A Framework Incorporating Lean Six Sigma and Life-Cycle Assessment in Sustainable Manufacturing

Haitem Khalifa Masud Fargani

A thesis submitted in partial fulfilment
of the requirements of the
University of Northumbria at Newcastle
for the degree of
Doctor of Philosophy

Research undertaken in the
Faculty of Engineering and Environment

November 2017

Abstract

Manufacturing companies must consider the environmental and social aspects of their business in order to meet the requirements of sustainable manufacturing (SM). In this context, traditional manufacturing management techniques are being challenged because they do not address environmental concerns. Therefore, to meet the commitment to sustainability, a new manufacturing paradigm is needed to improve these techniques in order to assist practitioners and researchers in overcoming this new challenge. This study addresses Lean Six Sigma (LSS) and Life Cycle Assessment (LCA) as important live manufacturing improvement techniques that are currently handled independently, but there could be value in bringing them together. Researching the integration of LSS and LCA is expected to reveal improvement opportunities that would enhance the financial and environmental performance of SM. The main objective of this research has been therefore to design a framework to integrate LSS and LCA so as to yield an outcome better than that obtained if the two methods are applied in isolation.

The thesis explores SM through an extensive literature review and then proceeds with data collection using a mixed-methods approach. Analysis of the knowledge and data acquired reveals that communication, environmental strategy and the market are important factors in integrating LSS and LCA. The data is also used to examine the current state of sustainability in a sample of companies by examining the recommendations put forward by other researchers for the transition to SM. The results show that most companies struggle in SM because these recommendations are not adopted.

The findings of the study lead to the development of a framework that can be used to support decision making in sustainable manufacturing and to guide environmental improvement projects. The framework illustrates how conducting a LCA study provides the information to formulate an environmental strategy, and how to undertake a LSS project to make improvements. The framework highlights the importance of upgrading standard LSS tools to include environmental measures. Finally, thought experiments are conducted to demonstrate the usefulness of the framework.

Acknowledgement

The completion of this research has not been a solo endeavour. My gratitude goes out to the great people and the wonderful minds around me who enabled me to reach the point of writing this PhD thesis.

First of all, I gratefully acknowledge the sponsorship of my country, Libya, despite experiencing political and civil unrest. I hope the knowledge I gained during this PhD project would open the door for me to give back and serve my country. I should also acknowledge the support of all participants in the surveys, without their voluntary participation, this thesis would not have been possible

My special thanks go to my supervisor, Dr. Wai Ming Cheung (Denny), for his inspiration. I am indebted for his support and sound advice on how to do better research. His sense of humour made the journey most enjoyable and his friendship will stay with me. A great appreciation is also due to my second supervisor, Dr Reaz Hasan, for providing his wealth of experience in all aspects of PhD research.

The last but most important gratitude goes to my beloved wife, Nsren, and my parents, Khalifa and Amal, for giving me the confidence to reach my fullest potential in my career, and as a human being.

List of Publications

Conference Proceedings

1- FARGANI, H., CHEUNG, W. M. & HASAN, R. 2017. A Proposed Implementation Process for a Sustainable Manufacturing Framework. Proceedings of the 17th International Conference on Manufacturing Research (ICMR). Greenwich University.
2- FARGANI, H., CHEUNG, W. M. & HASAN, R. 2015. An Approach to Achieve Operational Effectiveness and Sustainability Requirements in Manufacturing. Proceedings of the 13th International Conference on Manufacturing Research (ICMR). Bath University.
3- FARGANI, H., CHEUNG, W. M., HASAN, R. & BIRKETT, M. 2014. An integrated approach incorporating lean six sigma and life cycle assessment to support sustainable manufacturing. *Proceedings of the 12th International Conference on Manufacturing Research (ICMR).* Southampton Solent University.

Journal Papers

1. FARGANI, H., CHEUNG, W. M. & HASAN, R. (2017). Ranking of the Factors That Underlie the Drivers of Sustainable Manufacturing Based on Their Variation In A Sample Population. Paper accepted by: the International Journal of Manufacturing Technology and Management (IJMTM)
2. FARGANI, H., CHEUNG, W. M. & HASAN, R. 2016. An Empirical Analysis of the Factors That Support the Drivers of Sustainable Manufacturing. Procedia CIRP, 56, 491-495.

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List of Abbreviations

ANOVA	Analysis of Variance
CSF	Critical Success Factor
CSR	Corporate Social Responsibility
Df	Degree of freadom
DfE	Design for Environment
DMADV	Define Measure Analyse Design Verify
DMAIC	Define Measure Analyse Improve Control
EMS	Environmental Management System
EVSM	Environmental Value Stream Map
GSCM	Green Supply Chain Management
JIT	Just In Time
KMO	Kaiser-Meyer-Olkin (statistical measure)
LCA	Life-Cycle Assessment
LSS	Lean Six Sigma
M	Mean
OM	Operations Management
p	Probability value
PCA	Principal Component Analysis
PESTLE	Political Economic Social Technological Legal Environmental
r	Correlation coefficient
SCP	Sustainable Consumption and Production
SD	Sustainable Development
Sig	Significance
SM	Sustainable Manufacturing
SME	Small and Medium Enterprises
SMED	Single Minute Exchange of Dies
SWOT	Strength Weaknesses Opportunities Threats
TPS	Toyota Production System
TQM	Total Quality Management
VSM	Value Stream Map
WMO	World Meteorological Organisation

CHAPTER 1. INTRODUCTION

1.1 Preamble

Manufacturers have been under pressure to survive as global competition continues to increase. Only companies that employ advanced management techniques have been able to achieve the economic prosperity that secures their existence and growth. One of these management techniques is Lean Manufacturing which has helped transform Japanese businesses, with Toyota in the forefront, from being manufacturers with very limited resources to becoming world leaders in the automotive industry. Lean manufacturing has been adopted in many other industries and also in the service sector as Lean Thinking has proven to be effective in reducing the waste associated with production processes and in creating an environment which encourages employee involvement.

Six Sigma is another important technique that has been proven to assist in the effective management of operations. The use of statistical tools in Six Sigma allow variations in output to be controlled so as to ensure consistency. Six Sigma has been developed to become a comprehensive management system and merging Six Sigma and lean manufacturing to form Lean Six Sigma (LSS) was a natural step forward as the two systems support one another to achieve greater levels of performance.

However, a current challenge is to move beyond operational effectiveness and financial performance since manufacturers are now required to simultaneously consider the economic, environmental and social implications of their business in order to meet the requirements of Sustainable Manufacturing (SM) (Chang et al., 2017). Garetti and Taisch (2012) define SM as

> "A set of technical and organisational solutions contributing to the development and implementation of innovative methods, practices and technologies, in the manufacturing field, for addressing the world-wide resources shortages, for mitigating the excess of environmental load and for enabling an environmentally benign lifecycle of products."

The focus of manufacturing companies is increasingly shifting from merely considering the financial side of the business to a broader perspective that includes social and environmental (ecological) considerations (Golini et al., 2014).

1.2 The Problems Faced by Manufacturing Industry

Since the industrial revolution, manufacturing has driven the growth of civilisation and has continued to generate wealth and jobs. Meanwhile, awareness of industry's impact on the environment grew during the 1970s and 1980s. Prior to this period, most manufacturing practices, research and technological developments were focused on economic growth. However, this perspective started to change due to environmental concerns and an increasing awareness of the impact of exponential growth on resources. An important trigger in this change was the publication of *The Limits to Growth* in 1972 (Meadows and Club of Rome., 1972). This book used computer modelling to predict the impact of economic growth on our planet's finite resources. The world's population, industrialisation, pollution, food production and resource depletion were investigated and the book concluded that there was the risk of stagnation and even collapse of the global system in the future if economic growth carried on in the typical manner.

1.2.1 Resource scarcity and pollution

Three decades after the release of *The Limits to growth*, its authors published the *Limits to growth: The 30-year Update* (Meadows et al., 2004a) which argued that some of their predictions were indeed coming true. Examples of the decline of food production in per capita terms were provided. For instance, grain production and marine catches peaked in 1984 and 1988 respectively and have been in decline ever since (Meadows et al., 2004a). The following summary of the signs that humans are consuming resources faster than they can be restored were provided (Meadows et al., 2004b):

- Sea levels has risen by 10–20 cm since 1900. Most non-polar glaciers are retreating, and the extent and thickness of Arctic sea ice is decreasing in summer.
- In 1998 more than 45% of the globe's people had to live on incomes averaging $2 a day or less. Meanwhile, the richest one-fifth of the world's population owned 85% of global GNP. The gap between rich and poor was widening.

- In 2002, the Food and Agriculture Organization of the UN estimated that 75% of the world's oceanic fisheries were being fished at or beyond capacity. The North Atlantic cod fisher sector, which had fished sustainably for hundreds of years, has collapsed, and the species may have been pushed to biological extinction.
- The first global assessment of soil loss, based on studies by hundreds of experts, found that 38%, or nearly 1.4 billion acres, of currently used agricultural land had been degraded.
- Fifty-four nations had experienced declines in per capita GDP during the period 1990–2001.

Pollution is also a matter of concern, because pollutants such as CO_2 are responsible for climate change. In its latest report, the Intergovernmental Panel on Climate Change (IPCC, 2014) noted that weather extremes in regions of food production are already causing price increases, and claimed that the impact of climate change could cut crop yields by up to 25% due to the effect of weather patterns and rainfall, causing either floods or droughts. As this thesis is being written, a report by the World Meteorological Organisation (WMO, 2016) has revealed that the period 2011-2015 was the hottest on record, and the year 2015 was the hottest since modern observations began in the late 1800s. Rising temperatures are causing weather events such as heatwaves, droughts and floods that are more frequent and more extreme. The WMO report also revealed that CO_2 exceeded 400 parts-per-million in the atmosphere for the first time in recorded history in 2015 and is unlikely to drop for many generations.

Using a computer model, *The Limits to Growth: The 30-Year Update* presents 10 scenarios for the future up to the year 2100. In each scenario, variables are controlled to predict industrial output, resources, population, food and pollution. The first scenario assumes "business as usual" where humanity proceeds in the same manner as in most of the 20th century where non-renewable resources and rising pollution ultimately lead to a decline in industrial output, food production, and world population as shown in Figure 1.

