produced at the lowest price and as fast as required by the customer (Bhamu and Sangwan, 2014).

There are a total of seven wastes (Ohno, 1988) identified and their descriptions are summarized in Table 2.1.

Table 2.1 Description of seven wastes (Liker, 2004)

Waste	Description
Overproduction	Produces extra products which do not have order and generates overstaffing, storage and transportation cost due to excess inventory.
Waiting	Workers have no work resulting in merely watching and standing around for the next processing step. This may be due to stockouts, lot delays, equipment downtime and capacity bottleneck.
Unnecessary transport	Inefficient movement of WIP due to long distances.
Overprocessing	Unnecessary steps and inefficient processing due to poor tools or product design.
Excess inventory	Extra raw material, WIP and finished goods causing longer lead time, obsolescence, damaged goods, transportation cost, storage cost and delay. Extra inventories hide problems such as imbalance production, supplier late delivery, defects, equipment downtime and long setup time.
Unnecessary movement	Wasted motion such as walking, looking for, reaching for and stacking parts or tools.
Defects	Defective parts which need repair, rework, scrap and inspection that causes wasteful handling, time and effort.

To eliminate wastes in Lean Manufacturing there are five basic principles of implementation. They are specify value, identify the value stream, flow, pull and pursue perfection (Womack and Jones, 1996) as illustrated in Figure 2.4.

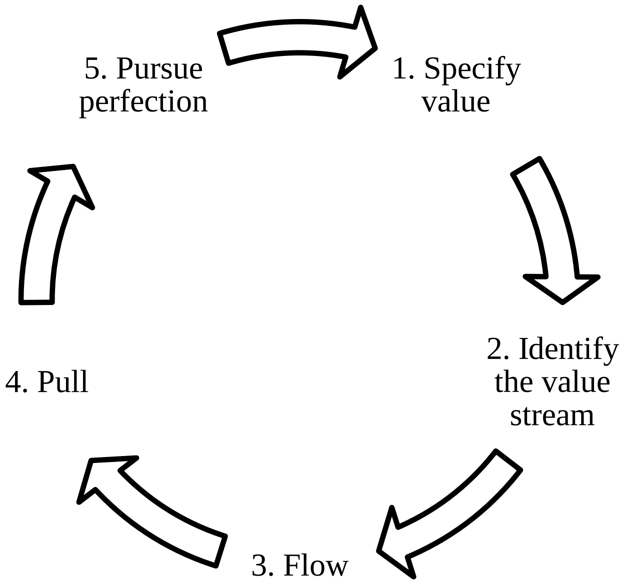

Figure 2.4 Five principles of Lean Manufacturing

In the first principle, the manufacturer needs to specify the value which is defined by the customer. For example, the customer wants the product to be delivered in 3 days. In the second principle, all the activities to produce the products are identified and categorized according to value added activities, required non-value added activities and non-required non-value added activities. Value added activities are processes that enhance the product, for example, the cutting process of a piece of wood into the size of a pencil. Setting up the machine for the cutting process is a required non-value added activity because it does not enhance the wood but it is required so that the cutting process can take place. In the third principle, the flow of product from one process to another until completion is to be tightened. This requires rethinking work practices while ignoring job boundaries to make the product flow continuously. For example, the setup for the cutting process can be readjusted to its minimal in order to increase the production flow of the pencil. Subsequently the fourth principle allows the customer to pull value upstream in which products are being produced only when they are required by the customer. The final principle which is pursuing perfection requires manufacturers to continuously repeat the first four principles until perfection is achieved.

A wide range of approaches exists to eliminate waste such as value stream analysis, total productive maintenance, Kaizen, Just-in-time (JIT), pull production and engineering management accompanied by tools like value stream mapping, kanban tool cards and JIT system. Each of the approaches individually does not make the management system but together they constitute the system (Shah and Ward, 2007).

