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A supply chain improvement methodology for the process industries

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CERTIFICATION

I, Matthew P. J. Pepper, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Management and Marketing, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Matthew P. J. Pepper

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ABSTRACT

Over the last few decades, approaches to continuous improvement have evolved, undergoing several transformations. Each transformation has built upon strengths of a previous approach, while also shifting the emphasis between the use of a scientific and cultural underpinning necessary to achieve "quality" within an organisation.

In order to achieve the correct alignment between the scientific and cultural aspects necessary for a comprehensive improvement approach, the critical elements necessary for sustainable change must be identified and understood. This research identifies and examines the critical elements in the literature, culminating in the creation of a generic framework of the elements for continuous improvement. This framework identifies two key stages of knowledge transformation (Foundation Knowledge and Dynamic Knowledge) that must take place within an organisation if sustainable changes are to be implemented.

The literature surrounding the application of continuous improvement initiatives is well established; however the application of such techniques is less well defined in the process industries, presenting opportunity and scope for the application of continuous improvement techniques.

The application of improvement techniques in discrete or mass production environments is well established. However, the process industries present new opportunities and scope for the exploration and application of such approaches. In response to this, the generic framework for continuous improvement has then been used as a platform for the derivation of an industry specific lean six sigma methodology, referred to as the Supply Chain Improvement Methodology for the Process Industries (the SCIMPI model).

This thesis demonstrates the application of the proposed SCIMPI model in three separate case studies, each within a different sector of the process industry, and designed to explore a different aspect of the SCIMPI model.

The first case study considers a lead refinery plant, and serves as a preliminary study, exploring the feasibility of the SCIMPI model. From this, it is shown that batch-flow process facilities are well suited to continuous improvement techniques and the use of simulation.

The second case study considers a newsprint manufacture facility, successfully highlighting opportunities for improvement that had not been identified or addressed in previous improvement initiatives.

The final case study looks at an internal supply chain in the steel industry. Demonstrating the use of the SCIMPI model in a supply chain context, the case study highlights the interface of hard and soft systems approaches to drive continuous improvement initiatives.

The three case studies illustrate that the proposed SCIMPI model represents a unified, industry specific methodology, scientifically underpinned to effectively integrate the lean and six sigma approaches, in order to address the cultural and operational needs of a sustainable improvement approach.

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ABBREVIATIONS

Abbreviation	Meaning
5S	Sort, Simplify, Sweep, Standardise and Sustain
ABC	Activity Based Costing
ABM	Activity Based Management
ACF	Autocorrelation Function
AR(1)	First order Autoregressive Process
BBC	British Broadcasting Corporation
BOS	Basic Oxygen Steelmaking
BSC	Balanced Scorecard
CANDO	Cleanup, Arrange, Neatness, Discipline and Ongoing Improvement
CEO	Chief Executive Officer
CI	Continuous Improvement
CPCM	Coupled Pickle Cold Mill
CT or C/T	Cycle Time
DIP	De-inking Process
DOE	Design of Experiments
DMAIC	Define, Measure, Analyse, Improve, Control
DT	Dump Tank
ERP	Enterprise Resource Planning

FPP	Fibre Preparation Plant
GE	General Electric
HCPD	Hot Coil Processing Despatch
HSM	Hot Strip Mill
IMVP	International Motor Vehicle Program
IT	Information Technology
JIT	Just in Time
LDMAICE	Lead & Learn, Define, Measure, Analyse, Improve, Control, Enterprise
M/MC	Moulding Machine
MIT	Massachusetts Institute of Technology
MRP	Materials Requirement Planning
NHS	National Health Service
NN	Neural Network
NUMMI	New United Manufacturing Incorporated
OTIF	On Time In Full
PB	Post-bleaching
PIVOT	Paper Industry Value Optimisation Tool
PPC	Production Planning and Control
QFD	Quality Function Deployment
SCIMPI	Supply Chain Improvement Methodology for the Process Industries
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference Model
SCV2	Supply Chain Velocity Project

SHPCM	Sustainable High Performance Culture Model
SMED	Single Minute Exchange of Die
SPC	Statistical Process Control
SPM	Skin Pass Mill
SSM	Soft Systems Methodology
TPM	Total Productive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
UK	United Kingdom
US	United States
VSM	Value Stream Map(ping)
VV	Value Velocity
WIP	Work In Progress

1.0 Introduction

1.1 Background

In the last fifty to sixty years, a myriad of approaches, techniques and philosophies for continuous improvement have been (and continue to be) developed, in an attempt to address the efficiency, quality and cultural concerns of industry. Each one of these approaches seems to have a brief shelf-life before being replaced by an updated version or opinion. As each of these approaches, or 'fads' (as they might popularly be known) is replaced, or fades from view, it leaves behind a legacy of core strengths and weaknesses, which in turn form the foundation for the next wave of improvement initiatives.

However, with each new fad or wave of philosophies that become part of everyday business language, a shifting focus between philosophical, cultural concepts and a data driven scientific approach can be found. This skewed development over time could be attributed to the loose associations between quality, the scientific approach, and the cultural aspects inherent in any system. To achieve sustainable continuous improvement, a balance between these elements must be attained.

Lean and six sigma are two of the most widely used and discussed improvement paradigms to emerge in recent times. However, the concept of lean six sigma as a conjoined approach to process improvement has yet to fully mature into a specific area of academic research (Bendell, 2006). Furthering this point, it can be said that in practice the majority of efforts to fully and comprehensively implement a lean six sigma

initiative to its full potential have not been realised (Smith, 2003). The two approaches have often been implemented in isolation (Smith, 2003), creating lean and six sigma sub-cultures to emerge within the organisation. This can cause conflicts of interest, drain resources (Bendell, 2006), or even competition for the same resources (Smith, 2003).

Bendell (2006) suggests that it would be beneficial for all if a single approach that effectively brought the two philosophies together was available. Although there appears to be a number of consultancy models for lean six sigma freely available on the internet by consultants, the presented methodologies are put together without logical explanation (Bendell, 2006) and more importantly, with no theoretical underpinning or explanation for the choice of techniques.

Improvement efforts need to be directed by a strong approach that is capable of maintaining direction and focus within the business. Both lean and six sigma have the same end objective, to achieve quality throughout, whether it is customer service, the product, the process or training and education of the workforce. They are effective on their own, but organisations may well find that after initial improvement, they reach a plateau; and find it difficult to create an ongoing culture of continuous improvement (Arnheiter and Maleyeff, 2005). To overcome this, the lean approach must integrate the use of targeted data to make decisions and also adopt a more scientific approach to quality within the system. Six sigma on the other hand needs to adopt a wider systems approach, considering the effects of muda on the system as a whole; and therefore quality and variation levels (Arnheiter and Maleyeff, 2005).

A state of equilibrium needs to be achieved between the two, moving away from a fixed approach in any one direction. The balance lies in creating sufficient value from the customer's viewpoint, so that market share is maintained, while at the same time, reducing variation to acceptable levels so as to lower costs incurred, without over-engineering the processes.

In order to meet the requirements of today's businesses, an improvement framework needs to be effective on two levels, providing strategic direction while also considering the process level improvements to achieve the strategic goals. Equilibrium between complexity and sustainability must be found, balancing the two philosophies of lean and six sigma, so that the advantages of both can be realised. Finally, the framework should be structured around the type of problem experienced. These points present key questions to be answered when considering the construction of an effective lean six sigma framework. Taking this a stage further, is to develop an industry specific framework.

Continuous improvement techniques such as lean have had success in a number of industry sectors and experienced limited success in others. The implementation of lean techniques within the process industry continues to present new scope for the application of continuous improvement approaches.

Traditionally successful, with easily made profits, the process industry experienced significant growth up until the 1960s (Anderson, 1997). Facilities were designed with huge storage capabilities (Anderson, 1997), a legacy which has left many of today's businesses in the sector with inflexible facilities. If the contribution of the process

industries to national economies is considered (Burgess et al., 2002), and in the face of increased competition through globalisation, then the importance of maximising value added activities and ensuring durable market presence in the global arena is critical.

Although the literature describes a number of improvement efforts within the process industry sector, it is suggested that an industry specific lean six sigma framework will further these efforts, highlighting the benefits of a customised approach, derived from the critical elements necessary for sustained improvement, so that process industries may remain competitive and overcome the legacy of inefficiency and mass storage.

1.2 Aims and Objectives

This aim of this research is to identify and address the need for sustainable improvement archetypes. The following objectives have been developed to address the perceived gaps in the literature and provide industry with a solution to sustainable continuous improvement:

1) Review the literature surrounding the strengths and weaknesses of the lean manufacturing philosophy, the evolution of the six sigma paradigm, and the characteristics of change. The purpose being to identify the key elements required for a generic framework for continuous improvement.

2) In response to the findings of the literature review, develop a generic framework for continuous improvement, to guide the creation of an industry specific lean six sigma methodology for the process sector.

3) Test the efficacy of the proposed methodology using three industry based case studies. The case studies will be based in different process industry environments to analyse their responses to the proposed methodology.

1.3 Philosophy

Based on the objectives established in section 1.2, a comprehensive literature review will be conducted on the area of lean and six sigma. The findings from this review of the literature will be used to derive a generic framework, comprising of the perceived critical elements that are necessary for a sustainable continuous improvement initiative. This generic framework is then used as a platform for the creation of a lean six sigma methodology, designed specifically for the process industry sector, the SCIMPI methodology. Different aspects of the SCIMPI methodology are then explored through its application to three case studies, each within a different sector of the process industry, to illustrate the potential of the SCIMPI methodology.

1.4 Scope

This research emphasises the criteria essential for sustainable continuous improvement. Focussing on the integration of lean and six sigma techniques, this thesis concentrates on the application of a proposed and scientifically underpinned lean six sigma methodology within the process industry. The efficacy of the proposed methodology is considered through the use of three individual case studies, each based in a different sector of the process industry. The scope of this thesis does not extend to a full longitudinal investigation of the cultural implications of continuous improvement within these case studies due to the obvious time constraints. However, the thesis does provide a basis for instigating such change in the organisations. This thesis solely deals with retrospective redesign of current process industry organisations. It is considered beyond the scope of this thesis to address original system design, as this is a vast area of research in its own right, and would require a different approach to retrospective redesign. However, in principle, similar methodologies can be adopted to achieve this.

1.5 Layout of Thesis

Chapter two presents a literature review of the lean manufacturing philosophy, six sigma methodology, and the integration of lean and six sigma techniques. The application of lean techniques in the process industry sector is reviewed, before the characteristics of change are explored.

Chapter three discusses the creation of a generic framework for continuous improvement, derived from the literature analysed in chapter two. This framework is then used to construct an industry specific lean six sigma framework for application to the process industry sector, the Supply Chain Improvement Model for Process Industries (SCIMPI). The scope of the framework is discussed, before a comparative study between the SCIMPI model and existing lean six sigma frameworks is put forward. The SCIMPI model is then discussed further, in relation to Soft Systems Methodology.

Chapter four presents the first of three case studies. Each case study is specifically designed to highlight different aspects of the proposed framework. This case study follows a straight forward application of the SCIMPI methodology in a European lead refinery, and provides an exploratory investigation using simulation.

Chapter five discusses the more detailed application of the SCIMPI methodology, using a paper making facility in Europe as the focus of the initiative. This case study highlights the use of value stream mapping to leverage soft computing techniques for

the analysis of variation. The implementation path is discussed, followed by the results and conclusions.

Chapter six details the application of the proposed methodology in a steel manufacturing supply chain, and is designed to highlight the SCIMPI methodology in a larger, supply chain context. The application of SCIMPI in this instance explores the interface of hard and soft systems as part of the journey towards continuous improvement. Conclusions are then brought together from the findings of the project.

Chapter seven draws together the findings of the three case studies, providing discussion and conclusions on the implementation and testing of the SCIMPI methodology in practice, before discussing potential aspects of the research suitable for future consideration.

2.0 Literature Review

2.1 Introduction

The lean philosophy is an established concept that due to its very nature is continuously evolving with applications in new areas. Although research has been undertaken on the implementation of lean within various industries, the many tools and techniques that form the 'tool box', and it's integration with six sigma, there is no definitive implementation guide that informs which parts of this tool box should be used, when and how, via industry specific methodologies. This chapter provides a review of the literature, through the discussion of successful lean implementations and its expansion into supply chain management; followed by the examination of areas where lean initiatives have had limited success. The current direction of lean research is addressed, culminating in its application in one of the less travelled paths, the continuous process industry. The integration of lean principles with six sigma methodology is examined, and in response to this, the chapter attempts to identify the scope of a specific methodology for the continuous process industry, with key lean and six sigma tools at its foundation.

2.2 The Toyota Production System (TPS)

The Toyota Production System (TPS) provided the basis for what is now known as Lean Thinking, as coined by Womack and Jones (1996). The development of this approach to manufacturing began shortly after World War II, pioneered by Taiichi Ohno and associates, while employed by the Toyota motor company. Forced by

shortages in both capital and resources (such as storage) Eiji Toyoda, the then president of Toyota, instructed his workers to eliminate all waste. Waste was defined, as "*anything other than the minimum amount of equipment, materials, parts, space and time which are absolutely essential to add value to the product*" (Russell and Taylor, 2000, p. 737). Working to this brief through a process of trial and error, Ohno would go on to develop the philosophy known as the Toyota Production System (TPS).

Bicheno (2000), outlines Ohno's five Lean Principles:

1. Specify what does and does not create value from the customers' perspective.
2. Identify all the steps necessary to design, order and produce across the whole value stream to highlight waste.
3. Make those actions that create value flow without interruption.
4. Only make what is pulled by the customer.
5. Strive for perfection by continuous improvement.

The philosophy behind the Toyota Production principles, as noted by Balakrishnan (2002) is to maintain the continuous flow of products in systems, so that demand changes will not cause disruption to the system. Established production management methods were followed, ultimately leading to the elimination of all unnecessary inventories, of both finished and unfinished goods within the production line. Following from the refined and methodical integration of these practices, the Japanese went on to achieve a total, new manufacturing paradigm, as discussed by White and Prybutok (2001), which as Bartezzaghi (1999) examines, became the dominant production model to emerge from a number of concepts around at the time (Katayama

and Bennett, 1996). As a result of this, today, Toyota manufacturing facilities remain the benchmark when considering the lean transition.

Through their participation in the International Motor Vehicle Program (IMVP), which analysed the performance differences between the Japanese and Western automotive industries, Womack et al. (1990) marked the beginning of the realisation that becoming a global company was crucial if organisations wanted to remain in business and maintain existing (or identify new) areas of competitive advantage. Able to see the increasingly competitive stance Japan's manufacturing industry was taking, Western industry had no choice but to try and adopt this new, sometimes counter-intuitive way of thinking. The TPS was adapted and under the title of Just-In-Time (JIT) manufacturing, US and European companies began their lean journey.

As suggested in the name, JIT requires only necessary products to be provided in necessary quantities at necessary times. As discussed by Russell and Taylor (2000) "*if you produce only what you need when you need it, then there is no room for error*" (Russell and Taylor, 2000, p. 737). White and Prybutok (2001) outline the key factors of the JIT methodology as follows:

JIT is an integrated management system that consists of the following ten elements:

- Flexible resources
- Cellular layout
- Pull production system
- Quick set-up times (to reduce overall lead time)

- Kanban production control
- Quality at the source (so that nothing of poor quality is passed on to the next process)
- Small-lot production
- Total productive maintenance
- Uniform production levels (in order to react to changes in demand)
- Supplier networks

Svensson (2001) argues that while Ohno and associates of Toyota are widely regarded as establishing the JIT theory through the TPS approach, many of the key concepts have been around since the beginning of the twentieth century. Peterson (2002) also points out that JIT ideologies were founded in part through the work of Ernest Kanzler and Henry Ford, and the key success factors for JIT production, such as manageable supplier networks; efficient transportation and materials handling have long been in the minds of manufacturers. However, while these key concepts and techniques have been adapted from the early figures of manufacturing, they have evolved and adapted to modern society through the pioneering work of Ohno and others.

Storhagen (1995) discusses the transition of JIT principles from East to West and the different perspectives encountered when looking at the initial divide in manufacturing industries between them. The differing results between Japanese implementation projects and those undertaken in the West have provided useful insight into the reasons behind the success of JIT in the respective countries, proving that cultural changes are essential for a successful transition. The Japanese have long understood that

empowerment, involvement and working as a team in order to achieve the same goal goes hand in hand with success.

Furthering this perspective, Stewart (1998) goes on to provide a comprehensive summary of the cultural benefits that entail the implementation of a lean culture:

(1) Lean production allows workers to work “smarter not harder”.

(2) Lean production creates a safer work place through increased
investment and an increase in skilled workers.

(3) Accordingly, lean production increases job satisfaction.

(4) Lean production creates a new industrial democracy whereby employees
have a mutual share in the success of the company – trade unions are
thus irrelevant where they pursue a traditional Anglo-Saxon agenda.

(5) While lean production may have begun in Japan, it is now no more
Japanese than is Fordism any longer American.

(6) There is one best way to promote business success.

Point 5 is especially useful in illustrating just how much other countries have embraced lean methods, and by being recognised as an essential path to tread, it has become part of the everyday language within the manufacturing organisations throughout the World.

2.3 Lean Philosophy and Principles

Lean manufacturing is the next stage of the Toyota Production philosophy, using many of its techniques and tools. The foundation of the lean vision is still a focus on the individual product and its value stream, identifying which activities and processes are value added and non-value added, and to enhance the value and eliminate all waste, or *muda*, in all areas and functions within the system (Womack and Jones, 1996).

In order to implement lean, it is important to understand what the customer is prepared to pay for (i.e. value added processes). A comprehensive strategy needs to be implemented, incorporating benchmarks, so that any changes within the system can be quantified.

The main target of lean thinking is the elimination of waste that isn't always apparent when first considering a system. Seven forms of waste have been identified; over-production, defects, unnecessary inventory, inappropriate processing, excessive transportation, waiting, and unnecessary motion. These wastes have been thoroughly discussed in literature surrounding lean research. The following summarises Ohno's seven wastes:

Overproduction. In other words making too much too soon. This is generally seen as the most significant of all the wastes due to the fact that it can cause any number of potential problems and other wastes.

Waiting. This is in direct conflict with the third lean principle, flow.

Unnecessary motion. This refers to the excess turning, bending, stretching etc. of operators within the workplace in order to do their job.

Any movement of material around a factory is not a value added activity therefore it is waste, referred to as **unnecessary transportation**.

Inappropriate processing brings attention to the employment of a sophisticated machine to carry out a number of processes when one or two more simple machines would achieve the task, or the use of machines that are not capable of producing sufficient quality.

Defects are products or components that do not match customer specifications. (External defects can encompass warranty, repairs, and even lost custom (Womack et al., 1990)).

The driving force behind the JIT and lean ideals is the waste represented by **unnecessary inventory**. This can cause long lead times, hides problems and uses more space. Many people believe lean to be a counter intuitive methodology, as it lends itself to getting rid of safety buffers of inventory (Bicheno, 2004). However, any reduction in inventory should be underpinned by a comprehensive strategy of incremental reductions that eventually lead the way to minimal inventory levels within the system (be it a facility or supply chain). While being the overall goal, 'zero inventory' is not practical in many situations. The lean philosophy emphasises *flow*, therefore the minimum inventory that enables or encourages flow is the objective. Buffer inventories may be necessary to achieve this, but again, a strategic approach must be taken so that inventory

may be reduced to these optimum levels in a controlled manner, with minimum disturbance to the system.

Every level within the organisation, from top management down to shop-floor workers must make a concerted effort to commit to lean in order to complete a full implementation. This commitment from employees must be used in conjunction with a comprehensive strategy for analysis and implementation; otherwise management can become distant from the shop-floor and drift away from the lean change.

Ahlstrom (1998) identifies these issues through an implementation study, and discovers that there are optimal sequences for the implementation of lean techniques, which can be sub-divided according to the amount of effort and resources management supply.

This commitment must also come from the shop floor employees, who of course are just as important as management to any implementation or change of strategy. It is essential that sufficient training, empowerment, and motivation is given to these employees to make a lean transition a successful venture.

A true lean initiative will give the employees the power to stop production flow whenever a problem is encountered, and promote the concept of helping each other out in times of difficulty. In turn, employees become multi-skilled, and provide a real commitment to the continuous improvement of every stage of production within their facility (Forza, 1996).

In today's ever more competitive environment, the idea of lean thinking, as popularised by Womack et al. (1990) has become a staple for the manufacturing industry, where being flexible to constantly changing and more demanding customers has become essential for survival and growth, rather than an option. Since its rapid spread among the manufacturing community from the 90s onwards a myriad of diverse industries are having to challenge their thinking (Katayama and Bennett, 1996), and constantly question every process. Management now not only need to manage effective budgets and deliver quality to the customer, they should also develop and sustain a culture of continuous improvement within their organisation. This creates opportunity to identify paths to long term strategic advantage.

To emphasise the continuous and expanding nature of the lean approach throughout the modern business world, Figure 2.1 illustrates the lean cycle, outlining the four key elements that should be inherent within any lean initiative (whether applied locally, or within the total supply chain context), as identified from the literature review in section 2.4 of this thesis.

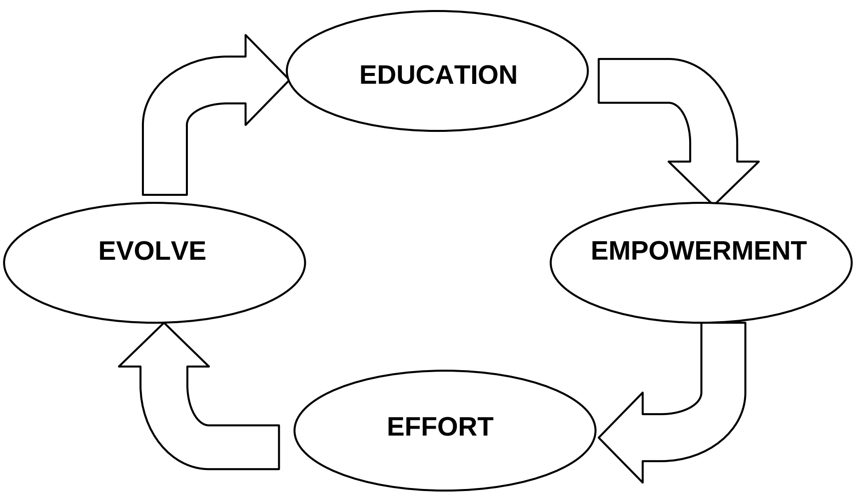


Figure 2.1 The Lean Cycle

Education refers to the culture change necessary for a lean initiative to work. It also refers to teaching employees how to 'think lean', i.e. what the seven forms of waste are, and how to tackle them.

Empowerment refers to the power and authority given to employees to identify problems and solve issues within the organisation. In other words, ownership of the process, and how it is managed. Knowing that their voice will be heard, and their opinion discussed rather than dismissed.

Empowerment and education work hand in hand through the use of kaizen events where the mapping and analysis of a process leads to physical changes being made.

Effort describes the work put in to identify opportunities for improvement, and kaizen events – the need to constantly be aware of the work environment and how it can be changed for the better.

Evolve emphasises the cyclical nature of continuous process improvement, and also the need to consider the environment outside of the facility. Extending lean thoughts throughout the supply chain, is the only way to fully implement lean successfully without its suppliers and customers adhering to the same working principles.

2.3.1 Lean Tools

There are a number of tools that can be used in order to identify and eradicate sources of muda within any particular system, for example, Value Stream Mapping, Total Preventative Maintenance and SMED among others. The following section discusses these tools and the part they play in the transition to Lean status.

"Whenever there is a product for a customer,

there is a value stream.

The challenge lies in seeing it."

(Rother and Shook, 1999, p. ii)

The most important step at the beginning of a continuous improvement effort is the mapping of the facility. This is so the current state of operations can be identified, and the resulting map can be used as a platform for analysis. Value Stream Mapping (VSM) is an approach used to differentiate between value added and non-value added processes in material and information flow within a system. The current state system is defined, followed by a perceived/desired future state process. This future state map is then used to develop strategies to implement lean manufacturing philosophies and concepts. VSM is concerned with three types of flow: materials, information and people.

Obvious areas for improvement, which can be implemented with minimal expenditure by the company, can be identified, such as parallel working, and flexibility through multi-skilling on the shop floor. As discussed by Rother and Shook (1999)**,** value stream

mapping provides a common language when talking about manufacturing processes. It also ties together all of the lean techniques, which avoids the temptation to cherry pick just one or two of the easiest to implement. No other tool depicts the linkages between information flow and material flow, and it is a qualitative technique that is used to describe how an organisation should ideally operate for continuous flow to be achieved.

It should be noted here that the book “Learning to See”, written by Rother and Shook (1999) has become the definitive text for any organisation wishing to start the lean journey.

VSM is commonly applied independently without any other tools or techniques, under the misconception that this is lean. In fact, this is not the case, as a whole strategic philosophy is needed in order for a system to be running at a truly lean level. To achieve this, VSM needs to be methodically applied before any other tools such as Single Minute Exchange of Die (SMED) and 5S is implemented to achieve a fully comprehensive approach. Some would argue that 5S is or should be done first, so that any ‘low-hanging fruit’ may be picked. However, implementing 5S before anything else is done may well lead to the organisation stumbling when it comes to implementing other, more involved or technical tools and techniques. VSM must be the starting point for a lean/six sigma/lean six sigma initiative. By highlighting opportunities for improvement, VSM provides direction for the application of specific tools and techniques. When used as part of an effective methodology, a comprehensive strategy for improvement can be drawn from the current state map produced. Without this direction, it is difficult to define the scope of the project. This may result in tools such as 5S being implemented in every situation, whereby the focus of overall improvement

is consumed with 5S, detracting from the rest of the viable techniques that will lead to sustainable changes within the system. This is not to say that 5S is not a powerful approach, rather that to be effective as part of a whole initiative, it needs to be directed and managed appropriately, so that the most can be gained from it's use.

Sheridan (2000) puts forward the theory that the practical nature of VSM (i.e. the paper and pencil approach) limits the amount of detail collected and also detracts from the actual system workings (the action of using pencil and paper to draw the map may remove focus fropm the actual system being analysed). This dynamic view looks beyond VSM as giving a quick, succinct overview of where "muda" is present, and develops the idea of the mapping process itself becoming a continuous tool, constantly being updated via software (Sheridan, 2000). Although designed to be a snap-shot of the overall system, when constructing a VSM in the traditional manner, it is limited in the data that it can represent. Academics such as McDonald et al. (2002), Lian and Landeghem (2002) and Abdulmalek and Rajgopal (2007) have explored the integration of VSM with a simulation approach, while a multitude of VSM software has become available over the internet. The introduction of such software to the market has provided users with the ability to create functional VSMs that include significantly more data than the traditional approach. The software also presents the user with a dynamic view of the value stream, rather than a static picture, providing valuable insight through the exploration of potential improvements and their implications on the system, and as a result, will play an important part in the formation and focus of implementation strategies for continuous improvement. VSMs will become a powerful aid for continuous improvement initiatives, driven by the flexibility and increased information

made available to improvement teams, coupled with the ability to observe the 'real-time' impact of proposed improvements.

While VSM provides direction, scope and information for a lean initiative, using the key techniques of 5S and SMED as foundation blocks for improvement, simulation, TPM and six sigma take the initiative further still, targeting the opportunities for improvement brought to light by the foundation block tools. Six sigma addresses specific quality issues, by introducing statistical monitoring of the system. In order to get an efficient process, it is necessary to adopt lean ideas. Six sigma can be used in conjunction with lean to reduce the variation. If six sigma was the sole improvement methodology used, the variation would be minimised, but on generally wasteful processes (Dahlgaard and Dahlgaard-Park, 2006).

Developed by Shigeo Shingo in the 1950's, the Single Minute Exchange of Die (SMED) approach has had particular focus, selected in order to banish the high volumes of inventory that has long been necessary due to the lengthy set-up times of machines on the shop floor (Dailida, 2000).

SMED is concerned with the reduction of the time taken for a machine to change from producing one product to another. Historically, long set-up times have forced companies to manufacture components and products in large quantities. In contrast, lean philosophy directs production in small batch sizes, to ensure that customers can be supplied in required quantities without the holding of large stocks. As part of this lean view, SMED is viewed as a "*key pre-requisite for increased flexibility*" (Mileham et al., 1999, p. 785). Mileham et al. (1999) further this concept through their action research

approach to the creation and application of “Design for Changeover” (Mileham et al., 1999, p. 785), experiencing positive results from a number of applications. Moxham and Greatbanks (2001) discuss the initial thoughts surrounding SMED, mainly that limitations are found outside of traditional press manufacture. However, as is outlined in their writings, work has been done to adapt and add to SMED techniques in order to provide a universally relevant tool.

Total Productive Maintenance (TPM) is another tool integral to lean. It is concerned with prevention of anything that causes an interruption to the system – such as machine breakdowns, instead of “fire-fighting” problems when they occur. There are seven TPM pillars, as discussed by Ireland and Dale (2001), which consolidate the focus of TPM implementation: Focussed improvements, autonomous maintenance, planned maintenance, quality maintenance, education and training, early equipment maintenance, and safety and the environment.

A system cannot be flexible and responsive to customer demands if the reliability of any section of that system can be brought into question.

Closely linked with Total Quality Management (TQM), the scope of TPM covers issues resulting from breakdowns, to machine/process performance and quality. (Yamashina, 2000, p. 139) illustrates the synergies between TPM and TQM and JIT in the following statement:

"In Japan it is said that in order to be strong enough in manufacturing one has to have good brains which require total quality management (TQM), but one also needs to have strong muscles or, in other words, strong manufacturing capability which requires total productive maintenance (TPM). Moreover, one has to have a good nervous system to connect the brains with the muscles, which means just-in-time production."

This summary clearly explains the interactions and needs of the three techniques. A system cannot be flexible and responsive to customer demands if the reliability of any section of that system can be brought into question. Essentially, the integration of lean or JIT thinking provides cohesion TQM and TPM, bringing together the concept of management commitment, teamwork and a scientific approach underpinned by a reliable system and the strategies necessary to achieve this.

Willmott (1994) emphasises the need for constant awareness training sessions in order for a successful culture change into TPM. A comprehensive approach covering the ongoing training and inclusion of all employees, is key to success, and should be used in conjunction with measures to quantify the results in order to present the management with proof of the ongoing gains witnessed. Lean philosophy assumes sufficient machine availability and reliability (Smalley, 2005), which is where TPM provides the support for lean through scheduled maintenance etc., ensuring no equipment failures and maximum reliability – essential for a lean culture to function properly.

As perceived by Ravishankar et al. (1992), TPM (as with any initiative) cannot be expected to produce great results overnight. Bamber et al. (1999) go on to discuss how many organisations fail to successfully implement TPM, citing reasons such as lack of

management support, and insufficient time allowed for the evolution of a TPM culture. Due to the nature of the approach (a cultural change), many of the issues encountered when implementing TPM are echoed in lean implementation efforts. This underlines the synergies between the two philosophies, as being culture driven approaches that rely on one another to be fully comprehensive.

As can be seen from the literature, both TPM and lean have common themes and approaches to implementation, as well as cultural change. To this end, Cua et al. (2001) suggest a case for the joint application of TPM, and JIT, and highlight the compatibility of these philosophies, continuing on to investigate the manufacturing performance associated with the level of implementation. The synergies between TPM and lean make them prime candidates for providing a comprehensive approach to continuous improvement activities. Yamashina (2000) adds weight to this by dealing with the benefits and necessity of looking at JIT in conjunction with TPM to achieve world-class manufacturing status.

The installation of a TPM system is crucial to maintain the flexibility and dynamism within a lean environment, while six sigma focuses on a data driven approach to target variation within a system. Simulation provides dynamic views and analyses of proposed improvements from all angles, such as; inventory tracking, economic justification and data, and the effects of physical layout alterations. All of these parameters are targeted by lean, but are not interpreted on the traditional static Value Stream Map, constructed with pencil and paper.

Perhaps the most widely used of the lean tools is 5S, or the good housekeeping approach. 5S itself refers to; Sort, Straighten, Shine, Systemise and Sustain. Also known as CANDO, as outlined by Bicheno (2000), it is concerned with changing the mindset of the organisation and making ordered and standardised processes normal routine instead of an exception. It drives the need for pride in the workplace or 'good housekeeping'. 5S is fundamental to achieving a lean business and is equally at place on the shop floor, or in the office.

Sort refers to throwing out what is not used – categorise everything into sections depending on how often they are used. Straighten directs the employee to locate everything that is used in the best relevant place for it to be easily reached or seen. This can be summarised as, if something needs to be seen, put it where it can be looked at, while if something needs to be used, put it where it can be picked up etc.

Shine describes the action of physically tidying up the work area, and constantly keeping check for things that are out of their correct place.

Once all of the first three "Ss" are in place, the fourth S, Standardise, can be introduced, and finally Sustain this by committing to a continuous improvement workplace ethic.

2.3.2 Simulation as a Lean Tool

Variation within a system is not specifically targeted by lean tools such as value stream mapping. Simulation models allow the user to analyse this variation by modelling the interactions between the entities, resources and activities within the system. Through the application of random distributions, complex systems and their inherent variation

can be understood. Once the complexity and variation of the existing system has been accurately modelled, this can then be used to predict the effect that potential changes to the system will have on the behaviour of the variation and interactions.

At present, a number of software companies are employing initiatives trying to develop software that can be used for the implementation of lean tools and methods. Griner and Hanson (2001) discuss the application of fully integrated Windows based Enterprise Resource Planning (ERP) software to automate job-shops and connect the information flow to the shop floor. However, ERP systems are expensive and time consuming to implement and are better suited to much larger organisations.

Simulation mapping of lean tools, such as Kanban allocation and just-in-time methods, are also beginning to produce interesting innovations, as suggested by Savsar and Choueiki (2000).

The most recent step towards the implementation of software to ease this problem of value stream mapping is the utilisation of simulation tools to enhance the capability and ease of implementation to various production settings, as investigated by McDonald et al. (2002). Conversely, simulation can be viewed as being contradictory to the lean approach; in as much as it is a lengthy and expensive process. It should be noted that simulation packages are a tool used to aid decisions, not solve problems. Researchers such as Donatelli and Harris (2001) introduce simulation as the movie to value stream mapping's snapshot. It could be said that this detracts from some key lean principles, such as going to the shop-floor for yourself and viewing the action (such as the gemba approach). However, the simulation approach could form an extremely powerful tool

for gaining the co-operation and involvement of all employees, and the formation of cross-functional teams, enabling employees to analyse, reflect upon and change their own working environment through hands on discussions covering the current state system and also potential future state scenarios.