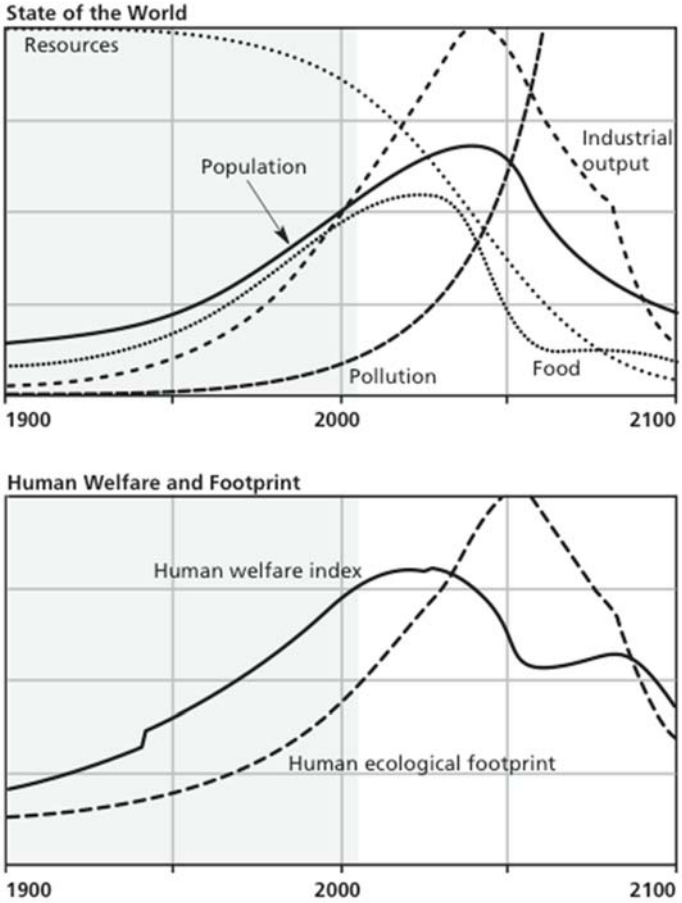

Figure 1: Future prediction with no regard to sustainability: non-renewable resources and rising pollution. Source (Meadows et al., 2004b)

Sustainable Development (SD) has three dimensions: the economy, environment, and society. SD aims to reduce the burden on the environment by employing technologies that reduce pollution, conserve resources and protect agriculture and biodiversity. On the social level, SD is aimed at improving the average welfare of humanity. Manufacturing industry is concerned about and is under pressure to adopt SD because manufacturing is a major contributor to air pollutant emissions (IEA, 2007, EEF, 2014). If SD is implemented sooner, the world is predicted to have a greater chance of a sustainable society with high levels of welfare and a recovering environmental system, as shown in Figure 2.

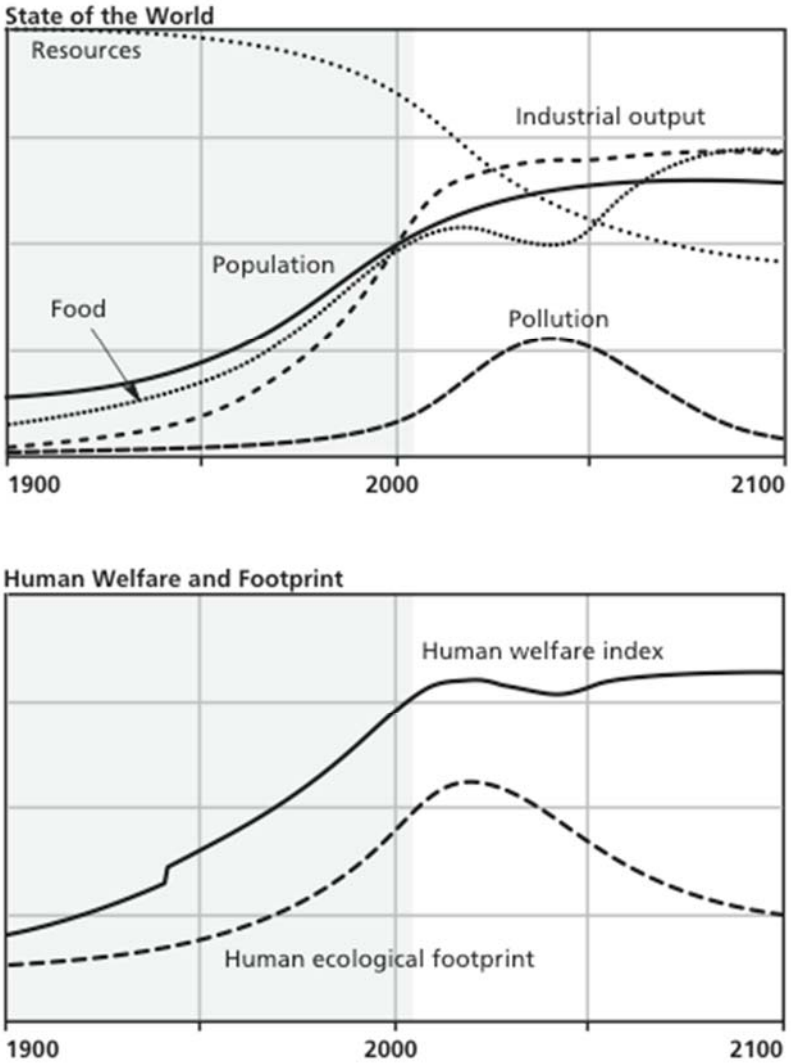

Figure 2: Future prediction applying Sustainable Development: renewable resources and environmental protection. Source: (Meadows et al., 2004b)

1.2.2 Operations management problems

Operations management techniques have advanced over the years and a number of different techniques have been developed by manufacturing firms. A notable, and relatively new, technique is Lean Six Sigma (LSS), which combines the benefits of lean manufacturing and the control offered by Six Sigma to achieve an optimum improvement in processes. However, manufacturing continually changes as business environment changes. The demand to implement SD is rising and gaining more attention. Firms are now required to act to sustain the eco-system and shift to Sustainable Manufacturing (Lentes et al., 2017).

Operations management techniques have been developing rapidly since the industrial revolution to cope with new demands. These demands are related to various aspects of business, such as process speed, product quality, government regulations and markets. In general, the evolution of manufacturing can be represented in a development model such as that shown in Figure 3.

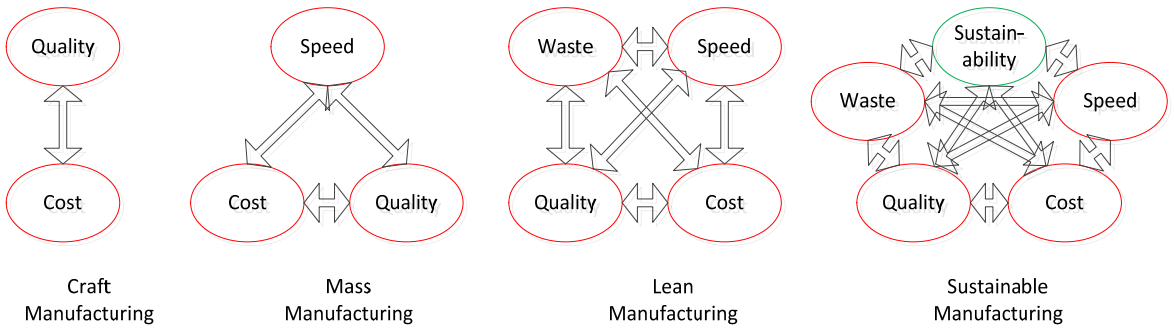

Figure 3: Evolution of manufacturing from simpler to more complex models. Adapted from (Kaebernick et al., 2003)

The first model of manufacturing is craft manufacturing which combines quality and production cost. The goal here is simply to produce good quality products at a minimum cost. Then, high-volume production changed the model when speed became a requirement. Different industries moved to the second model at different times. In the textile industry, for instance, this change took place in the 18th century with the invention of mechanised textile machines. In the automotive industry, Ford's moving assembly line, introduced in 1913, led to significant improvements in the speed of production, which helped reduce the cost of cars in mass production. Quality was at risk of being compromised in this model. However, quality control techniques such as Total Quality Management (TQM), were adopted to keep the model operational.

After that, a new element was added to the model, placing the focus on waste reduction. Achieving more with less capital, space and effort is the purpose of lean manufacturing. Toyota and other Japanese companies created this model and performed exceptionally well by eliminating seven types of waste in the production process, thus reducing the capital and resources needed for a job. And with its just-in-time approach, one-piece-flow and other innovative techniques, Toyota created an effective balance between the four elements of the model, which are quality, cost, speed and waste. The change from Ford's mass production to Toyota's lean manufacturing is as significant as the change from craft to mass production (Womack

et al., 1990). It took manufacturers in Europe and the US decades to realise that Toyota's production system is a revolutionary approach, and is the means to future survival. Publications such as *The Machine that Changed the World* (Womack et al., 1990) gave insights into the tools and ideology of the system and helped to spread lean manufacturing.

The current change taking place in industry is towards Sustainable Manufacturing, which considers the environmental impacts of manufacturing as well as social and economic factors, and aims to reduce the footprint and increase the efficiency of resource use. The challenge at this stage is to incorporate the requirements of sustainability into the model.

The change to SM is gradually taking place and changing the business environment. One of the main problems in industry is that small changes in the business environment may go unnoticed. Indeed firms, small and medium-sized enterprises (SMEs) in particular, are focused on short-term targets for survival, which makes them oblivious of slow, but possibly fatal, changes that are caused by a shifting paradigm. Barton et al. (2002) used the example of frog in boiling water to demonstrate the risk of not detecting a shifting paradigm. If a frog is dropped into boiling water, it will jump out. However, if it is dropped into cold water which is then heated up gradually, the water will boil and the frog dies without noticing the change. SM is widely recognised by researchers as a revolution currently changing global manufacturing (Westkämper et al., 2000, Rothenberg et al., 2001, Jovane et al., 2008). For practitioners, it is a new way of doing business. For researchers, it is a shift of paradigms. Manufacturers, therefore, have to prepare for the change before it is too late to act.

As manufacturing paradigms change, the complexity of managing production operations increases. In the SM model, the difficulty of managing operations and addressing sustainability requirements increases the complexity of the situation (Mustafa and Cheng, 2016). Complexity within an organisational context is the level of diversity in factors such as technologies, customers, suppliers, and regulations (Chakravarthy, 1997). In this context, the sustainability model adds complexity to operations management because more factors need to be considered. These factors are either long-standing but which need improvement, such as in energy efficiency, or new, such as environmental measures and the concept of the product life-cycle. For

manufacturers, sustainability is a major challenge because as complexity increases, firms find it more difficult to set a coherent strategy for the business (Abdulmalek and Rajgopal, 2007)., Hertwich et al. (2000) state that in environmental management, the problem of complexity is inherent in environmental processes due to the lack of data and the pervasive uncertainty even in the extensively researched economic dimension.