2.4.5 Business process reengineering (BPR)

Business process reengineering (BPR) became popular as a reaction towards recession in the same period of time as Deming's system (Davenport and Short, 1990). BPR is a quality management system which requires a quick response to changes. This system focuses on the voice of customer and leads to improvement in cost, quality, service and speed in processes. BPR uses a top down approach in its implementation which raises the importance of senior management in making fast and aggressive decisions (Knights and Wilmott, 2000). Employees are empowered and the emphasis shifts from individuals to team effort (Hammer and Champy, 1993). Rinaldi et al. (2015) developed five steps for the BPR approach, namely, preparing for reengineering, analysis of As Is processes, data collection, development of simulation model and design of To Be processes. Since BPR is 'pro-IT', this system requires computers, software and databases to take advantage of predominantly software-based tools such as project management, brainstorming, cause-effect diagrams and problem solving. These tools involve mapping, benchmarking and IT.

2.4.6 Deming's system of profound knowledge

Deming's system of profound knowledge is summarized in William Edwards Deming's last book *The New Economics For Industry, Government, Education* edited in 1993. Deming's system consists of four interconnected components made up of the appreciation of the system, knowledge of variation, the theory of knowledge and psychology (Stephanovich, 2004). This system gives managers a special role to manage and lead a group in reducing variation. Deming (1993) did not favor the practice of management by objectives because it does not lead to improvement for the whole system and all stakeholders. This system stresses that every department in an organization should cooperate to solve problems, hence leading to a transformed new style of management system. There is no emphasis on particular tools, and each organization has the freedom to choose its tool.

2.4.7 Lean Six Sigma (LSS)

The phrase Lean Six Sigma is coined to describe the integration of two management systems (Shah et al., 2008) which are Lean Manufacturing and Six Sigma that exploits the benefits of both systems (Arnheiter and Maleyeff, 2005; Sheridan, 2000). George (2002) defined LSS as a methodology that maximizes shareholder value by achieving a significant improvement in customer satisfaction, cost, quality, process speed and invested capital. Lean Manufacturing alone cannot bring a process under statistical control while Six Sigma alone cannot dramatically improve process speed (George, 2002). LSS is a philosophy comprising of a Black Belt to adopt Six Sigma methodology where various statistical and lean tools are selected within each DMAIC phase (Hilton and Sohal, 2012).

Lean Manufacturing and Six Sigma are complementary (Andersson et al., 2006). Both of these systems stem from TQM (Dahlgaard and Dahlgaard-Park, 2006) and are meant to bring changes and improvement to the organization; particularly as a cost reducing mechanism (Achanga et al., 2006). They share the same final objectives, that is to provide improvement throughout the organization and both stress the need towards continuous improvement at all levels in the organization (Pepper and Spedding, 2010). LSS combines speed introduced by Lean Manufacturing and Six Sigma's capability of reducing process variation (Chiarini, 2011). They extend the tools and approaches evolved to achieve continuous improvement (Karthi et al., 2011). Antony (2011) compares the similarities and differences between Lean Manufacturing and Six Sigma, as shown in Table 2.2.

Table 2.2 Comparison between Lean Manufacturing and Six Sigma.

Similarities	**Differences**
• Both are process focused or process-centric. • Both need management support for success, especially in terms of creating the infrastructure and allocation of required budget and time for changing the culture of the business. • Both can be used in non-manufacturing environments. • Both methodologies are focused on business needs as defined by the customer. • Both concepts use multi-disciplinary teams to address business problems. • Both offer complementary tool sets which can be used together with each other and with other best management practices	• Application of Six Sigma methodology requires more intensive training compared to Lean methodology. • Implementation of Six Sigma requires more investment as opposed to Lean implementation. • Lean is fundamentally used to tackle process efficiency issue whereas Six Sigma is primarily used to tackle process effectiveness issue. • Six Sigma eliminates defects in processes, but it will not address the question of how to optimise process flow. In contrast, Lean principles lack the ways to achieve high capability and high stability processes.

Assarlind et al. (2013) explained that the difference in improvement targets of both systems does not imply system incompatibility as the uniform process output could be the secondary effect of Lean Manufacturing while reduced lead time could be the secondary effect of Six Sigma. In addition, they argued that the combination of both systems is a natural way of achieving an appropriate approach which can be result enhancing. One researcher who points out the limitation of this integration is Bendell (2006) who questioned the practicality of the 'Control' phase in Six Sigma to control attempts of wastes elimination without real prioritization. Furthermore, Bendell (2006) added that such integration is may not be effective as either one system may 'dominate' the other. However, multiple researchers who advocated the LSS integration describe the benefits in Table 2.3.