Leading on from this, simulation can also be used to great advantage for certain higher level lean or six sigma techniques, such as Statistical Process Control (SPC) (Spedding and Chan, 2001), where control charts may be constructed, showing tool wear etc, so that when the information is fed into a simulation engine, a comprehensive Total Productive Maintenance (TPM) schedule may be configured for the whole system. Schroer (2004) goes on to discuss the benefits of simulation as a learning aid for lean through the use of a simulated manufacturing set-up to lead the user through continuous improvement concepts. This approach has a lot of potential for the training of employees in a lean deployment, and could be used as an effective off-line demonstration tool, illustrating the effect of cell redesigns and other lean tools that would temporarily effect production.

2.4 Successful Lean Efforts

Originally, lean philosophies were applied to large manufacturing operations, in high volume, low variety facilities, to continuously improve efficiency in production. Not surprisingly, following its inception at Toyota, some of the first western companies to consider the transition to a lean culture were US automotive manufacturers. The reason for this is twofold. Firstly, these companies were in direct competition with Toyota, and were watching from a distance as their market share shrank to Toyotas emerging

dominance. Secondly, the market was becoming increasingly demanding for greater choice in the product portfolios. It was no longer a case of merely selling the customer what you made (and told them they wanted); companies had to start listening to the customers and responding to their newfound perception of, and demand for value. This situation, coupled with the strong possibility of an economic crisis if they remained stagnant in their production philosophies, presented no choice but to radically change current manufacturing techniques. Japanese managed plants were continuously outperforming their American counterparts. Between the years of 1968-78, US productivity increased by 23.6%, but the Japanese experienced an impressive 89.1% increase (Teresko, 2005). Their response was to negotiate strategic partnerships between themselves (major US) and Japanese car manufacturers, such as Mazda and Ford (Chan and Wong, 1994), and the New United Motor Manufacturing Inc (NUMMI) set up between General Motors and Toyota (Chan and Wong, 1994, Waurzyniak, 2005). This enabled the West to take advantage of the TPS paradigm, producing more variety at minimal cost, supplying downstream customers with only what they require, when required, in the correct volume. Additionally, these alliances provided a safety net of reduced risk for the Japanese partners (Chan and Wong, 1994), normally associated with the development of overseas facilities.

Numerous examples of successful lean initiatives exist within the automotive and aerospace sectors. Mitsubishi started a joint venture with Volvo (NedCar) that saw the same advantages experienced through the NUMMI initiative. By using IT to underpin the monitoring of production, and focussed efforts on the reduction of down-time, real time data was used effectively to increase the visibility of information within the organisation, resulting in increases in morale and efficiency (Anon., 2004). Chrysler

used resources to extend in house training of lean philosophy to its major suppliers, emphasising the commitment needed from all parties in order to establish lean, and realise the full potential for everyone involved (Anon., 1997a). Delphi took a multi-pronged approach, looking at supplier development, cost management, strategic sourcing and quality issues (among others), led by top management**,** again emphasising the long term commitment needed, and highlighting the importance of knowledge management provide clear examples for the automotive sector (Nelson, 2004).

Boeing and Lockheed Martin (Blake and Eash, 2003, Olexa, 2003) offer examples of success within aerospace manufacture. Through directed efforts concentrating on education and demonstration of improvement tactics, and developing in-house expertise to manage and continue implementation projects (Blake and Eash, 2003), Boeing successfully cultivated a continuous improvement culture and in turn passed on their knowledge to suppliers through a Supplier Management Lean Integration Team. Such efforts led to the halving of lead time on the delivery of 737s and consolidating factory space by some 30% (Park, 2004). Lockheed Martin took advantage of being able to start with a fresh canvas, designing operations before manufacturing began. From design for rapid assembly, utilising common parts wherever possible, to mistake proofing assembly processes and using cellular design, final assembly now takes 2 hours for the F-35, as opposed to six days for its predecessor (Olexa, 2003).

Lynds (2002) recognises the importance of leadership and commitment needed by top management to embrace the lean approach and share their experiences company wide, so that communication barriers are overcome, and experiences are shared. In this example, floor space is reduced, resulting in more cash for the company after being able to sell off excess space. Although labelled ‘common sense’ in this article, it can be said

that this is one of the barriers to lean implementation, as some key elements of lean, such as reducing inventory as much as possible, is counter intuitive, as any work in progress has traditionally been thought of as a safety net helpful to ride out any problems in the system.

2.5 Lean Supply Chains

It is possible for an organisation to implement lean without its suppliers adhering to the same working principles, but the result is a fractured pull system that does not adhere to the true ideals of lean. Moving towards one piece flow is impossible, while many forms of waste are present. It is evident that to become truly flexible and responsive to customer demand, lean principles must extend along the supply chain. The emergence of globalisation and its resulting international competition is driving organisations to examine the efficiency of the total supply chain in order to retain a competitive edge. In other words, when applied locally, a lean philosophy itself isn't enough to guarantee sustained market share, and does not automatically lead to the lowest cost solution (Jones et al., 1997).

One notable scenario that emerges in supply chains is that any larger organisation within it will rely on the flexibility of their suppliers in order to fulfil customer demand, and because of their dominance, can afford to be inflexible and demanding themselves (Bamber and Dale, 2000). To improve this situation, total visibility is required between suppliers and their customers, in order to break the cycle of reactive fulfilment of orders, and create a truly lean enterprise (Tinham, 2005b).

The essence of lean supply was first put forward by (Lamming, 1993):

> "*The state of business in which there is dynamic competition and collaboration of equals in the supply chain, aimed at adding value at minimum total cost, while maximising end customer service and product quality.*"

Although not easy (Anon., 1997b), the journey towards becoming a lean supply chain must be first based upon a good level of cooperation and understanding between the final assembly plant and the first tier suppliers. This in turn should lead to supplier associations evolving, creating an environment where all parties undertake research and development for the greater good – creating a knowledge bank of information that is available to all, enabling the production of superior products. Once on its way to being established, this culture can then lead to all nodes within the supply chain driving towards cost reduction objectives. As noted by Srinivasan et al. (2005, p. 21) "*properly executed, lean is an effective growth strategy*".

However, to achieve this, the differing interests and attitudes of all parties involved within any supply chain must be understood to be successful (Lamming, 1996). The comprehensive implementation of lean is certainly not an easy one to extend along the chain. The research of Hines et al. (1998) explores the development of lean supplier networks and the structure of supplier associations necessary to develop a lean supply chain, while Kale et al.(2001) examine the benefits that can be achieved through the integration of strategic alliances. Langfield-Smith and Greenwood (1998) provide further insight into the development of supplier relationships, emphasising the fact that

if each partner within the supply chain comes to some sort of long term commitment to the other parties involved, it would be mutually beneficial to everyone.

Visibility is key to the establishment of effective supplier networks and strategic alliances, and trust is critical to establish this visibility (Kwon and Suh, 2005). Due to the vast amounts of data involved in the creation of a 'transparent' supply chain, the role of information technology is imperative to establish real-time supply chain visibility, replacing material flow with information flow (Gort, 2005, Tinham, 2005a).

On a micro level, examining the value stream of a product within a system can achieve a certain degree of improved efficiency, but in order to comprehensively address the value added activities from procurement of raw materials through manufacture, to delivery to customer, it is necessary to consider the macro level operations, or in other words the total value stream. This extends in both directions along the supply chain, and considers every activity that the product or service encounters. Taylor and Brunt (2000) consider the importance of the total value stream of a product family, and illustrate the true scope of a value stream below:

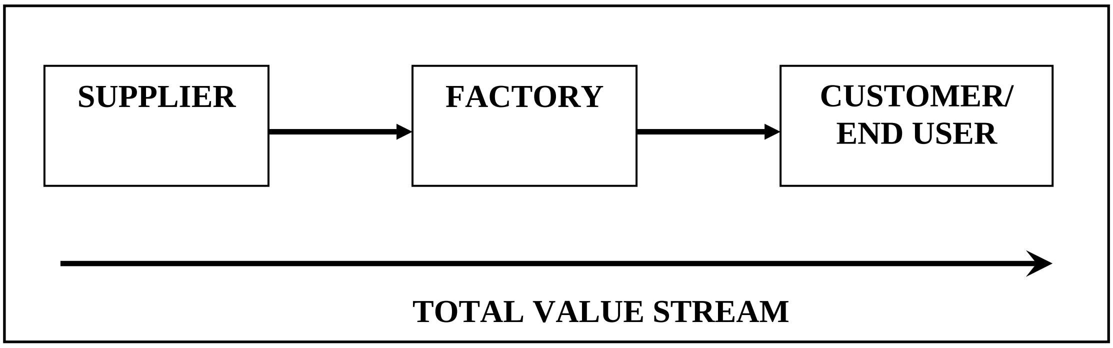


Figure 2.2 Value Stream Scope

(Taylor and Brunt, 2000)

Figure 2.3 below extends the illustration in Figure 2.2 (Taylor and Brunt, 2000) from the individual system to the complete supply chain, with lean principles underpinning the concept of agility. Where lean addresses efficiency, and agility addresses flexibility.

This is best described by Naylor et al. (1999, p. 111):

"Agile calls for a high level of rapid reconfiguration and will eliminate as much waste as possible, but does not emphasise the elimination of all waste as a prerequisite. Lean manufacturing states that all non-value adding activities, or muda, must be eliminated. The supply chain will be as flexible as possible but flexibility is not a prerequisite to be lean".

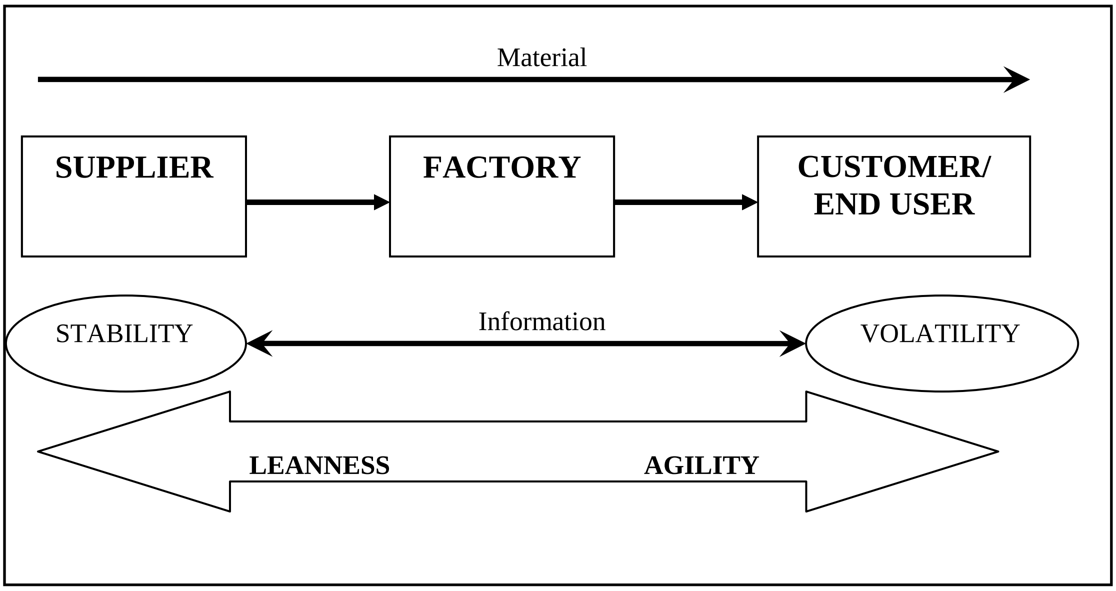


Figure 2.3 Leagile Map

The concept of agility centres on four key points outlined below:

1) Delivering value to customer
2) Being ready for change
3) Valuing human knowledge and skills
4) Forming virtual partnerships

(Katayama and Bennett, 1999)

As Kidd (1994) points out in his extensive work on the concept, lean is necessary but in itself not sufficient to achieve agility. McCullen and Towill (2001) provide insight into the synergies of agility and leanness, and suggest that leanness is achieved through the application of agility. It can be discerned from this that a system must be operating efficiently before it can be aligned to enter niche markets and cater for ever more demanding customers (Robertson and Jones, 1999).

Instead of regarding lean and agility as individual philosophies, it has been discussed most notably by Naylor et al. (1999), Prince and Kay (2003), and Huang et al. (2002) among others; that the two approaches in fact compliment each other, forming the new paradigm of ‘leagility’ (Naylor et al., 1999).

When only lean techniques are applied, they will lend themselves to functional, predictable markets (low variety high volume) (Childerhouse and Towill, 2000). Conversely, when the concept of agility is also introduced, the two tools together will lend themselves to both the functional, predictable markets, and the volatile and niche

markets (low volume high variety). These volatile markets had not yet been able to fully realise the potential gains from lean.

Both lean and agile paradigms need to be part of a total supply chain strategy (Naylor et al., 1999). The key to the alignment of lean and agile paradigms revolves around achieving the correct balance of the two throughout the supply chain. Figure 2.3 also shows how the balance between the two concepts varies along the supply chain structure.

2.6 Limited Success of Lean

The automotive industry's adoption of lean does not escape without criticism, with not every attempt at becoming lean proving beneficial for the employees or successful for the overall company (Parker and Slaughter, 1994, Rinehart et al., 1997). This seems to stem from a lack of understanding, direction and/or commitment from management (Hancock and Zayko, 1998), not helped by the heavily unionised culture of the majority of industrial workers (Hall, 1992). The following reveals the importance of changing the existing organisational culture within a company for the purpose of lean implementation. Namely that the management and their communications are the most critical part of the transition to lean thinking, and provide the backbone of any continuous improvement effort, while employees require transparency from management and their own education and empowerment in the change process.

In a development beyond lean's initial application to low variety, high volume facilities, some attention has been given to the viability of applying lean principles to 'job-shop'

companies, i.e. high variety, low volume (Winter, 1983, Jina et al., 1997, Hendry, 1998, Irani, 2001). In fact, research (Boughton and Arokiam, 2000) suggests that lean applications are essential for survival and growth in today's job-shop industry. However, the relevancy of lean manufacturing in these operations has been brought into question through the suggestion that value-added activities do not take into account the size, complexity or manufacturability of a product. Therefore if the theory behind lean is flawed, then the [sic] universality of lean must clearly be questionable (James-Moore and Gibbons, 1997). As discussed by Irani (2001), job-shops face the toughest obstacle when trying to map and analyse the flow of approximately 100-2000 plus product routes through their manufacturing facility. Complicated and in depth algorithms and often prohibitively expensive IT solutions are needed to overcome this difficult scheduling task.

Ultimately, lean implementation has not been as successful here as in their mass producing counterparts for three main reasons. Firstly, huge product portfolios mean that each 'job' is likely to be different and therefore production approaches cannot be standardised. Secondly, the products' characteristics create production constraints. Thirdly, the job-shops or smaller firms simply cannot match the dominance or resources that the larger firms enjoy, allowing them to be inflexible along their supply chains (Bamber and Dale, 2000).

This is not to say that the implementation of lean has always been successful in the low variety, high volume environments. Rinehart et al. (1997) provide perhaps the most well documented account of how lean can fail, through a detailed account of the consequences brought about through inappropriate management of continuous

improvement, and the reaction of disillusioned union members associated with the plant. It is suggested in this work that although the management of the situation was inappropriate, ultimately the employees were disillusioned with the lean production philosophy itself. Staff became offended by the reduction of everyday operations to repetitive and relatively easy tasks, along with the lack of collaboration and communication from management, resulting in directed orders, rather than a cooperative step forward. However, if correctly structured and communicated, sustainable inclusion of the employees in the lean movement would be obtained, and issues arising from any changes made would be feedback to the system and managed accordingly. If this does not happen, it has to be a fault of the management and driving force behind the implementation effort.

Building on this, the suggestion that lean is pro company, not pro employee has some validity, and cannot be dismissed. For example, it is said that, employees feel a sense of insecurity, perceiving lean as a threat, i.e. a method for reducing staff numbers. The opinion is also held that management avoid accountability when problems arise, letting it filter downwards onto the lower levels of hierarchy (Parker and Slaughter, 1994).

This is to miss the fundamental underpinning that is empowerment and cultural change, resulting from a failure by management to approach lean with the correct goals. Instead, it should be remembered that lean requires and relies on a review of organisational values, which in itself is key to the long term development of an organisations' lean efforts. From this we learn that if an appropriate strategy is not planned and managed for the existing organisation (in terms of culture), the desired cultural change will not be achieved. Instead there results an adverse affect on morale,

increasing levels of worker unhappiness and withdrawal, ultimately leading to operational failures (Hines et al., 2004).

The lack of employee education and empowerment, when coupled with the resistance of management to invest in relatively cheap mechanisms for waste reduction and quality improvement, can have a devastating effect on the chances of lean success throughout the facility. This highlights the need for a total and long term commitment from management to complete the internal culture change, so as to become a lean enterprise. Management tend to concentrate on tools and practices, rather than viewing lean as a philosophy, aiming to teach new improvement tools to employees, rather than immersing them in the practical side of solving opportunities for improvement with a lean approach (Spear, 2004).

If the “pro company” attitude is present within an organisation, it has the potential to not only damage the existing improvement efforts, but also any future efforts as well. If appropriate leadership is lacking, and the company culture is not already one of continuous improvement, it is likely that a new initiative such as lean will be adopted by the organisation and used in name only. This new initiative will then be used as an excuse to cut back jobs, because the company is ‘improving’ or ‘going lean’. The whole organisation and its operating culture will be affected by such a move, leaving a legacy of mistrust.

Further, even if the people responsible for the situation and/or top management were replaced by fresh, effective leaders of change, it will prove difficult if not impossible to

obtain any employee trust and therefore participation and cooperation for any new move towards change.

The memory of the failed improvement ingrained in the organisation's psyche will present huge resistance to any further attempts at implementing improvement initiatives. In this case, it will take years to overcome the barriers caused by the incorrect management practices that occurred previously. This is why it is so important to take the correct approach and communicate clearly the reason for change, and why the improvement initiatives are being adopted, laying the foundation for a positive "*learning culture*".

The legacy of using lean, or any other improvement approach as an excuse for reducing numbers is long standing and will dictate how the organisation responds and evolves for at least the next generation of employees.

In summary, the reasons for the unsuccessful attempts to adopt a lean philosophy can be separated into two categories:

1) The lack of management understanding and/or involvement in a top down approach and a lack of attention given to the organisational culture change required from the very beginning, resulting in an incorrect approach to implementation.

2) Failure by operative staff to perceive the value of adopting a new working paradigm.

Koenigsaecker (2005) explores how the lack of senior management involvement can detrimentally affect the organisation, while the incorrect approach, an example of which is given by Plankey Videla (2004), saw supplier forced organisational change, totally lacking in support and resulting in the company making promises of higher wages and financial incentives that couldn't be met, in turn leading to strike action.

2.7 Current Lean Direction (Broadening Scope of Lean)

The scope of lean is broadening as it is recognised by new fields. As more information becomes readily available through sources such as the internet, peer reviewed journals and magazine articles, which effectively market lean as a solution for improving business operations; it is becoming increasingly easy for management to access material that will help them on their journey of continuous improvement. One successful adoption is the application of lean principles to the construction sector. Ballard et al. (2003) provide an example of lean techniques including 5S, cellular design, work flow and standardised design being used in pre-cast concrete fabrication, that led to a reduction in lead times, and increases in factory throughput and productivity. Dunlop and Smith (2004) have demonstrated how the identification of waste and efficient scheduling within concrete pour can lead to increased productivity.

'Transactional lean' is the label given to lean's presence in service industries and office environments, where information and not manufactured products, are the commodity. Examples of this being Straker (2004) and Ehrlich (2006) among others. Research has begun to take the direction of proposing 'lean academia', where standardised coursework, and activities such as the value stream mapping of administration processes

in order to reduce student waiting time (i.e. for examination results etc) (Comm and Mathaisel, 2003) can all be implemented in a value driven, customer focussed environment. Emiliani (2004) proposes the use of focussed, shorter reading lists, along with regular student feedback (so as to keep the customer in mind) and the use of shorter, regular examinations, rather than long, bi-semester assessments, effectively bringing load levelling principles to academia. The same common theme runs throughout these different applications of lean - certain tools and techniques from the lean philosophy are being cherry-picked, either on their own or with a select few other management techniques (Beachum, 2005). There is finally a start to the development of a whole multi-industry appreciation of the benefits, and need for a shift into customer driven supply, be it a service or a manufactured product. It appears that all industries are being forced to take on these techniques due to the competitive global market, and adapting what they can now see, are an effective set of tools in order for survival and growth.

Areas of high innovation, for example, telecommunications (Robertson and Jones, 1999), and personal computer manufacture show how lean is critical to achieving flexibility and quality in sectors where rapid technological advances are inherent within the nature of the product. A key example being Dell Computer Corporation (Pritchard, 2002). The need for synergy between the manufacturing and marketing functions within such applications are critical, as the service dimension is brought to manufacturing in order to remain competitive in situations where as soon as a product rolls out, the technology behind it is obsolete (Fynes, 1994).

Since adopting lean philosophy, Pulte Homes Inc., have seen profits increase by up to 61% through cherry-picking lean ideas like the standardisation of better quality fixtures in their homes, centralising their approach (Kerwin, 2005).

The application of lean in the healthcare industry is considered the current direction of lean efforts to date, with objectives in place to reduce waiting time on the NHS in the UK (Jones and Mitchell, 2006), through the mapping of variation with capacity usage, leading to its eventual reduction (Silvester et al., 2004). Daniel (2005) describes how the processes involved in seeing a patient (waiting times etc) can be streamlined through the analysis of value added activities.

In the literature there appears to be three key areas of discussion surrounding lean. Namely the:

- Successful implementation, for example (Anon., 2005)
- Examination of key elements or techniques that have been used in such applications, for example (Kasul and Motwani, 1997)
- Enabling power of IT within an organisation implementing such philosophies (Anon., 2005, Tinham, 2005b)

While providing useful commentary on the scope and direction that lean initiatives should take, the need or identification of specific industry dependent methodologies has so far remained an area of relatively minimal investigation.

2.8 Continuous Process Lean

As examined in the previous sections of this chapter, the lean approach to continuous improvement has had success in a number of diverse industries and encountered limited success in others. The transfer of lean techniques to the process industry sector continues to present new scope for the implementation of continuous improvement techniques.

A member of the process industry may be defined as:

"A manufacturer who produces with minimal interruptions in any one production run or between production runs of products which exhibit process characteristics such as liquids, fibres, powders, gases"

(Fransoo and Rutten, 1994, p. 47)

The process industry sector enjoyed considerable growth up until the late 1960s (Anderson, 1997). Due to the fact that profits were easily made, it can be argued that a certain amount of complacency became embedded in the manufacturing culture of these organisations. Throughout these boom years, facilities were designed with significant storage capacities, but issues of efficiency were not addressed (Anderson, 1997). As a consequence of this, a number of today's process industries are left with inflexible facilities due to their original setup and ingrained mindset that holding inventory is a positive attribute in the supply chain, due to uncertainty in demand. However, if this uncertainty is identified and managed in the correct manner, significant savings, along with increased efficiency and flexibility to demand can be achieved.

When considering the contribution made by process industries to national economies (Burgess et al., 2002, Van Donk, 2005), the importance of maintaining existing market share, as well as seeking growth cannot be underestimated. Anderson (1997) addresses this issue in his work, and also emphasises that this sector must look to technology to help improve process measurement and control. For example, management need to harness soft computing techniques such as neural networks to help underpin process measurement and control. These and other emerging technologies must be embraced not avoided. Such tools are cost effective, providing significant economic savings necessary for sustainability and growth. As put forward by Anderson, "*the return on investment of the innovative application of control and measurement technologies is very large*" (Anderson, 1997, p. 161).

This is not to say that every business operating within the sector must solely rely on technology to remain competitive. The relevancy of utilising technological solutions must be carefully assessed for applicability. This is a view presented by Jones (2005), when considering the increasing scale of the global industrial arena, created by the emergence of economies such as China. "*The initial reaction of western firms and policy makers to the Chinese threat is to increase spending on technology and innovation…..those with responsive lean processes will win…..technology is not enough*" (Jones, 2005, p. 5) This is how technology should be integrated. It must be applied to process control, so that manufacturing systems can be made manageable and flexible; through continuous improvement, driven by a scientific approach in alignment with the philosophical ideas of lean thinking.

The process industry differs from discrete manufacturing in a number of ways. For example, it can be said that there is relatively little opportunity for WIP to accumulate, as there are no discrete processes in which inventory can queue between or act as a buffer. Winters et al.(p. 1) provide the following statement regarding the characteristics of the process industry:

"Process industries are typically characterized by very high fixed capital, concentrated in a small number of workstations. The production equipment is often physically large, and relatively fixed in nature. In most discrete manufacturing operations, the capital investment is smaller and spread across many workstations. As a result, continuous process manufacturing operations are less flexible to change than discrete manufacturing operations."

(Winter et al., p. 1)

The work of Fransoo and Rutten (1994) considers the differences inherent in various process industries, leading to the identification of two key groupings: flow process and batch process industries. A summary of the characteristics of both groups can be found in Table 2.1 (adapted from Fransoo and Rutten, 1994).

Table 2.1 Process Flow/Batch Flow Characteristics (Fransoo and Rutten, 1994)

Flow Process Industries	**Batch Process Industries**
High production speed, short throughput time	Long lead time, high Work In Progress (WIP)
Clear determination of capacity, one routing for all products, no volume flexibility	Capacity not well defined (different configurations, complex routings)
Low product complexity	More complex products
Low added value	High added value
Strong impact of changeover times	Less impact of changeover times
Small no. of production steps	Large no. production steps
Limited no. of products	Large no. of products

Furthering this work, Dennis and Meredith (2000) decompose the characteristics of the process industry even further, identifying four different dimensions of production and inventory management in the process industry through detailed studies of nineteen process facilities: simple, common, WIP-controlled and computerised.

Van Donk and Fransoo (2006), go on to categorise the literature and research surrounding the process industry into three key areas: Production Planning and Control (PPC), empirical studies, and research into the characteristics of process industries. From this, there appears to be a shift in the literature, with more attention being paid to the diversity within the sector from the early 1990's, rather than comparative studies contrasting continuous processing against discrete manufacturing (Van Donk and Fransoo, 2006). However, there is a thread of discussion surrounding the transferability of techniques and approaches from the world of discrete manufacturing to the process industry. Cooke and Rohleder (2005) advocate this transferability of methods to handle the demands of process facilities. This is characterised by capital intensive machinery working at high utilisation levels. On reflection, this situation would benefit from

having a responsive planning schedule, driven by strategic leadership and continuous improvement strategy.

This can be said to build on the work of Billesbach (1994) who considers the use of JIT principles within the textile industry, through their application to the discrete parts of manufacture, utilising a kanban solution for the materials handling within the facility. Cook and Rogowski (1996) have extended this view along the supply chain, and illustrating the point with a successful implementation of JIT philosophy in Dow Chemical North America, quoting improvements such as 25% increase in demand forecast accuracy, lead time reduced by 25%, and lead time variability reduced by 50%.

Loos and Allweyer (1998), Philpott and Everett (2001), Berning et al. (2004), Cooke and Rohleder (2005), and Appelqvist and Lehtonen (2005), all consider scheduling problems within the process sector. Loos and Allweyer (1998) emphasise the importance of the full integration of all logistics systems within an organisation, and conveys the belief that the design and management of lean business processes and their support by integrated IT systems is a critical success factor. Philpott and Everett (2001) developed the PIVOT optimisation model to address scheduling difficulties in the paper industry. Although it encompasses the whole supply chain, the complexity of the model could be seen as a barrier for timely adoption and comprehensive understanding.

Berning et al. (2004) propose the configuration of a fully customised optimisation algorithm that addresses the scheduling of production on a multi-plant level. Although a comprehensive approach to the problem of scheduling production on a macro scale, it needs to be embedded in the culture of the organisation through a philosophy of

continuous improvement; in order to make an ongoing enhancement of production processes. Otherwise it runs the risk of becoming an expensive tool that is restricting due to its technicality.

Hameri and Lehtonen (2001) examine the paper process industry. Here it is suggested that due to a limited number of specialist suppliers of large scale machinery, sustainability has to be created through strategic market acquisitions.

Simulation as a tool for the analysis and optimisation of process industries is a well explored theme. The work of Lehtonen and Holmstrom (1998) uses simulation, and discusses the suitability of JIT within paper industry logistics, outlining the benefits that can be achieved through a comprehensive implementation of lean tools, with JIT as a platform. The applicability of the lean philosophy is addressed, with Lehtonen (2000) demonstrating the benefits of adopting lean manufacturing principles through simulation. Appelqvist and Lehtonen (2005) take a simulation approach to validate a scheduling algorithm for the steel industry, but as with the previous simulation studies, the cultural aspects of continuous improvement have not been given any significance in the literature.

Although Hameri and Lehtonen (2001) suggest that optimisation through the application of lean thinking is rare, where it has been used, it has achieved its aim. Roy and Guin (1999) discuss the successful application of JIT purchasing in an Indian case study, and Brunt (2000) discusses a successful example of value stream mapping and other lean techniques in the steel industry. Through a comparative investigation of the UK's printing industry against the performance of "Britain's Best Factories", Benson

(2005) notes that the printing industry sector displays a certain amount of lean success, if only limited. Although safety levels within the industry are above average, other business metrics such as the “added value per employee” and the On Time and In Full (OTIF) order figure are lower than expected, which is especially surprising “*given the customer service nature of the industry”* (Benson, 2005, p. 2). Perhaps this can be attributed to the level of training within the organisations being insufficient for any transition to World Class performance. Again, this is essential if any attempt at continuous improvement is to be sustained. Continuous training must be an inherent part of the journey to continuous improvement, and be constantly revised for relevancy. Drawing on his experience as a judge for the UK’s Best Factory Award, Benson (2005) notes that the leaders, or ‘winning industries’ “*are responding to these pressures by delivering lean manufacturing, by proving outstanding customer service and quality to their customers and by continuously innovating in their products, manufacturing and office processes”* (Benson, 2005, p. 2).

Moving on from this, and as an effective solution, Ahmad et al. (2005) discuss the impact of using lean in conjunction with benchmarking and performance measurement to create manufacturing strategy on an operational level. This approach could equally apply to the training and continuous feedback needed to sustain levels of improvement within a facility. However, a step-by-step guide to mapping, improvement and benchmarking should be in place to ensure that any performance measurement and control of a system binds together the scientific approach and cultural inclusion necessary for such an initiative.

Recently, the work of Abdulmalek (2006) has focussed on the application of the lean philosophy and tools within the steel industry. Abdulmalek et al. (2006) provide a comprehensive overview of the implementation of lean tools in the process sector, and argues for a classification scheme which considers lean techniques on an individual basis. It aims to provide direction for engineers, attempting to select the most appropriate tools for their organisation through the consideration of material flow and product characteristics. This work leads the way in supporting the idea that process industries "*share characteristics with discrete industries that make it possible to implement lean techniques, but in varying degrees according to the specific industry*" (Abdulmalek, 2006, p. 24). It also provides evidence that if a framework for specific industries were to be designed, the organisation would benefit from a customised step-by-step guide, not to mention the resulting economic benefits.

Abdulmalek and Rajgopal (2007), go on to illustrate the benefits, through the use of simulation to model the improvements possible in the future state scenarios in order to inform the decision to move to lean philosophy, while providing a transparency of ideas to the lean team. Sustaining motivation when implementing change of any sort within an organisation is critical if it is to fully realised. It is believed that simulation, where resources allow, helps the case for change through dynamic views of current state and what-if scenarios. It also helps to provide a results orientated and total systems view of the improvement initiative and scope of the project, giving the opportunity to demonstrate to the entire organisation positive impact the improvement actions are having along the way.

As stated before, the need for a whole supply chain view is crucial when introducing the lean philosophy, or any continuous improvement initiative. Zhou et al. (2000) highlights how trust between suppliers and the building of strategic relationships are essential if a business is to compete and grow. Shah (2005) suggests that in terms of WIP, efficiency and supply chain cycle times, process industry benchmarks perform poorly when compared to the automotive sector. Conceivably, this could be due to the inflexibility inherent in the original facility design constraints, as previously discussed by Anderson (1997). However, strategic decisions and solutions must be found for these constraints, as "*it is often difficult to effect large improvements simply by changing logistics and transactional processes – fundamental changes at the process and plant level and at the interfaces between …….the value chain……are often required*" (Shah, 2005, p. 1225)

In summary, if continuous process industries are to remain competitive and achieve sustainable improvements, business strategies must be aligned with operational improvement objectives and process measurement and control. Taking a broader perspective, as part of these strategic decisions, it will also be opportune to extend the service provided to the customer, for example, "*looking to provide extra value….by improving customer service or providing additional services*" (Potter et al., 2004, p. 208). Shah (2005) describes this as moving from a product orientated focus, to service orientated focus, with life cycle solutions being offered in conjunction with already value efficient products.

2.9 Six Sigma

It can be said that the six sigma approach was born out of the Total Quality Control philosophy, a phrase coined by quality management guru Feigenbaum (1991), but conceived and conceptualised through the work of Deming (2000) and Juran (1999). Under the moniker of Total Quality Management (TQM), Deming introduced the then revolutionary theory that the people element had a place in process improvement, which must be aligned and managed along with technical knowledge and process data, to achieve true continuous improvement. Through this work, Deming brought worldwide exposure and recognition to the philosophy. Provokingly, TQM was as successful in it's time as six sigma is at present, but it is not around in its entirety today, and has somewhat faded from view. Due to the fact that the TQM movement was predominantly led by consultants, this meant that the fundamental concepts were not ingrained in the organisations that adopted the approach. The skill base was external from the organisation, with the consequence that once newer management concepts (lean, six sigma) started to gather more publicity, TQM had not taken root sufficiently to survive completely. The basic premise behind the six sigma approach is essentially the same as TQM – the concept that if continuous improvement is to be realised, the support of the whole organisation is essential, with a push from top-down, and a continuous training and development program must be sustained to drive change forward (Black and Revere, 2006).

To fully appreciate the strengths of the six sigma approach and its fierce and widespread adoption in today's business arena, it is important to explore the reasons behind the failures of TQM, once a profound paradigm in the evolution of management science, but now somewhat superseded by six sigma. TQM presented an all encompassing,

comprehensive philosophy to the management of quality and continuous improvement. Numerous reasons for, and reflections on its failures can be found in the literature. Examples cited include the lack of continuous training and education within the organisation (Masters, 1996), failure of management to properly lead the change initiative (Curry and Kadasah, 2002, Sebastianelli and Tamimi, 2003), and what the author believes to be the most significant reason, the fact that *"TQM systems are not designed to fit the cultural circumstances of the organisation"* (Sebastianelli and Tamimi, 2003, p. 3).