The links between the elements in the models in Figure 3 explain how the models function. For example, the link between "speed" and "cost" is strong and negative, where increasing production speed, as in mass production, results in cost reductions. This link is sustained by requirements such as a large market. At the operational level, the link between speed and cost is supported by techniques such as the interchangeability of parts, which is one of various techniques that Henry Ford used to make mass production possible in the automotive industry. The link between speed and quality is also negative because quality problems are inherent in the process of speeding up production, so that as production speed increases, product quality decreases. Therefore, the later link has to be supported by means of quality control, rework areas, standard tasks, etc.

1.3 An Exploratory Study of Prior Work in the Literature

The existing body of knowledge serves as the foundation upon which the study is built (Ellis and Levy, 2009). A study of prior work is important to narrow the research problem as discussed in the introduction. Thus, a literature review was the starting point of this project which also continued during its whole course. The first task was to specify the research topic of Lean Manufacturing, Six Sigma, Lean Six Sigma, and Sustainable Manufacturing as the main topics of this research. Keywords from these topics were used with online search engines to identify relevant literature. Google Scholar, Emerald, and Web of Science and other search engines were used to find relevant peer-reviewed publications. Peer reviewers who evaluate potential publications bring a wealth of individual knowledge and usually make every attempt to ensure that what is published is accurate (Lyons and Doueck, 2010). Wikipedia is also worth mentioning as a good source for introductory information. However, because its articles are not peer-reviewed, the accuracy of the information it provides is in doubt and thus is not directly referred to in this thesis. The full literature review is given in chapter 3. This section, however, provides an initial review of the main

areas covered in this thesis and a summary of the gaps in knowledge that prompted this research project.

Sustainability has been discussed for more than three decades, and there is a general agreement on its principles amongst researchers and industry leaders (Kaebernick et al., 2003). Research emphasises the importance of shifting towards sustainability and continuously proposing new methods, innovative solutions, and new technologies to support and encourage the quest for sustainability (Holliday, 2001, Kaebernick et al., 2003, Seuring and Müller, 2008, Kuik et al., 2011, Garetti and Taisch, 2012, Gimenez et al., 2012)

Lean and Six Sigma are two of the most researched areas in operations management (Arnheiter and Maleyeff, 2005, Pepper and Spedding, 2010, Assarlind, 2013, Antony et al., 2014, Cherrafi et al., 2016). There is a large number of studies on Lean and Six Sigma as separate techniques where there is common agreement on the models, tools, and philosophy used in both of them. Combining the two as Lean Six Sigma (LSS) has been a focus of research in the last decade following its success in industry (Pepper and Spedding, 2010, Assarlind, 2013). However, there is no common model for LSS. Life Cycle Assessment (LCA) on the other hand has reached maturity when the International Organisation for Standardisation (ISO) introduced the series ISO14040 standard in the late 1990s. The current update of the standard, published in 2006, is unlikely to change in the near future (Pryshlakivsky and Searcy, 2013). Previous research has largely covered how to employ the system-wide analysis of LCA to develop sustainability practices (Zamagni, 2012).

Research on the links between the two methodologies of LSS and LCA, and how to integrate them has not however been addressed by researchers. At the start of this project in 2013, an extensive literature search could not find any study of the integration of the two methodologies. In recent years the integration of sustainability as a general concept and operations management, has started to develop. However, most studies in this area have been generic and do not provide details on what tools and methods should be used and how to use them (e.g. (Kashmanian et al., 2011, A. S and Gati, 2009, Faulkner and Badurdeen, 2014, Dües et al., 2013, Cherrafi et al., 2016).

The state of prior work determines whether a research area is nascent (emerging), intermediate or mature. The preceding discussion suggests that the area of this research has more of the features of intermediate research because "Intermediate theory research draws from prior work—often from separate bodies of literature—to propose new constructs and/or provisional theoretical relationships" (Edmondson and McManus, 2007). The research questions for this type of research concern proposed relationships between new and established constructs. To answer such questions, a mixed research approach is recommended to collect qualitative and quantitative data.

1.4 Research Questions

Following the assessment of prior work in section 2.1, the present research has identified areas in the research topics that have been examined by others, what they have found and their recommendations for future work. This has helped to narrow down the research questions. In addition, the identification of areas that have not been examined was key in forming questions which address gaps in the existing body of knowledge. The investigation was narrowed down to the following research questions:

Q1: How LSS and LCA can be integrate to achieve sustainable manufacturing?

Q2: What are the characteristics of a company that might benefit from the proposed integration?

Q3: What adjustments to LSS and LCA are required to enable the framework to be implemented?

Q4: What is the current strength of drivers for sustainable manufacturing?

As mentioned earlier, quantitative data is required in this type of research so as to conduct a 'very preliminary' quantitative analysis to support the logic underlying the qualitatively induced propositions (Edmondson and McManus, 2007). The following five hypotheses were developed to examine the strength and relationship of variables to be examined in the quantitative analysis:

H1. Introducing an environmental strategy will improve the efforts made by manufacturers to improve their environmental performance.

H2. The proposed framework can support in achieving the requirements of true sustainability, which manufacturers are still struggling with.

The path to sustainability requires progression through stages that involve certain requirements. Not fulfilling these requirements takes the company to a state of flawed sustainability where there is no acceptable return for the efforts and investments allocated to improve environmental performance.

H3: Effective association and communication between LSS and LCA is required.

Collaboration and information sharing between teams or departments that run LSS and LCA is important to obtain better results from both systems. This hypothesis will be tested by examining the communication between different departments of the company. It is expected that the results of a LCA study would not be fully transferred to LSS staff who might not have been involved in the study in the first place.

H4: LSS is fundamental to a strategic approach to sustainable manufacturing.

Based on a survey of academics working on sustainable manufacturing (discussed in chapter 4), responses as to whether or not Lean is needed prior to conducting LCA were relatively inconsistent. Respondents mostly viewed the two methodologies as totally independent systems, and their view that "LSS cannot add much to what LCA can find" signals a lack of strategic thinking within the research community. One of the arguments that this thesis proposes is that LSS is necessary to support LCA because the former has the tools to put LCA recommendations into action.

1.5 The Research Gap

A preliminary review of the literature indicates that rich knowledge exists in the three SD dimensions of economy, society and the environment. In manufacturing, the economic dimension has been extensively examined in a series of studies on methods for improving operational performance. Most notable are studies on operations management techniques such as Lean and Six Sigma. Researchers have also looked into methods to improve and measure the environmental performance of manufacturing companies using new technologies and techniques such as Design for Environment (DfE).

Although sustainability appears to be a hot topic that is attracting much research interest, field studies show that the transformation towards SM by many companies is not straight forward. Survey data suggest that sustainability is often not reflected in company strategy because manufacturers are still focused on operational effectiveness (quality, speed, flexibility, cost) and are not yet capable of progressing with SM (IMSS, 2011). Raiborn et al. (2013) argue that companies might adopt SD rhetorically rather than in reality. They might express great concern for environmental issues in their mission statements for publicity reasons, but their words are hardly translated into action.

Several scholars have attempted to provide a road map for implementing SM by defining its stages and how to progress through these stages. Yet there is still substantial room for presenting detailed information, plans, and improvements to enhance SM because there is a lack of frameworks for transformation in the literature. The work of scholars who provided transformation road maps such as Kashmanian et al. (2011) and Zadek (2004) lack details on what tools to use and how to use them. Their work, therefore, should be elaborated to fill this gap. In addition, the manufacturing literature seldom covers the integration of the various techniques that underpin SM. As discussed earlier, SM is a complex model that combines various techniques, and creating harmony between these techniques will certainly improve SM.

This lack of frameworks was the initial motivation to carry out this study. However, an extensive literature review that has continued throughout the research project reveals more gaps that this study addresses. These are detailed as follows.

- The literature on environmental strategy was not extensive and no principles or frameworks are available to guide practitioners through the process of linking environmental practices to business strategy (Dangayach and Deshmukh, 2001). In recent years, despite the increase of studies on sustainability, this gap still exists as pointed out by Orlitzky et al. (2011) who argues that "unfortunately, key issues regarding frameworks, measurement, and empirical methods of social responsibility and sustainability have not yet been resolved because existing research has been too fragmented".

- There has been no empirical assessment of true sustainability which fulfils the criteria proposed in previous research (Kashmanian et al., 2011).
- Although there is a wealth of literature on SM drivers, no research has looked into the factors that support these drivers.
- The challenges highlighted by authors such as Singh et al. (2008) that face SMEs when forming a competitive strategy have not been addressed in the context of environmental sustainability.

1.6 Research Proposal

The discussion in the previous sections shows the growing importance of SM and the increasing pressure on manufacturers to meet its requirements. It also shows that there is a research gap that has not been addressed in the existing literature. Meeting the requirements of SM adds to the complexity of operations management. This complexity is often the cause of out-of-focus effort as companies attempt to engage in sustainability without setting a clear strategy. This study, therefore, emphasises the need to form an effective environmental strategy that directs the efforts manufacturers make to improve environmental performance.

For this strategy to be effective, this research proposes the integration of two techniques. The first is Life Cycle Assessment (LCA) because it is a technique that:

- Illustrates the environmental impacts of decision making and shows the important areas that should be considered. Decision making in manufacturing is typically focused on managing production bottlenecks. Life cycle thinking adds environmental information about the impacts which need to be considered in decision making.
- Avoids shifting problem from one stage of the life cycle to another. Problem shifting happens when a company reduces its environmental impact at the manufacturing stage at the expense of increasing it in other stages of the life cycle. For example, a raw material may be substituted by another that requires less processing and energy, but which may, however, have a greater impact when disposed of.
- Supports the optimum utilisation of resources allocated to reduce the environmental impact. LCA provides this benefit by targeting the largest impacts in a product's life cycle that can be reduced with less effort and budget.

A life cycle assessment allows the company to choose the most feasible option from multiple improvement opportunities, such as design for environmental processing, design for environmental packaging, design for disposal/reuse, and design for energy efficiency.

The second technique that is required for the environmental strategy is Lean Six Sigma (LSS) for the following reasons:

- Manufacuring companies are still focused on operational performance for survival and view LSS as the solution. Any improvement programme that is connected to this theme will be adopted without resistance and considered to be beneficial.
- LSS is a widespread technique in manufacturing that has proven to be successful in many respects, including improving productivity, employee thinking and involvement, cost savings, and managing improvement projects. These are essential requirements for SM.
- LSS provides a suitable launch-pad for advanced environmental programme because it starts with basic waste reduction to open the door for progressive improvements.

Integrating the aforementioned techniques of LCA and LSS will be achieved through the design of a suitable framework. This framework solution proposed by this thesis to address the research gap identified and the problem faced by the manufacturing industry.

1.7 Aim and Objectives

The aim of this research is to support manufacturers in transforming to SM by building on manufacturing management's experience and success in Lean and Six Sigma, and to enhance them with life cycle thinking to improve their environmental performance. This will be the approach used to meet the needs of industry and fill the gaps in the literature that have been discussed earlier. This will be achieved by supporting manufacturing companies embarking on sustainability with a framework that incorporate Lean Six Sigma and Life Cycle Assessment to improve their operational and environmental performance.