Table 2.3 Benefits of Lean Six Sigma

Advocates	**Benefits of Lean Six Sigma**
Sunder (2016)	increases the speed and effectiveness of any process and revenue, reduces cost and improves collaboration
Andersson et al. (2014)	improves process flexibility, robustness and cost-efficiency
Nicoletti (2013), Laureani et al. (2010)	is a business strategy and methodology that increases process performances
Arumugam et al. (2012)	improves process efficiency and reduces process variation in one effort
Duarte (2012)	drives operational efficiency and effectiveness
Gnanaraj et al. (2010)	facilitates the achievement of zero defect complemented by elimination of non-value adding activities
Snee (2010)	is an effective leadership development tool
Kumar et al. (2006)	increases the scope and size of improvements achieved by either concept alone

The following sections will cover common tools and techniques for Lean Manufacturing and Six Sigma.

2.5 Tools and techniques

When integrating the two approaches, it becomes apparent to understand the roles of various tools and techniques. Tools and techniques are practical methods, skills, means or mechanisms that can be applied to tasks and are usually used to facilitate positive change and improvement (McQuater et al., 1995). A tool is described as having a narrow focus and a clearly defined application (Antony et al., 2003, Antony, 2006). Examples of tools are process map, cause and effect analysis, affinity diagrams, run charts, relationship diagram, pareto analysis, control chart and histogram to name a few.

In contrast, a technique has a broader application and requires creativity, specific skills, training (Antony, 2006) and knowledge to tackle a particular problem (Antony et al., 2003). Some examples of techniques are statistical process control (SPC), quality function deployment (QFD), failure mode and effects analysis (FMEA) and design of experiment (DOE) among others. A technique can also be viewed as a collection of tools which are necessary for a larger scope of applications (Basu, 2009). This is clearly shown in SPC which utilizes tools such as control chart, histogram and root cause analysis within it (Antony, 2006).

Uluskan (2016) stated that there exist inconsistencies in the classification of tools and techniques. For example the supplier-input-process-output-customer (SIPOC) model is being referred to as a tool (Basu, 2009) and as a technique (Ismyrlis and Moschidis, 2013). Since a technique is a collection of tools and due to the discrepancies as shown, this research uses the term ‘tools’ to refer to both tools and techniques in the rest of thesis for simplicity purposes.

2.5.1 Tools of Lean Manufacturing

Lean Manufacturing tools are important because they can help to define, analyse and target sources of waste in specific ways when systematically applied (Wong et al., 2009). Numerous lean tools have been developed and those that have the most appearances in publications are value stream mapping (VSM), Kanban, Just-in-time (JIT) and 5S (Bhamu and Sangwan, 2014).

VSM is a tool that illustrates the production current state map using material and information flow symbols (Jones and Womack, 2000) to identify value added and non-value added activities beginning from the supplier's delivery of raw material to the delivery of products to customers (Rosentrater and Balamuralikrishna, 2006). This tool measures the current 'leanness' level of the mapped system (Wan and Chen, 2008) and is deployed at the early stages of an improvement project. This way, manufacturers can understand the condition of the production so that improvement opportunities can be identified and action plans derived. This is exemplified in Vinodh et al. (2010) where various improvement plans such as 5S, mistake proofing and WIP reduction are developed after understanding the production leading to reduction in lead time, WIP and defects. Other positive impact such as improvement in process ratio, takt time, process inventory time, line speed and reduced manpower were also reported (Jasti and Sharma, 2014). This has led to VSM being regarded as one of the best (Braglia et al., 2006), vital (Vinodh et al., 2015) and effective tool for identification and reduction of waste (Singh et al., 2011). In certain cases, VSM is paired up with a simulation tool to analyse and compare performance measures of current and future state VSM as a verification step (Gurumurthy and Kodali, 2011).

Kanban which means sign board is the best known visual tool (Machado and Leitner, 2010). Kanban regulates the flow of WIP using signal cards in a pull