This is a view supported by Blackiston (1996), who suggests that companies may choose the wrong techniques, strategy or tools for their specific environment. This misdirection of appropriate strategy and/or tools could also result in the project focus being concentrated on non-value added areas of the business, as suggested by Black and Revere (2006, p. 259) "*quality efforts were sometimes aimed at processes or operations not critical to the customer"*. This resulted in TQM efforts no being aligned to the business case of the organisation, and therefore it proved difficult to quantify improvements in terms of key performance metrics that the organisation could relate to.

This issue has been compounded by the fact that TQM was embraced as a "cure-all" business elixir by a myriad of management consultants, consequently the driving force and leadership came from outside influences rather than within the organisation itself. Much like the approach of many continuous improvement consultants today, generic improvement models were being applied to vastly different situations, with a belief that "*a set of general concepts and generic principles could be applied in all circumstances"* (Micklethwait and Wooldridge, 1997, p. 62). In most cases this led to suboptimal

performance improvements, despite organisations having invested significant sums of money.

Six sigma as recognised today was developed at Motorola through the efforts of Bill Smith, a reliability engineer in the 1980s (Brady and Allen, 2006). However, the real turning point in six sigma's shift in popularity came with the attention of Jack Welch, the then CEO of General Electric in 1995. Welch had observed the success experienced through Bill Smith's approach and intensely championed the six sigma methodology in GE through effective leadership (Black and Revere, 2006).

The term 'six sigma' refers to a statistical measure of defect rate within a system. Underpinned by statistical techniques, it presents a structured and systematic approach to process improvement, aiming for a reduced defect rate of 3.4 defects for every million opportunities, or six sigma (Brady and Allen, 2006). To help illustrate the meaning of six sigma defect rates within a system, Pande et al. (2000) provide some useful examples of working at the rate of 99% quality, or the superior rate of six sigma quality in a number of different situations. For example, if the post office was working at a 99% quality rating, for every 300,000 letters delivered; there would be 3,000 misdeliveries, compared to only one misdelivery if they were operating at a six sigma level. If television stations operated at 99% there would be approximately 1.68 hours of dead air time experienced per week in comparison to the 1.8 seconds experienced if working at six sigma levels (Pande et al., 2000).

Six sigma brings structure to process improvement by providing the user with a more detailed outline of Deming's Plan-Do-Check-Act cycle by guiding the initiative through

a five stage cycle of Define-Measure-Analyse-Improve-Control (DMAIC) (Pande et al., 2000). Each stage has a number of corresponding tools and techniques such as Statistical Process Control, Design of Experiments and response surfaces, providing the user with an extensive tool box of techniques, in order to measure, analyse and improve critical processes in order to bring the system under control (Keller, 2005).

Andersson et al. (2006) draw from the literature the objectives of each of the DMAIC stages as follows:

Define: Define which process or product needs improvement. Define the most suitable team members……..Define the customers of the process, their needs and requirements, and create a map of the process that should be improved.

Measure: Identify the key factors that have the most influence on the process and decide upon how to measure them.

Analyse: Analyse the factors that need improvements.

Improve: Design and implement the most effective solution. Cost-benefit analysis should be used to identify the best solution.

Control: Verify if the implementation was successful and ensure that the improvement is sustained over time.

(Andersson et al., 2006, p. 287)

Intensive training of key staff is critical in order to follow the DMAIC cycle effectively and gain significant results, as is the buy-in of senior management if the initiative is to take root. Management must play an active role in the selection of projects for the newly trained six sigma teams to focus on, and also ensure that all required resources are made available (Raisinghani, 2005). From this, the roles required for

implementation must be specifically defined and made clear within the organisation before embarking on the six sigma journey, so that everyone involved knows their responsibilities, exactly what needs to be done and in what order (Pande et al., 2000). Emphasising this point, it is essential that six sigma should be understood to be a philosophy as well as a scientific approach.

Keller (2001) has noted the shift in acceptance of six sigma from a set of tools to an overall management philosophy. This highlights an important point in the prevention of six sigma becoming stagnant and coming to the same fate as its TQM predecessor. It needs to evolve if it is to remain a relevant and sustainable approach for business. McAdam and Lafferty (2004) suggest it needs to be embraced as a continuous improvement management philosophy in order to embed itself in the psyche of organisations. [Six sigma] has "*some way to go before it is fully accepted as a broad change philosophy*" (McAdam and Lafferty, 2004, p. 546). The two authors go on to show that six sigma is not in fact a replacement for TQM, but refocusses the mechanised side of it, providing important business metrics. This is key when looking at the broader context of six sigma, and its roots in the TQM approach.

From this, it is useful to illustrate the pioneering work of Joiner (1994), and the Joiner Triangle (Figure 2.4), representing a distinct shift in how quality management initiatives have been embraced by business.

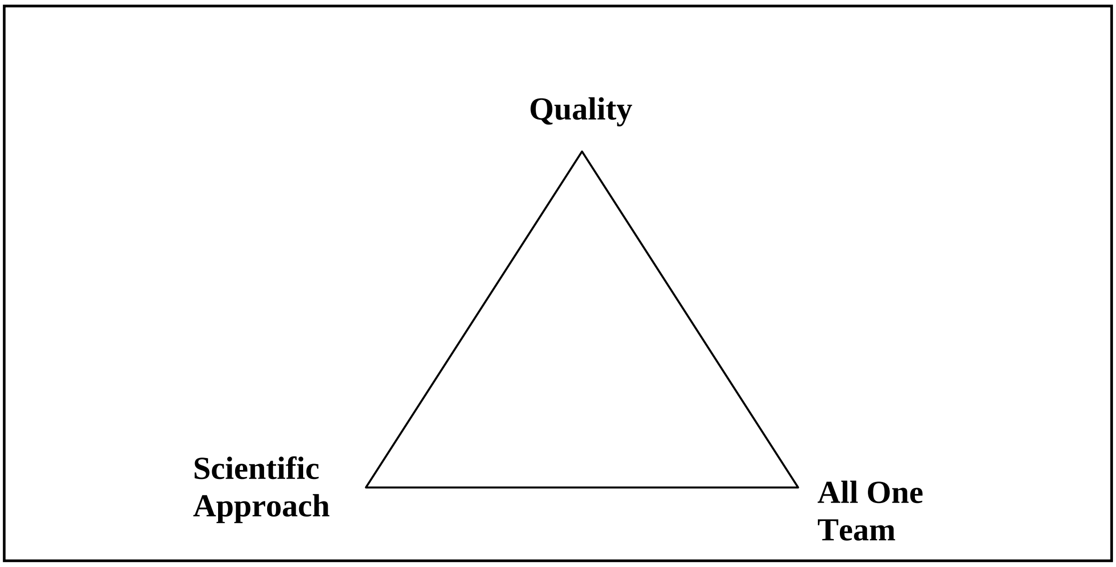


Figure 2.4 The Joiner Triangle

(Joiner, 1994)

The original Joiner triangle is equilateral in nature, depicting the equally interrelated core elements of "Fourth Generation Management".

However, when using the above to reflect upon the evolution of the TQM philosophy, the Joiner Triangle becomes skewed (Figure 2.5), as management focus became disproportionately geared towards the organisations people and the philosophical and cultural concepts behind Total Quality. Quality was still the driving force, but it lost emphasis on the scientific approach.

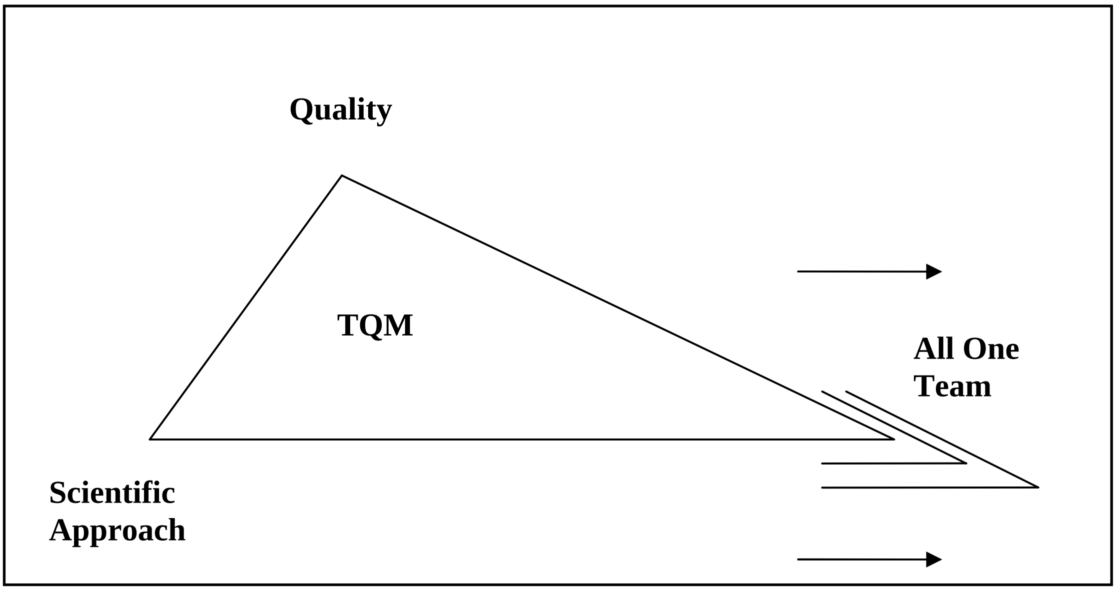


Figure 2.5 The Shift in Focus of TQM

Moving on from this, the six sigma methodology has brought about another change in focus. This has the result of skewing the Joiner Triangle in the opposite direction, so that the scientific approach is emphasised (Figure 2.6), at the cost of the critical people element. However, six sigma continues to be regarded as an overall philosophy for improvement.

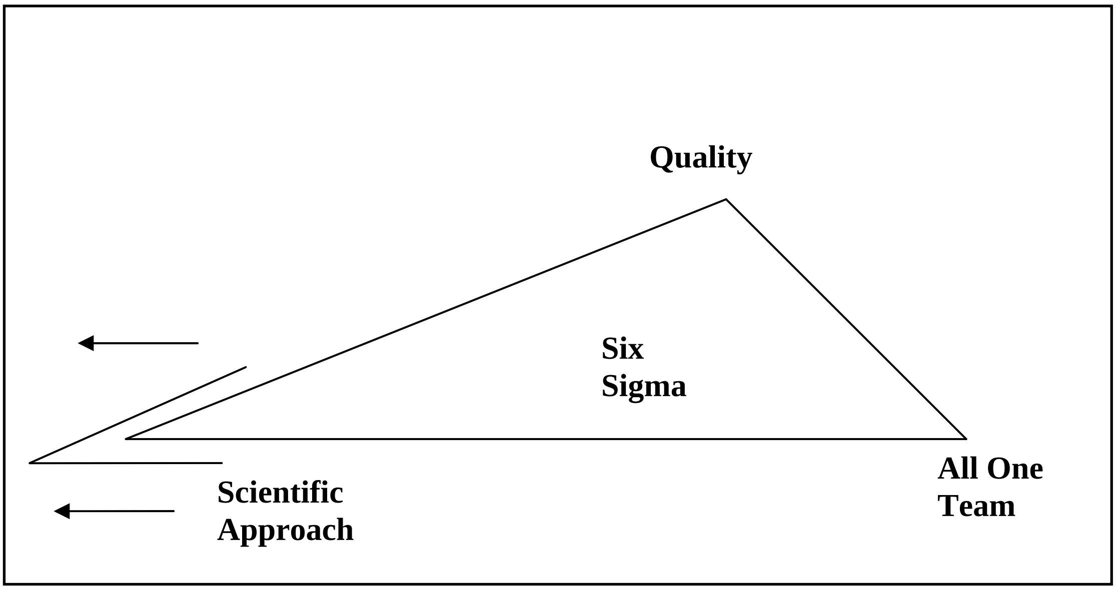


Figure 2.6 The Shift in Focus of Six Sigma

The shift in focus depicted between Figures 2.5 and 2.6 is a direct result of the loose associations between quality, the scientific approach, and the people perspective inherent in any system. These associations must be tightened and equally managed, if we are to achieve a sustainable outlook for continuous improvement. In other words, we need to aim for an equal growth on each side of the triangle, taking a systems view of the organisation as an organic, complex entity (Figure 2.7).

There have been a number of modifications to the Joiner Triangle including the placement of Management Commitment at the apex, which is often neglected at all levels of hierarchy within an organisation. Other incarnations have focussed on the fact that TQM failed because of the lack of foundation or underpinning of a sound quality system such as ISO 9000.

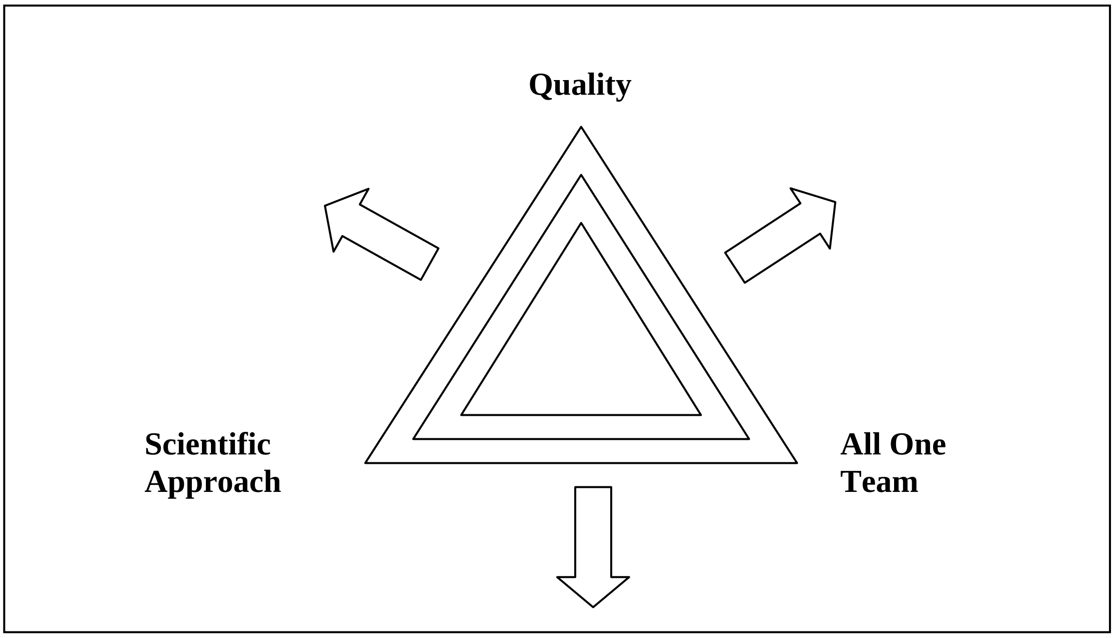


Figure 2.7 The Desired Holistic Focus for Continuous Improvement

Figure 2.7 better represents the objectives of continuous improvement, returning to the strengths of the original Joiner Triangle. It takes a holistic view that the people, data and overall goal of improved quality within a system are equally interrelated, and growth must be even in all directions, a notion somehow lost in translation in previous efforts.

However, the legacies of models such as the Joiner Triangle and the TQM approach have not been totally lost in management history. As an example, it is well established in the literature that six sigma has evolved from TQM, offering more to today's businesses in terms of tying improvements to business metrics. The fact is that all new improvement methodologies or approaches are decreed 'management fads' by those expected to use them in industry and academia alike. However, if we look back over the evolution of these 'fads', each one seems to disappear from view, but the essence is not completely forgotten, and certain parts of that 'fad' are carried forward into a new paradigm. In the eyes of the practitioner, every new improvement approach has a shelf life. It will only be a matter of time before six sigma is replaced by an updated methodology that will meet the shifting requirements of industry, but no doubt this will include some of the DNA left behind from TQM, six sigma, and the myriad of other approaches that have existed before them.

2.9.1 Six Sigma in Practice

The application of six sigma in a variety of industries is well documented in the literature. Examples in the manufacturing sector include Knowles, Johnson et al. (2004), Thomas and Barton (2004), and Motorola and GE (Pande et al., 2000) as perhaps the most famous. Six sigma has also been used successfully in the construction

industry (Stewart and Spencer, 2006) and accounting practices (Brewer and Bagranoff, 2004). The main body of current literature however is focussed on the application of six sigma principles in the service sector (Sehwail and Deyong, 2003, Antony, 2006, Chakrabarty and Tan, 2007).

Chakrabarty and Tan (2007) provide a comprehensive review of the literature in service industries, finding that most applications of six sigma occur in the banking and healthcare sectors. They go on to highlight that proper identification of key performance indicators, and success factors critical to quality metrics are essential if organisations are to succeed. This appears to be one of the major challenges for the deployment of six sigma in the service industry context. Sehwail and Deyong (2003) discuss the challenges of six sigma in service industries, with particular emphasis on the healthcare sector; three key issues arise from their research. Firstly, due to the greater variability in responses from processes in a service environment, it is difficult for organisations to identify the equivalent concept of a 'defect'.

The second issue of creating cultural change by nominating six sigma leaders within the business is a challenge shared by any organisation implementing change. This is discussed further in section 2.11 of this chapter. The final issue identified is the failure of service industries to capture the benefits of any improvements. This is consistent with the work of Chakrabarty and Tan (2007). They also point out that the failure to identify key performance metrics will make it impossible to quantify any benefits gained from the improvement process, and may lead to the approach being abandoned.

The importance of identifying key performance metrics is a recurring theme in the literature. Antony (2006) emphasises the importance of aligning projects to business objectives, and in agreement with Sehwail and Deyong (2003), reflects that the definition of six sigma as a quality measure must be taken in context for service industries. For example, "*a defect may be defined as anything which does not meet customer needs or expectations. It would be illogical to assume that all defects are equally good when we calculate the sigma capability of a process*" (Antony, 2006, p. 246). In other words, there is so much possible variation in the customer response, it is difficult to fit them in the constraints of whether they are merely a defect or not.

Taking a wider approach to the application of the methodology, Malin and Reichardt (2005) discuss the use of the Supply Chain Operations Reference (SCOR) methodology as a means to identify six sigma projects within the supply chain at Flexsys. Here, the scope of six sigma is broadened, as the SCOR methodology is used as a means to ensure optimal project selection, providing the in-house six sigma experts with an understanding of how the business operates when supplying different customers. This approach gives a more strategic outlook (Malin and Reichardt, 2005).

Yang et al. (2007) take a different approach, by way of an integrated "supply chain management six sigma" framework specifically designed for Samsung. Experiencing improvements such as a 37% drop in surplus inventory, the customised integration of supply chain management theory and six sigma methodology can be said to have been successful. However, it is important to note that the in-house experts will have been firstly trained in the generic six sigma framework, and secondly specialise to gain an understanding of a supply chain view. The cost effectiveness of resourcing and

implementing this two stage training must be questioned. It is also important to see six sigma as a continuous improvement tool for the whole supply chain as it stands, without separating the two concepts. Continuous improvement in any form must be approached from a systemic vision, and implemented throughout a supply chain if it is to become a sustained management philosophy.

On reflection, six sigma as a quality management approach, irrespective of industry or application, can be seen to have brought many positive elements to continuous improvement. Factors such as management commitment and open communication are essential for successful implementation as with any attempt at continuous improvement. In answer to this, it can be said that six sigma provides a clear focus on measurable financial returns through a sequential and disciplined manner, and establishes an "infrastructure of champions" with it's training style of introducing "belt" qualifications (green, black, master black belts etc.) within the organisation to lead the way in data driven decision making for improvement efforts (Antony, 2004).

However, for all of its supposed benefits, there are also a number of disadvantages that must be addressed for it to become a sustainable improvement technique, and not end up meeting a similar fate to its predecessors, and becoming just another 'management fad' that fades away when it has grown out of favour. First of all, the training for and solutions put forward by six sigma can be prohibitively expensive for many businesses, and the correct selection of improvement projects is critical (Senapati, 2004). Antony (2004) discusses the non-standardisation of training efforts (in terms of belt rankings etc.), and how this accreditation system can easily evolve into a bureaucratic menace, where time and resources are misspent focussing on the number of "belts" within the

organisation, and not he performance issues at hand. As with any business improvement approaches, techniques or philosophies, six sigma also faces a real danger of becoming lost in a consultancy practice, being oversold and incorrectly used, such as TQM. The relationship between six sigma and organisational culture has not been explored in the literature surrounding the subject (Antony, 2004), and it is essential that this gap is bridged so that the true potential of a comprehensive cultural improvement philosophy, underpinned by a data driven scientific approach is unlocked.

In summary, TQM was a profound, all-inclusive philosophy that presented huge potential to transform the way in which businesses of all disciplines were managed. However, this is also where the inherent weakness of TQM lies – the fact that it is only a “philosophy”. Six sigma moves beyond this view, and has recognised that organisations need direction in their efforts to achieve improvements, structuring the concepts and philosophical ideas provided by Deming into a methodology that can be followed to obtain process improvements. Six sigma has answered the critics of TQM, by associating quality improvement with specific business metrics, leading organisations to quantify any improvement made in performance terms. In conclusion, six sigma has succeeded in bringing the necessary expertise back into the firm through its strict accreditation process of sequential “belts” (green, black, master black belt etc.), and although expensive to train and implement, has at least brought about the recognition from practitioners that eluded TQM.

As with all avenues of process improvement however, it is critical that philosophy is aligned with scientific knowledge. Six sigma has long been seen as a statistics heavy, technical approach to process control. In order to prevent it becoming another ‘myopic

revolution' of improvement approaches, we must learn from our past mistakes, and ensure that the wider philosophy behind the structured technicalities of six sigma are recognised and acknowledged. In other words, we must not fail to recognise that without managing people correctly, or training new recruits, any technical improvements made to the processes will not be sustained.

2.10 Integration of Lean and Six Sigma

The literature reviewed so far has discussed the implementation of lean within a number of diverse industries. While the application of specific tools and techniques is present, there are no attempts to identify a methodology for a specific application or industry. This section goes on to identify the benefits of combining lean philosophy and six sigma, exploring what can be achieved through this integration.

The phrase "lean six sigma" is used to describe the integration of lean and six sigma philosophies (Sheridan, 2000). They share similar features, as they both evolved from TQM (Dahlgaard and Dahlgaard-Park, 2006). There is little literature available on the integration of these concepts when looking for a "*common model, theoretical compatibility or mutual content or method*", (Bendell, 2006).

The concept of lean six sigma as an approach to process improvement has yet to fully mature into a specific area of academic research (Bendell, 2006). It can be said that in practice the majority of efforts to fully and comprehensively implement a lean six sigma initiative to its full potential have not been realised (Smith, 2003). This failure to sustain a change towards continuous improvement can be attributed for one, to the lack

of commitment from management (Cusumano, 1994, Kotter, 1995). Specifically, in the case of fusing lean and six sigma, the two approaches have often been implemented in isolation (Smith, 2003), creating lean and six sigma sub-cultures to emerge within the organisation, which can cause conflict of interest and a drain on resources (Bendell, 2006).

Six Sigma complements lean philosophy in as much as providing the tools and know-how to tackle specific problems that are identified along the lean journey. Where:

> *"Lean eliminates 'noise' and establishes a standard"*
>
> (Wheat et al., 2003, p. 44)

Six sigma focuses project work on the identified variation from the proposed standard, which in itself does not entirely focus on the customer requirements, instead it is sometimes a cost-reduction exercise (Bendell, 2005) that can lose sight of the customer if not implemented alongside lean.

Similarities can again be drawn between lean and six sigma, and the need for a culture of continuous improvement operating at all levels within an organisation. Arnheiter and Maleyeff (2005) take this discussion further in their work on the integration of lean and six sigma, and put forward the benefits of such a consolidated approach. For example, providing lean with a more scientific approach to quality, so that through the use of control charts, processes can be kept on target, effectively reducing waste incurred through faulty processing.

Table 2.2 summarises the key lean implementation steps, along with the six sigma tool that can be used as an aid to achieve each task. It can be seen here, that lean and six sigma are ideally suited to be used in a comprehensive methodology incorporating the key elements of both, as each stage can gain from the respective techniques, both following the six sigma road map of *Define*, *Measure, Analyse, Improve, Control.*

Table 2.2 Synergies between Lean and Six Sigma, adapted from (Pyzdek, 2000)

LEAN	**SIX SIGMA**
Establish methodology for improvement	Policy deployment methodology
Focus on customer value stream	Customer requirements measurement, cross-functional management
Use a project-based implementation	Project management skills
Understand current conditions	Knowledge discovery
Collect product and production data	Data collection and analysis tools
Document current layout and flow	Process mapping and flowcharting
Time the process	Data collection tools and techniques, SPC
Calculate process capacity and Takt time	Data collection tools and techniques, SPC
Create standard work combination sheets	Process control planning
Evaluate the options	Cause-and-effect, FMEA
Plan new layouts	Team skills, project management
Test to confirm improvement	Statistical methods for valid comparison, SPC
Reduce cycle times, product defects, changeover time, equipment failures, etc.	Seven management tools, seven quality control tools, design of experiments

The integration of lean and six sigma aims to target every type of opportunity for improvement within an organisation. Whereas six sigma is only implemented by a few specific individuals within a company, lean levels the empowerment and education of everyone in the organisation to identify and eliminate non value adding activities (Higgins, 2005). The integration of the two methodologies attempts to provide empowerment even at the higher level process analysis stages, so that employees have true ownership of the process.

If the two are actually implemented in isolation, the outcome can result in neither being done effectively; constrained by one another's needs in the organisation (Harrison, 2006). Again, it could even create 2 sub-cultures within the organisation, competing for the same resources etc. (Smith, 2003).

When implemented as a stand alone philosophy, there is a limit to the scope and size of improvements achieved through the application of lean principles. Antony et al. (2003) suggest that this 'ceiling' of improvement is reached because the strategy used for improvement depends on the problem trying to be solved, and therefore must be aligned to achieve effective results. Antony et.al (2003) go on to suggest that this is a result of lean principles lacking a directed, cultural infrastructure as can be seen with the six sigma approach. This is a theme continued by Sharma (2003), who argues that six sigma methodologies should be used to help drive the implementation of lean efforts in an improvement initiative, as it can be difficult to establish any sort of momentum when attempting to extend the philosophy throughout the organisation or supply chain. Hence, these efforts need to be directed by a strong approach that is capable of maintaining direction and focus within the business.

Both approaches have the same end objective, to achieve quality throughout, whether it is customer service, the product, the process or training and education of the workforce. They are effective on their own, but organisations may well find that after initial improvement, they reach a plateau; and find it difficult to create an ongoing culture of continuous improvement (Arnheiter and Maleyeff, 2005). To overcome this, the lean approach must integrate the use of targeted data to make decisions and also adopt a more scientific approach to quality within the system. Six sigma on the other hand

needs to adopt a wider systems approach, considering the effects of muda on the system as a whole; and therefore quality and variation levels (Arnheiter and Maleyeff, 2005). Figure 2.8 shows how each approach can gain from being seen as a single framework, and also the balance that may be reached if effectively brought together. This is a key concept for the integration of the two continuous improvement approaches, as a state of equilibrium needs to be achieved between the two, moving away from a blinkered approach in any one direction, risking becoming too lean and therefore rigid in responses to the market and subsequently impacting on value creation. The other extreme is to concentrate too much on reducing variation beyond the requirements of the customer, and therefore wasting unnecessary resources in the pursuit of zero variation. The balance lies in creating sufficient value from the customer's viewpoint, so that market share is maintained, while at the same time, reducing variation to acceptable levels so as to lower costs incurred, without over-engineering the processes.

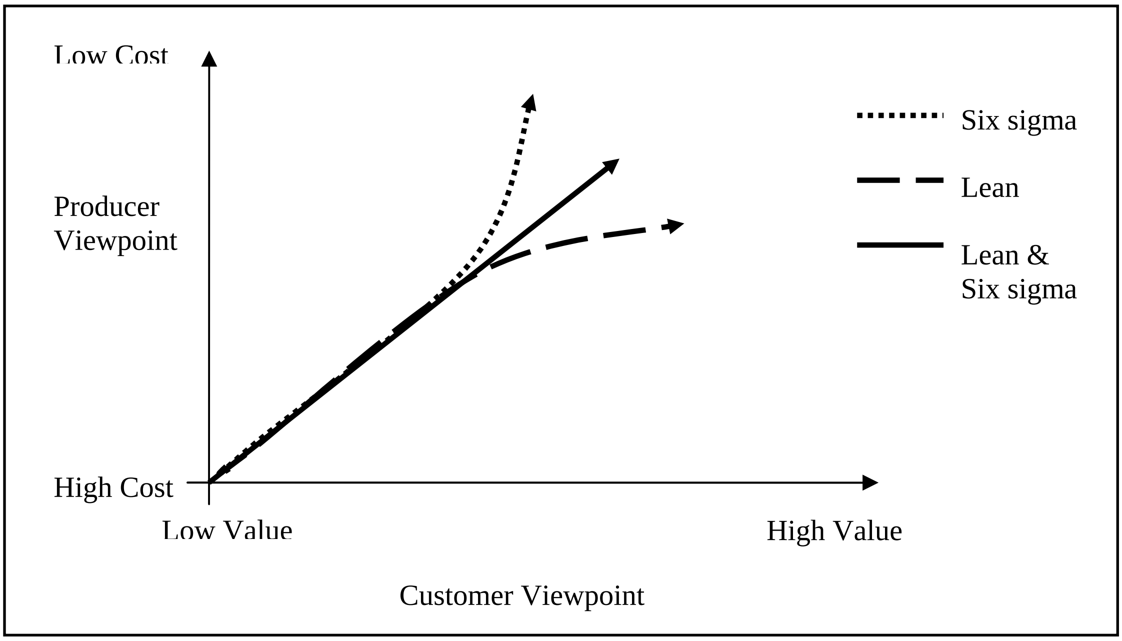


Figure 2.8 Competitive Advantage of Lean, Six Sigma and Lean Six Sigma

(Arnheiter and Maleyeff, 2005)

The integration of lean six sigma is not perceived by everyone to be an effective meeting of approaches. There is some criticism in the literature regarding the blending of the two approaches. Perhaps the most critical is Bendell (2006), who has extensive experience as both practitioner and academic in this field. He argues that lean and six sigma have become "*Ill defined philosophies*" (Bendell, 2006, p. 258), resulting in their dilution as effective tools due to "*relatively obscure…company specific training programmes*" (p258), going as far to say that "*the alleged combination is no more than a philosophical or near-religious argument about professed compatibility of approaches*" (p255). Bendell does go on however, to suggest that it would be beneficial for all if a single approach that effectively brought the two philosophies together was available.

These views reinforce the fact that although there appears to be a number of consultancy models for lean six sigma freely available on the internet by consultants, the presented methodologies are put together without logical explanation (Bendell, 2006) and more importantly, with no theoretical underpinning or explanation for the choice of techniques.

Spector and West (2006) take the view of the practitioner, pointing out that when adopting lean/six sigma, practitioners can find themselves commencing a large number of projects that yield insufficient results for the amount of time needed to complete them. In stark contrast, Mika (2006) takes the stance that the two approaches are completely incompatible with one another because six sigma cannot be embraced by the "*average worker on the floor*" (Mika, 2006, p. 1). He argues that lean is accessible by

these workers, and encourages effective teamwork through collaboration and participation through cross functional teams.

The key considerations based on this literature when constructing a new and a comprehensive framework for lean six sigma, are:

1) It needs to be strategic and process focussed.

2) The framework should be balanced between the two philosophies to harness the recognised advantages of both.

3) A balance between complexity and sustainability must be reached.

4) It should be structured around the type of problem experienced. Going one stage further than this is to develop an industry specific framework.

Lean six sigma is applicable to any system that has a series of processes. The next stage of development is to construct a lean six sigma framework that is geared towards nurturing the growth of commitment and sustainability. The framework needs to provide direction for the users, and more importantly results, over a relatively short timeframe. The author believes this is a particularly important criterion for an improvement framework, due to the need for quick improvements (i.e. proof of the value of such initiatives) to be realised in organisations for the benefits discussed earlier. It is not uncommon for pilot projects to be undertaken in order to demonstrate such initiatives.

In terms of successful lean six sigma efforts, Smith (2003) outlines two case studies that experienced impressive results from a combined approach to improvement. The first case study had been practicing lean for approximately 18 months when consultants were called in to push the improvements further. However, both case studies found that one of the two approaches became dominant in the improvement process. A fully integrated framework targeting specific industries will take away any such ambiguity over which techniques to apply where and in what situations.

Sharma (2003) also describes the benefits of using six sigma techniques in conjunction with lean, whereby strategic improvement goals are established by the company's leaders, and then a process of Quality Function Deployment (QFD) is used to prioritise the project work. Although effective in this implementation, there is no comprehensive framework present that specifically integrates lean and six sigma concepts through an implementation roadmap. The QFD approach can also be viewed as a more complicated approach to the selection of continuous improvement tools.

The work of George (2002) can be seen to lead the exploration of lean and six sigma techniques, providing the benchmark work for future researchers. Following on from this, one of the most comprehensive examples of research into this area is the work of Kumar et al. (2006), who have integrated some key lean techniques with the six sigma framework for implementation at an Indian SME. The approach taken was to develop a lean six sigma framework around the problems identified at the organisation, which while effective, may well be beyond the reach of most practitioners working under strict time and other resource constraints as discussed earlier. Some key points are made from this work as summarised on the following page:

1) There is no standard framework for lean six sigma.
2) There is no clear understanding concerning the usage of tools etc. within the lean six sigma frameworks.
3) With the framework presented, there is no clear direction as to which strategy should be selected at the early stages of a project.

(Kumar et al., 2006)

These points present key questions to be answered when considering the construction of an effective lean six sigma framework.

2.11 Characteristics of Change

"It seldom happens that a man changes his life through his habitual reasoning. No matter how fully he may sense the new plans and aims revealed to him by reason, he continues to plod along in old paths until his life becomes frustrating and unbearable—he finally makes the change only when his usual life can no longer be tolerated."

(Tolstoy, unknown)

Different people experience different emotions when faced with change. As introduced previously in this chapter, the reality is that today's businesses need to reflect on how they can change their approach to the way in which they do business, in order to remain competitive and gain and sustain market share. Continuous improvement initiatives have been adopted with varying degrees of success by organisations wishing to gain advantage in their domestic or international arena. This drive to analyse, reflect and improve organisations on an operational and more importantly strategic level is littered

with obstacles for the manager to effectively implement and sustain change. It is not only the processes or operations that need long term management interaction, but also the people directly involved with and surrounding these processes. This is succinctly put by Dawson (2005) *"The shaping and reshaping of technology and workplace arrangements is as much a social process as it is a technical issue"* (Dawson, 2005, p. 386).