The specific objectives of the research include:

1. To justify the need for this project and identify research gaps through a literature review.
2. To design a framework to integrate Lean Six Sigma and Life Cycle Assessment.
3. To define the factors and drivers that affect the use of the framework.
4. To collect quantitative and qualitative data that will allow for more understanding of SM.
5. To empirically assess the readiness to implement the framework in a sample of manufacturing companies.

1.8 Thesis Structure

Lyons and Doueck (2010) describes a thesis as a guided, though substantive, piece of research that makes use of a disciplined and methodical process to contribute to a body of knowledge by the discovery of non-trivial information or insights. The thesis, therefore, should progress according to a structure that best explains to the reader why and how the research was conducted. The following structure does not necessarily represent the step-by-step progress of the research project, but rather provides a logical structure to answer the questions that the reader expects to find answers for. Figure 4 shows the seven chapters of this thesis and the questions they aim to answer.

Chapter 1 gives an introduction to the research to answer the question 'Why do this research?' by showing the significance of the issue of SM in industry. It also answers the question 'What is expected to be discovered?' by setting the research aim and objectives.

Chapter 2 answers the question 'How to discover the answers to the research questions?' by outlining a research methodology that explains the overall design of the research. This chapter starts with a preliminary literature review that helps in defining a specific set of questions that the research aims to answer. An initial framework is then presented to guide the research. The philosophical stance and the rationale for choosing the methods of collecting data are also discussed in this chapter.

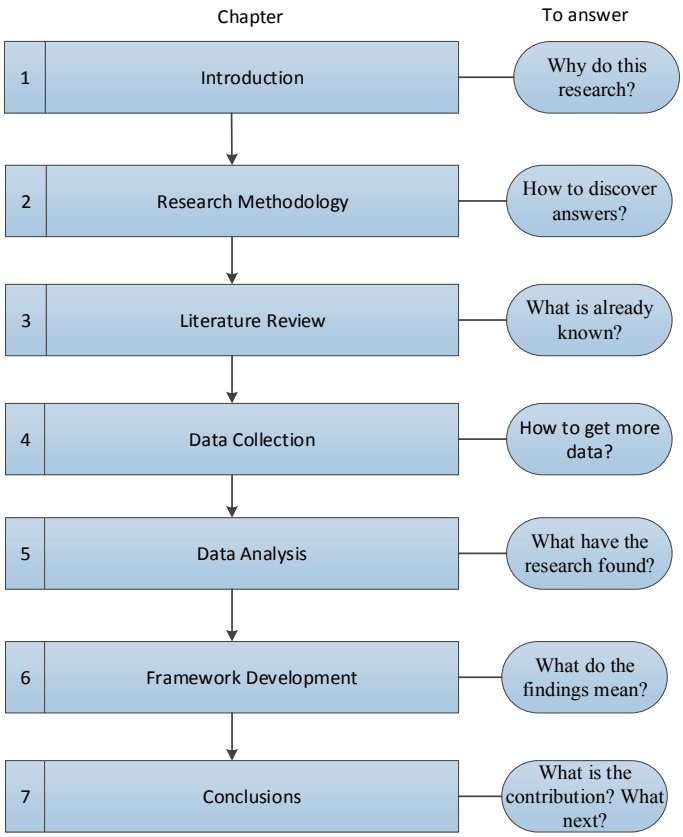

Figure 4: Thesis structure

Chapter 3 is an extended literature review that answers the questions 'What is already known?' It reviews the main concepts and management tools that will be utilised to design the framework and also defines the gaps in literature.

Chapter 4 describes the data collection process through the use of questionnaires and interviews.

Chapter 5 partially answers the question 'What have the research found?' as it presents the analysis of data. Various statistical analyses were conducted to evaluate various aspects of SM using the data. The findings of this chapter establish how to improve the framework.

To answer the question 'What do the findings mean?, Chapter 6 accumulates the findings of the study and show how the initial framework was developed from a basic idea to a framework that captures the main requirements to integrate LSS and LCA. The proposed framework that resulted from this study is presented and discussed in terms of how to implement it and, what critical success factors would affect its success. The chapter also covers how the validity of the framework was assessed, and

concludes with an attempt to show the benefits of the framework by conducting thought experiments.

Finally, Chapter 7 provides a summary of the answers to the research questions and the contributions of the study to knowledge. The chapter then discusses the implications of the study and suggests possible directions for further research.

CHAPTER 2. RESEARCH METHODOLOGY

Kothari (2004) defines research methodology as “a way to systematically solve the research problem”. It shows the steps adopted by the researcher to study the research problem, and the elements of the research process and methods used for data collection are explained. Scholarly research starts with the identification of a specific problem following a literature review (Ellis and Levy, 2008), which becomes the starting point for the research. The nature of the problem and the field of study control by and large the type of research and the methodology to be used to carry it out. The present research follows a deductive approach, where a theory exists and the research examines it in order to support it or reject it. This research began with the statement that LCA can bring focus to the waste elimination approach of LSS, and integrating the two methodologies would improve the environmental and financial performance of manufacturing companies. This statement will be invistigated through multiple methods of research and analysis. The need to define the appropriate methodological fit for this research is crucial. Edmondson and McManus (2007) defined the methodological fit as “internal consistency among elements of a research project”. These elements are shown in Table 1, and the three elements of research question, prior work, and the research design are examined in this chapter.

Table 1. Four key elements of field research. Source (Edmondson and McManus, 2007)

Element	Description
Research question	• Focuses a study • Narrows the topic area to a meaningful, manageable size • Addresses issues of theoretical and practical significance • Points toward a viable research project—that is, the question can be answered
Prior work	• The state of the literature • Existing theoretical and empirical research papers that pertain to the topic of the current study • An aid in identifying unanswered questions, unexplored areas, relevant constructs, and areas of low agreement
Research design	• Type of data to be collected • Data collection tools and procedures • Type of analysis planned • Finding/selection of sites for collecting data
Contribution to literature	• The theory developed as an outcome of the study • New ideas that contest conventional wisdom, challenge prior assumptions, integrate prior streams of research to produce a new model, or refine understanding of a phenomenon • Any practical insights drawn from the findings that may be suggested by the researcher

2.1 Initial Framework

Creating a framework is an essential starting point in this thesis, as the research proposal for combining LSS and LCA can be presented in a way that helps guide the research. Miles and Huberman (1994) defined a framework as a product that "explains, either graphically or in narrative form, the main things to be studied—the key factors, concepts, or variables—and the presumed relationships among them". Maxwell (2005) described frameworks as those that "bring in ideas from outside the traditionally defined field of your study, or that integrate different approaches, lines of investigation, or theories that no one had previously connected". In industry, a frameworks is an important tool that force the management to address a substantial list of key issues which otherwise might not be addressed (Mostafa et al., 2013). According to Maxwell (2005) , a framework can be constructed from pieces of other models, theories, and research; however, its structure must be uniquely developed by the researcher and not ready-made.

The initial framework shown in Figure 5 is a simple visual display of the main proposal of this thesis concerning combining LSS and LCA. According to Anfara et al. (2006), frameworks can also help to guide data collection and analysis and clarify ideas. This research aims to expand this initial framework to include theories, models, and

concepts that are established in the literature, and to collect empirical data that will provide an understanding specific to SM. Qualitative data will be collected to widen the current understanding of sustainable manufacturing and cover areas that previous research might have ignored. The improved framework as an outcome of this research will still be, however, only an incomplete attempt to capture complex phenomena, as no framework can capture everything important about the phenomena under study; every framework is a simplified and incomplete model of a more complex reality (Maxwell, 2005).

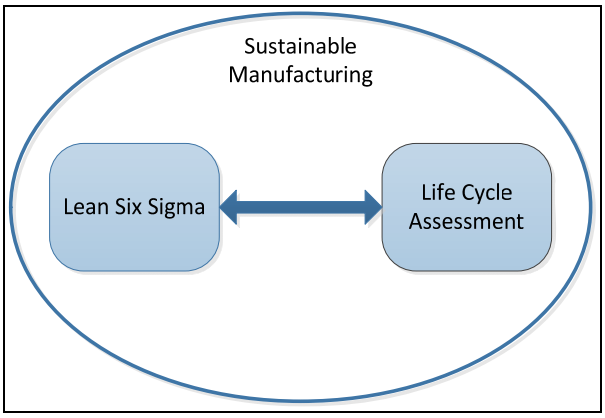

Figure 5: Initial framework showing the intended research focus for developing an advanced framework to integrate Lean Six Sigma and Life Cycle Assessment in sustainable manufacturing

Frameworks and models are used in research to represent concepts and theories, and used in industry to "provide a set of generic level descriptors of how a firm organises itself to create and distribute value in a profitable manner" (Baden-Fuller and Morgan, 2010). Kistelle (2012) describes frameworks as another form of models, and argues that frameworks that are not being put forward as models are still, in fact, models. The two terms, model and framework, are often synonymous. An example of a model is Johnson's four-box business model (2012). In his work, Johnson presents a model (Figure 6) that covers the four interdependent elements that represent all of the issues that must be addressed by a company to ensure success. An example of a framework is given in Letens et al. (2011) study on lean product development, in which a framework (Figure 7) was designed to cover three organisational levels and the interactions between them. Although the two examples shown in Figures 6 and 7 are described differently as a model and a framework, both are similar in that they capture key principles and define interactions between elements to achieve certain goals.