To reiterate this point, the implementation of any continuous improvement effort, which inevitably has the desired result of changing the culture of an organisation to some degree, cannot be implemented from a purely operational standpoint. Mechanisms or identified techniques need to be established within the improvement initiative that helps the existing culture to evolve into one with a foundation of listening and thinking (Atkinson, 2004). This is a point emphasised by Balle (2005) when discussing the behavioural and affective aspects of lean, and their importance to successful implementation. Similarly, Boyer (1996) asserts that embedding the necessary skills and knowledge required for potential change efforts is crucial for the full adoption of lean by an organisation.

After an organisation has decided to follow a path of lean or lean six sigma continuous improvement; the common first stage is to target the most obvious opportunities for improvement and quick return (Balle, 2005), providing instant, visual improvements. Targeting the low hanging fruit of wasteful activities or elements of processes with techniques such as 5S can achieve quick gains that demonstrate the power of continuous improvement tools (Davies, 2005). The targeted implementation of these tools and techniques can lead to short, sharp, effective successes, which are key in gaining the

trust and “buy-in” of the employees involved (Davies, 2005), and helping lead the way for a lean culture to evolve.

The positive effect of this is that short term wins can give momentum to the initiative and motivate, building trust with stakeholders (essential for sustainable change) (Kotter, 1995). Ideally, this type of driving force for change would feature throughout an initiative; but this “honeymoon period” (Balle, 2005) of visible improvements and gains is often short-lived.

However, once again, management must fully understand the true scope of such techniques, and not latch onto them because of their relatively easy execution. The overuse of such techniques at the cost of ignoring other complimentary tools is in itself not a lean approach (Atkinson, 2004). This will not address, or even detract from other potentially fundamental issues that may benefit from lean/lean six sigma techniques to fully analyse and improve them. Once the scope and constraints of an improvement initiative have been established by a committed management, progress can then begin to establish the fundamental team competencies necessary, and select an appropriate approach for the business type.

After these more obvious opportunities are addressed, only situations that are in need of more detailed analysis, resources and commitment remain. It is at this point that the long-term commitment of the team, and more importantly management is put to the test. Like any project, clear goals and motivation need to be maintained to avoid myopia setting in.

The role and necessity for total managerial commitment to change programs such as lean six sigma cannot, and must not be underestimated. Literature discussing the importance of the commitment needed by managers and in turn the leadership skills required is well established (Kotter, 1995, Boyer, 1996, Brooks, 1996, Atkinson, 2004).

While effective leadership is essential for any organisational shift to a culture of continuous improvement such as lean/lean six sigma, it is also critical that the correct infrastructure of skills and knowledge, small working groups etc. is in place for success (Boyer, 1996). Although Boyer (1996) describes leadership as a supporting mechanism for a workplace infrastructure, leadership is a requirement for establishing any infrastructure in the first place. It is expected that the set up of any such business infrastructure will be a long and multi-faceted process.   It is imperative that the leaders of change (management) are not tempted to skip any of the stages or seek short cuts, despite possible frustration over the pace of implementation or return. Attempts to shorten the process will completely undermine the true potential of the initiative (Kotter, 1995).

A lack of commitment, or unwillingness to commit to change by management could be attributed to an information overload, due to the amount of literature, consultancies and other resources available to the business manager. This can make it extremely difficult to make a decision on any one approach. This is highlighted in the work of Atkinson (2004), who discusses how information overload can overwhelm management, even leading to total discouragement from committing to a strategy of continuous improvement. This could also cause the cherry-picking approach to manifest (as discussed earlier in the chapter), whereby managers are uncertain which of the

numerous approaches, tools or techniques would be the most effective for their organisation. It is crucial for managers to avoid this mind-set, and any weaknesses in the handling of the transition, as this will have a huge impact on the culture or thinking of employees (Kotter, 1995).

Weaknesses can be magnified when time limits are shorter than required. Although the application of lean techniques will shorten lead times within the system, if structured in the correct manner, the potential weaknesses identified will be anticipated and managed by the improvement framework being used by the organisation. The key to success at this point, is the recognition that the improvement framework must be aligned with the organisation and its specific objectives and vision.

Atkinson (2004, p. 21) makes an extremely valid point when he says "*time is not always on our side, whereas commitment is*". Furthering this point, it is essential to realise that a lean six sigma framework or any improvement approach, will not translate directly from the generalist textbook to specialised practice. Management must accept that lean six sigma needs to be adapted in order to fit the environment, as the lean, or lean six sigma "ideal" simply cannot be applied to every situation. If this is not acknowledged by management, the initiative is left to fade away because it does not follow the book exactly. As a result, potential cost savings will be missed (Beard and Butler, 2000), and the cost of the project so far becomes a significant form of 'muda' or waste.

In contrast, from the practitioners perspective, Spector and West (2006) note that "*companies invest wanting to see fast and sizable changes…they can't afford to wait months or years...when the competitive landscape changes so quickly*" (Spector and

West, 2006, p. 1). This presents an important consideration when companies are looking to invest their time and resources into a lean/lean six sigma journey. It is proposed that targeting the low hanging fruit of wasteful activities with techniques such as 5S can achieve this when part of a structured plan. The ever-present pressure of maximising profit margins, compounded by the fire-fighting of smaller issues that regularly surface, means that a framework for a lean six sigma journey, should be structured in such a way to guide the improvement team through a series of short, small scale but effective projects, resulting in significant changes. These (relatively) small scale projects can then be used to leverage motivation from other's success, creating that project momentum within the organisation found in earlier stages of projects improvements (Shukla, 2006). In other words, lighting a number of carefully sequenced small lean "fires" within the organisation, will eventually ignite a whole system into positive change.

Although not all lean concepts can be adapted for every organisation, a well managed and customised lean approach does bring change, within a relatively short timeframe. This can contribute substantially to the building of a lean culture without challenging the culture already embedded in the organisation (Shukla, 2006), paving the way for the culture of listening and thinking (Atkinson, 2004).

The recent work of Bateman (2005) has investigated the enabling mechanisms required for a sustainable culture of continuous improvement. From this work, three key enablers were identified:

1) The need to follow the Plan Do Check Act loop in closing out actions.
2) The need for an enabling process to allow CI to take place.
3) A supportive management infrastructure.

The first enabler is of particular interest, as it emphasises the fact that a structured, planned approach with inherent feedback is needed for teams to follow throughout the course of an initiative. This provides a safety barrier, whereby each action or stage in an improvement framework is considered and analysed. The next two stages really drive home the importance of having a correct and appropriate management infrastructure so that CI initiatives are effectively led and managed, while not being constrained by the system itself (this is in agreement with Boyer (1996) as mentioned previously).

Lucey et al. (2004) have demonstrated this through the application of a 5S initiative, which not only confirmed that sustained change can be achieved within a relatively quick time frame (in this case 10 weeks), but also highlighted five major drivers for sustainable change. These being: enthusiastic leadership, building employee engagement, using results from employee engagement to maximise lean ambition, celebrating success and regular communication. The level of employee engagement is critical for sustained improvement initiatives once effective leadership has been established, as these are the very people responsible for actioning the strategy put

forward by the upper echelons of management. Lucey et al. (2004) summarise the levels of this employee engagement necessary to undertake specific continuous improvement activities in Figure 2.9.

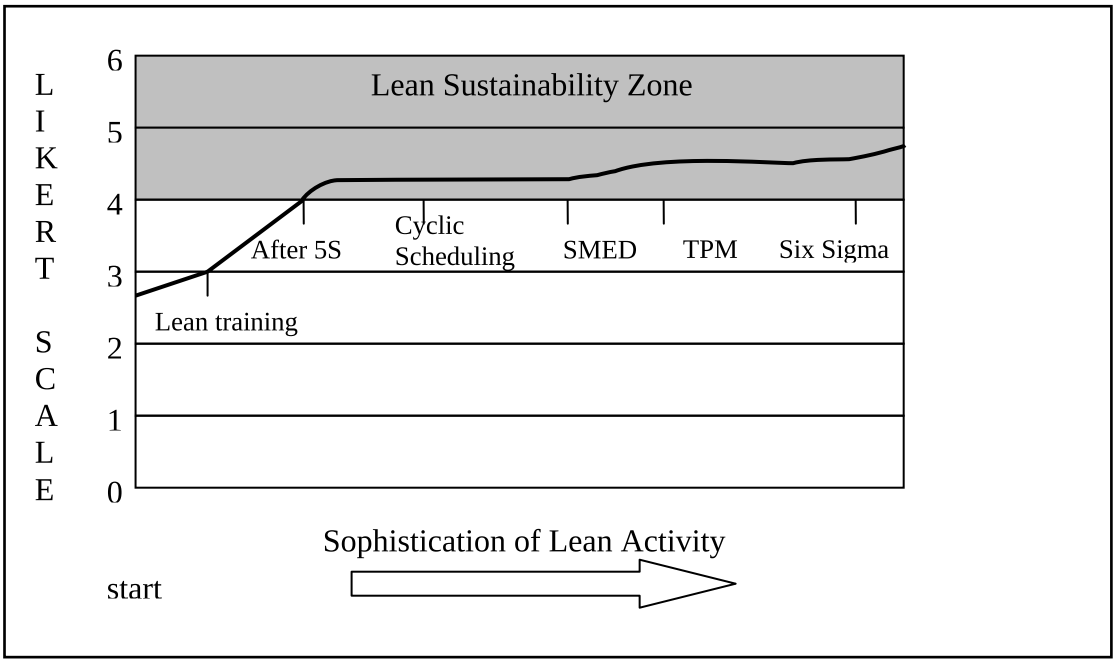


Figure 2.9 Phases of Employee Engagement (Lucey et al., 2004)

In order to address these issues of sustainability when implanting change, Owen et al. (2001) suggest that "*the ability of an organisation to sustain quality products and services……is a learnable organisational competence*" (Owen et al., 2001, p. 1). Five success factors for the creation of sustainable high performance and five gaps in performance are identified in a model for sustainable high performance culture, as shown in Figure 2.10.

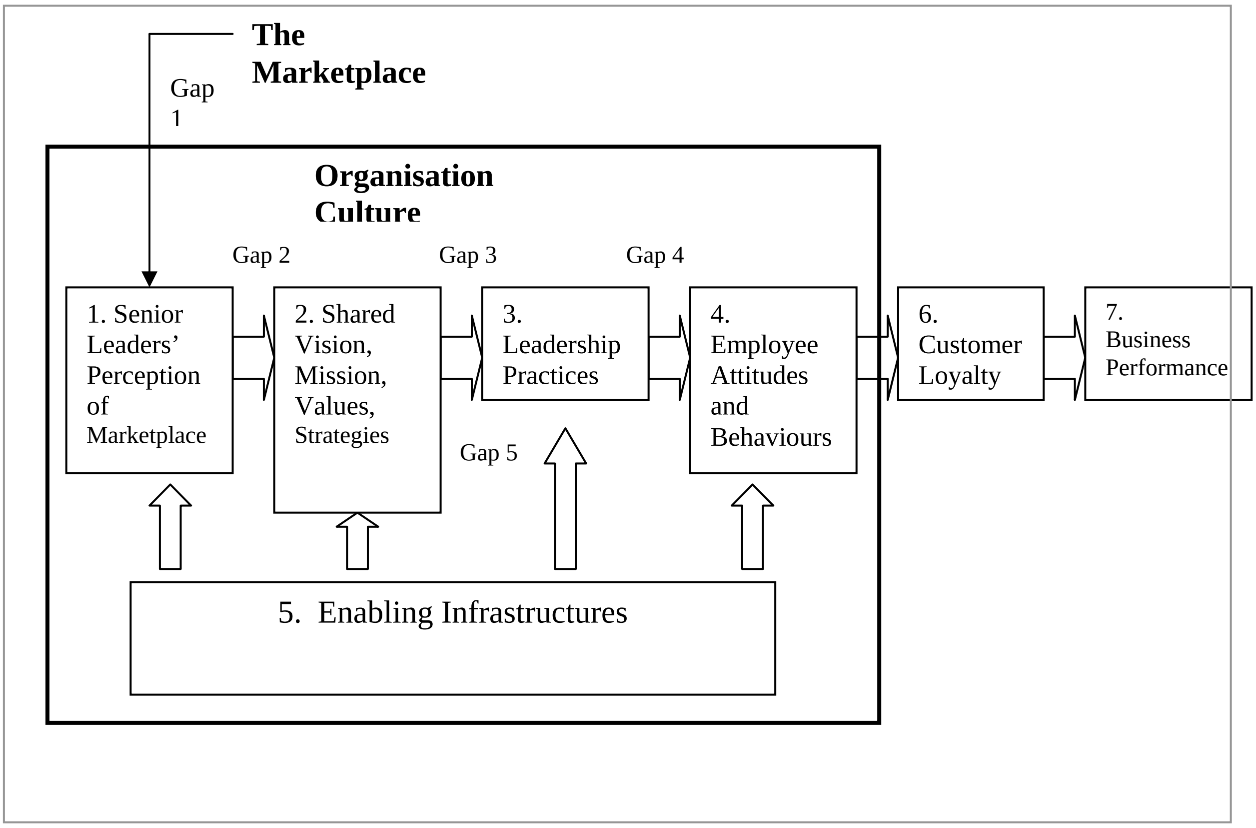


Figure 2.10 Sustainable High Performance Culture Model (Owen et al., 2001)

If an improvement framework can address these gaps to sustainability, while encompassing the philosophical and scientific aspects required for process and organisational improvement, it could potentially reach the so far elusive truly perpetual improvement paradigm.

2.12 Summary

In summary, it can be seen that the business improvement philosophy of lean thinking and the more scientific improvement paradigm of six sigma have experienced success in a wide ranging spectrum of industries. The two paradigms are influential catalysts of change as stand-alone methods, but more provokingly, if fused together, can potentially represent an exceptionally powerful tool. Aligning the cultural aspects of lean with the data driven investigations of six sigma holds huge potential in a bid for a genuine and sustainable approach to organisational change and process improvement.

Taking this review of literature a stage further, the next chapter proposes a dynamic generic framework of continuous improvement and the necessary relationships within it. Using this framework as scientific reference, an industry specific continuous improvement framework is then developed for the process industry sector.

3.0 Methodology

3.1 Introduction

The literature review in the previous chapter established the need for an integrated approach to continuous improvement based on six sigma and lean manufacturing. This chapter therefore establishes elements of a generic integrated framework for the purpose of continuous improvement, and describes how this may be used to construct an industry or situation specific improvement framework. This industry specific framework is a focussed and high impact project tool, using an integrated lean six sigma approach. The methodology is designed specifically for the process industry. The cultural impact and sustainability of the customised model is then analysed through comparisons of Soft Systems Methodology (Checkland, 1981), and the Sustainable High Performance Culture Model (Owen et al., 2001) frameworks.

3.2 Generic Framework for Continuous Improvement

It can be seen from the literature review in chapter 2, that for a continuous improvement initiative to be successful, it must address a number of vital core elements. These can be summarised as follows:

1) At first, the organisation (and its supply chain, depending on the scope of the initiative) must be understood as a system, including its complex interactions, variability, and their continuous transformation over time.

2) There must be an embedded mechanism of continuous feedback, reflection and action.

3) The cultural, philosophical aspect of the system must be aligned with a scientific, data driven methodology and change.

Lean in itself does not address all of these criteria. Through the application of lean techniques, significant changes can be made without this deep understanding of the system. However, this can lead to instability. If only lean techniques are applied, it would take too long to develop the necessary depth of understanding to take forward the improvement initiative, something that can also be viewed as a contributing factor to the unsustainable nature of many lean initiatives.

Taking a systemic view of the organisation is the backbone to the entire concept of continuous improvement. An appreciation of the organisation as a social system and the interactions between individual parts of that system as they work together is critical (Ackoff, 1999). An organisation must also be regarded as a complex and dynamic environment, where the modelling of these interactions must be understood (Forrester, 1999) before an organisation can look towards achieving sustainable improvements.

A system may be defined as:

"An entity that maintains its existence and functions as a whole through the interaction of its parts"

(O'Connor and McDermott, 1997, p. 2)

A system can be viewed as a complex set of interactions and variation, so that:

Complexity = variation + interactions

(Harrell et al., 2004, p. 28)

The variation and interactions within any given system are not independent from one another, but are interrelated and interdependent. It is the understanding and reduction of variation, along with the understanding and configuration of interactions to best drive the system which ultimately leads to its improvement. Lean manufacturing principles are an important first step in the approach to understanding systems, as it simplifies the system by reducing the complexity within it, therefore leading to a reduction in the inherent variation and interactions that form part of that system. Statistical process control is a fundamental technique to attain this thorough understanding and management of this variation (Wheeler and Chambers, 1990). It is important to note that not all systems are complex and have variation, an example of this is in practice is the Beer Game, created by John Sterman at MIT, but in manufacturing in particular this is almost never the case.

In order to maintain an ideal operating state, continuous feedback must be delivered to the system. This feedback strengthens the understanding of the discrete parts of that system operating together, enabling them to be brought under control (Wheeler and Chambers, 1990). Feedback must also take the form of customer needs and requirements, so that the process and interactions within the system may be aligned in order to satisfy these criteria effectively (Wheeler, 2000).

To illustrate this, Figure 3.1 shows the cycle of continuous improvement on a system, driven by the feedback process. Information from the system is used for the management and implementation of further positive change.

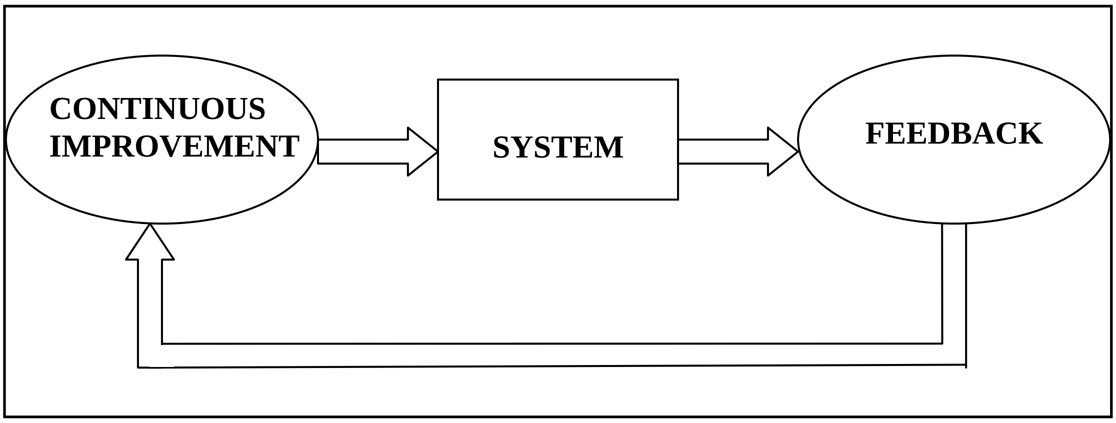


Figure 3.1 Simplified View of Continuous Improvement

A reflective "*learning organisation*", "*where people are continually learning how to learn together*" (Senge, 1998, p. 3) must be established so that this feedback mechanism can take place, enabling a long term view and a shared vision to be formed as "*Building a shared vision fosters a commitment to the long term*" (Senge, 1998, p. 12), providing a dynamic strategic direction for the organisation as a whole, and the improvement projects taking place within it.

Continuous feedback is the second foundation of continuous improvement, stemming from the work of Deming (2000) and his Plan-Do-Check-Act philosophy, more recently reflected in the D-M-A-I-C approach of six sigma methodology (Pande et al., 2000). Building on the work of Forrester (1999), Sterman (2000) introduces "*Systems Dynamics*" as a methodology to further map the interactions driving complex feedback mechanisms within systems, and the corresponding decisions made by management surrounding these interactions (Sterman, 2000, p. vi).

Once the interactions between different parts of the system have been identified and understood, along with the information flow surrounding these interactions, it is possible to manage this information, configuring it to best respond to system requirements brought about through continuous feedback.

The key relationship in the system is that between productivity, cost and quality. The interactions between these criteria must be analysed and understood before they can be managed effectively, with the objective of improving these relationships through feedback and revised training objectives – following the P-D-C-A/D-M-A-I-C cycle. The balance between the three variables must be maintained as it is analysed and improved, so that any action taken to improve one, does not jeopardise the other two.

From this, learning to manage the organisation as a system, understanding variation and making decisions based on actual data are essential. To do this, it is necessary to align the organisational culture within that system, and to train and manage the people within it appropriately. Any journey of continuous improvement must be driven by the people within the organisation looking to improve. Whether considering a transition to lean

thinking, six sigma, or a combination of the two, it is critical for employees to drive the evolution of change. It is the lack of commitment to provide effective leadership, and failure to gain the understanding and commitment of the people within the organisation that cause many improvement initiatives to fail. For this involvement and empowerment to take place, effective leadership is required to provide the necessary vision. Once effective leadership has been established, the overall vision can be used to influence the necessary cultural changes that must happen, and in turn drive this organic system forward, whilst configuring interactions and value adding activities to achieve a true state of perpetual improvement.

Figure 3.2 presents a causal loop, providing more context on the role of the system in a continuous improvement initiative. The system and its complexities need to be understood and managed so that value adding activities can be created, increased and strategically implemented so as to improve the system. When these initiatives have been established, feedback from the implementation should be fed back to the system so that the creation and sustaining of value can continue. As seen in Figure 3.2 this process should be a positive cycle, with each step in the process adding to the next, so as the feedback from any improvements is sent back to the system, the understanding of the variation, interactions, and the relationship between productivity, quality and cost in that system is constantly improved. This greater understanding leads to more opportunities for the creation or enhancement of value adding activities to be recognised and managed accordingly. It is also important to note that in addition to this, it is essential to have the appropriate tools and techniques to leverage this understanding, which the proposed methodology in section 3.3 aims to provide.

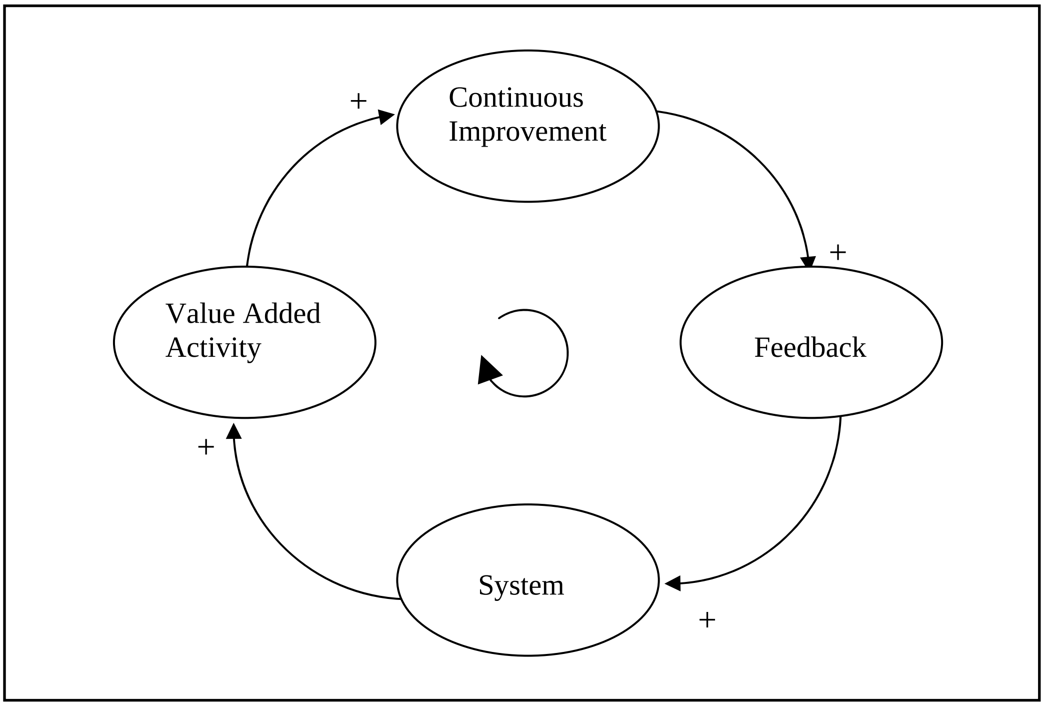


Figure 3.2 The System in Context

Building on this view of the system improving through time, the journey to implementing continuous improvement within an organisation is an organic path, where improvements are experienced as time proceeds, while the system itself evolves on a holistic level at the same time. However, this journey of change must not be too organic; instead it must be harnessed and shaped into frameworks that are suitable for its specific environment.

Figure 3.3 depicts the desired outcome of this organic pathway for the organisation. As can be seen, the system is acted upon and improved in real time, but at the same time it strategically evolves on a broader, holistic level. This evolution is not necessarily an improvement, but it is important, and the responsibility of the management team to ensure that this evolution is in a positive direction that results from the local improvements to the system. A strategic linear path to improvement is preferred, so

that organisations may avoid pitfalls previously experienced with the application of approaches that involve rapid reconfiguration of the system to gain improvements which are difficult to susain, such as Business Process Re-engineering, whereby the problems brought about by such quick action include:

> *"Lack of sufficient preparation, problems associated with implementation, organisational weaknesses ...and problems that develop in the aftermath"*
>
> (Drago and Geisler, 1997, p. 297)

and

> *"failing to take a holistic view of the change process"*
>
> (Drago and Geisler, 1997, p. 298).

The job of the leader and those involved in the management and deployment of any improvement initiatives is to ensure that a linear path is maintained in the evolutionary journey of the organisation, while improvements are being made in real time. An evolutionary path that is too steep, will result in an unstable foundation for continuing improvement, leading to instability of any changes made, resulting in an unsustainable course.

Conversely, if the process of evolution is too slow, then the rate of improvement will not be sufficient to establish any sustainable changes within the organisation. Sufficient momentum will not be gathered that invariably leads to the discontinuing of the initiative.

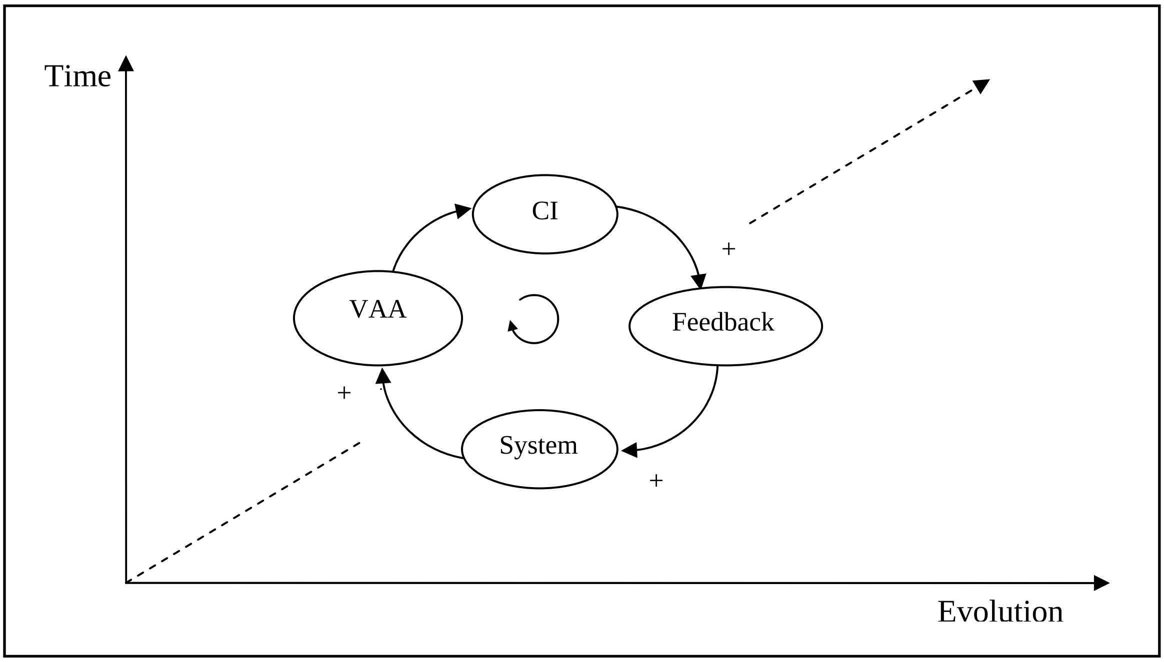


Figure 3.3 Path to Continuous Improvement

This is not to say that step changes or breakthrough improvements are the wrong approach to achieve improvements within an organisation. However, from a strategic perspective, these breakthrough improvements still need to follow a linear path over time (Figure 3.4), so that the changes are sustainable, and not over ambitious.

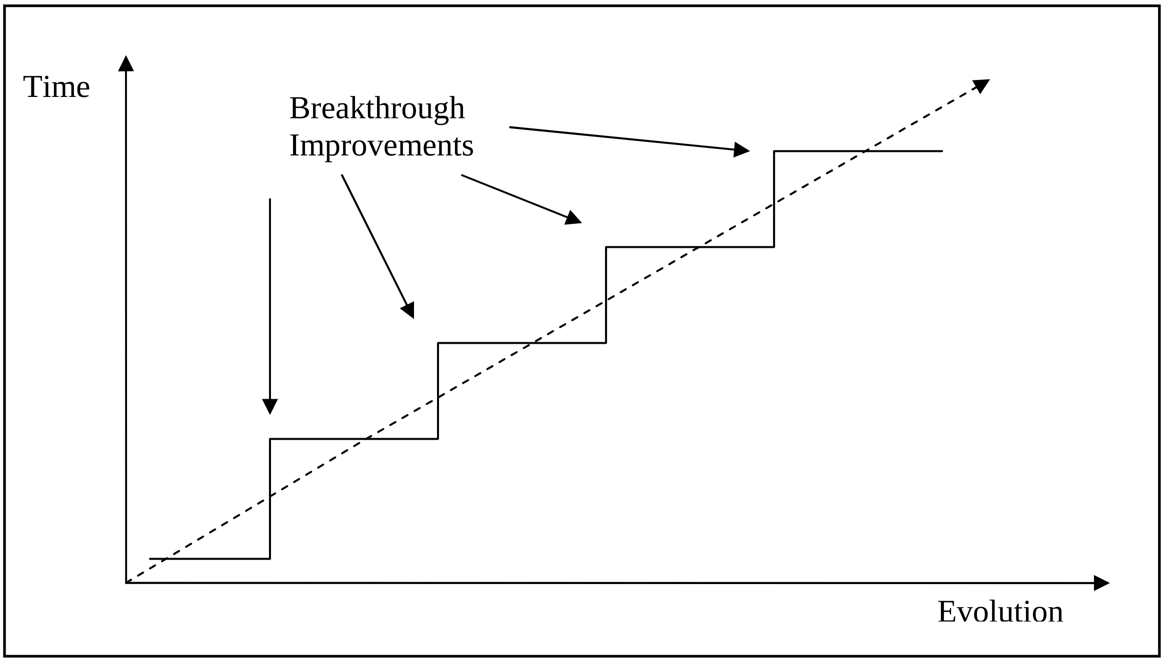


Figure 3.4 Strategic Path for Breakthrough Improvement

In essence, equilibrium between an operational philosophy and a cultural philosophy, the data and the people must be achieved. The importance of this is demonstrated in the Joiner Triangle (Joiner, 1994), which is explained in section 2.9 of this thesis. If we look towards the most effective improvement philosophies in recent history, lean thinking and the six sigma methodology are currently regarded as being at the forefront of improvement paradigms. Although lean thinking can be regarded as a collection of tools and techniques for process improvement, the foundation principles (outlined in section 2.2 of this thesis) provide a philosophical element to the pursuit of continuous improvement. This philosophical underpinning, coupled with the data driven process improvement of six sigma, are considered to achieve this balance of philosophy and science. However, to guide this balanced approach, and drive change throughout a system on any level, effective leadership is again critical, exercising influence over culture, processes and interactions.

Figure 3.5 brings together the main elements discussed so far in this chapter, resulting in the creation of a generic framework for continuous improvement. It is believed that every node depicted in this diagram must be addressed by organisations looking to embark on the journey of sustainable continuous improvement. Using this holistic view as an underpinning, it is then possible to extract and focus on each section in order to create a customised framework for specific application to a given business environment. In this way, the most suitable techniques may be selected to address the particular problems experienced by an organisation, resulting in a directed, structured methodology. This methodology can then be used to guide the organisation through a stable rate of sustainable improvement, while avoiding the pitfalls of cherry-picking individual techniques without regard for the implications on the system as a whole.

Authors associated with each section are included on the diagram, in an attempt to show how each area of the literature is interrelated to one another. Between them, Ackoff (1999), Checkland (2000, originally published 1981), and Forrester (1999, originally published 1961) have produced seminal work in the area of systems thinking in all its forms (social systems, soft systems and systems dynamics respectively), furthered through the work of Senge (1998) and Sterman (2000). The seminal work of Shewhart underpins much of the way in which variation is analysed and managed in processes and systems in industry today. Credited with the creation of control charts and process quality control, Shewhart recognised that variation may be identified as either special or common cause, and if the type of variation can be identified, then it can be managed appropriately. Shewhart also realised that if a process is brought under statistical control, then the behaviour of that process may be predicted over time.

Furthering this, Wheeler has explored variation and contributed significantly to its understanding, while academics continue to explore the relationship between productivity, quality and cost (Spedding and Chan, 2001, Voros, 2006). Cooper and Kaplan (1988) challenged the traditional approach to costing within organisations, arguing that *"virtually all of a company's activities exist to support the production and delivery of today's goods and services. They should therefore all be considered costs"* (Cooper and Kaplan, 1988, p. 96). Developing the Activity Based Costing (ABC) methodology, a more focused costing tool was delivered to industry. The strategic penalties of mismanaged accounting are highlighted in their work, making ABC *"as much a tool of corporate strategy as it is a formal accounting system"* (Cooper and Kaplan, 1988, p. 97).

With this use of ABC as a strategic tool, the information provided provides a platform for Activity Based Management (ABM), which in itself *"Refers to the entire set of actions that can be taken, on a better informed basis, with activity-based cost information"* (Kaplan and Cooper, 1998, p. 137). In other words, ABC links the causes of any change in the overall cost (increase/decrease) together with the product. This cause and effect relationship then allows management to differentiate between value adding and non-value adding activities, providing leverage for strategic decisions to be formed around the creation of value within the organisation (Kaplan and Cooper, 1998).

These areas are all woven together through the pioneering work of gurus such as Deming (2000, first published 1982) and Joiner (1994), as depicted in the Figure 3.4. The work of Shewhart greatly influenced Deming, who studied his theories and brought exposure to his methods on statistical quality control, and furthering the field with his

own thoughts on *Profound Knowledge.* Following his experiences in Japan in the early 1950's, Deming realised that a scientific underpinning was required for quality, but management commitment was the driver, with the focus being on people as the most important part of an organisation. Deming originally tried to implement a scientific approach to (statistical process control) quality management; however it did not bring about the improvements that he anticipated. Deming realised that without the buy-in and commitment of management and employees, any efforts to improve the system would ultimately fail. This led to the creation of Deming's Fourteen Points (Neave, n.d.).

Lean and six sigma are included on this diagram due to their overwhelming presence within today's' business environment. As previously mentioned in chapter 2 of this thesis, Womack and Jones (1996) are credited with the popularisation of the Toyota Production System in the Western World under the moniker of Lean Thinking, and introducing industry to the concept of value creation and muda. Bateman (2005) has further investigated the lean perspective, questioning how improvement efforts, and specifically the lean approach may be made sustainable for those that embark on a continuous improvement pathway.

When searching for effective improvement techniques, it is the lean philosophy and six sigma methodology that are at the forefront within industry and the literature. Bringing these two approaches together in a co-ordinated, structured framework is not possible without it being driven by the people expected to adopt them in their working lives. As discussed in section 2.10 of this thesis, Bendell (2006) explores the gap between the lean approach and six sigma techniques, proposing that a true integration of the

approaches, creating one unified culture of improvement within an organisation, needs to be investigated, and would be beneficial to industry. The work of Dawson (2005) considers the management of change through a processual approach, drawing together technological and cultural impacts of change and how to manage it effectively. Bringing this all together is leadership, as no approach is sustainable, nor the people empowered without the vision and motivation provided by an effective leader of change. Kotter (1995) is a thought leader and pioneer in the area of leading change, while many authors (Boyer, 1996, Brooks, 1996, Atkinson, 2004) discuss the importance of leadership and the necessary qualities that must be harnessed for effective leadership.

Finally, true continuous improvement cannot be achieved within an organisation if the culture is not aligned with the strategic objectives. If this cultural change can be guided, through a specifically configured framework of projects within the system, then as discussed previously in this section, the very evolution of this organic entity may be configured and influenced accordingly.

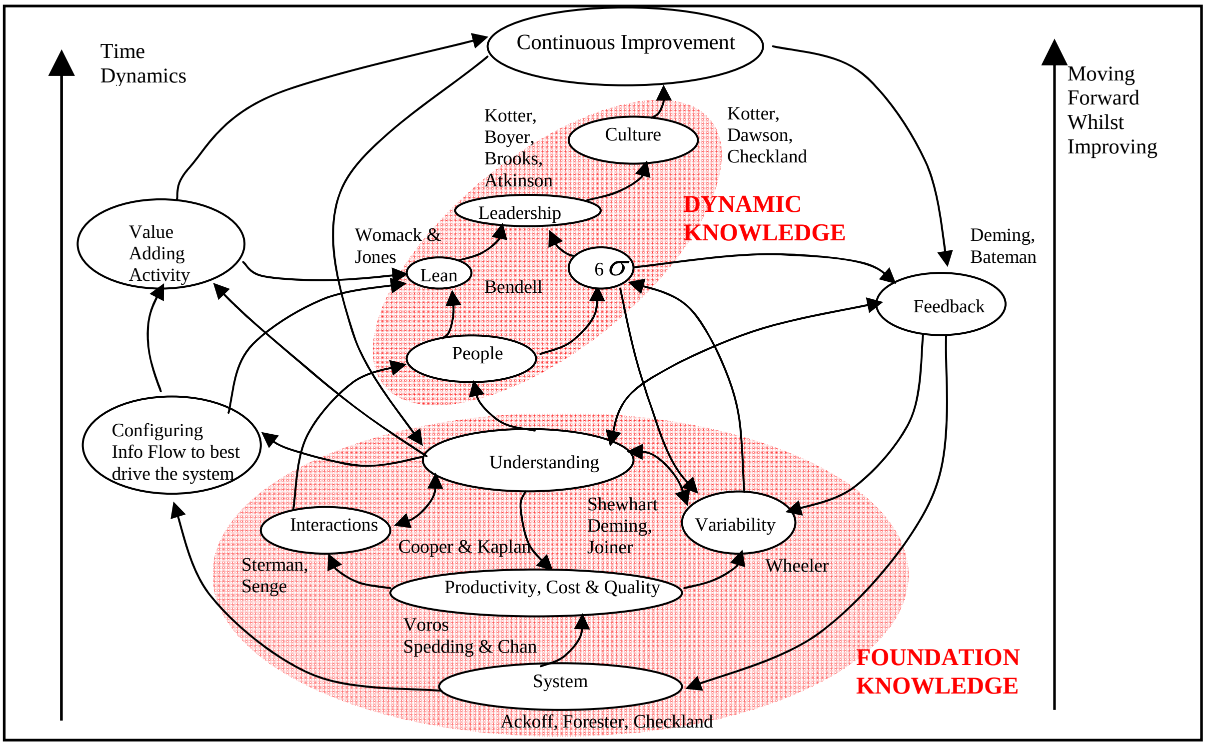


Figure 3.5 Generic Framework for Continuous Improvement

Moving a stage further, the concepts identified within the generic framework can be divided into two key sub groups. The first of these groupings, Foundation Knowledge, represents where the fundamental understanding that underpins the rest of the generic framework is established. This foundation knowledge must be achieved before an initiative of continuous improvement can progress any further. The foundation knowledge sub group represents the knowledge obtained by the team/organisation in the initial stages of the improvement journey. This includes the learning of the tools, techniques and concepts required to understand the organisation and follow the SCIMPI framework. The deep understanding of the system and its complexities is critical, so that the reactions and behaviour of the system can be fully understood and utilised for improvement.

The second sub group, Dynamic Knowledge, represents practical application. It encapsulates the tools, techniques and cultural aspects that must be applied and developed in practice. The concepts within this group are geared towards the practical application of improvement techniques and the guidance, development and evolution of the cultural changes that need to take place before a true continuous improvement environment is accomplished.

The Dynamic Knowledge sub group represents the practical application of the Foundation Knowledge principles through lean and six sigma techniques as part of the improvement initiative. The two stages are linked together, as Dynamic Knowledge cannot be achieved without first establishing the foundation knowledge. Continuous feedback further links the two sub groups in the evolutionary path of the improvement journey.

The SCIMPI methodology guides the organisation through this creation of foundation knowledge and the transition to dynamic knowledge, delivering a stable underpinning to a continuous improvement initiative for the organisation in question.

3.3 Supply Chain Improvement Methodology for the Process Industry (SCIMPI)

As explained in chapter 2, we know that different industries have different processes, and therefore need to find ways to adopt lean and/or six sigma methodologies (Beard and Butler, 2000). For many organisations which take on a lean initiative, it is the beginning of a successful journey into an environment of continuous improvement, as the very nature of lean is iterative. Once an organisation has started to follow the lean approach, opportunities for improvement should continually present themselves, leading to a continuous analysis of the material and information operations, which in turn will lead to an increasing flexibility to respond to customer demand.

When businesses try to extend the lean philosophy throughout their respective supply chain networks, it can often become problematic; with companies finding that they grind to a halt after taking the first few critical steps, if the wrong implementation strategy is followed.

The most common problem when implementing lean within an organisation, is the tendency of the management to 'cherry-pick' a few key lean tools. They implement lean initiatives, interpreting the methodology how they feel it best suits their facility. Individual aspects are identified, resulting in one or two lean ideas being implemented, with the organisation operating under the pretence that they have become 'lean', but find improvements plateau after some initial success. It can be argued that the 'kaizen blitz', or breakthrough improvement is a valid approach to cultural change. However, the danger of this approach is that it sets up employees for a big improvement that does

not happen once the easy pickings have been made, having a detrimental affect on morale and commitment in future ‘blitzes’. Another common problem is the fact that the information flow around the system is ignored, while the material flow is constantly under scrutiny. This is a direct result of organisations becoming too focussed on the application of ‘lean tools’ instead of a culture driven approach, while management under utilise their potential influence and neglect the need for total commitment.
This is also a direct result of the misalignment of systems such as Enterprise Resource Planning (ERP) or Materials Requirement Planning (MRP) packages and the lean philosophy. For example, if a business has invested in an MRP system, management may refuse to turn it off and rely solely on the lean infrastructure to take over, because of the initial outlay on the MRP software. This situation has the result of the organisation operating with competing systems, and therefore creating more muda, as value is not created when two systems are carrying the same information and doing the same job.

Building on the comprehensive work of Abdulmalek et al. (2006) concerning the application of lean in the steel industry, along with Kumar et al. (2006) and George (2002) with their work on lean six sigma, the proposed methodology presents a comprehensive mapping approach. SCIMPI integrates key business indicators with traditional mapping techniques and quality initiatives, providing a dynamic view and quantification of the results through models developed in simulation software. This results in a customised framework for lean six sigma projects specifically for implementation within the process industry. In other words, a lean six sigma framework, aimed purely at the process industries that encompasses the highest impact lean and six sigma techniques, emphasising the cultural change that must be adopted by

any organisation wanting to start and sustain a journey of continuous improvement. As in discrete manufacturing, in order to realise the full potential of such improvement methods, it is essential to focus on the whole supply chain.

The Supply Chain Improvement Method for Process Industries (the SCIMPI model) is developed here in order to provide a comprehensive mapping and analysis framework within the process industry, facilitating a dynamic approach for both the operational and business level. Instead of using the cherry-picking approach, which alone can be time consuming and lead to inappropriate application, the SCIMPI model aims to bring together the most suitable high-impact techniques which guide strategic direction and planning.

The generic framework establishes the core elements to arrive at, and sustain a continuous improvement initiative within an organisation. This provides a baseline from which more focused continuous improvement methodologies can be designed. In order to do this, the stages necessary to achieve continuous improvement must first be established according to the generic framework elements.

Taking the generic framework as a guide, the journey to continuous improvement can be deconstructed into five key stages that are based on the pioneering Deming Cycle of Plan-Do-Check-Act, but are considered more appropriate for use as a guide for organisations to align improvement tools with the Generic Framework of Figure 3.5.

***Map*:** To gain a systemic view and understanding of an organisation, and achieve the elements of the foundation knowledge sub group, it is necessary to map that organisation. The Value Stream Mapping and/or simulation approaches are seen as the most appropriate means to achieve this.

***Strategy*:** To aid in the role of leadership, and to ensure that for the duration of the initiative the system is moving forward whilst improving, strategic direction is needed to guide the organisation. This strategic direction can be drawn from the Value Stream Mapping process, and through the application of Balanced Scorecard Drivers (such as objectives, measures, targets and initiatives).

***Centre*:** Once the strategic direction is established for the journey to continuous improvement, it is then essential that the initiative is 'centred'. This stage establishes how the system operates, providing a base-line measurement from which it can be improved through the application of appropriate techniques. To achieve this, Value Stream Mapping is again considered to be a suitable approach, along with simulation in order to consider the interactions within the system, and to some degree the variation present. Statistical Process Control is also considered to be an essential tool, furthering the consideration of variation from the simulation and/or value stream map.

***Advance*:** This stage is concerned with the practical improvement of the system and the creation of value, once it has been centred. There are two main targets within this stage. The first target is the reduction of interactions in the system. This is achieved through increasing value added activity through the application of appropriate lean techniques, requiring the people in the system to drive the application of foundation knowledge.

For this purpose, value stream mapping is once more considered to address the interactions within the system, while additional lean techniques such as 5S, Single Minute Exchange of Die and Total Productive Maintenance are also considered suitable.

The second target is the reduction of variation within the system. The application of lean tools and techniques identifies key areas that can be leveraged by six sigma techniques. It is also necessary to configure the information flow to best drive the system, providing continuous feedback. This reduction in variation can be achieved through the application of techniques such as statistical process control, simulation and soft computing techniques. The application of these tools depends on the dynamics of the system; therefore it may be suitable to use SPC in one scenario, but neural networks in another.

Sustain: The final stage to achieving a state of true continuous improvement is the cultivation of an appropriate culture, in other words, ensuring that any improvements made can be sustained by the system. This can be achieved through the use of simulation as a reference model for feedback on proposed improvements, and the introduction of standard work practices and documentation. The improvement initiative must also be communicated to the rest of the supply chain, bringing cohesion to the improvement effort across business units.

Table 3.1 provides a summary of the five stages outlined above, along with the elements of the generic framework that they address, and also the tools and techniques required from the proposed methodology to actually achieve each stage.

Table 3.1 Aligning Tools to Generic Framework

Stages to achieve Generic Framework	Generic Framework Elements Addressed	Tools for Proposed Methodology
MAP	System, Understanding, Productivity, Cost, Quality, Foundation Knowledge	Value Stream Mapping, Simulation
STRATEGY	Leadership, Moving Forward Whilst Improving	Balanced Score Card, Value Stream Mapping
CENTRE	Feedback, Foundation Knowledge	Value Stream Mapping, Simulation, Statistical Process Control , Value Velocity
ADVANCE	Lean, People, Value Adding Activity, Configure Information Flow, Feedback, Six Sigma	Value Stream Mapping, Simulation, 5S, Single Minute Exchange of Die, Total Productive Maintenance
SUSTAIN	Culture, Continuous Improvement	Feedback, Standard Work, Simulation

It should be noted that although the Value Stream Mapping (VSM) approach is used to address a number of the five stages in Table 3.1, it is not suggested that the actual VSM exercise is repeated throughout. If VSM is used in the *Map* stage, then the information gathered and the value stream maps created should be used for the subsequent stages.

Building on the tools identified above that address the required stages to achieve continuous improvement, Figure 3.7 is an outline of the SCIMPI approach. The well established six sigma Define Measure Analyse Improve Control (DMAIC) framework is used as a platform providing direction for the continuous improvement implementation. In addition to this, another stage has been added at each end of the DMAIC cycle. *Lead and Learn* to launch the initiative, and *Enterprise* to restart the cycle of continuous improvement.

The SCIMPI methodology uses the DMAIC approach of six sigma as the baseline structure for the overall direction of the initiative. Lean techniques are then used within this framework to benchmark the system and provide strategic direction for the

initiative (i.e. identifying desired future state). Lean techniques are also used to consider and improve the organisation on an operational level, reducing complexity and interactions within the system, through the targeted removal of non-value adding activities. From this reduction in complexity, lean identifies opportunities for improvement that can then be leveraged through the application of high powered, more focused, six sigma techniques, driving the improvement of the system further towards a lean environment. Figure 3.6 illustrates this integration of lean and six sigma, and how both strategic and operational improvement is achieved.

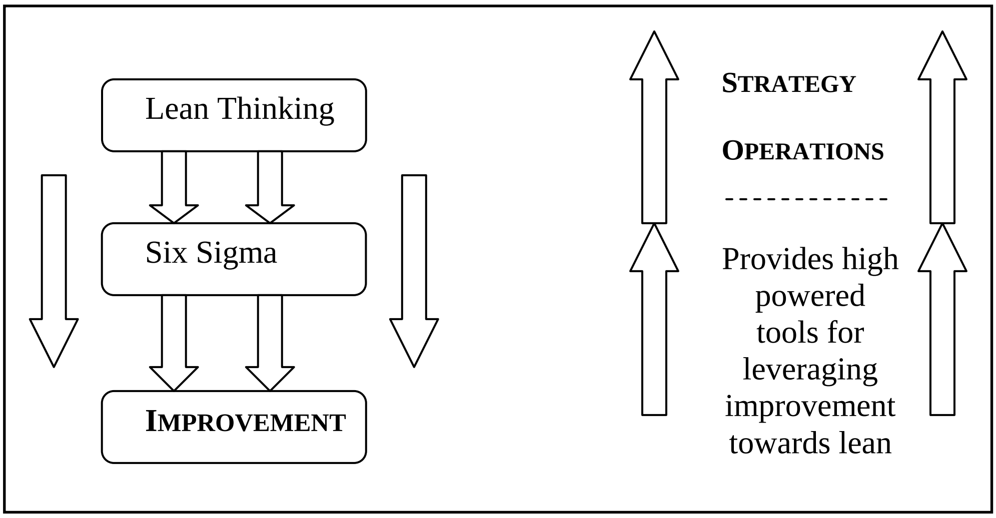


Figure 3.6 Integrating Lean and Six Sigma

Although tools and techniques are listed in each stage of the SCIMPI methodology, it is not proposed that they are used in this sequence. While VSM and simulation are both contained in the SCIMPI methodology, it is not intended for both approaches to be used in every application of SCIMPI. The VSM approach should be used to highlight opportunities for improvement within the system, and then used to leverage the use of other tools within the methodology to tackle these opportunities. If VSM highlights that

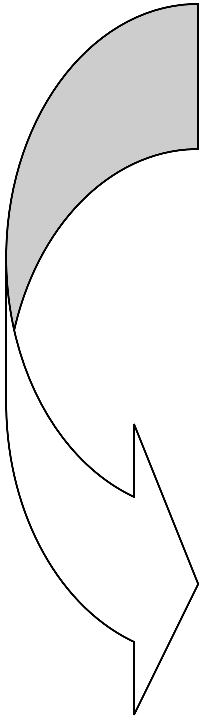
variation is an issue, then simulation could be used to address this. Simulation as a tool can be used in two ways. The first is as a mapping tool and as an analysis tool, where it provides a visual aid that can be used to facilitate communication between members of the organisation and management (Maani and Cavana, 2004), engaging their interest (Harrell et al., 2004), making it an effective tool for gaining the quick commitment of management and employees alike. Simulation models can also deal with complicated systems (Kelton et al., 2002) that may otherwise be difficult to understand or communicate to others, with their ability to run in real, delayed or compressed time (Harrell et al., 2004) providing quick feedback on any possible changes to the system. Simulation allows the user to explore possible changes to the system without disturbing the existing set-up, therefore avoiding the expense and time that is required to do so.

However, there are a number of acknowledged disadvantages to the use of simulation. Special training is required if simulation software is to be used effectively, and once personnel have been trained, the construction of an accurate simulation model can be expensive, and time consuming (Banks, 2000). It will take a substantial amount of time to achieve an accurate simulation model of a system, as the model needs to be tested and validated before it can be used as a resource. Associated with this, is the risk that by the time the model has been validated and is ready for use, the dynamics of the system may well have changed, and improvements could have been implemented because time was an issue. If any of these disadvantages make the use of simulation unfeasible for an organisation, then VSM can be used in its place.

The SCIMPI methodology alleviates the disadvantages of using simulation, by using VSM to identify where simulation can be used to best leverage improvement. With this

in mind, the SCIMPI methodology suggests using either, or if feasible, both together, leaving it to the preference of the organisation to determine which approach would be more beneficial. As an example of this, larger organisations may well have ready access to any number of simulation software packages, while smaller businesses may not have the resources required.

In summary, if lean is implemented without six sigma, then there is a lack of tools to leverage improvement to its full potential. Conversely, if six sigma is adopted without lean thinking, then there would be a cache of tools for the improvement team to use, but no strategy or structure to drive forward their application to the system.



	STAGE 0 MANAGEMENT COMMITMENT	
STAGE 1	**LEAD & LEARN**	Establish Continuous Improvement fundamentals with cross-functional teams
STAGE 2	**DEFINE**	Value Stream Mapping Balanced Scorecard
STAGE 3	**MEASURE**	Simulation Balanced Scorecard Activity Based Costing Value Velocity Statistical Process Control
STAGE 4	**ANALYSE**	Simulation Statistical Process Control
STAGE 5	**IMPROVE**	5S Single Minute Exchange of Die (SMED) Total Productive Maintenance (TPM) Neural Networks
STAGE 6	**CONTROL**	Standardised Work Simulation Customer Focus
STAGE 7	**ENTERPRISE**	Merge cross-functional teams with supply chain partners, strive to create lean enterprise

Figure 3.7 The Supply Chain Improvement Model for Process Industries

Stage 0

The very first, and most important stage for any organisation wishing to embark on a journey of continuous improvement (no matter which particular path they wish to follow), is to gain the commitment of top and middle management. Without this commitment driving the journey to continuous improvement, the initiative will almost definitely fail. The path to obtaining this commitment can be fraught with obstacles, and cannot be rushed. Adequate time and patience must be given so as not to jeopardise the development of this commitment.

Establishing this commitment is beyond of the case studies in this thesis. As with any approach to continuous improvement, management commitment should be established, and then the most appropriate agent of change selected. The SCIMPI methodology is intended to be the approach adopted by an organisation that already has gained the full buy-in of management.

The subsequent stages of the SCIMPI methodology present a selection of tools to map, analyse and improve a system. It is not suggested that all of these tools must be used in every case, or indeed applied in a particular order. These are the possible tools that should be used, however, depending on the dynamics of the system in question, it may be more beneficial to use certain techniques and not use others. For example, in the first instance, it may be beneficial to use simulation software to map and analyse a system, where in another situation it may not be necessary. The following stages describe what each tool or technique provides, where it fits within the methodology, and what is achieved through their application. The planned time frame of the SCIMPI project and

its implementation should be considered, and in the case that all techniques within a stage are appropriate, then the order of their application should be based on the available resources.

Stage 1

Lead and Learn is the first step, directing the user to establish cross-functional teams. The beginning of any improvement initiative needs to centre on the selection of appropriate team members for the project in question. The team needs to be cross-functional, comprising of members or representatives from every unit that will be considered during the project. A team leader, or champion needs to be appointed at this stage, and their selection must be based on their cognitive skills, technical skills, and enthusiasm. It is the responsibility of this team leader to make sure that all members of the team understand the vision and goals of the project. It is essential that the team leader or facilitator maintains vision and guidance throughout the project, and must be accessible by all group members.

This approach of having an established Team Leader trained in the SCIMPI methodology is aimed at bringing the skill base back to the company. This is so that the organisation does not need to rely on outside consultants to provide the necessary skill base and expertise, with the people trained in the SCIMPI framework having a vested interest in the organisation (also an important aspect of the six sigma approach). Over a period of 1 day or 1 shift, the team leader (a project manager or facilitator) must then discuss with the team the fundamentals behind the rest of the SCIMPI lean sigma approach. It is at this first defining moment, that cultural change within the organisation

begins, and the realisation of empowerment is introduced. The role of simulation, and the tools used in all of the following stages should be introduced and understood before moving on any further with the SCIMPI model. The first stage after bringing the team members together should adhere to the following typical structure:

- Introduction of all team members, with the facilitator explaining what business unit they come from and why they are there, relating the explanation to a systems view and emphasising that everyone has an important role in the supply chain.

- The aim of the project needs to be clearly stated, along the lines of "this is our situation as a company, these are some of the perceived problems, and these are the tools we are going to use to remedy the situation". It needs to be underlined to all team members at this stage of the project, that the business is there to make money, and if some of the problems are not tackled, then it will affect everybody. This is not to be used as a scare tactic, but it is used as a levelling statement, so that everybody realises that through a collaborative effort, management is trying to maximise the efficient operation of the business as a whole, without compromising on product quality or reducing employee numbers. The initiative is being undertaken to make sure everybody will keep their jobs.

- The scope of the project must then be discussed, outlining what section of the supply chain will be considered, along with the project time frame, and deliverables to be achieved along the way. Weekly deadlines should be set for

specific points of the project, covering points such as mapping and data collection. The project must also be given context in terms of the whole supply chain, and how it fits into the overall strategy of continuous improvement. The expectations of what the successful outcomes will lead to, and how it will benefit the organisation, and therefore the people involved.

- Resources available to the team, including information, time and money needs to be made clear, so that there is no confusion over where to go, how to collect data, what authority is needed and what can be done when a problem is identified.

- The SCIMPI lean sigma framework, with a brief overview of the LDMAICE flow, outlining the tools used for each stage. The key areas of lean thinking must be addressed here, including the main tools and techniques utilised in the SCIMPI framework, including:

    - The 7 wastes. How to spot them and manage them.
    - The importance of real data collection.
    - An overview of 5S.
    - An overview of SMED.
    - An overview of TPM.
    - Standardised work, and how it is used.
    - Customer focus, being careful to highlight that business is there because customers are there. This needs to be related back to the 7 wastes and the concept of value.

On the second day (or shift), the Value Stream Mapping approach to be used should be explained, along with how all everything is brought together at this point. An introduction to the concepts of VSM (including the symbols used, data needed etc.) should be followed by an introduction to the current state map. The next stage of the SCIMPI framework follows the VSM techniques in more detail.

This stage serves the purpose of communicating to the team the vision for the organisation and the journey of improvement, and the dialogue that the leader has with the team derives from the theories and concepts identified in Figure 3.5. In particular, the concepts of system, productivity, quality and cost, variability, interactions and understanding are considered, which together form the 'Foundation Knowledge' sub group within the generic framework (Figure 3.5). This is also the first step in the encouragement of employee engagement and the starting point for the development of a continuous improvement culture. Although leadership is essential at every stage in the journey of continuous improvement, it is at its most critical at this point, together with clarity. It is at the very beginning that the people involved in the team are influenced the most – first impressions of the reasoning behind the project will dictate the way in which the whole initiative is perceived by the employees.

Stage 2

The *Define* stage of the SCIMPI methodology is perhaps the most enlightening part of the journey. It is at this point that the team 'walk along the supply chain' to create a current state Value Stream Map, seeing for themselves the interactions and variation within the system, and seeing how the system works as a whole first hand. An enhanced

version of Value Stream Mapping (VSM) is used. The limited technical information concerning cycle times, changeover time, and so on for each process, leaves the VSM with a few key indicators of system performance. It was found considering the course of the mapping phase that different data would be more beneficial when mapping the operations of process industries.

As it stands, with traditional VSM, the only indicator of quality performance for each process is the defect rate. However, this only highlights how much of the product is within the specification limits. The addition of quality data in the form of process capability, using data from the construction of x-bar charts (i.e. the percentage of data outside of the control limits) is included in the VSM data-boxes found below each key process. Along with the down-time, this provides an immediate view of how well the process is performing at the time of mapping.

This is deemed critical as a benchmarking tool, whereby each process is considered, so as to highlight areas of high variation to direct the focus of statistical techniques in the next stage of the framework. It is important to get an early indication of the variation present within the system, so that if any of the processes are operating out of control, they are highlighted and managed as soon as possible before moving on to any other process improvements.

Although this means that the creation of a current state VSM will take longer than the traditional approach, the result will provide more than just a brief overview of the system. If data such as control charts or process capability is not available at the time of mapping, then this should trigger a feedback loop making the collection of this data the

very next task, so that it may be added to the current state map at a later date and used to inform the strategy of improvement. The collection of this data is essential, providing the improvement team with a comprehensive overview of the system, and how it is behaving at the key processes. Without this, if any changes were made to the system while some of the key processes were not in a state of statistical control, then not only would the improvements be unsustainable, but they would relocate the problem to another point in the system, perhaps even amplifying the situation.

From this current state VSM, targeted processes can be quickly and effectively identified by all team members and pursued with subsequent statistical techniques. This will also act as a visual aid, showing all team members the extent of variation within the system, and discussion can ensue regarding its effect. There is a need to establish systems boundaries and interfaces when a systems approach is used. The value steam mapping exercise carried out in this stage identifies the scope of the system that is to be improved through subsequent stages of the framework. The boundaries of the improvement exercise are demonstrated in the resulting current state value stream maps, with the purpose of providing clear scope and focus for improvement teams when embarking on an improvement project using the SCIMPI framework.

The scope of the project is experienced directly, and a deeper understanding of the interactions and variation within the system will be gained, and as a result the relationship between productivity, quality and cost within the supply chain is further appreciated. This now brings an understanding of the concepts of the 'Foundation Knowledge' sub group being put into practice.

Team members are encouraged to discuss with each other the VSM they are observing and mapping in relation to the lean tools and six sigma techniques covered in stage 1 of SCIMPI. Stage 2 provides an inclusive activity, bringing all team members together at the source of analysis. This in turn provides a platform for acceptance of the continuous improvement initiative, building on the key concepts identified in the 'Dynamic Knowledge' sub group of Figure 3.5, through communication from management (who guide the stages set out in the SCIMPI methodology), and also developing some cohesion between group members. This transition to the "Dynamic Knowledge' stage of continuous improvement encourages employees to bring forward their ideas and develop as a team. Getting everybody involved at the process level has a positive impact on motivation and focus of the team.

The next key addition to the VSM tool is that of the balanced scorecard approach (Kaplan and Norton, 1996), so that the "*critical success factors considered necessary to fulfil the corporate goal(s) to ensure future success*" (Hepworth, 1998, p. 559) are identified. Once the current state VSM has been constructed, the map should be divided into sections, or loops, of key processes, including inventory and storage, so as to provide focus for each section of the system. For example, one loop could incorporate the customer end of the supply chain, or the information flow between customer and producer, or even production control. These sections need to be identified through focussed discussions between team members, so that a multidimensional approach (i.e. from different business perspectives provided by a cross-functional team) to deconstructing the current state VSM into smaller projects or sections can be achieved. Once the sections have been identified, the identification and quantification of objectives, measures, targets and initiatives for each stage should be discussed and

prioritised in line with the lean six sigma framework. Although not fully utilising the balanced approach of the BSC, the four criteria are seen as important measures, taken and used as an integral part of this stage, providing focus on applicable lean six sigma initiatives that may be pursued.

This process mapping stage also provides the direction and scope for smaller scale, data intensive projects, which are tackled with six sigma theory. The four key information points for each loop are used as a platform to keep the initiative focussed on providing value for the customer. So in effect, they form a micro "customer scorecard" for each section of the supply chain, asserting the drivers of vision and management strategy in the initial defining stage of the SCIMPI framework.

The VSM exercise needs to be carried out by the team, as a team, ensuring that every member has a part to play in the collection of data and drawing of the value stream. Once this current state stream exercise has been constructed, it is important for the group to convene and discuss the resulting map.

Effective leadership is essential at this stage, as the drivers for the key process loops are discussed and linked to the overall vision and strategy, ensuring that all team members are able to contribute to this.

Stage 3

The *Measurement* stage introduces a selection of simulation to record the current state of operations in a dynamic environment. The use of simulation at this point in the

SCIMPI model serves a number of purposes. First of all, it reinforces the view of the organisation(s) from a systems perspective, and therefore the interactions and variation that take place within that system, drawing from the Foundation Knowledge group in Figure 3.5. Using the VSM created in the previous stage, the simulation model should be constructed by the team leader (unless a team member has previous experience of simulation software). The simulation model must be presented to the team for review at regular intervals, in order for the team to check its accuracy.

Once the simulation model has been completed, and its accuracy verified by the team, it can be used as a dynamic visual aid to both demonstrate the problems in the supply chain, and also model any changes to be made before physically committing to them. This exercise is essential because it illustrates that the ownership of any problems is not down to any one individual or department. The team members will of course be picked for their analytical skills and cooperation, and may well be managers of their own section. By running the simulation model at this point, it can be clearly demonstrated how variation effects the system, how logistics impacts lead times and so on. The model can also be used to show the capacity may well be there, but the variation within the system is driving poor performance. Such a visual approach, demonstrating how any bottlenecks or problems will not go away and just transfer to a different section of the supply chain unless the whole system is considered and the root causes are targeted, is a powerful tool to bring cohesion to the group and move towards a realisation that change needs to happen, overcoming any of the ownership issues such as “it’s not in my department, so it doesn’t effect me”.

The SCIMPI framework is aimed at providing these people with the vision, objectives, motivation and skills for continuous improvement. It is then the responsibility of these managers or supervisors to implement action down through the hierarchy to an operator level. This decision has been made to get effective results, quickly. If operators are not involved from the very beginning, problems with attendance, commitment or unions may provide more issues than necessary.

Activity Based Costing (ABC) is seen as an important benchmarking data, and also easily fits into the simulation environment. ABC in itself is an involved and complicated technique to comprehensively apply to a system. However, when a simulation approach is used, data required for ABC, such as materials costs, machine operating expenses, along with other fixed or variable costing data can easily be included, making the process of ABC far easier to implement. ABC is an intrinsic function of modern software packages, such as ProModel, Arena, and Witness. This aspect of simulation modelling is demonstrated in the work of Spedding and Sun (1999). Therefore, simulation provides a platform for the use of ABC, and this can provide positive feedback to or about the system in order to configure value adding activities and strategy accordingly. This can be seen on Figure 3.5. whereby feedback occurs and filters back to the Foundation Knowledge group concepts, and in practice activities. As with all stages in continuous improvement, feedback is a recurring theme in stage 3.

Incorporating cost into the dynamic map of the value stream is aimed at quantifying both problems and solutions in real terms for all those involved. ABC also helps focus on what ‘value’ is being used where. In other words, it provides an accurate measure of

how much money is being used to process, move and store product or information in the supply chain. Translating opportunities for improvement into cash figures is universally understood and brings back the terms of change into a single common ‘currency’. The introduction of ABC at this point also aids further understanding of the relationship between productivity, cost and quality within the system, by providing a structured, traceable account of all product related costs. Any areas of expenditure that are incurred by non-value adding activities will be highlighted in the simulation model, so that they may be reviewed and minimised through lean techniques.

In addition to the ABC data, but not used as an inherent part of the simulation, the Value Velocity (Botha, n.d.) index is used as an indicator of “*the rate at which value is added*” throughout the supply chain. This is seen as a valuable indicator of performance throughout the value stream. The value velocity index is calculated by:

$$\text{Value Velocity} = \$K/\text{Day} \qquad \text{Eqn. 3.1}$$

Where:

\$ = Net income before tax, or profit made.

Day = Inventory days (the average inventory value is averaged over the time period considered). According to Botha (n.d.), 360 days is typically used for this calculation.

The value velocity measure at this stage is used as a feedback mechanism to the system, so that the improvement team and wider organisation can see how efficient the supply

chain is as a whole. It is perceived to be a valuable leadership tool, providing a common focus for the supply chain, and therefore strategic vision can also be linked to this indicator.

Being both a management and data driven costing system, BSC lends itself to such a methodology, providing key business process strategic data, while ABC is used to identify indirect and direct costs associated with production, so that an economic break even point can be drawn upon. When combined with the value velocity index, these tools can indicate long term strategic direction, which in turn leads to a stronger market position compared to the competition. ABC lends itself to the continuous process industry, as errors within a continuous process environment are extremely expensive, and ABC addresses this through complete traceability of its actions. The Value Velocity index is used as an indication of supply chain performance and its practical usage, by benchmarking the amount of profit per day experienced at any point in the supply chain.

Both of the included costing tools are used to highlight the economic advantages of change to the various hierarchical levels of management, whose participation provides the keystone to any such successful program of change, and also presents the long term strategic needs of the organisation, especially when dealing with the many factions included in complicated supply chain structures. The methodology has the potential to fulfil the need for strategic alignment of the many differing interests encountered when considering total supply chains, and also unify the direction of every node within the respective chain through its correct use. This is achieved through the use of multi-disciplinary data, which represents all facets of the supply chain business and

operations, such as demand, process times, variation and business data. Statistical Process Control (SPC) is introduced at this stage as a data driven technique that controls the variation within any process highlighted as having an incapable process in the enhanced VSM. More data is recorded at this point, so that analysis can be carried out in the next stage of the framework.