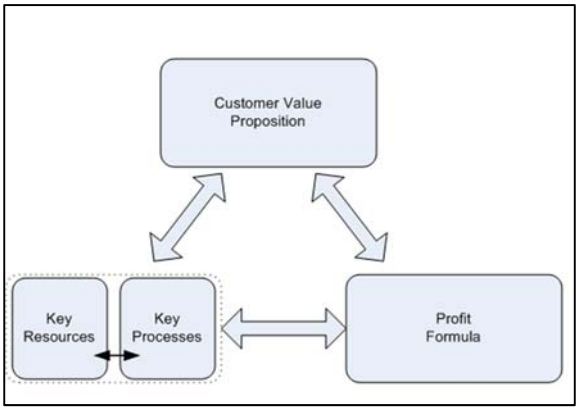

Figure 6: The four-box business model. Source (Johnson, 2010)

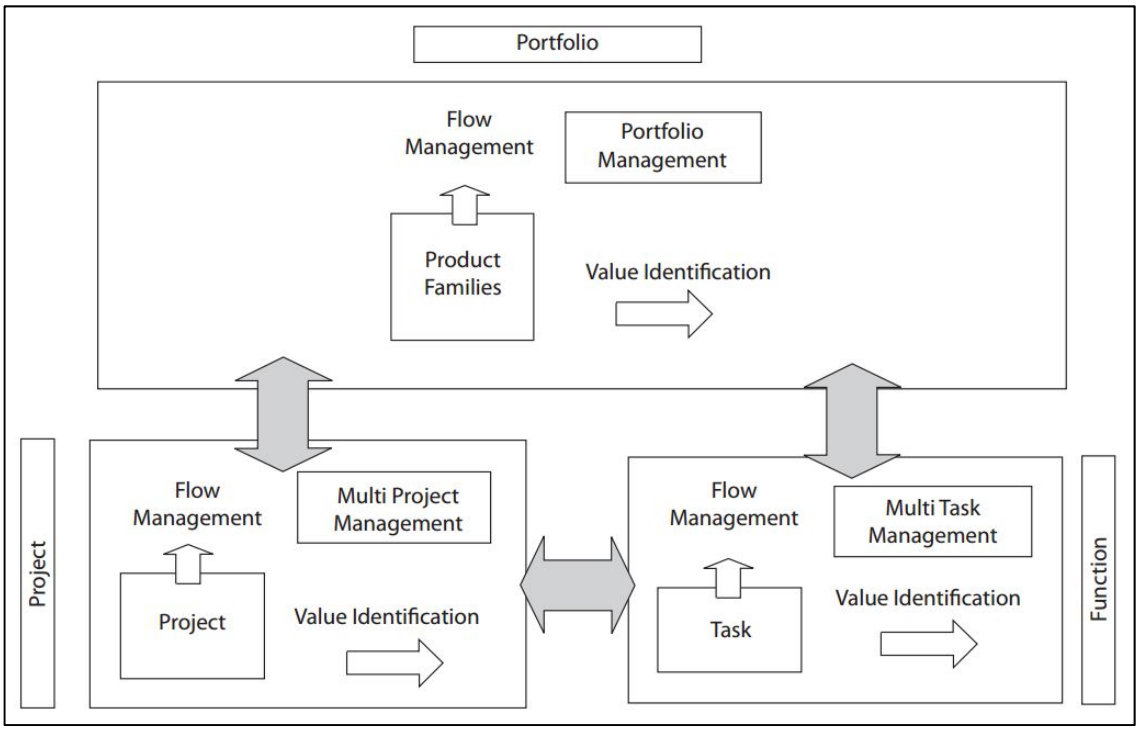

Figure 7: Framework for lean product development system design. Source (Letens et al. (2011)

2.2 Research Design

Based on the state of prior work, it was determined that this research project involves intermediate theoretical research as discussed in section 2.1 . In this type of research, qualitative and quantitative data are required. Ellis and Levy (2009) described this type of research as developmental research and assert that "developmental research attempts to answer the question: How can researchers build a 'thing' to address the problem?". The 'thing' this research aims to build is a framework. Having identified the research questions in the previous section, the following step is to prepare a research design that allows the researcher to answer the research questions and

improve the initial framework. Kothari (2004) defines research design as "the arrangement of conditions for collection and analysis of data in a manner that aims to combine relevance to the research purpose with economy in procedure". He also states that the important features of a research design are the following:

- It is a plan that specifies the sources and types of information relevant to the research problem.
- It is a strategy specifying which approach will be used for gathering and analysing the data.
- It also includes the time and cost budgets involved, since most studies are conducted under these two constraints.

Figure 8 shows the research design of this project. It consists of three main stages that are influenced by the prominent define-measure-analyse-improve-control (DMAIC) cycle of Six Sigma projects. The time span of the research project is three years, which is the standard duration for PhD studies. The three stages of the project are discussed in the subsequent sections.

2.2.1 Phase 1: Define - literature review and a survey in academia

A survey of relevant literature is the most simple and fruitful method of formulating a research problem and developing a hypothesis (Kothari, 2004). This is the foundation of the research that aims to establish the background and to formulate the research problem. A review of the literature was conducted across the fields of sustainability, LSS, LCA, strategy, and systems integration. The main concepts and issues in these areas were identified. The findings from the literature review focused the research towards specific questions. It also contributed towards the further development of the research framework and preparing it for empirical testing to be conducted in the later stages of the study. The literature review process continued throughout all the research phases. The literature review itself is presented in the next chapter. A survey of researchers working in the field of sustainable manufacturing was then conducted to obtain insights into the integration of LSS and LCA, which has not so far been covered in the literature. The purpose of this survey is to evaluate the views of academics in order to explore ideas and the essential requirements needed for designing the framework.

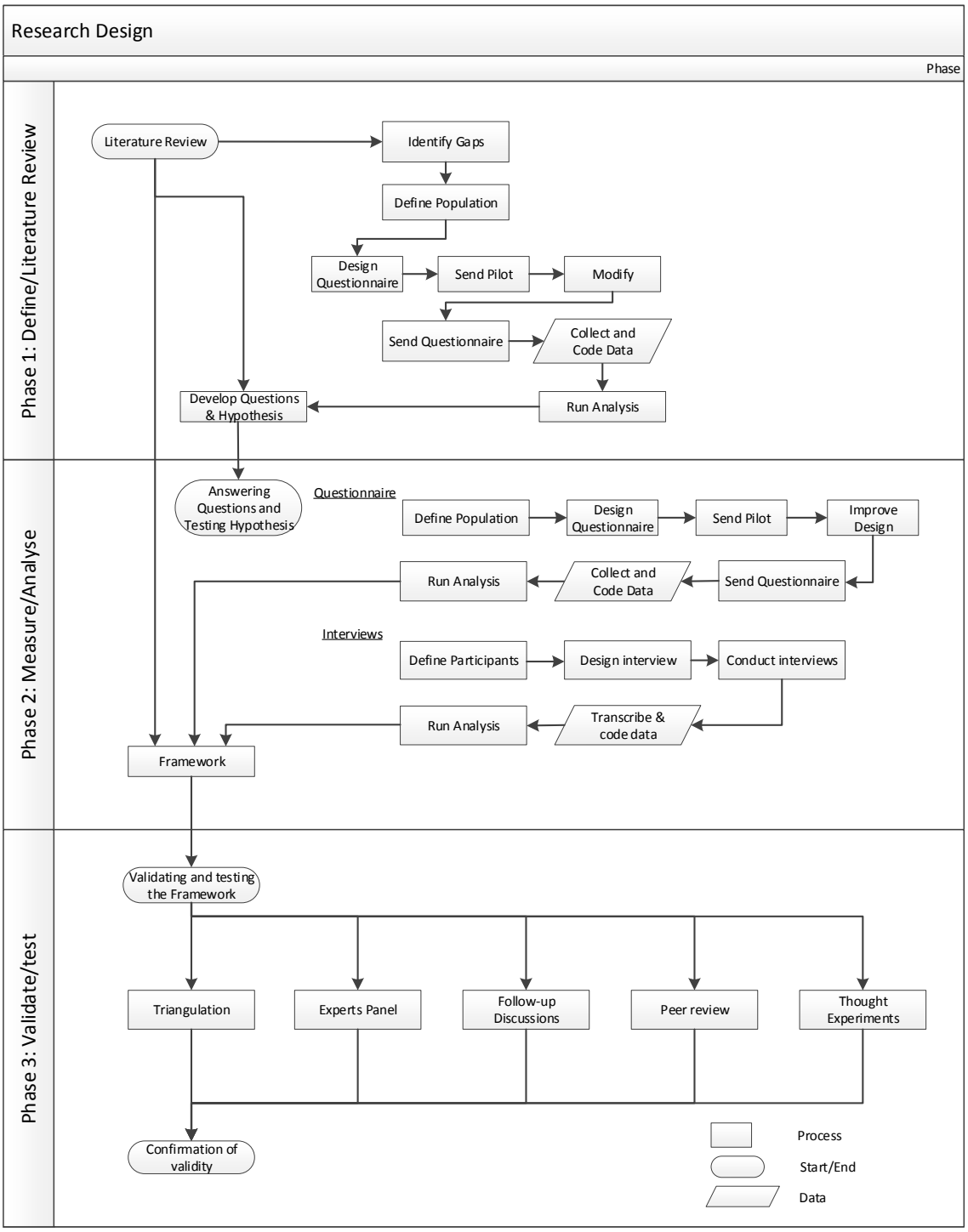

Figure 8. Research design

2.2.2 Phase 2: Measure/Analyse - survey in industry and interviews

In the second phase of the study the empirical tests were conducted. The collection of primary data was necessary in this research in order to support the findings from the literature (e.g the drivers of SM) and also find answers to the questions that are not

answered in the existing literature (e.g integrating LSS and LCA). A questionnaire was designed to gather information from manufacturing companies. The data gained was then coded in order to be statistically analysed. Semi-structured interviews were also conducted in this phase to provide qualitative insights. The purpose of the second phase of the research was to develop the framework.

2.2.3 Phase 3: Validate - validity assessment and experiments

The last phase of the research concerns the validation of the developed framework. Four methods of validity assessment are employed to ensure that the framework is fit for the purpose it is designed for. Classic methods of research validation will be applied. In addition, the framework will be tested in hypothetical scenarios to prove its potential benefits. This method is known as 'thought experiments'.

The types of data used and the methods employed for its collection in the three phases as shown Figure 8 are outlined in the following sections.

2.3 Mixed Methods Approach to Data Collection

A mixed methods approach was recommended for the current study (Edmondson and McManus, 2007 , Ellis and Levy, 2009). Mixed method research involves employing more than one type of research method and working with different types of data (Brannen, 2005). Questionnaires and semi-structured interviews were the methods chosen. They are often used together in mixed methods studies to collect quantitative and qualitative data (Harris and Brown, 2010). Both methods have their inherent strengths and weaknesses. Questionnaires can be well-structured, specific, and can be tested for their validity and reliability. However, they can be disconnected from the real issue. Semi-structured interviews might lack some of the features of questionnaires or have them to a lesser degree. Thus, they are less specific and not as precise. However, interviews provide information about personal feelings, perceptions and opinions that may be needed when exploring new areas. Kumar (2011) concludes that both methods are important in painting a complete picture of phenomena.

The two methods of questionnaires and interviews will be used to produce empirical data, i.e. data based on real world observations or experiments, which can realistically describe the problems under study. Empirical methods, however, are associated with some risk as they require the commitment of respondents to participate and give

accurate information. They also require resources of time and money which increases the risk as repeating data collection would be very costly, unlike in other methods such as mathematical modelling and simulation, which are considered "safer" to conduct. However, the present author accepts these risks because empirical research is the most appropriate option in operations management research (Flynn et al., 1990). Chase (1980) supports this view and states that, "we cannot avoid some high-risk research if we are to capture the critical characteristics which are contained in the management component of the operations management field."