The SPC used in this third stage is a development of the culture nurturing first and second stages of the SCIMPI framework. The issue of variation at key processes necessary to achieve the future state within the system is explored in more detail, so that team members, and eventually the organisation as a whole gain a deeper knowledge of how the interactions and value/non-value adding activities influence the behaviour of the system. The use of SPC encourages the team to observe the behaviour of key processes within the system through a scientific lens, and should be used to focus investigation on any anomalies present. It is important that SPC is used as a means for measurement *and* feedback within the system. This stage represents the beginning of a transition from Foundation Knowledge to that of Dynamic Knowledge as seen in Figure 3.5.

Once the Foundation Knowledge has been achieved, the move to Dynamic Knowledge is formed through the implementation of lean and six sigma techniques, focussed by the feedback to the system. The Dynamic Knowledge sub group represents a shift to the application of improvement techniques and the cultural aspects of improvement as a consequence of these improvements being made.

Stage 4

At the *Analysis* stage of the approach, the current state simulation model developed in the Measure stage is used, along with SPC techniques to analyse the highlighted process(es). Here, variation is addressed, as well as information and product flow. Any anomaly is refined to an optimum situation within the simulation model, allowing off-line flexibility to the analysis, causing the minimal disturbance to the real system. The mapping and analysis of variation through the use of SPC techniques will lead to identifying opportunities for improvement on two levels. First of all, the causes of variation at a process level will be identified for consideration.

Continuing the SPC from the previous stage of the SCIMPI framework, it is through this analysis that team members develop a deep understanding of the processes and behaviour of the system. The people (improvement team, and subsequently the organisation) are brought together encouraging a cultural development of hard and soft systems developing and evolving as they interact together. This is also underpinned through the use of lean thinking and six sigma techniques. It is from this point that the team start questioning the information flow in more detail, and how the behaviour of the system reacts to changes influenced upon it. Reflection and feedback from these behavioural changes of the process is used to guide the next stage of the framework.

Secondly, behaviours that cause variation within the supply chain will also be identified for consideration. In this way, SCIMPI aims to use a hard systems approach as a driver for the change in soft systems elements of a system. For example, if a delivery time is fluctuating over a period of time, after plotting the data and analysing the reasons

behind those fluctuations, common reasons will keep occurring for those fluctuations over a period of time. These regularly occurring causes of variation can then be used to drive change in the way the deliveries are approached.

Simulation modelling is also used to explore the relationship with productivity; quality and cost, while considering sources of variation that are demonstrated within the model. The simulation model should also be used to explore possible improvements to the system, and their effect on the variation and interactions. Led by the improvement team, these future-state scenarios must be discussed and fully understood, with any possible implications explored so as to provide feedback for potential improvements to be made.

In summary, stage 4 of the SCIMPI methodology represents a full transition from Foundation Knowledge to Dynamic Knowledge for the team (and subsequently the organisation). It is at this point that the knowledge from the deep understanding of the system obtained in the first three stages of the SCIMPI methodology.

Stage 5

The *Improve* stage guides the implementation team brought together in the *Lead and Learn* stage to apply the key tools for the improvement of the system. Building on the reflection and feedback encouraged in the previous stages of the SCIMPI framework, stage 5 drives the influence and manipulation of the information and product flow within the system, with a view to increasing the amount of value adding activities in accordance with the feedback received in the previous stages. These high impact tools

are 5S, also known as Good-Housekeeping, Single Minute Exchange of Die (SMED), Total Productive Maintenance (TPM), and Design of Experiments (DOE). 5S (which is covered in stage 1) is used in this case to make everything in the facility standardised and in the right place, at the right time. It is seen as a key driver for cultural change and gaining the buy-in necessary from employees, effectively being the catalyst for the Dynamic Knowledge sub-group.

Due to the very nature of the processes within continuous process industries (that is, extremely expensive to be off-line) SMED is used to optimise the changeover routine, so that down-time is minimised. TPM is also used to target any possible downtime by providing reliable machinery and/or processes, which underpins the efforts made in obtaining a lean facility. Leading on from this, soft computing techniques (i.e. neural networks) are applied to any highlighted process (on-line or off-line using the simulation model, as appropriate), so that the optimum results can be realised for that given process.

The use of soft computing techniques for improvement is seen by the author to be of particular importance within the process industry environment. In general, due to the nature of the industry, techniques such as Design of Experiments (DOE) (an important aspect of the six sigma approach) are difficult to implement in practice unless it can be used in a safe operating window (often not the case). This is because of the inherent constraints (i.e. heavy, expensive machinery may be involved, inflexible processes may be under consideration, extremely fast or extremely slow cycle times etc.) , so the system cannot be disturbed. Soft computing techniques do not need a structured methodology and therefore it is not necessary to run a series of structured experiments,

which need specific machine settings, and interfere with the online performance of the machine. When using neural networks for example, changes in process outputs are apparent within historical data obtained from the processes, which cannot be done using DOE. With DOE, specific settings are required, and therefore it is necessary at some point to go “online” and actually test machine settings, therefore interfering with the process.

Stage 6

The *Control* stage is where standardised work is introduced (configured from the feedback from stage 5), so that the improved procedures and processes that have been developed in the previous stages are not lost, and any newcomer to the system has a record of how tasks should be approached to fulfil their potential. In this way, the knowledge and awareness developed in the two sub groups (Dynamic and Foundation) is used to influence the information flow to best drive the system. A future state simulation model will have been developed within the A*nalysis* stage, which is maintained at this point so that demonstrations can be provided for each process, as well as a dynamic illustration of the system. Customer focus should be emphasised throughout the SCIMPI approach, but is mentioned at this stage, because customer demands on quality and so on are constantly changing. These changes need to become the driving point for future change. The cultural dynamics of the system/project team should be at an advanced stage, and well on the way to becoming an environment of continuous improvement, value creation and customer focus.

Stage 6 represents a fully fledged transition to the Dynamic Knowledge stage of the generic framework in Figure 3.5. It is at this point in the journey that the value creation, cultural development and feedback are evolving as the system evolves; creating a flexible, learning environment that responds quickly and effectively to any processual or cultural changes brought about by improvements made to the system.

Stage 7

The final stage of the SCIMPI approach, *Enterprise*, depicts the expansion of the previous stages towards customers and suppliers. Stage 7 also represents the final stage of the Dynamic Knowledge period represented in Figure 3.5, and is the first stage which considers engaging the rest of the organisation and subsequently other partners in the supply chain. It is at this point that the improvement team have established the Foundation Knowledge of the organisation/supply chain, and have used this underpinning to leverage the appropriate tools and techniques to create value, while configuring the information flow around this value creation. This happens in parallel with the team itself being guided through a micro cultural change as a group, but more strategically, influencing and guiding the transition of the whole system to one of continuous improvement, through the application of the SCIMPI methodology.

At this point, relationships need to be started with key suppliers, with a view to extending the SCIMPI approach throughout the supply chain. It is suggested that key personnel from the team brought together for the project in stage 1 should become champions in stage 7. These champions can then lead future collaborative improvement efforts in their own organisations, as well as downstream to their suppliers, continuing

the journey of continuous improvement. In this way, it can be demonstrated to the new teams by employees who have had experience and success using this model, and go on instigate cultural change, as it is often difficult for management to get this message across effectively.

Being continuous in nature, the Supply Chain Improvement Methodology is only the start of any continuous improvement implementation. When new SCIMPI teams are nurtured in *Stage 7*, taking the approach to their own facilities, the process of analysis starts again within the starting organisation and hence forth, the supply chain in question will embark on a dynamic journey of change that will transform the way in which process industry supply chains integrate, resulting in flexible, competitive supply chains, with the ability to compete in any given market.

Drawing on the necessary elements for continuous improvement suggested in the generic framework of Figure 3.5, the proposed SCIMPI methodology leads the organisation through five key phases on the path to continuous improvement. This pathway is outlined in Figure 3.8 below.

Taking a holistic view of the SCIMPI methodology, the first phase of the journey is to understand the current state of operations. Once this Foundation Knowledge has been achieved, the next stage of the journey is to identify areas or opportunities for improvement through the application of lean principles.

The third phase of the journey is the application of six sigma techniques to the areas identified in the previous phase. From this, a move to the future state can be made

through the further application of lean and six sigma techniques. This results in the reduction of lead time and uncertainty in order variation (phase 5), which in turn reduces the reliance of the system on forecasting techniques.

As a consequence of this pathway being followed, the system is more flexible to customer requirements due to the 'noise' being removed from the information flow. As with all continuous improvement initiatives, this process is iterative, so continuous feedback from phases 1-4 is delivered to the system in order to start the process over, where the future state map developed in phase 4 becomes the new current state map, and the pathway is followed again.

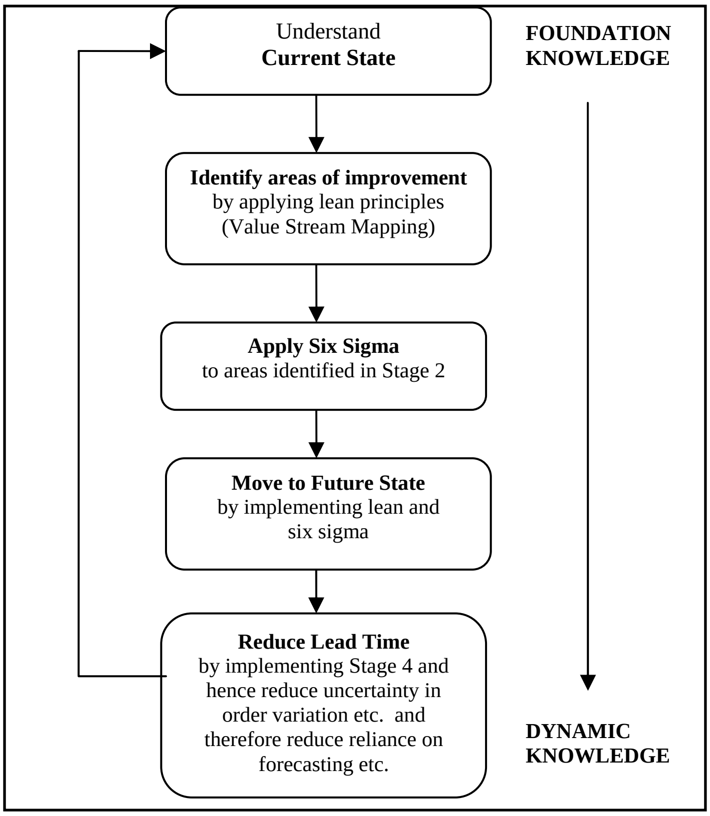


Figure 3.8 Stages to Improvement

The techniques brought together in the formation of the SCIMPI approach have been chosen in an attempt to provide a comprehensive and focussed analysis tool for members of the process industry wishing to improve their competitive stance within their respective industries, and realise the potential of becoming competitive on a supply chain scale.

The SCIMPI methodology attempts to increase the scope of mapping and analysis, and target the four key areas of *Mapping*, *Business*, *Improvement* and *Variation* using specific tools and techniques. Figure 3.9 in section 3.4 of this chapter depicts the four key areas addressed, and illustrates the relationships between these and the techniques used within the SCIMPI model.

3.4 Scope of Implementation

As can be seen in Figure 3.9, the largest concentration of techniques is used to address the *Mapping* and *Business* sections of the SCIMPI model. Value Stream Mapping is often applied to a manufacturing system on its own, under the misconception that a full journey of lean continuous improvement has been carried out. VSM is of course a useful and powerful tool in its own right, but using it in isolation will not achieve a fully lean organisation. A whole strategic philosophy throughout the supply chain is required in order for a system to be running at a truly lean level.

In addition to this, while the VSM tool itself does have an impact on variation, achieved by reducing the complexity of the system and thereby reducing the interactions and

variation within it, not all variation is addressed. Lean reduces interaction variation but not quality variation. When considering a current state VSM, there is also no feedback indicative of the costs involved at each process. To achieve this, VSM needs to be used in conjunction with other tools as proposed in stage 2 of the methodology. This view looks beyond VSM as giving a quick, succinct overview of where waste is present, and develops the idea of the mapping process itself becoming a continuous tool, constantly being updated by simulation models. In other words, simulation provides a roadmap for an evolutionary and dynamic implementation. In this case, VSM underpins the whole strategy, using the additional data supplied through the addition of the Balanced Scorecard and Activity Based Costing techniques. Used in conjunction with 5S, a foundation is made for the *Business* case to be improved in the subsequent SCIMPI stages.

Three key lean tools have been used to target process improvement and reliability, and also have a bearing on the business case itself, by providing a system which is more flexible to customer demands and changes downstream.

Finally, simulation and six sigma techniques address the variation within highlighted processes through the construction of control charts, as well as providing a dynamic vision to the mapping phase. Although simulation could be seen to address the *Business* and *Improvement* case of an organisation or supply chain, this is only the case when costing techniques etc are applied to the current state model itself. That is, without the use of artificial intelligence and so on, simulation relies on the input of the user in order to model the future state – it will not provide a solution of its own accord. SCIMPI brings together the four key areas necessary for a comprehensive approach to make

significant changes and explore opportunities for improvement on all levels, as well as providing a starting point for an organisation wanting to embark on a journey of continuous improvement. The enhanced six sigma stages of the proposed framework (Lead and Learn, Define, Measure, Analyse, Improve, Control and Enterprise) are used to underpin the approach, providing focus and direction for all involved– a necessity for any initiative.

Before using simulation software, it is important that the benefits and drawbacks are understood by the implementation team (as mentioned in section 3.3). Due to the expense, lack of training in a simulation software, or scope of the project, a simulation approach may not be justifiable for every project. A series of questions need to be addressed before the implementation team consider whether or not a simulation model of the project in question will yield beneficial results that really add value to the improvement initiative. The SCIMPI methodology suggests using simulation and/or the VSM approach at the discretion of the organisation, following reasons in section 3.3 for their choice.

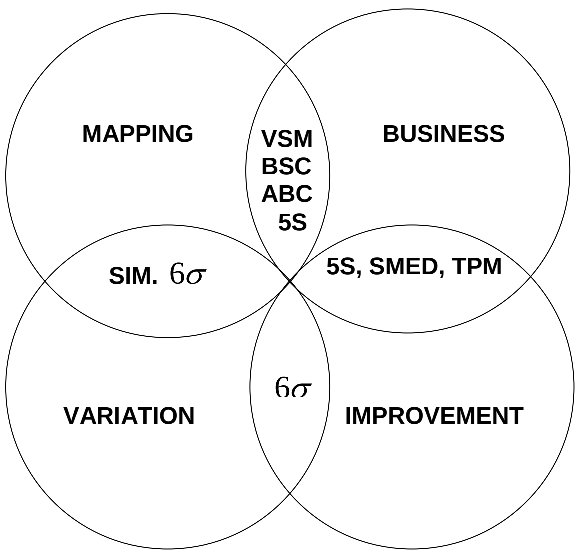


Figure 3.9 Scope of SCIMPI Approach

However different process industry environments are to discrete process organisations, the same implementation issues still exist and must be managed correctly – namely the SCIMPI approach needs to have the backing of everyone from the top management down within the organisation.

By providing this methodology, the arduous and time consuming task of management looking at various improvement philosophies, tools and techniques (which may lead to their commitment being spread too thinly) is reduced. When confronted with a number of tools and techniques, it is easy to attempt implementation efforts for a few of them, and see if they happen to work. Unsure of which techniques to follow, inappropriate efforts may be made, leading to high resource usage only to obtain small incremental improvements, meaning that economic justification of such tools makes it an unviable approach.

3.5 Existing Lean Six Sigma Frameworks

Table 3.2 shows the strengths and weaknesses of existing lean six sigma models .

Table 3.2 Strengths and Weaknesses of Existing Lean Six Sigma Frameworks

	Strengths	Weaknesses
Existing Lean Six Sigma Models	• Value Stream Mapping • DMAIC	• Costing • Complexity • Roadmap • Underpinning • Exhaustion

Existing frameworks available for lean six sigma are available from a number of consultancy companies (examples being those on offer from companies such as Segla, and CBIA Training and Consulting). All of these frameworks have two main strengths. The first one being that the DMAIC progression is used to underpin the main body of the approach. The second is that the VSM technique is used in the first stage of the framework to map the operations, providing a comprehensive means to gaining a quick understanding of the scope and operations of a system. However, there are a number of weaknesses within these frameworks. The first is an unclear understanding of what environment or application the frameworks are intended for.

Existing frameworks are designed to be generic in nature, and they comprise a vast number and range of tools and techniques of both a relatively straight forward, and more complex statistical nature. The frameworks present to the user a complex gathering of lean and statistical tools, with no particular roadmap identified, in an attempt to cover 'every base', and does not provide a scientific methodology for the application of these tools. Although this lets the user know what range of tools there are available to use in a lean six sigma toolbox, it is easy to get overwhelmed by the presence of so many tools without a scientific methodology to guide the implementation. This may also result in a 'scatter gun' approach, whereby a number of tools are used, in the hope that one of them may solve a particular problem.

Faced with such choice, management may well find themselves with 'project exhaustion', where people and all other resources are taken to their limit in an attempt to progress with a larger number of projects, instead of focussing on a single and effective implementation and analyses. There is also a lack of costing information within such frameworks, which could replace some of the more specialised tools put forward in such frameworks, so that the project improvement team will focus on relevant data and strategy, without becoming saturated in complex matrices or statistics, taking away focus from the opportunities at hand.

The proposed framework put forward in section 3.3 of this chapter aims to fill in some of the gaps not addressed by such consultancy models, and provide a roadmap for users. Firstly, the SCIMPI framework has been constructed with special consideration and focus on the process industries. Therefore clarity has been provided in terms of tools and techniques that need to be selected, providing appropriate targets and an accessible

roadmap for lean six sigma continuous improvements. The negative effects of cherry-picking (as discussed in chapter 2) are also minimised. Being aimed at a specific industry, the framework attempts to make lean six sigma activities both phase and situation dependent.

In terms of culture in the context of change, the SCIMPI framework aims to engage the team members throughout the project duration. Three key criteria are addressed in an attempt to bring about and measure of positive cultural change along with the initiative. These are:

1) Setting the scene.
2) Measurement of before and after scenarios.
3) Hard systems to drive soft systems thinking.

The first of these is *setting the scene* whereby the current state environment is mapped and analysed. This current state situation, when reviewed against the environment post the improvements, i.e. the *before and after* will identify if the notion that when faced with positive results, the employees respond positively to positive change results. The last important point here is that by providing measurable change (through tools such as SPC, value velocity and ABC), changes in the *soft* systems will be focussed by *hard* data. In other words, the framework is using hard systems to drive soft systems thinking. The tools and techniques at each stage of the framework aim to develop and nurture a change in the culture of the team eventually leading to a company wide shift. In this way the framework becomes sustainable through commitment from the people who drive it and operate within it. This is explored in more detail in section 3.6.1 of

this chapter, where the SCIMPI model is discussed in context with Soft Systems Methodology and the Sustainable High Performance Culture Model (SHPCM).

A diagram (Figure 3.11) in section 3.6.2 goes on to summarise how SCIMPI addresses the stages of Soft Systems Methodology (SSM), and also addresses the gaps identified in the SHPCM.

The proposed SCIMPI framework is also designed to provide a more manageable and less overwhelming lean six sigma for the process industries. The author believes that usability is a prime factor in the effectiveness of any continuous improvement approach, and this is achieved through maintaining an equitable balance between complexity and sustainability. A succinct and simplified roadmap is presented, providing a high impact methodology by way of a project management tool, constructed to address the limited time and resources available to practitioners.

The next section of this chapter goes onto discuss such a framework that attempts to bring together both approaches in a succinct and easy to follow methodology that is designed to have maximum benefit when applied to continuous process industry applications.

3.6 Aligning SCIMPI with Soft Systems and Sustainability

When applying continuous improvement techniques, productivity, quality and cost cannot be considered in isolation. There needs to be a complete and open systems view of the organisation and how actions affect different parts of that system. The SCIMPI framework aims to bring about this cultural systems view, by tracking each of the seven

stages in the framework to that of the well established Soft Systems Methodology (SSM) pioneered by (Checkland, 1981). This section describes how each of the stages of the SCIMPI framework relates to the stages developed in the SSM approach.

The question of sustainability is also considered by tracking the SCIMPI framework against the SCHPM framework as suggested by (Owen et al., 2001) and discussed in section 2.9 (p37) of this thesis. The SCIMPI framework aims to fill in the gaps identified in Figure 2.5 (p44).

3.6.1 Comparison of SCIMPI and Soft Systems Methodology

Soft Systems Methodology can be described as a collection of seven activities that form a "*circular learning process*" Checkland (2000, p. 19). The seven stage diagram is shown in Figure 3.10.

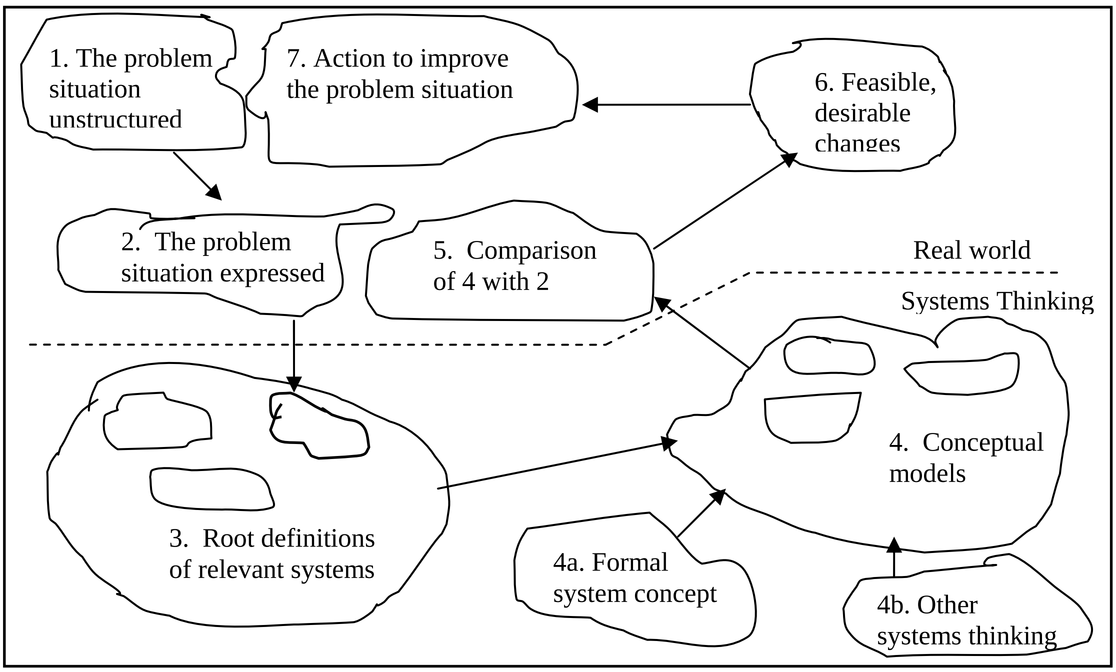


Figure 3.10 Soft Systems Methodology (Checkland, 1981)

The first two stages of SSM are concerned with building a “rich picture” of the situation in which there is a problem. The first stage of the SCIMPI model (Lead and Learn) is used to create this picture through the training of employees, centred on the scope of the project – discussing the current operating environment and placing everything in context for the next stage. The second stage of SCIMPI (Define) uses an enhanced VSM approach, which provides all team members with an appreciation of the size and the scope of the project. The environment in which problems are thought to be in is captured in the VSM, while certain data is present, such as cost and variation provide more context to the situation, giving a slightly more in depth understanding of the whole system. The use of Balanced Scorecard criteria in this phase, providing a more strategic view of the project and also augments the picture created by the team. Once the second stage of SCIMPI has been achieved, the first two steps of the SMM have been covered, so that the problem situation and environment surrounding it has been captured, while the problem situation has been expressed through the addition of data and strategic indicators such as objectives, measures and vision. This follows Checkland’s guidelines of “*forming a view of how structure and process relate to each other within the situation being investigated*” (Checkland, 1981, p. 164).

The ‘Define” stage of the proposed methodology also fulfils the third step in the SSM, whereby the root definitions of the relevant systems are recorded. The relevant systems are highlighted in the VSM, and can be spotted easily, as value stream maps provide almost a photograph of the current system. Any areas for improvement are highlighted in conjunction with the general data surrounding them as discussed previously. Again, the inclusion of the balanced scorecard indicators of objectives, measures, targets and

initiatives are included to shape the nature of the systems to be considered. In addition to this, the more focussed data collected in the Measure stage of SCIMPI also goes toward shaping the nature of the problem, as a more refined picture of the system can be seen, as more information is gathered. Statistical Process Control (SPC) techniques form an important part of this measuring stage, so that the behaviour of the system, in terms of variation and control can be considered and understood. In this way, a complete understanding of how the system works, along with the problem area and processes/people involved can be drawn from the enhanced VSM and the ensuing discussion of the results. It is essential that after each stage of SCIMPI has been achieved, team members meet and reflect upon the results obtained so far. Therefore, any anomalies or questions can be raised and answered by the group.

Stage four of SSM states that conceptual models are to be constructed of the human activity systems which are named and defined in step three. The root causes in step three are used to describe the human set of activities that can be thought of as a transformation process. This is answered by stages three and four of the SCIMPI methodology, which uses the data previously obtained in the first three stages, along with simulation modelling, to provide a view of the state of the system as it stands, enabling the team to explore the interactions between each element within the system, and how the system is affected by changes to these elements. Along with the VSM, a conceptual model of interactions and what the system must become, or operate as, is developed with the simulation environment. As a result, the team members are presented with both a strategic view of the system as well as a dynamic interpretation of activities. The information gathered from SPC techniques at this point will also provide some direction for the model. This is done through the behaviour of specific points

within the system being traced by the SPC analysis, which can then aid in the formation of a desired state operating model in the simulation environment. As mentioned previously in this chapter, this use of 'hard' systems to drive 'soft' systems is seen as a strong addition to the framework, especially when considering the whole supply chain structure. From these approaches, the system can be described on a number of different levels, both operational and strategic, while also considering the cultural state and desired changes to that culture that are necessary for sustained improvement.

From here, SSM suggests that the conceptual model should now be compared with the actual system. This is so that the conceptual model may be analysed closely with the issues identified in step two of SSM. Once the simulation model has been established as an accurate representation of the system, and possible future state scenarios have been modelled, the team must compare these models with the current state situation, and all possible changes to be made discussed with reference to the current and proposed state models. Stage five within the SCIMPI model builds on this reflective step, because as each improvement technique is considered, it must be discussed in context to the real system. Through this, each technique should be discussed with reference to the particular issues identified, and the team must be encouraged to take a holistic view of the effects of any improvement. Soft computing techniques, as used in this stage of SCIMPI provide a platform for observing how the system interacts and behaves according to controlled input factors. In this way, more detailed possible changes in the system may be considered.

To complete the needs of step five in SSM, the control stage of SCIMPI guides the implementation team to consider both the current and conceptual states through the

creation of standardised working practices. In order to structure these standard approaches for the system, it is necessary to consider the existing system/environment, along with the conceptual model, so that the desired state is maintained. Through this process, areas of the conceptual model may be identified as inappropriate, and therefore changed as required. However, before this happens, the revised conceptual model should be simulated, and compared to the current state, so that its applicability can be discussed. Customer focus is also essential to this reflective step in SSM. By maintaining customer focus and reminding ourselves of its importance when implementing standard work (which will have considerable bearing on how the system ultimately operates). The comparison between current state and proposed system models must be viewed from the customer's perspective, and constantly reviewed with this vision in mind, being careful to consider the implications to the customer resulting from any changes to the system environment. Discussion around these points must be encouraged in order to maintain the best possible results from the group.

The discussion of possible or feasible changes to be made to the system (as pursued in step six of SSM), is addressed through a number of stages in the SCIMPI model. It is first approached in the lead and learn stage, as this is where the context and scope is discussed with the team, and they are focussed on what type of improvements are feasible within the project environment. However, the most focus given to this is during the '*Analyse*' and '*Improve*' stages of SCIMPI. Both stages are focussed on creating possible solutions that are feasible within the system being considered. It should be noted that the an inherent part of the SSM approach is to ensure the sustainability of any action taken to improve the system.

3.6.2 Comparison of SCIMPI and the Sustainable High Performance Culture Model

Figure 3.11 presents a summary of the mapping between SSM, SCIMPI and SHPCM, providing a graphical representation of sections 3.6.1-3.6.2. The shift in cultural change from management push to employee pull, as proposed in the work of Shiba and Walden (2001) is also included to illustrate the shift in thinking as a SCIMPI approach is progressed. Each numbered square represents a stage within the respective methodology, while the arrows joining the squares represent the links between the stages of the three approaches.

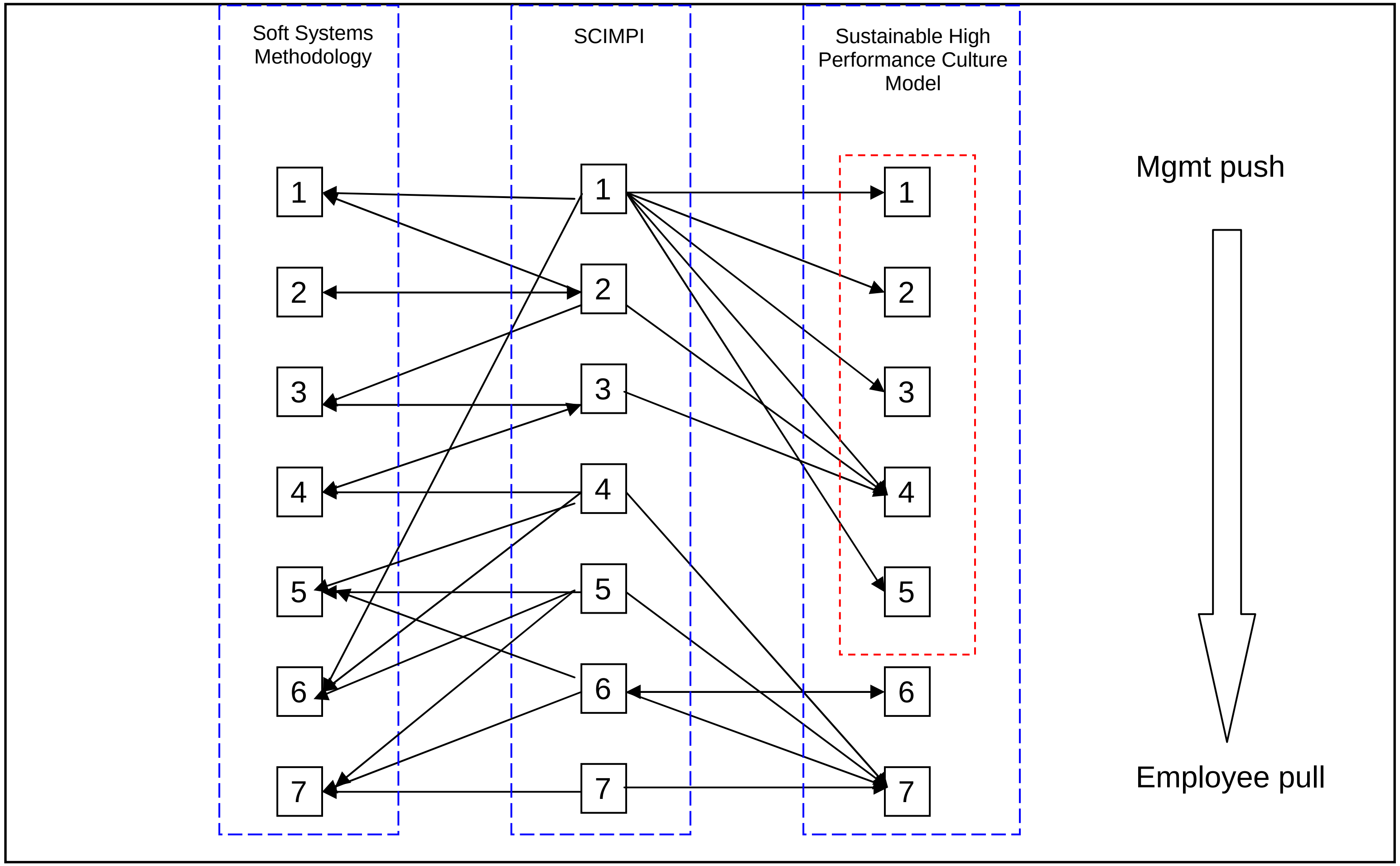


Figure 3.11 SSM, SCIMPI and SHPCM Interactions

3.7 Discussion

As mentioned previously, improvement initiatives often fail due to management commitment, cultural change, or the uncertainty brought about though the cherry-picking approach of tools and techniques, or the shear complexity of the tools/techniques experienced when using any one approach in depth. The author is taking this position in developing the SCIMPI model, i.e. achieving a balance between complexity and sustainability. As seen in Figure 3.12 it is believed that SCIMPI provides an equitable balance between sustainability and complexity, which is achievable and realistic in a project time frame, and so has high impact when applied. This is achieved through the use of specific, high impact tools geared towards having maximum benefit within the process industry.

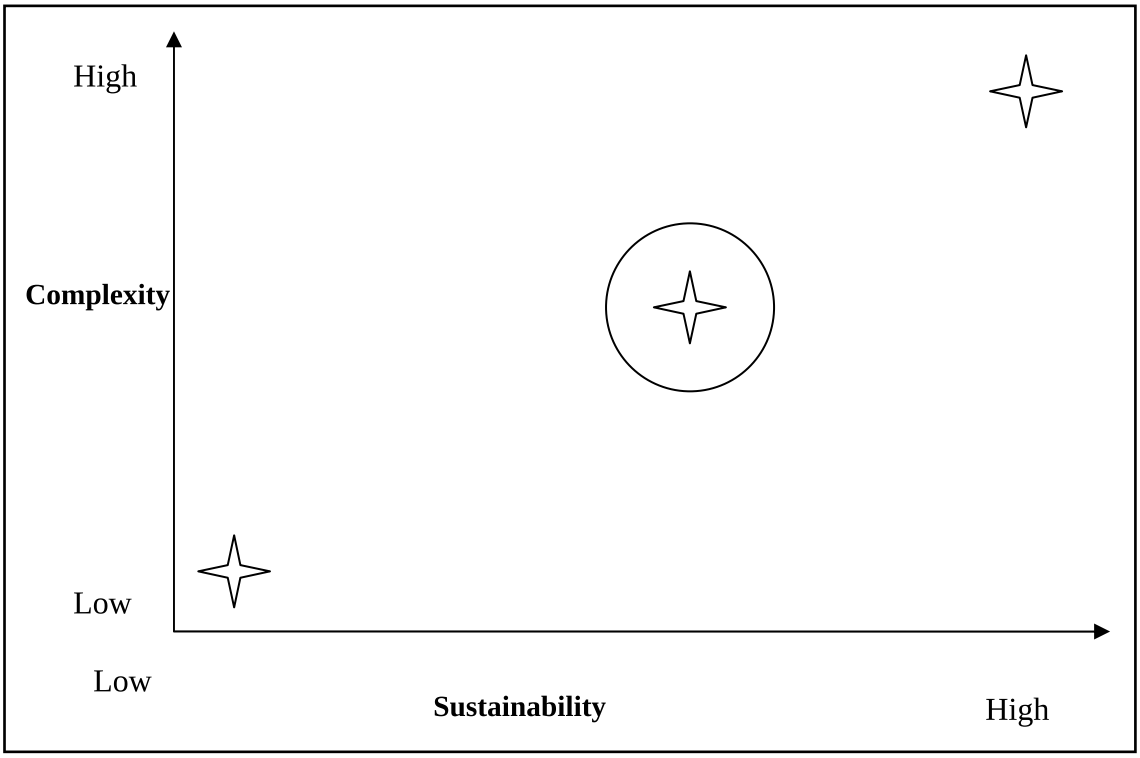


Figure 3.12 Sustainability vs. Complexity

In summary, it is proposed that the SCIMPI model has the following contributions to the body of research in the field of lean six sigma. Firstly, this is the first time that a unified methodology incorporating lean philosophy and six sigma has been developed for the process industry, while it is also the first methodology developed that provides a sustainable, high impact approach to lean six sigma. Implementation efforts are not sustainable; due to the fact they are based on a cherry-picking approach, or too complicated for a comprehensive implementation plan to be followed. While techniques such as "*Learning to See*" as developed by Rother and Shook (1999) provide an excellent, quick and succinct way to identify and manage waste within a system, it also has some limitations, as there are a number of key criteria that may be included in the improvement approach, such as variation and cost indicators that could be used for more comprehensive analysis and decision making.

The Value Stream Mapping technique has been modified to provide a more comprehensive and focussed tool deemed more appropriate for the process industry. No other approach has used the VSM technique as a platform in conjunction with other tools to provide a more comprehensive technique, incorporating costing and process capability.

Inherent in the roadmap for operational and strategic level improvement of an organisation, the SCIMPI model provides a model for growth, considering the business case as well as the usual operational focus by incorporating key business issues within the methodology, while cultural issues are also addressed. The challenge of sustainability is also considered by developing the model with reference to the SHPCM model of (Owen et al., 2001).

Finally, the SCIMPI lean six sigma framework provides a more strategic level view of the organisation, preventing businesses getting overwhelmed in complex detail through the use of one specific tool.

3.8 Summary

In this chapter, an integrated lean six sigma methodology (the SCIMPI model) is proposed, derived from an original generic framework for continuous improvement. The generic framework has been formed from the fundamental elements critical to an improvement initiative, bringing together the knowledge based attributes in a Foundation Knowledge sub group, and the practical application of this foundation in a Dynamic Knowledge sub group.

The next chapter goes on to discuss a preliminary application of the SCIMPI model within a process industry environment, a lead refinery in Europe. The case study is designed as an exploratory implementation of SCIMPI before more detailed case studies are discussed.

The first case study (chapter 4) presents a straight forward application of the SCIMPI methodology, exploring it's feasibility within a process environment, using simulation as the main technique for analysis. The second case study (chapter 5) highlights the use of lean techniques to leverage the application of statistical tools and soft computing techniques. The final case study (chapter 6) extends the application of the SCIMPI methodology to a larger scale improvement project, the scope of which covers the internal supply chain of Australia's leading producers of steel.

4.0 Case Study 1 Preliminary Testing of SCIMPI Model

This chapter withheld and may only be viewed or copied with the permission of the author or supervisor.

5.0 Case Study 2 Newsprint Manufacture Supply Chain

This chapter withheld and may only be viewed or copied with the permission of the author or supervisor.

6.0 Case Study 3 Steel Manufacture Supply Chain

This chapter withheld and may only be viewed or copied with the permission of the author or supervisor.

7.0 Conclusions

The purpose of this research centred around three objectives. The first concerned the review of literature surrounding the success and limited success of the lean manufacturing philosophy, the evolution of six sigma, and the characteristics of change. The literature reviewed has explored these areas and from this, identified critical elements for sustainable continuous improvement efforts.

Building on this, the second objective was the creation of a generic framework for continuous improvement. Using the critical elements identified from the literature review as a platform, a generic framework was created, identifying two key stages of knowledge development in an organisation's transition to continuous improvement. Bringing together the knowledge based attributes in a Foundation Knowledge sub group, and the practical application of this foundation in a Dynamic Knowledge sub group, the framework promotes the deep understanding necessary for sustainable continuous improvement. This proposed generic framework has then been used to derive a lean six sigma methodology specifically for the process industry sector, the SCIMPI methodology.

The third objective concerned testing the efficacy of the SCIMPI methodology through its application to three case studies based in different process industry sectors. The proposed Supply Chain Improvement Methodology for Process Industries (SCIMPI methodology), has been successfully tested in three case studies that were designed to highlight different elements of the SCIMPI framework. The first two case studies were developed in the UK, while the third case study was based in Australia.

The first case study presented a straight forward, exploratory application of the SCIMPI methodology within a process industry environment, using simulation as the main technique for analysis. This case study demonstrated that continuous improvement techniques were well suited to the batch-flow process industry and simulation modelling.

The second case study was designed to test the statistical and soft computing techniques that form part of the SCIMPI methodology, and their applicability in a high technology process industry environment. It should be noted that although techniques such as simulation or neural networks are not considered by everybody to be “shop-floor” techniques, they form an important part of the SCIMPI framework. The proposed framework is designed to provide long term strategic change, and is not intended to be taken as an “off-the-shelf” solution by all business. Long term strategic investment is necessary to effectively implement the SCIMPI framework, and realise the gains of a comprehensive approach to improvement. The organisations participating in this research were all familiar with these techniques and had access to a number of different simulation packages, with dedicated research and development departments, which may be beyond the reach of smaller facilities. In the future, it may possible for smaller sized companies to purchase an “off-the-shelf” improvement package designed around the SCIMPI framework with the necessary software built into its functionality.

The effectiveness of the SCIMPI methodology as a lean six sigma framework for the process industry has been demonstrated through the identification of opportunities for improvement that had been overlooked by previous efforts. When following the

SCIMPI methodology in this case study, the non-independence of controlled data was highlighted, something of particular relevance and concern in the process industry sector. This has led to a different quality management approach being suggested to the organisation. As a result of this, hard systems techniques have been used to drive a soft systems approach required to deal with quality management issues. This integrative view of hard and soft systems is seen as a critical path towards sustainability of improvement initiatives.

The final case study was designed to extend the application of the SCIMPI methodology to a larger scale initiative, which considered the internal supply chain operations of Australia's leading steel producer. Taking a top-level, rather than operational view of the organisation, the application of the SCIMPI methodology proved successful, overcoming the legacy left behind from previous improvement efforts.

The issue of mistaking common cause variation for special cause variation was highlighted, resulting in a number of improvement stages to minimise the 'tampering' effect while a strategy for the re-design of the system is discussed by management. The work brought forward through the SCIMPI methodology is expected to be sustained in the organisation, and following this case study, the initiative is being pursued with an internal customer of the supply chain.

On an operational level, the case studies shared similar characteristics and opportunities for improvement. However, on a cultural level, it can be said that the Australian based organisation is faced with different challenges to the UK based companies. Importantly, AB Steel experiences greater influence from union bodies. It is expected

that they will be involved in any continuous improvement process that affects working practices for the employee. This places certain constraints at the planning stage, for example, increased time and resources for employee consultation and perhaps a negative influence on the employees' perception of the improvement process.

Building on the findings of this thesis, a number of observations can be made in conclusion. The first, is that much of the inherent mistrust surrounding lean as a philosophy is due to the limited and myopic way that it has been implemented. For example, reducing inventory levels cannot be enforced in volatile environments, usually leading to even greater variability and exposure to risk. Therefore, a systematic approach needs to be adopted which optimises the whole system and focuses the right strategies in the correct places.

It is important to recognise that lean has moved away from being a one-stop cure all philosophy. Instead, lean six sigma should be seen as the platform for the initiation of cultural and operational change, leading to total supply chain transformation. In other words, it forms a small but important piece of the jigsaw. When used in combination with other complimentary continuous improvement techniques such as six sigma, lean provides leverage for comprehensive strategies and therefore provides a more integrated, coherent and holistic approach to continuous improvement. Lean must be viewed, understood, and accepted as a coherent methodology and therefore a step beyond previous ad hoc continuous improvement strategies.

When combined in a scientifically underpinned framework such as the one resented in this thesis, lean and six sigma offer organisations a comprehensive approach to

identifying and managing opportunities for improvement. The lean approach provides direction and scope for improvement projects, reducing complexity and interactions by targeting non value adding activities identified through the value stream mapping technique, which can then be used to identify key leverage points to be targeted through six sigma tools (Refer to section 3.3, pages 103 & 106).

Lean six sigma should be seen as a precursor to producing more responsive supply chains through effective communication leading to strategic alliances and visibility. Organisations will need to be as lean as possible, providing clarity for the implementation of six sigma techniques, moving forward to additional concepts such as agility and total supply chain integration. This is not to say that every element of the lean philosophy or six sigma approach should be adhered to, as not every lean tool or technique is suitable for every situation or company. What this does mean, is that it is critical for management and the wider organisation to achieve the understanding developed in the Foundation and Dynamic Knowledge sub groups of the generic framework in Figure 3.5 if they want to pursue sustainable, effective, and meaningful improvements within their business. It is evident from research that both a hard and soft approach is necessary for a successful implementation, and the correct synchronisation is critical. The dynamics of the system must be fully understood before effective internal relationships can be developed and maintained in order to create a truly efficient and responsive enterprise able to compete with strong global competitors.

Lastly, organisations must be careful not to remain static once the first iteration of a continuous improvement approach has been completed. If the improvement efforts do grind to a halt, under the impression that the system has been improved, then the

business will enter a rigidity-sustainability paradox (as discussed in section 2.10 of this thesis), caused by the misunderstanding that the journey is finite. It is the job of the leader, along with the management within the organisation to ensure that this is clearly communicated and understood.

The proposed SCIMPI methodology presents a fully integrated lean six sigma framework, incorporating the critical elements of sustainable continuous improvement as identified in the generic framework presented in chapter three (Figure 3.5) of this thesis. The SCIMPI methodology provides operational focus and strategic direction for improvement teams, with an equitable balance between sustainability and complexity, in turn avoiding the pitfalls of the cherry-picking approach to improvement techniques. This is achieved by guiding project teams, and in turn organisations, through two critical stages of knowledge development, with focussed tools and techniques.

This thesis provides an industry specific lean six sigma methodology, designed using a solid scientific underpinning, and based on the critical elements of continuous improvement and the comprehensive integration of lean manufacturing and six sigma techniques. The addition of soft computing techniques within the proposed lean six sigma methodology informs management decisions on improvement approaches to be made; with minimal disturbance to the system. This is of particular importance in the process industry sector, where particularly large losses are to be experienced if a process is taken off-line for any amount of time. The process industries examined in this research signify new scope for exploration of the application of continuous improvement, in particular, a specialised integration of lean six sigma techniques.

7.1 Contributions to Knowledge

In response to the findings of the literature review, a generic framework has been derived that identifies the key elements that are essential for sustainable continuous improvement. Resulting from this, two critical stages of knowledge creation in the journey towards continuous improvement have been identified.

This generic framework, along with the two stages of knowledge development, have been used as a platform for the creation of an industry specific lean six sigma framework (The SCIMPI methodology). This is the first time that a unified methodology, presenting a true integration of the lean philosophy and six sigma approach, has been developed with a scientific underpinning. This research also represents the first time that an industry specific lean six sigma methodology has been developed.

The SCIMPI methodology proposed in this thesis draws together the need of industry for an improvement approach that addresses the cultural aspects as well as the business needs of an organisation. The SCIMPI methodology provides a comprehensive and integrated model for cultural and business cases, as well as a roadmap for the operational level improvement of an organisation. The business case (as well as the usual operational focus) is considered through the incorporation of key business issues within the methodology.

7.2 Future Research

The first stage of future research would be to continue the analysis of the SCIMPI methodology with the aid of a longitudinal case study spanning perhaps four to five years in length, so that the cultural change and the true sustainability of the approach may be explored further. The findings from such a case study would provide a valuable insight into the effectiveness of the SCIMPI methodology as a long term improvement approach.

In line with the lean vision, the next stage of development for the SCIMPI approach is the production of clear, concise, visual instructions so that organisations can follow the methodology and start the implementation of continuous improvement. An aid to this would be the design of a tailored simulation package as a decision support mechanism, similar to that of McDonald, Van Aken et al. (2002), but providing focus on the business case through the integration of the discussed costing models. Leading from this, virtual environments for teaching the SCIMPI model could be created, following on from the work of Chi, Pepper et al. (2004).

In order to extend the scope of the SCIMPI model still further, an examination of the relationships needed for effective supply chain management could be considered, leading to commentary on the blend of lean and agile techniques needed within the process industry, and whether the decoupling point would experience a shift due to the nature of the sector. Steps to incorporate strategic planning and market analysis would also be beneficial, to provide a broader scope for organisations once they have started the SCIMPI cycle. This has potential to lead on from the strategic alliance stage, and

develop frameworks such as design for lean six sigma, and provide a design for continuous improvement, or SCIMPI.

A number of potential limitations for the proposed framework that may be addressed in future research may also be identified. The first opportunity for further research to come from this is that comprehensive implementation of the framework is perhaps dependent on the size of the organisation. For example, only larger organisations (such as those presented in the three case studies) may have access to those tools not considered "shop-floor" techniques, such as simulation software or neural networks. However, each organisation participating in this research was either open to the use of these techniques, or had already purchased sophisticated analysis software, which is inherent in the SCIMPI framework, such as simulation software.

The sustainability of improvements made through the SCIMPI approach is dependent upon management commitment and the legacy of previous organisational change. If this legacy is negative, then this will prove a barrier to any change within the business. In an attempt to minimise the impact of such a situation, SCIMPI attempts to guide the team through a structured roadmap of change.

The proposed SCIMPI framework should not be viewed as a "quick-fix" by organisations. Instead, it must be considered as a plan for strategic change that requires investment in a number of areas such as simulation software and other soft computing techniques, and the ongoing training and development of employees. Due to the multidimensional nature of the SCIMPI framework, incorporating a number of different tools and techniques that require training and/or previous knowledge or experience,

application will need a truly cross-functional team from the participating organisation if it is to succeed. Such a team should include representatives from production, management, accounting and human resources in an effort to deliver a complete perspective of change to the journey of improvement.

Finally, moving away from the SCIMPI model, the generic framework for continuous improvement (as defined in section 3.2 of this thesis in figure 3.5), should be used as a scientific underpinning to explore the development of additional industry, or situation specific lean six sigma frameworks. Using the five stage approach of *Map, Strategy, Centre, Advance* and *Sustain* (as described in section 3.3 of this thesis), appropriate tools and techniques may be configured to each application or industry.