The decision to employ a mixed methods approach was based on the nature of this study, as explained earlier. Edmondson and McManus (2007) suggest that qualitative illustration is required in support of quantitative findings to give credibility to newly developed measures in intermediate research. Using questionnaires and interviews as methods to collect quantitative and qualitative data is beneficial as the disadvantages of one method can be overcome by the other. There are also other reasons that encouraged the researcher to employ mixed methods as a research strategy. Firstly, mixed methods research presents an opportunity for learning and skills enhancement in collecting and analysing questionnaire and interview data. Secondly, mixed methods research encourages thinking in multiple directions and, hence, helps in exploring phenomena from more than one prospective (Brannen (2005). Moreover, a pragmatic rationale for a mixed methods approach is related to the researcher's limited resources. Other methods, such as focus groups and case studies, were considered less likely to be successful due to the researcher's limited connections in the manufacturing industry, whereas questionnaires and interviews are relatively simple to administer and are more acceptable among participants when no prior relationship exists.

Mixed methods research produces different types of data which can be used for triangulation. Triangulation is determining how different methods can be used to check, validate or corroborate findings. However, there are reasons other than triangulation for combining the results from different types of analyses. The following practices, as suggested by Brannen (2005), are important reasons for choosing a mixed methods approach in this study:

(1) Elaboration or expansion – for example interview data analysis may exemplify how patterns based on questionnaire data analysis apply in particular cases. In this

case, the use of one type of data analysis adds to the understanding that is gained from another type.

(2) Initiation: the use of a first method sparks new hypotheses or research questions that can be pursued using another method.

(3) Complementarity – interviews and questionnaire results are treated as different sets of findings. Each type of data analysis enhances the other. Together the data analyses from the two methods are put together to generate complementary insights that create a bigger picture.

(4) Contradiction - where interview data and questionnaire findings conflict, contradictions between different types of data assumed to reflect the same phenomenon may lead to an examination of the validity or reliability of the methods used and to the cancelation of one method in favour of another.

With regards to the arrangement of the methods used, the research design can implement either a simultaneous design, where questionnaires are done simultaneously with interviews, or a sequential design, where the use of one method is followed by the other (Brannen, 2005). In both designs, there could be one dominant method that is supported by another, or two equally important methods. A sequential design is adopted in this research for two main reasons. Firstly, it allows for the gradual exploration of the research problem. This is particularly important due to the researcher's limited experience in conducting research. A simultaneous design would overwhelm the researcher with data and jeopardise the quality of the analysis. Secondly, limited resources dictated that the researcher should undertake all of the research activities on his own, including the research design and collection, coding and analysis of data.

It was then determined that a sequence of questionnaires followed by interviews, also known as the explanatory sequence, is better suited for this research. Creswell (2013) defines the explanatory sequential mixed method as "one in which the researcher first conducts quantitative research, analyses the results and then builds on the results to explain them in more detail with qualitative research", and recommends it for research fields with a quantitative orientation such as the field in this study. In addition, conducting the questionnaire first helps in identifying companies that have the

potential to contribute more detailed data in interviews. Finally, using interviews at a later stage allows the researcher to gain full understanding of the research problem so that more productive discussions are generated in the interviews.

2.4 Philosophical Stance

It is important that the philosophical basis for a study is clearly described (Lyons and Doueck, 2010). The 'What to research?' and 'How to research?' questions are essential and require the researcher's careful consideration. They can be answered by a thorough examination of the literature and choosing a suitable research methodology. However, central to the researcher's answers is the perspective taken on the question 'Why research?' (Remenyi and Williams, 1998). The answer to this question requires a philosophical solution that will involve more than the practicalities of 'What?' and 'How?', and provides a deeper understanding of the research (Holden and Lynch, 2004).

Developing a philosophical perspective on science involves two main approaches, objectivism and subjectivism, which are distinguished according to core assumptions about ontology (reality) epistemology (knowledge), and human nature (pre-determined or not) (Holden and Lynch, 2004). This research is based on the following assumptions which are similar to much of the research that has been conducted in organisational science (Holden and Lynch, 2004):

- Ontology: The view held of reality is the cornerstone of all other assumptions. The present research problem of environmental sustainability has an objective existence and is not an imaginary product of the mind. This is known as the realistic approach and is the starting point of this research, because it would not have been initiated if the researcher had assumed that the problems of resources and climate change could not be controlled without hurting economic growth, which some still argue (Hayward, 2009).
- Epistemology: Knowledge about the research problem can be discovered and communicated to others, which is known as the positivist approach.
- Human Nature: the researcher has to decide whether humankind is the controller or the controlled (Burell and Morgan, 1979). The present researcher assumes that people have a willingness to act in support of sustainable development and that they are in control and are capable of making change.

The two philosophical approaches of objectivism and subjectivism, which are also described by other names as shown in Table 2, have major implications for the research. The view of objectivists is that research can be conducted independently of what is being observed and that the researcher's interests, values and beliefs will have no influence on what to study or how to study it. Otherwise, social scientists might employ twisted logic and control empirical data in order to support pre-determined views (Holden and Lynch, 2004). On the other hand, subjectivists argue that researchers have inherent bias caused by their background and values, which cannot be avoided. However, subjectivity can be distinguished from bias in that the former "is related to your educational background, training and competence in research, and your philosophical perspective. Bias is a deliberate attempt either to hide what you have found in your study, or to highlight something disproportionately to its true existence" (Kumar, 2011). Both philosophical approaches have their supporters and critics. Opponents of objectivism perceive it as not appropriate for the social sciences due to the complexity of human beings. Opponents of subjectivism, on the other hand, consider it to be an approach that cannot aid scientific progress because its outcomes are personal or group-specific. There may be no absolute right or wrong in adapting any of the two approaches. In fact, utilising the two together and mixing objectivism and subjectivism, is recommended in order to triangulate results (Holden and Lynch, 2004), or to generate greater understanding of the mechanisms underlying quantitative results in at least partially new territory (Edmondson and McManus, 2007).

Table 2. Alternative philosophical paradigm names. Source (Holden and Lynch, 2004)

Objectivist	**Subjectivist**
Quantitative	Qualitative
Positivist	Phenomenological
Scientific	Humanistic
Experimentalist	Interpretivist
Traditionalist	
Functionalist	

2.5 Assumptions, Limitations, and Scope of the Research

Assumptions, limitations, and scope of a study need to be carefully articulated so that it is clear what the researcher assumed when conducting the study, and what prevented the study from being richer and having an even stronger impact (Ellis and Levy, 2009).

According to Williams and Colomb (2007), identifying the assumptions behind a given research study is one of the hardest issues to address. Such difficulties arise due to the fact that by nature "we all take our deepest beliefs for granted, rarely questioning them from someone else's point of view" (Williams and Colomb, 2007). Explicitly identifying the assumptions may help reduce misunderstandings concerning the research as it brings the reader closer to the author's perspective. Some of the assumptions that have been made during the course of this study include the following:

- There is a willingness by manufacturing companies to participate in sustainability initiatives and mitigate environmental impacts in all life cycle stages. If companies do not have this willingness, the proposed framework might not be accepted by companies whose interest is to reduce the impact of one life cycle stage.
- Companies that participate in the study will make a sincere effort to provide accurate information.
- It is assumed that data collected from the questionnaires and interviews is provided according to the participants' best knowledge and is assumed to be correct. Although there may be answers given where companies might overstate their position for publicity reasons, such as in environmental activities, these answers are assumed to be a result of misunderstandings or cultural factors rather than intentional falsifying.
- A small sample is sufficient for the study.

As this is developmental research, the aim of sampling is to develop theory rather than to generalise the results to a larger population (Kothari, 2004). In addition, findings can be reported based on a limited number of cases, provided that the conceptual argumentation is plausible and the cases are used as additional justification for arguments (Siggelkow, 2007)

The assumptions made also imply some of the limitations of this study. Stating the limitations explicitly is important for the assessment of the research outcomes as limitations explain how the study could have been better. It is also important in order to allow other researchers to replicate the study or expand on it (Ellis and Levy, 2009). The following are limitations of this study.

- Small sample size.

A larger sample would provide a better representation of the wider population. If statistical requirements are met, the study's results would have more impact and generalisation becomes possible.

- All target participants are volunteers and do not have a commitment to the study (such as in a collaborative project).

  This strongly affected the design of the questionnaire and the interviews in terms of length and depth of detail sought. A better study could be conducted in a research centre/group that has a collaborative agreement with companies who would be willing to provide more information and dedicate more time to the research.

- One participant is targeted in each company.

  A better study would target more than one respondent in each company and compare their answers to check reliability. In this study, one participant only was targeted in order to increase the response rate.

- Risk of bias.

  Although every effort has been made to eliminate bias in all of the research activities, such as in the literature review, survey design and analysis, the researcher's personal beliefs concerning protecting the environment may have created a level of bias in favour of sustainability. However, the same level of bias can be expected in all studies of sustainability where an emphasis on its worth is prevailing (Kaebernick et al., 2003, Seuring and Müller, 2008, Stavins, 2009, Mittal and Sangwan, 2015). Kumar (2011) described this type of preconception as subjectivity which is "an integral part of your way of thinking that is 'conditioned' by your educational background, discipline, philosophy, experience and skills." Meanwhile, bias, he argues, is "a deliberate attempt to either conceal or highlight something".

It was important to determine the scope of the study that is appropriate according to the time and resources available. Sustainability is a large area of research that has various economic, environmental, and social dimensions. Conducting a study that covers all three dimensions would not have been feasible within three years. Hence, this research addresses the integration of the economic and environmental dimensions, which is only part of sustainability. Although throughout the rest of this thesis the term

sustainability is used, what is being referred to is environmental sustainability as this area of sustainability is the focus of this study.

Despite its relevance to other sectors, the scope of the investigation has been limited to the manufacturing sector due to the wide application of the concepts of LSS and LCA in this sector. The researcher's background in manufacturing management was also a factor in narrowing the scope of the study in this direction. The scope is further narrowed to focus on manufacturers in the UK as global coverage was not feasible giving the above limitations.

2.6 Summary

This chapter has presented the overall plan for conducting this study. It started with a preliminary literature review to identify specific research questions and hypotheses. An initial framework proposed for this study was discussed and is considered to be the starting point of this research. All activities performed within this study were to be conducted in order to improve the initial framework. Data collection would use a mixed methods approach as this was found to be suitable for this study. Questionnaires and interviews are used to collect quantitative and qualitative data.

The philosophical stance of the study was defined by stating the assumptions made about ontology, epistemology, and human nature. It was determined that the philosophical approach taken in this research is a combination of objectivism and subjectivism.

The chapter finally identified the assumptions, limitations, and scope of the study. The discussion of assumptions illustrates the researcher's viewpoint, while the scope and limitations of the study highlighted the conditions that shaped the research.

The next chapter discusses in detail the relevant literature and explains the main concepts and techniques that will be used in developing the initial framework.

CHAPTER 3. LITERATURE REVIEW

The study of SM is multidisciplinary and must be grounded in a thorough knowledge of various research fields that together allow an understanding of how to achieve it. In Chapter 2, a brief review of the literature was conducted to narrow the research focus. In this chapter, an extensive literature review is conducted to cover in detail the research topics that provide the theoretical basis for this thesis. It starts with a review of SM and its drivers. Then Lean manufacturing and Six Sigma are reviewed and critically analysed to explain why they cannot achieve the environmental requirements of SM. Life Cycle Assessment is presented and proposed as a technique that will support LSS in achieving these environmental requirements. In order to integrate the two techniques of LSS and LCA, the concepts of strategy and system integration are also discussed.

3.1 Sustainable Manufacturing

The term "sustainability" according to the Oxford Dictionary means to: "Keep something going over time or continuously". A sustainable society, for example, is one in which the birth rate exceeds or equals the death rate, so that it continues to exist. Although sustainability is a general term that covers economic, social and environmental developments (Gimenez et al., 2012), in this thesis it is largely related to environmental issues. So, the definition given by the Encarta Dictionary is more specific to this theme: "Sustainability is: Maintaining an ecological balance, exploiting natural resources without destroying the ecological balance in a particular area". Therefore, a sustainable business, similar to a sustainable society, has to protect the natural environment and reuse or regrow resources so the business continues to exist.

The importance of sustainability has gained much attention with the dramatic rise in global warming, public health issues, poverty and resource scarcity. Governments in developed and developing countries have started to act in support of sustainable practices for the common goal of improving the quality of life for current and future generations (Kaebernick et al., 2003, Hauschild et al., 2005). The United Nations defines sustainable development as: "…development that meets the needs of the

present without compromising the ability of future generations to meet their own needs" (Hauschild et al., 2005)

The importance of environmental issues has increased over the years, and awareness of the facts that global resources are becoming depleted and that the environment cannot absorb human waste indefinitely grew in the early 1970s (Bishop, 2006). However, global agreement on action to protect the environment took decades to form. It started at the Rio Summit (Earth Summit) in 1992, a United Nations event held in Brazil. 172 governments, 108 of which were represented by their heads of state to signify the event's importance, gathered to discuss various issues related to the environment. An important achievement of that summit was the Convention on Climate Change that led to the Kyoto Protocol. The efforts on the part of industrialised nations that followed to save the environment are remarkable; in particular, the determination to cut rates of carbon emissions. Leading nations in this field such as the EU have made ambitious commitments to reduce their emissions. These commitments have always been the subject of debate between environmental activists and politicians, as the economic argument over shifting to renewable energy persists (Hayward, 2009, Stavins, 2009, Dreyfus, 2013, Harrabin, 2013).

Sustainability has been discussed for more than three decades, and there is a general agreement on its principles amongst researchers and industry leaders (Kaebernick et al., 2003). Since the 1980s, sustainable development has been considered the goal of a desired new industrial revolution (Jovane et al., 2008). However, the implementation of sustainability practices is still not wide spread (IMSS, 2011). An argument that environmental practices place constraints on manufacturing operations has traditionally been made (Rothenberg et al., 2001). However, various studies (Yang et al., 2010, Kuik et al., 2011, Gimenez et al., 2012), and companies (Holliday, 2001) have given evidence that the 'green way' is, in fact, feasible and rewarding. Nevertheless, in the latest report of the International Manufacturing Strategy Survey (IMSS, 2011), it was indicated from data collected from more than 650 companies in 19 countries, that sustainability is poorly considered in the manufacturing strategy of participating companies, but is becoming "a hot trend". The IMSS concludes that:

> "For innovation and sustainability as the basis for future wealth is not reflected in industrial strategies. Apparently, companies are

still too busy learning effectively to combine operational effectiveness criteria (price, quality, plant flexibility, speed) and compete on that, and not yet ready to make the next step and add innovation and sustainability to their competitive competences."

3.2 Sustainable Manufacturing Drivers

To transform to SM, some drivers play an important role in enabling manufacturers to integrate environmentally friendly technologies and practices in their management systems. Research on the drivers of SM has been very active in the last two decades. The most influential driver to be identified prior and during the 1990s was legislative regulations (Reinhardt, 1998). However, as companies started to look beyond the requirements of the law for various reasons, such as pressure from non-governmental bodies, cost savings, PR and customer demand, the strategies of these companies have been shifting from being merely in compliance to going beyond compliance; beyond fence line; and beyond footprint (Kashmanian et al., 2011). As a result, the importance of SM drivers is changing and legislative requirements are no longer dominant for many companies. Research in this area has grown rapidly to cover the influence of various drivers that facilitate the pursuit of better environmental performance. The drivers reviewed in this section can also be considered as barriers depending on a company's standpoint. Top management, for instance, can hinder or promote sustainability. Figure 9 illustrates how drivers are also viewed as barriers by companies as found in the fifth State of Corporate Citizenship survey (BCCCC, 2012) which includes items on environmental sustainability. In the following discussion all aspects that influence sustainability are considered as drivers in examination of their positive contribution.

A study by Mittal and Sangwan (2015) into the drivers of SM supports the view that the importance of drivers is changing. They developed a fuzzy TOPSIS method to rank 13 drivers and concluded that four drivers were the most important in adopting SM, which are;

- Competitiveness
  The level of competition between companies in operational performance, efficiency, and product quality which is demanded in a green market.
- Incentives

Incentives given by governments or other parties to support companies who adopt sustainability.

- Organisational resources

  The funds allocated to environmental programme, as well as the skills and experience of the employees who implement them.

- Technology

  The availability of advanced green and efficient technologies

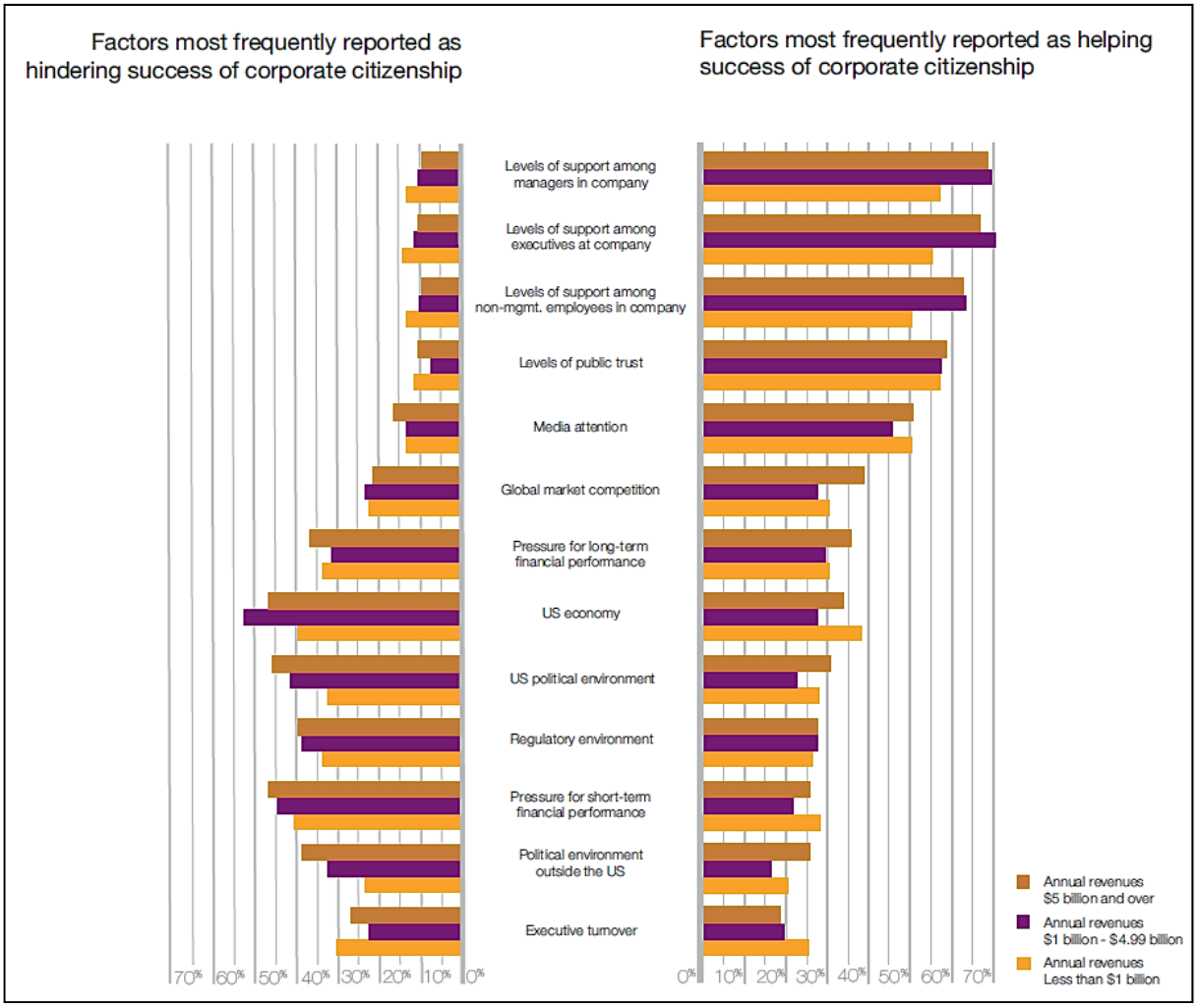

Figure 9. Drivers or barriers? Views from companies on sustainability. Source (BCCCC, 2012)

Table 3 shows the SM drivers in their ranking order. The ranking, however, depends on the type of industry concerned, region, and the maturity of the market. For example, Zhu et al. (Zhu et al., 2007) found that the most important drivers for the Chinese automotive industry were regulatory requirements and market pressure. The current study takes a different approach to the evaluation of SM drivers, by considering the factors that underlie them rather than directly ranking the drivers. Exploring these

factors has not been previously attempted in prior work and this approach is an original contribution of this study. The following is a review of the drivers and their underlying factors that the study aims to evaluate.