8.0 References

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APPENDICES

Appendix 1 X Bar and R Charts for AB Paper

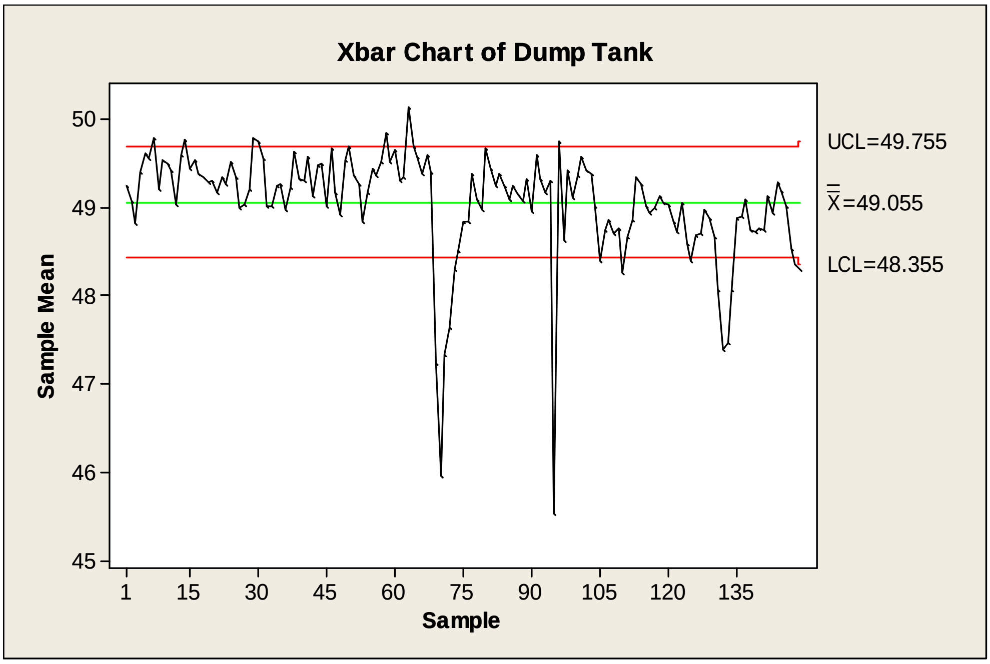

Figure A1.1 X bar Chart of Dump Tank Process

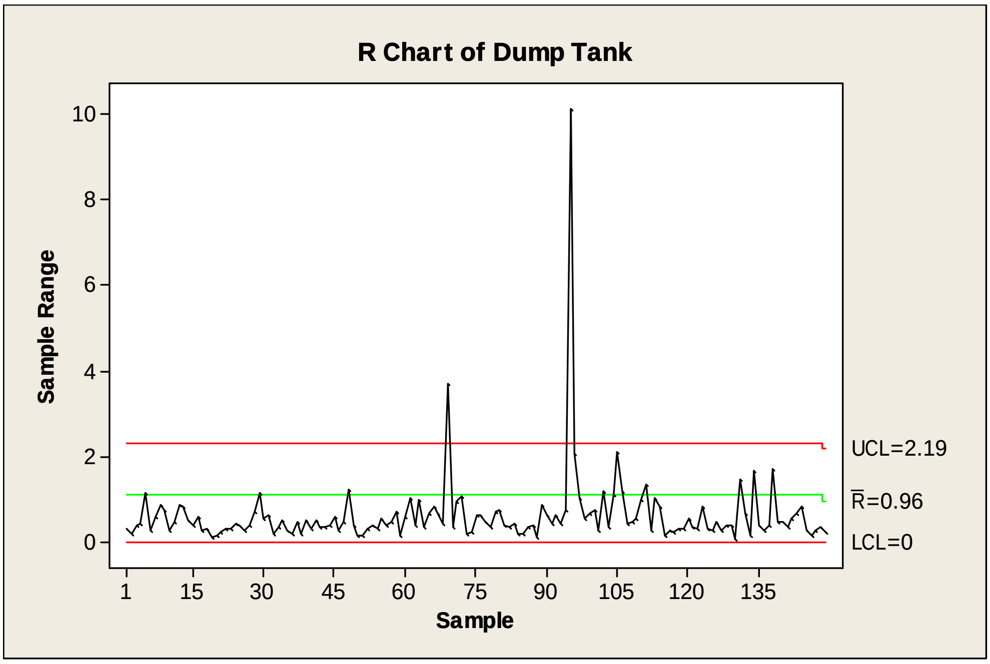

Figure A1.2 R Chart for Dump Tank Process

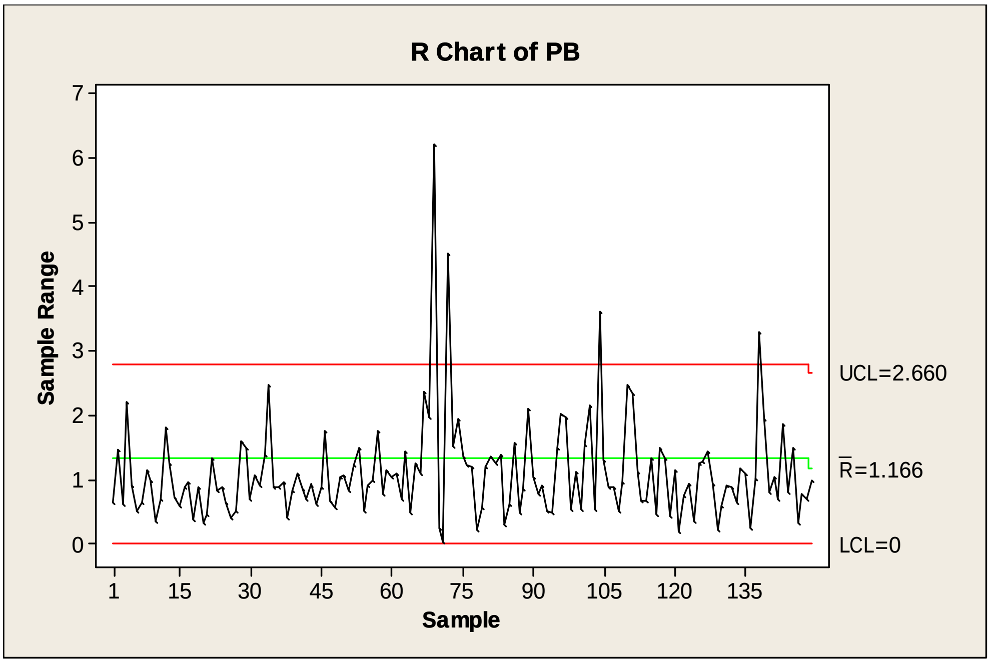

Figure A1.3 R Chart for Post-bleaching Process

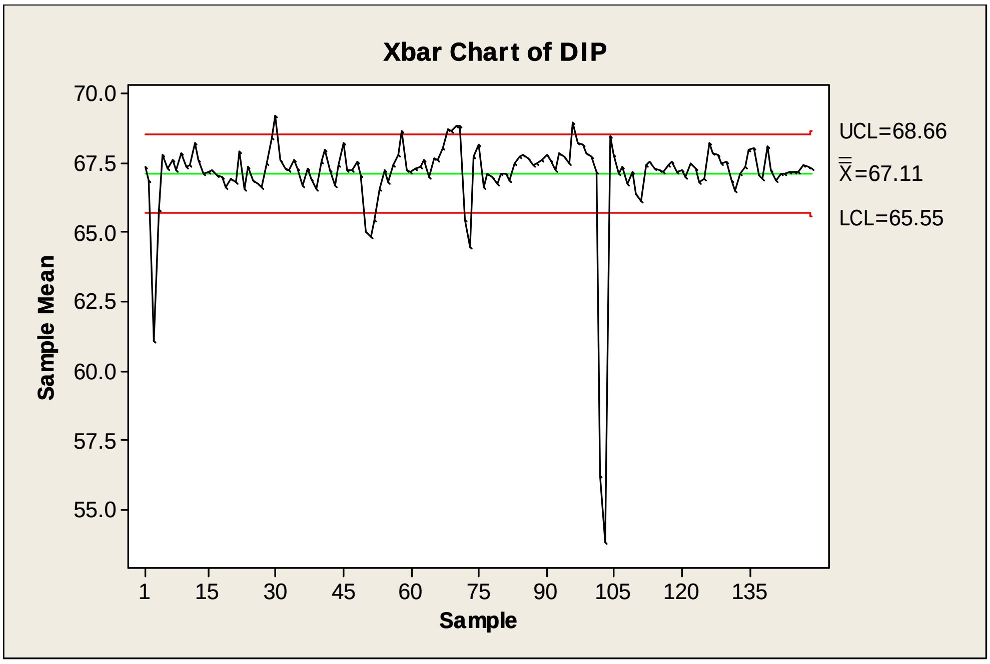

Figure A1.4 X bar Chart for De-inking Process

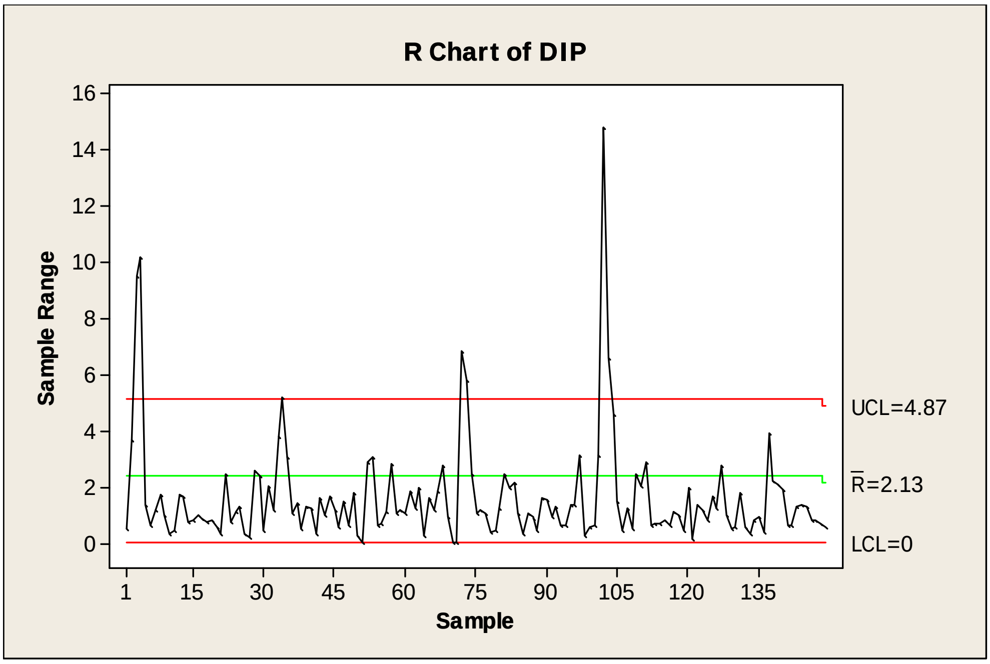

Figure A1.5 R Chart for De-inking Process

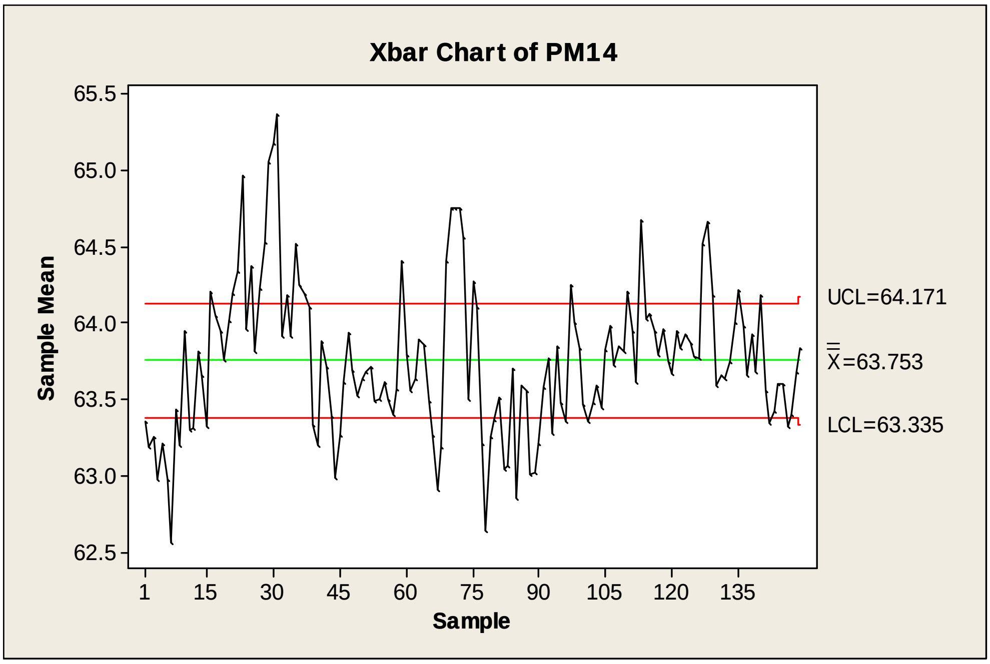

Figure A1.6 X bar Chart for PM14 Process

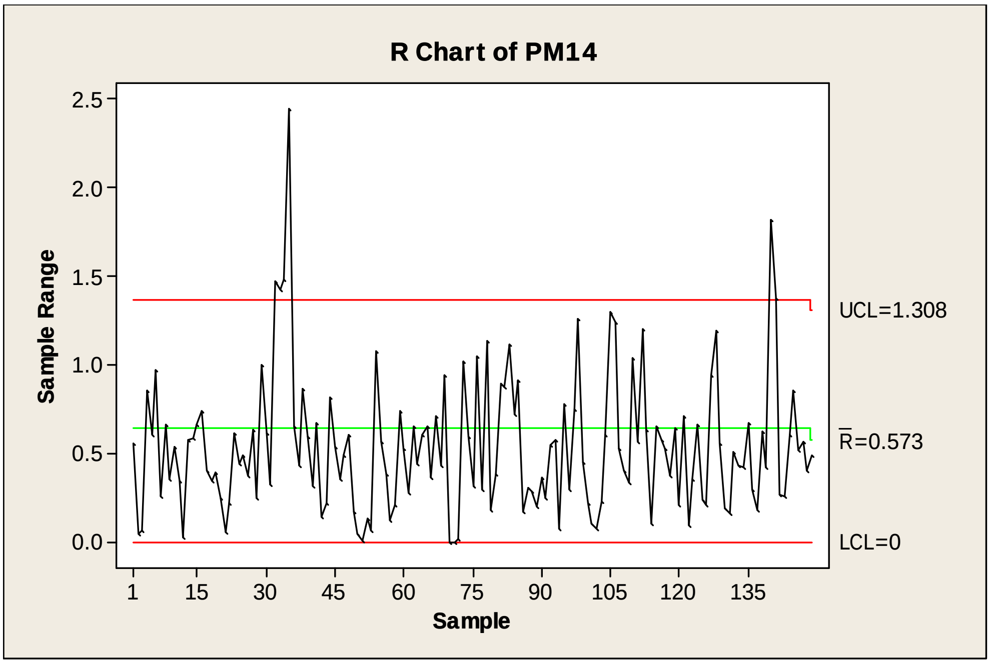

Figure A1.7 R Chart for PM14 Process

Appendix 2 New Control Limits for AB Paper

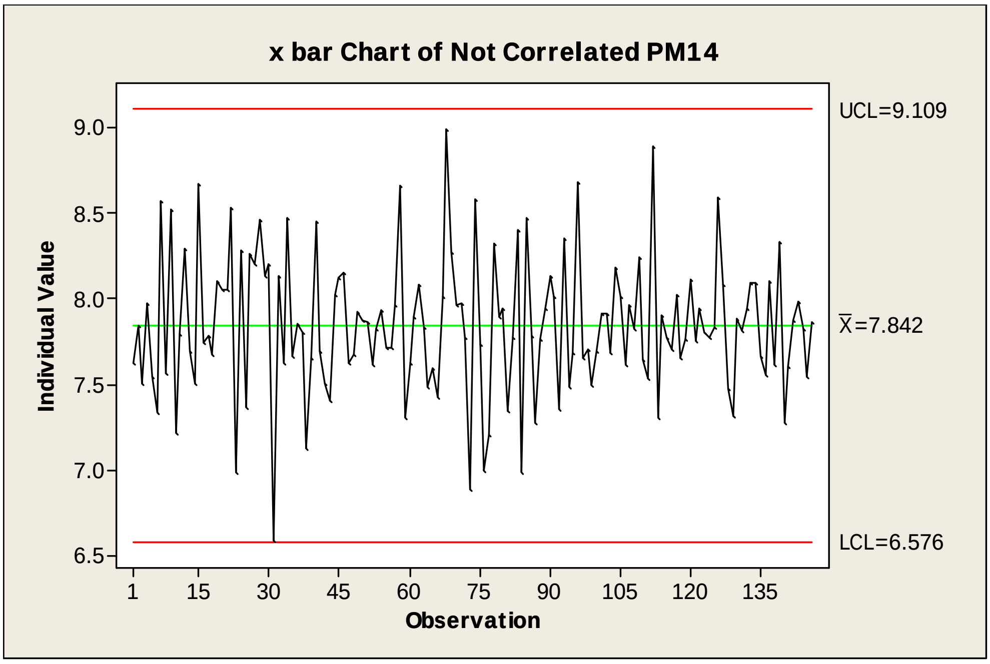

Figure A2.1 X bar Chart for PM14 - Independent Data

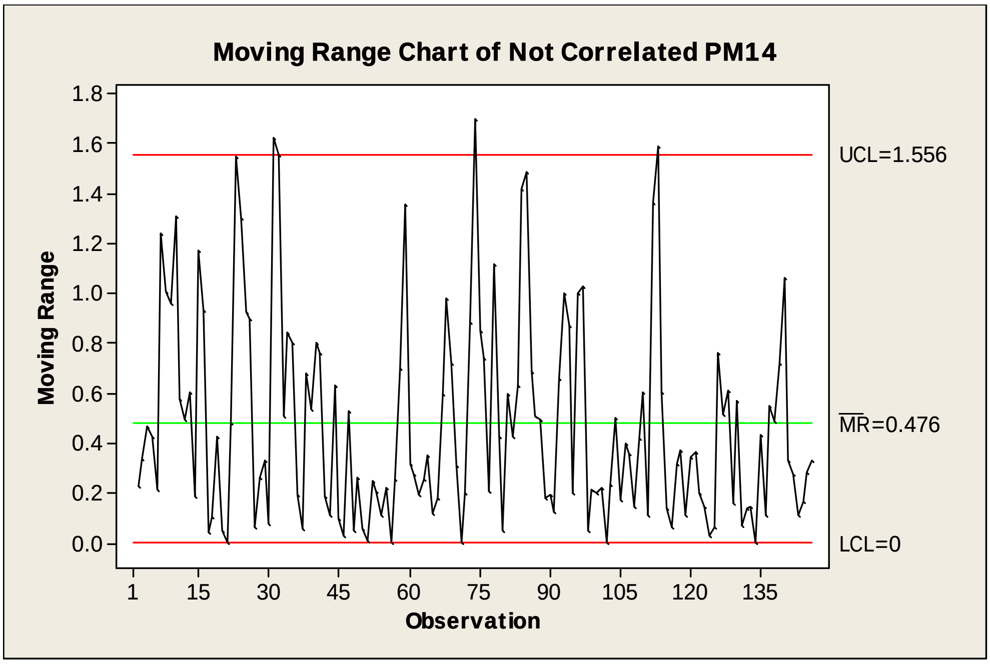

Figure A2.2 R Chart for PM14 - Independent Data

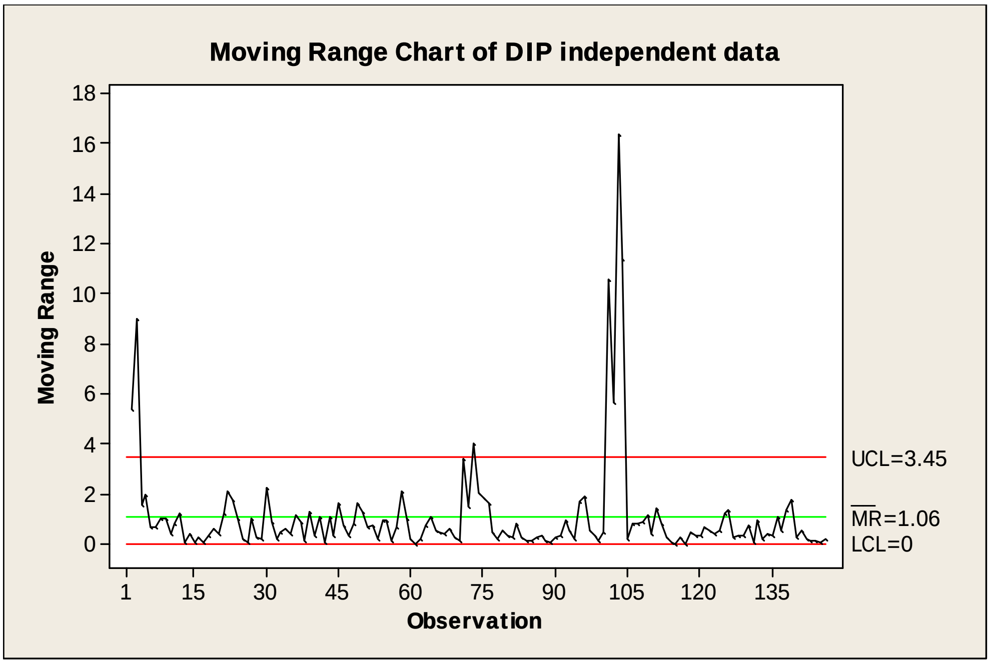

Figure A2.3 R Chart for De-inking Process - Independent Data

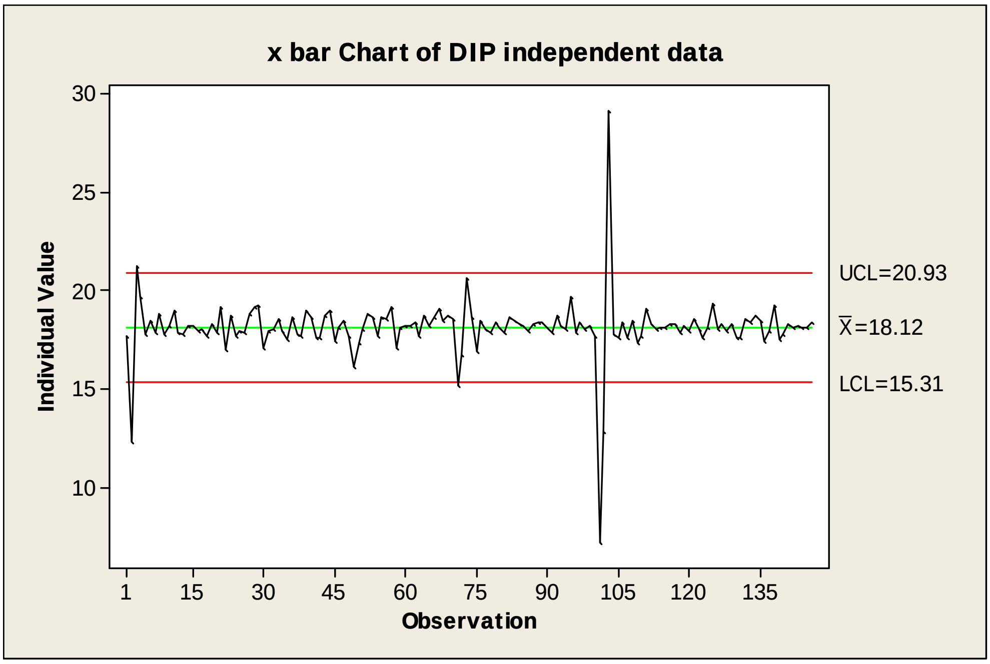

Figure A2.4 X bar Chart for De-inking Process - Independent Data

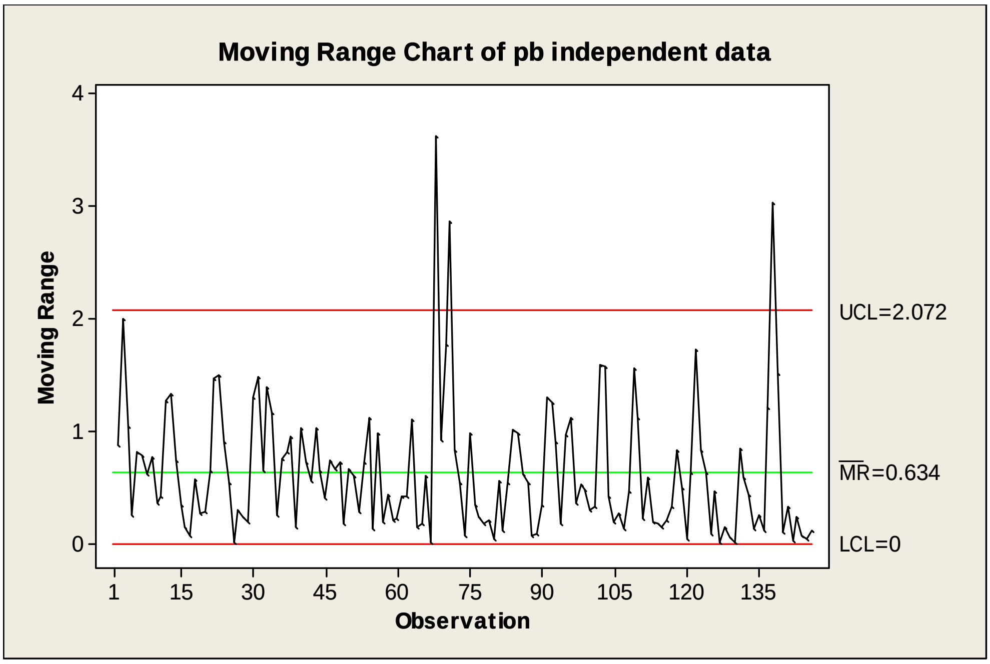

Figure A2.5 R Chart for Post-bleaching Process - Independent Data

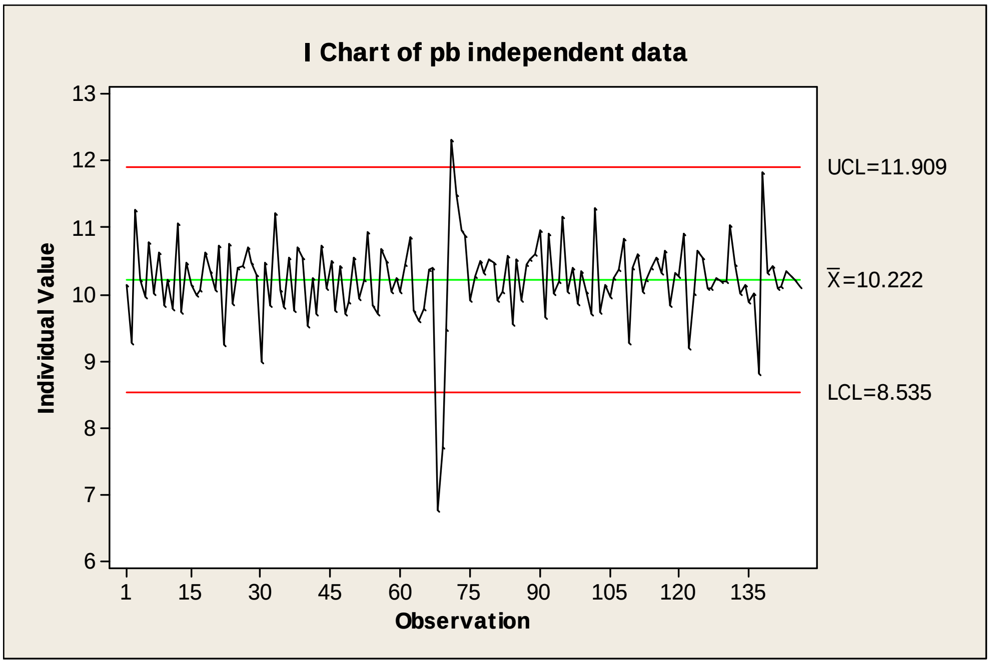

Figure A2.6 X bar Chart for Post-bleaching - Independent Data

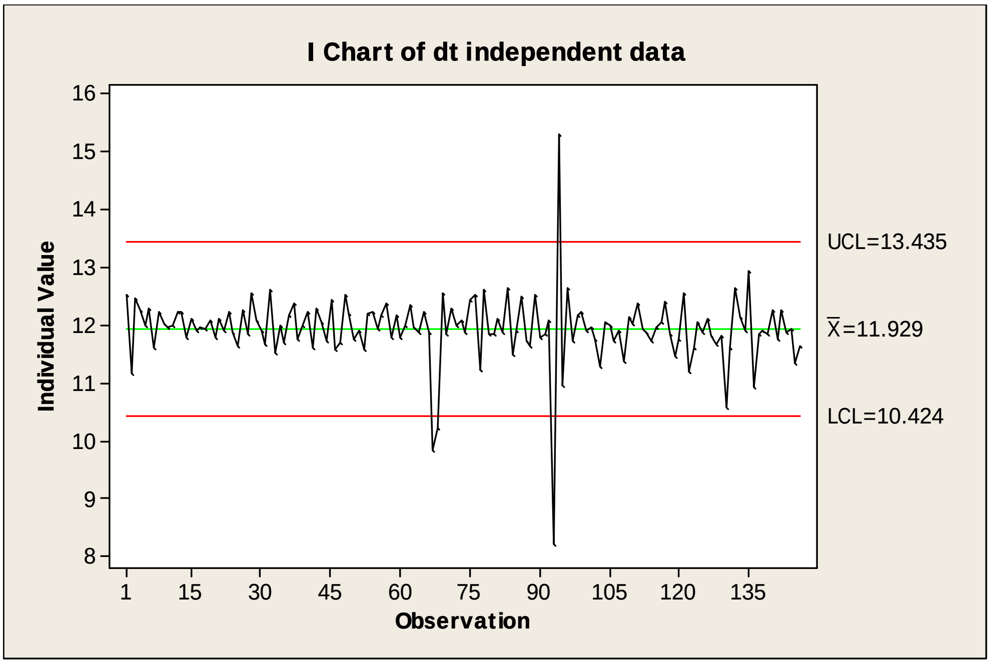

Figure A2.7 X bar Chart for Dump Tank Process - Independent Data

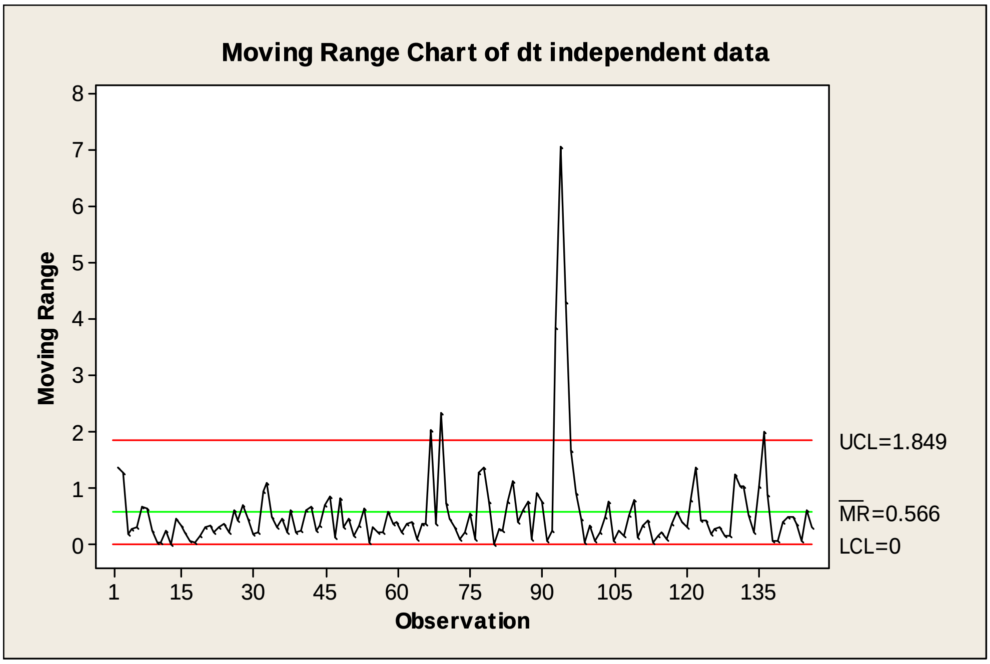

Figure A2.8 R Chart for Dump Tank Process - Independent Data

Appendix 3 Bottom Loss Data for Jumbo Newsprint Reels

Table A3.1 Bottom Loss Data for Newsprint Reels

Length	Bottom Loss	Length	Bottom Loss	Length	Bottom Loss	Length	Bottom Loss
84,860	50,487	96,460	1,862	108,100	1,287	103,920	373
93,510	566	96,620	2,236	108,770	521	104,250	627
93,440	570	96,950	1,363	108,610	985	104,420	761
93,220	389	96,490	2,195	108,940	1,367	104,250	513
93,040	-43	95,910	2,798	107,570	-629	104,760	641
92,880	260	102,180	-6	108,760	284	106,100	1,356
92,540	72	102,670	316	108,090	294	80,860	308
93,220	564	92,440	7,312	107,760	144	104,540	-1,069
	0		0	108,260	308		0
93,390	93	105,120	2,591		0	106,330	195
	0		0	107,080	106		0
93,050	457	95,700	-6,323		0	106,510	330
	0		0	108,240	309		0
93,550	641	102,850	800		0	107,000	660
	0		0	106,900	599		0
93,390	221	35,910	1,642		0	99,140	-746
	0		0	106,900	364		0
93,390	72	103,900	1,738		0	100,790	156
	0		0	102,770	2,337		0
93,050	3,793	102,890	87		0	101,260	1,071
	0		0	100,600	-52		0
92,890	1,921	102,900	446		0	101,440	988
	0		0	101,450	464		0
99,830	-351	102,880	399		0	100,310	344
	0		0	100,460	173		0
100,500	320	38,020	3,547		0	22,880	22,880
	0		0	101,710	333		0
99,670	178	102,670	1,150		0	92,950	13,722
	0		0	100,850	191		0
99,830	326	80,870	12,883		0	68,190	3,916
	0		0	100,800	162		0
99,610	311	102,810	1,258		0	25,870	-10,423
	0		0	99,640	163		0
99,440	945	91,920	-10,188		0	100,370	1,649
	0		0	100,660	238		0
100,280	891	65,180	-5		0	100,630	1,697
	0		0	109,760	3,529		0
101,120	1,222	103,140	1,074		0	61,830	11,901
	0		0	106,190	139		0
100,620	70	102,700	295		0	65,410	962
	0		0	106,710	425		0
101,300	484	107,300	5,304		0	32,759	-12,361

	0		0	106,380	29		0
101,130	433	106,280	-1,106		0	44,080	10,898
	0		0	106,890	699	99,610	221
100,970	817	87,550	1,290		0		0
	0		0	90,410	4,985	21,950	1,925
101,140	285	108,770	1,746		0		0
	0		0	105,200	-414	46,890	168
104,620	139	106,780	331		0		0
	0		0	18,660	-590	27,790	415
106,150	676	106,950	212		0		0
	0	107,440	393	100,630	2,602	100,390	3,628
105,980	1,546		0		0		0
	0	29,880	-13,476	32,430	12,329	53,990	3,178
105,990	218		0		0		0
	0	15,520	15,520	96,870	-9,583	100,570	-317
105,970	1,033		0		0		0
	0	86,380	2,096	101,400	607	102,630	3,013
105,300	210		0		0		0
	0	28,770	-736	18,300	18,300	100,190	5,270
105,290	854		0		0		0
	0	100,780	539	84,750	-15,361	102,540	1,724
104,780	233		0		0		0
	0	101,880	274	82,560	2,628	103,280	1,342
104,440	446		0		0		0
	0	101,880	1,502	41,290	1,311	104,420	2,131
104,610	437		0		0		0
	0	110,510	4,217	112,660	5,448	102,560	198
104,610	922		0		0		0
	0	107,530	293	111,230	958	102,150	579
104,090	248		0		0		0
	0	107,470	213	19,260	-2,832	101,440	275
23,520	2,579		0		0		0
	0	107,670	1,152	88,610	5,712	100,380	448
94,010	0		0		0		0
	0	107,550	152	109,180	990	104,320	-206
24,510	8,276		0		0		0
	0	108,020	294	109,020	292	104,800	325
92,190	-6,303		0		0		0
	0	107,930	460	108,870	846	105,390	544
30,520	263		0		0		0
	0	108,090	271	109,040	62	105,820	273
98,654	574		0		0		0
	0	108,090	232	108,860	247	44,360	2,138
63,750	1,512		0		0		0
	0	108,040	261	109,360	496	106,640	257
81,710	518		0		0		0
	0	108,430	4,148	109,540	183	105,400	454
104,470	530		0		0		0
104,310	780	108,160	107	27,380	4,906	105,590	164
	0		0		0		0
104,150	145	107,720	489	109,420	488	106,260	155

	0		0		0		0
104,150	1,060	107,730	224	108,930	-93	106,270	327
	0		0		0		0
104,490	1,002	107,870	732	109,370	1,834	106,780	119
	0		0		0		0
104,500	819	108,120	193	109,570	392	107,020	475
	0		0		0		0
98,450	-819	78,920	3,188	111,920	408	105,820	467
	0		0		0		0
97,950	34	108,790	1,127	111,720	204	106,480	460
	0		0		0		0
99,280	901	108,290	247	64,170	635	106,130	41
	0		0	109,270	1,599		0
98,940	2,958	108,130	-24		0	106,100	460
	0		0	108,420	2,376		0
98,940	550	19,690	1,539		0	105,700	287
	0		0	109,600	1,445		0
99,280	232	34,760	1,320		0	105,370	415
	0		0	100,790	-543		0
99,110	667	110,290	3,164		0	98,890	-1,077
	0		0	101,970	357		0
98,610	143	109,020	2,590		0	99,870	252
	0		0	101,970	268		0
98,940	238	32,689	247		0	100,040	244
	0		0	101,970	124		0
98,940	202	26,740	8,710		0	100,370	415
	0		0	101,460	254		0
98,430	403	12,890	-5,076		0	100,240	132
	0		0	102,140	527		0
98,090	140	91,790	2,424		0	100,340	162
	0		0	101,470	2,679		0
98,090	480	108,900	2,571		0	100,520	212
	0		0	101,810	1,441		0
97,420	247	43,820	7,683		0	100,860	341
	0		0	101,470	472		0
97,600	445	15,190	15,190		0	99,680	156
	0		0	100,800	345		0
98,120	401	103,000	1,454		0	100,030	391
	0		0	101,290	2,239		0
98,280	-470	104,560	1,701		0	100,350	398
	0		0	106,300	1,275		0
98,950	835	31,270	31,270		0	99,800	169
	0		0	106,310	444		0
98,790	610	109,470	843		0	100,410	387
	0		0	105,650	88		0
99,460	606	108,390	339		0	91,290	-270
	0		0	105,310	267		0
99,280	427	108,390	265		0	93,490	474
	0		0	105,120	256	65,040	2,696
99,610	507	17,410	17,410		0		0
	0		0	105,130	271	93,210	460

99,440	554	80,440	8,552		0		0
	0		0	104,780	209	94,180	588
99,110	765	108,830	1,020		0		0
	0		0	105,800	935	94,830	474
75,850	584	108,340	196		0		0
	0	107,880	1,238	105,290	640	94,330	579
98,203	645		0		0		0
	0	110,270	4,653	60,650	438	94,000	443
47,425	408		0		0		0
	0	109,530	813	97,510	9,398	94,530	934
97,581	325		0		0		0
	0	109,440	1,014	101,480	1,977	94,710	313
98,670	484		0		0		0
	0	109,440	937	106,410	273	94,730	996
99,010	504		0		0		0
	0	109,840	1,464	107,960	1,251	94,390	213
99,010	375		0		0		0
	0	109,790	894	108,180	256	94,230	887
99,180	264		0		0		0
	0	109,980	818	108,160	1,480	94,720	301
100,020	493		0		0		0
	0	78,630	-8,028	107,090	356	94,880	917
99,350	44		0		0		0
	0	110,920	1,277	106,990	360	95,060	425
99,530	488		0		0		0
	0	109,000	1,005	107,440	350	94,890	648
99,520	-44		0		0		0
	0	108,970	143	107,460	291	101,340	3,052
99,190	415		0		0		0
	0	109,130	644	108,520	298	102,390	121
98,500	559		0		0		0
	0	112,370	1,094	108,130	302	101,870	240
98,670	632		0		0		0
	0	111,410	873	107,980	302	102,060	143
101,440	-1,361		0		0		0
	0	88,370	217	107,360	443	101,910	232
103,000	547		0		0		0
	0	16,180	16,180	107,050	1,135	101,740	354
102,840	237		0		0		0
	0	101,910	15,031	106,610	219	101,560	219
95,810	13,672		0		0		0
	0	51,280	-13,143	106,690	320	101,790	153
102,850	999		0		0		0
86,770	-12,884	112,040	711	106,700	282	101,210	671
	0		0		0		0
103,690	1,144	112,050	1,788	100,530	-274	101,550	299
	0		0		0		0
102,850	582	112,550	165	101,100	1,077	80,790	528
	0		0		0		0
103,190	248	112,880	1,894	101,050	364	100,560	487
	0		0		0		0

27,140	137	112,510	910	100,960	550	101,720	813
	0		0		0		0
103,340	1,686	112,420	2,488	101,000	230	100,870	826
	0		0		0		0
103,830	343	112,410	300	100,720	268	102,050	1,609
	0		0		0		0
104,010	456	112,620	1,876	100,810	44	101,220	804
	0		0	100,660	304		0
104,020	118	112,650	174		0	101,450	264
	0		0	100,660	509		0
104,520	173	113,830	1,657		0	101,800	961
	0		0	100,710	555		0
104,690	509	113,560	233		0	101,300	628
	0		0	100,660	183		0
104,690	236	113,890	1,688		0	48,600	5,952
	0		0	100,670	462		0
105,030	355	113,150	855		0	112,890	9,263
	0		0	39,210	211		0
104,170	345	113,630	1,837		0	47,000	4,525
	0		0	99,860	-346		0
98,800	178	113,130	402		0	108,570	3,461
	0		0	102,250	1,353		0
104,090	2,565	98,030	8,616		0	91,720	8,517
	0		0	101,780	1,164		0
104,910	2,314	112,220	-180		0	93,570	9,927
	0		0	93,950	747		0
102,720	164	104,770	-7,287		0	9,357	-90,488
	0		0	94,400	1,098		0
103,890	329	113,240	654		0	98,000	-7,883
	0		0	94,560	1,272		0
103,550	720	112,740	1,016		0	105,040	374
	0		0	94,080	1,009		0
104,220	262	107,650	-553		0	45,240	2,936
	0		0	94,400	987		0
51,940	71	109,110	1,412		0	18,700	-104
	0		0	95,200	900		0
104,130	1,791	107,950	610		0	105,490	2,489
	0		0	95,350	949		0
104,450	276	106,950	851		0	106,350	919
	0		0	95,020	883		0
78,300	-74	106,940	450		0	45,770	3,479
	0		0	95,670	1,624		0
105,380	1,331	107,100	474		0	105,540	1,864
	0		0	95,520	1,394	12,450	12,450
104,700	1,237	107,780	323		0		0
	0		0	95,860	1,223	95,600	-9,829
104,200	298	108,780	1,605		0		0
	0		0	102,030	458	104,520	250
104,340	497	108,310	1,119		0		0
	0		0	102,380	17,327	105,540	332
104,730	775	107,670	694		0		0

	0	107,460	355	102,180	870	105,370	438
105,650	379		0		0		0
	0	106,710	976	101,940	-14,542	78,770	16,196
105,350	212		0		0		0
	0	107,210	350	101,640	648	106,030	1,561
105,350	2,336		0		0		0
	0	107,380	1,262	101,220	253	92,040	-12,503
105,350	122		0		0		0
	0	19,370	-2,008	101,340	783	105,520	1,019
105,320	971		0		0		0
	0	107,480	1,494	101,250	307	105,520	169
104,310	268		0		0		0
	0	27,120	5,872	101,250	877	105,700	1,621
104,660	86		0		0		0
	0	107,750	2,590	101,080	417	106,210	520
105,300	808		0		0		0
	0	100,830	1,264	101,090	1,195	106,210	644
105,200	118		0		0		0
	0	100,770	453	100,780	287	108,410	-1,366
105,540	487		0		0		0
	0	101,100	708	101,500	777	110,580	1,052
105,880	178		0		0		0
	0	101,460	388	101,150	94	110,750	310
104,700	408		0		0		0
	0	101,270	1,181	101,160	707	110,750	801
106,240	885		0		0		0
	0	57,990	1,135	101,480	451	69,510	3,639
47,290	13,658		0		0		0
	0	100,960	-153	100,640	136	109,690	462
14,710	60		0		0		0
	0	93,680	-146	101,150	876	110,010	179
82,930	-11,954		0		0		0
	0	94,520	506	101,670	556	110,520	708
35,570	646		0		0		0
	0	94,370	839	101,160	936	111,200	269
106,330	2,419		0		0		0
	0	93,910	289	100,470	380	103,110	15,093
98,500	-910		0		0		0
99,330	756	95,060	890	100,310	1,102	111,840	2,090
	0		0		0		0
85,530	7,025	95,390	581	101,150	466	94,850	-13,824
	0		0		0		0
100,660	6,623	95,390	830	100,300	616	48,260	677
	0		0		0		0
101,690	2,418	95,720	1,037	100,800	475	47,750	5,856
	0		0		0		0
100,140	693	95,390	298	100,810	1,115	46,110	3,903
	0		0		0		0
100,450	1,067	95,060	895	100,310	71	113,060	2,197
	0		0		0		0
100,110	636	95,230	1,078	100,850	830	109,840	2,288

	0		0		0		0
99,950	304	94,900	782	100,270	238	32,970	233
	0		0	99,940	300		0
100,290	755	95,390	513		0	108,260	1,365
	0		0	102,310	-476		0
98,860	1,097	95,390	1,084		0	109,440	296
	0		0	103,990	349		0
99,280	2,046	94,740	543		0	110,040	2,617
	0		0	104,160	1,827		0
100,170	323	100,970	-620		0	110,710	1,290
	0		0	105,530	1,825	105,270	876
82,550	4,808	101,770	533		0		0
	0		0	103,540	2,086	105,110	962
94,740	609	101,690	1,185		0		0
	0		0	104,040	121	104,440	584
96,130	1,629	97,150	12,839		0		0
	0		0	104,840	818	104,770	1,272
96,770	1,414	101,080	466		0		0
	0		0	105,010	267	105,280	798
96,560	2,135	74,250	-9,952		0		0
	0		0	105,510	1,379	104,940	1,245
96,930	1,290	18,460	1,300		0		0
	0		0	105,500	950		
96,940	2,011	100,930	571		0		
	0		0	20,190	-14		
105,270	827	105,770	-219		0		
	0		0	104,600	784		
104,770	1,355	107,550	1,359		0		
	0		0	105,610	1,459		
105,440	748	107,740	389		0		

Appendix 4 Standardised Customer Reel Sizes

Table A4.1 Standardised Customer Reel Sizes

Standardised Customer Reel Size (m)			
1300	14100	17200	20300
2400	14200	17300	20400
3400	14400	17400	20500
3800	14500	17500	20600
5600	14600	17600	20700
6000	14700	17700	20800
6300	14800	17800	20900
6600	14900	17900	21000
6700	15000	18000	21100
7000	15100	18100	21200
7100	15200	18200	21300
7700	15300	18300	21400
8100	15400	18400	21500
8600	15500	18500	21600
9600	15600	18600	21700
9800	15700	18700	21800
10500	15800	18800	21900
11000	15900	18900	22000
11200	16000	19000	22100
11400	16100	19200	22200
11500	16200	19300	22300
11600	16300	19400	22400
12200	16400	19500	22500
13100	16500	19600	22600
13300	16600	19700	22800
13600	16700	19800	22900
13700	16800	19900	23000
13800	16900	20000	23100
13900	17000	20100	23200
14000	17100	20200	23500

Appendix 5 Visual Basic Code – Reel Scheduling

```
<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.0 Transitional//EN"> <HTML>
<HEAD> <TITLE> New Document </TITLE> <META NAME="Generator"
CONTENT="EditPlus"> <META NAME="Author" CONTENT=""> <META
NAME="Keywords" CONTENT=""> <META NAME="Description" CONTENT="">
</HEAD>



<BODY>
<%
      s7=Int(request("T7"))
      s1=Int(request("T1"))
      s2=Int(request("T2"))
      s3=Int(request("T3"))
      s4=Int(request("T4"))
      s5=Int(request("T5"))
      if request("t6")<>empty then
            s6=Int(request("T6"))
      end if

      Set objConn = Server.CreateObject("ADODB.Connection")
      objConn.ConnectionString =
"Provider=Microsoft.Jet.OLEDB.4.0;Data Source=" &
Server.MapPath("anl.mdb")
      objConn.Open


      Set rs = Server.CreateObject("ADODB.Recordset")

      LeftLength=s7-(s1+s2+s3+s4+s5+s6)

      strSQL="select * from reel where [CustomerLength]<="&LeftLength
      rs.Open strSQL,objConn,1,3
      if rs.eof then
            response.write "what are these sample numbers?? I can't
find the rest in the database!"
      else
            tempNext=rs("CustomerLength")
            do while not rs.eof
                  if leftlength>rs("CustomerLength") then
                        tempNext=rs("CustomerLength")
                  end if
                  rs.movenext
            loop

      end if
%>
<form method="POST" action="default.asp">
      <p>Total Jumbo
<input type="text" name="T7" size="20" value=<%=s7%>><p>spec
      1
<input type="text" name="T1" size="20" value=<%=s1%>><br>
      spec
      2
<input type="text" name="T2" size="20" value=<%=s2%>><br>
      spec
      3
```

```
<input type="text" name="T3" size="20" value=<%=s3%>><br>
      spec
      4
<input type="text" name="T4" size="20" value=<%=s4%>><br>
      spec
      5
<input type="text" name="T5" size="20" value=<%=s5%>><br>
            spec
      6
<input type="text" name="T6" size="20" disabled=true
value=<%=s6%>><p><p><input type="submit" value="Submit"
name="B1"><input type="reset" value="Reset" name="B2"></p> </form> <%
response.write "the left length on this jumbo is: " & int(leftlength)
& "<br>" %> Your next avaliable reel size is: <%response.write
tempNext%> </BODY> </HTML>
```

Appendix 6 Wagon Availability at HCPD Plant

Table A6.1 Wagon Availability at HCPD Plant

Shift	Switch	Pull	Coils on floor shift end	Rake	Loading Start	Loading Finish	Wait for Shunt (hrs)	Wait for Shunt (min)	T's on rake	Loading Time Available	
					Pull	**0:00**	**0:00**				
D	5:00	9:40		A	0:00	5:00	4:40	280	527	5:00	
	12:50	14:30		B	9:40	12:50	1:40	100	607	3:10	190
	15:40	16:45		C	14:30	15:40	1:05	65	668	1:10	70
N	20:20	22:45		A	16:45	20:20	2:25	145	602	3:35	215
	0:05	1:50		B	22:45	0:05	1:45	105	765	1:20	80
D	3:40	9:45		C	1:50	3:40	6:05	365	549	1:50	110
	12:00	12:45		A	9:45	12:00	0:45	45	610	2:15	135
	16:45	17:10		B	12:45	16:45	0:25	25	687	4:00	240
	18:40	20:00	40	A	17:10	18:40	1:20	80	613	1:30	90
	23:03	23:05		C	20:00	23:03	0:02	2	561	3:03	183
N	23:55	0:40		A	23:05	23:55	0:45	45	497	0:50	50
	2:35	3:20		B	0:40	2:35	0:45	45	682	1:55	115
	4:10	5:10		A	3:20	4:10	1:00	60	585	0:50	50
D	10:00	11:30		C	5:10	10:00	1:30	90	640	4:50	290
	12:50	13:30		A	11:30	12:50	0:40	40	517	1:20	80
	15:15	16:45	70	B	13:30	15:15	1:30	90	666	1:45	105
N	19:20	21:30		C	16:45	19:20	2:10	130	687	2:35	155
	23:20	0:30		A	21:30	23:20	1:10	70	587	1:50	110
	1:20	2:00		C	0:30	1:20	0:40	40	682	0:50	50
	3:55	4:45	80	B	2:00	3:55	0:50	50	678	1:55	115
D	7:15	10:45		A	4:45	7:15	3:30	210	555	2:30	150
	11:50	13:00		C	10:45	11:50	1:10	70	591	1:05	65
	14:00	16:07		B	13:00	14:00	2:07	127	629	1:00	60
	17:00	17:57	130	A	16:07	17:00	0:57	57	604	0:53	53
N	20:45	22:20		C	17:57	20:45	1:35	95	652	2:48	168
	0:23	1:25		B	22:20	0:23	1:02	62	694	############	123
	2:45	5:00	47	C	1:25	2:45	2:15	135	653	1:20	80
D	7:40	9:10		B	5:00	7:40	1:30	90	692	2:40	160
	10:20	13:50		C	9:10	10:20	3:30	210	665	1:10	70
	15:25	17:00	0	B	13:50	15:25	1:35	95	687	1:35	95
N	23:45	0:45		C	17:00	23:45	1:00	60	578	6:45	405
	2:40	3:45	40	B	0:45	2:40	1:05	65	659	1:55	115
D	6:00	9:25		A	3:45	6:00	3:25	205	606	2:15	135
	10:25	13:30		C	9:25	10:25	3:05	185	728	1:00	60
	15:25	16:35		A	13:30	15:25	1:10	70	656	1:55	115
	18:05	20:00	0	C	16:35	18:05	1:55	105	678	1:30	90
N	22:50	23:15		B	20:00	22:50	0:25	25	599	2:50	170
	1:05	3:20	0	C	23:15	1:05	2:15	135	598	############	110
										Full or no rake	**3983**
										Empty Rake	**4657**
										Total Hrs	**8640**