Table 3. Drivers of SM with some examples and the factors under study. Adapted from (Mittal and Sangwan, 2015)

Drivers	Cases	Supporting factors under study	Rank
Competitiveness	Better process performance, higher product quality, higher efficiency, competing with best practices in sector, etc.	Lean Manufacturing, Six Sigma.	1
Incentives	Investment subsidies, awards, R&D support, tax exemptions, duty free imports, etc.		2
Organizational resources	Availability of financial resources and skilled staff to implement programme.	Annual spending on environmental programme	3
Technology	Opportunities, advantages and performance of available green and efficient technology		4
Cost savings	Reduction of energy consumption, reduction in virgin material use, less waste, etc.		5
Top management commitment	Management, owners or investors are highly committed to enhance environmental performance, ethics, social values, etc.		6
Customer demand	Demand for environmentally friendly products	Market competition, market concentration, importance of environmentally-friendly products to win orders, bargaining power of customers	7
Supply chain pressure	Demand by suppliers, distributors, OEM, compliance with legislation in global markets	Level of supply chain integration, bargaining power of suppliers	8
Public image	Importance of a positive public perception of company, green image, etc.		9
Future legislation	Expected development of stricter laws, increased level of enforcement.		10
Current legislation	Pollution control norms, landfill taxes, emission trading, polluted water discharge norms, eco-label, etc.		11
Public pressure	Local communities, politicians, NGOs, media, insurance companies, banks, etc.		12
Peer pressure	Trade and business associations, networks, experts, etc.		13

3.2.1 Supply chain pressure

In the area of Green Supply Chain Management (GSCM), the drivers to change are similar to those affecting a single manufacturing company. Walker et al. (2008) found that studies of GSCs tend to focus on SM drivers rather than barriers due to the desire to focus on positive aspects of GSC research. They also found that large organisations in the private and public sectors are likely to hold the power to influence suppliers to respond to the environmental agenda. This makes the size of the company a very important underlying factor in supply chain pressure and, indeed, an important underlying factor of other drivers.

Another important factor is the level of supply chain integration. Growing evidence suggests that, the higher the level of supply chain integration with suppliers and customers, the greater the potential for environmental benefits (Frohlich and Westbrook, 2001).

In addition to the above-mentioned factors, the bargaining power of suppliers is very important in increasing or decreasing the pressure from the supply chain to adopt SM. Porter (1979) found that a supplier or a supplier group is powerful if:

- It is dominated by a few companies.
- Its product is unique or at least differentiated.
- It is not obliged to contend with other products for sale to the industry.
- The industry is not an important customer to the supplier group

The aforementioned characteristics affect the ability of companies and SMEs in particular, to gain support from suppliers as they embark on the sustainability journey.

3.2.2 Market pressure

Zhu et al. (2007) used the term market pressure in their research to refer to multiple market related drivers such as customer demand, peer pressure and public image. The market associated with environmentally-friendly products has been researched for more than a quarter of a century. Welford and Gouldson (1993) reported that in the year 1990 the size of the market for environmental improvements was estimated at $200 billion worldwide and expected to grow rapidly. In 2011 in the UK alone the green goods and services sector was worth £122 billion (Department for Business Innovation and Skills, 2012).

Market opportunity for green products and services is not limited to developed countries that aim to reduce gas emissions. Developing countries are also driven by their lack of resources to innovate clean technologies and minimise waste. A World Bank report (infoDev, 2014) quantified significant opportunities in developing countries for SMEs to create jobs and generate profits in the clean technology market that is worth $1.6 trillion.

The findings of a global Corporate Social Responsibility (CSR) study (Cone Communications/Echo, 2013) also illustrate that a rapid shift is taking place in global markets towards environmental products and activities. The study covered more than 10,000 citizens from 10 of the largest countries by GDP. An important finding of the study is that customer awareness of social and environmental issues is a significant cause of this change. An important accelerator of this awareness is social media where bad or good news about a company's practices could change its reputation and consequently its market share.

On a global level, the CSR study found that more people tend to shop for products and services that provide social and environmental benefits. In addition, consumers use their purchasing power to protest against irresponsible products. For example, nine out of ten global participants would boycott a company if they learned of its irresponsible practices. In fact, more than half (55%) have done so in the preceding 12 months according to the same report.

The factors available for this study in evaluating the driver 'market pressure' are: market competition and market concentration. These two factors differ in nature as, in some markets, competition is fierce even if the number of dominant companies is small. Markets in new technologies are an example of this type of market. Meanwhile in other markets a large number of companies may work in an environment with low competition.

The bargaining power of customers and the importance of environmentally-friendly products to win orders are also factors that affect the driver 'market pressure'. Customers such as large companies and government units in countries that tackle climate change, contribute to strong demand for products and services with low ecological impact (CCC, 2008). According to Porter (1979), a buyer group is powerful if:

- It purchases in large quantities.
- The product it purchases is standard and undifferentiated.
- The product it purchases represents a significant share of the company's total sales.
- The product it purchases is unimportant to the quality of the buyer's product.
- It earns low profits, which creates a great incentive to reduce its purchasing costs.
- It poses the threat of making the product itself, as is the case with large companies.

In the context of sustainability, the purchasing power of green customers is determined by the same rules, with one important addition; green customers consider sustainability as an important feature of a product just like quality and price.

3.2.3 Competitiveness

A study comparing above-average environmental performers to those with average performance found that, in circumstances under which environmental regulations are considered, there is a potential for increase or decrease in innovation and hence a potential for competitive impacts (Hitchens et al., 2003). Sustainability is strongly associated with energy savings and the introduction of new technologies and management techniques, which all provide an opportunity for improving the competitiveness of the company. Competitiveness is a measure of the strengths of a company's physical and human capital, R&D spending, and productivity. Making the most out of resources is an important approach to improve competitiveness. Manufacturing companies learned a key lesson from the Japanese car maker Toyota as this company practiced lean manufacturing (Womack et al., 1990) to achieve better process performance, higher product quality and higher efficiency, which are the underlying factors that support the driver 'competitiveness'. Moreover, lean manufacturing provides a strong basis for SM as it reduces the consumption of resources and waste (Yang et al., 2011).

Six Sigma is another important management system that has been adopted very successfully in the manufacturing industry. Similar to lean manufacturing, Six Sigma improves product quality, delivery time and process flexibility to promote competitiveness. Integrating lean and Six Sigma for sustainability creates important

opportunities, with substantial competitiveness and sustainability gains as the outcome (Cherrafi et al., 2016) Lean and Six Sigma, therefore, are considered as factors that support the driver 'competitiveness' and are reviewed in the following sections.

3.3 Lean Manufacturing

Lean Manufacturing is the most successful and widespread methodology for improving operational performance (Andersson et al., 2006). After the Second World War, Japanese companies were operating in tough conditions, as resources were limited and the market was not adequate for adopting mass production techniques. The founders of Toyota learned from the success of Henry Ford and developed his thinking in a way that suited their environment. Toyota developed the Toyota Production System (TPS), which defines the management philosophy and the tools with which it can maintain the system, including pull production, Jist-In-Time, value stream mapping, and automatic mistake proofing. The system also gives a particular attention to respecting employees and involving them in problem solving. The TPS gained widespread recognition with the publication of "*The Machine That Changed the World*" by Womack et. al. (1990).The book describes how Toyota was unique in their thinking on how to manage people and operations. Most important was the focus on waste reduction, which led to the term "Lean". Womack et. al. defined Lean as "tools and methods through which waste is minimised while end user value is maximised and continuous improvement can be achieved.". There are various other definitions of Lean because it is more than just the tools and techniques used at some business level, but rather a philosophy for a whole system. For example, Alves et al. (2012) define Lean by looking at a different area and describe it as "a mode where the persons assume a role of thinkers and their involvement promotes the continuous improvement and gives companies the agility they need to face the market demands and environment changes of today and tomorrow".

3.3.1 Lean evolution

Having witnessing the level of performance of Lean companies compared to traditional mass production, Western manufacturers led by the automotive industry started to widely adopt Lean manufacturing in the early 1990s. Quick gains were easy to achieve by adopting the shop-floor tools and techniques of Lean. However, the greatest impact on a whole company was not always achieved, because thinking

beyond the shop-floor was lacking (Hines et al., 2004). Subsequently, there was a gradual increase in taking Lean principles beyond the shop-floor and into management (Hines et al., 2004). Lean ideas were recommended as an approach to solve management problems regardless of the industry it is applied in (Womack et al., 1990), and this view started to be taken up as businesses in diverse sectors adopted from the mid-1990s onwards to achieved remarkable improvements. Since then, Lean has been evolving through the 2000s and 2010s, for example, in the area of supply chain management (Agus and Hajinoor, 2012), and outside of high-volume repetitive manufacturing environments (Hines et al., 2004). Lean has also evolved in the area of environmentally-friendly manufacturing, where it is described as 'Green Lean'.

3.3.2 Green Lean

Associating Lean with environmental benefits is a common-sense idea as the system has the two fundamental principles of waste reduction and quality. Reducing the seven types of production waste identified in Lean is a key requirement for environmental sustainability as resources are then used most effectively. In addition, the disposal of excess material is kept to a minimum. Furthermore, ensuring product quality is good for the environment since resources for maintenance are minimised, including rework areas, delivery, and the energy and effort required if a product fails at any point in its life-cycle. Indeed, many researchers and experts have described Lean and Green as 'parallel universes' (EPA, 2009), where "green is the good public spill-over of Lean" and, "the move towards Green manufacturing is more than just a coincidental side-effect but rather a natural extension" (Dües et al., 2013).

Previous research (Rothenberg et al., 2001, Yang et al., 2011) has supported the notion that Lean manufacturing is a positive contributor to environmental performance. However, concerns over environmental issues have prompted researchers and industrialists to reconsider some Lean techniques that are likely to cause undesirable environmental impacts. Rothenberg et al (2009) found evidence that several Lean plants have shown a willingness to compromise some of the Lean management principles in order to reduce emissions. The case study supporting this evidence found that companies "have started to increase painting batch sizes (the number of similar colour vehicles painted in a row) in order to reduce volatile organic compound emission in the plant, although it conflicts with the (JIT) philosophy of the plant"

(Rothenberg et al., 2001). The concept of JIT in Lean manufacturing calls for smaller and more frequent deliveries to reduce inventory. And because transportation is a major producer of emissions, JIT can be a cause of increasing pollution. Indeed, in Japan, environmental concerns have forced plants to alter their JIT delivery of material and products in order to reduce air pollution and road congestion (Cusumano, 1994). Another Lean technique that has been described as a potential cause of environmental damage is the Single Minute Exchange of Dies (SMED).

In response to these limitations, Lean has been evolving into Green Lean in order to embrace environmental requirements. Green Lean extends the focus on the seven traditional types of production waste to consider waste that harms the environment. Research in this direction started as early as Lean started to spread during the 1990s (Maxwell et al., 1993). Hines (2012) identified eight forms of waste in Green Lean which he categorised as:

- Greenhouse gases
- Eutrophication
- Excessive resource usage
- Excessive water usage
- Excessive power usage
- Pollution
- Rubbish and
- Poor health and safety

To address these types of waste, traditional Lean tools have been reconsidered and modified to become Green Lean tools. Torres Jr et al. (2009), for example, developed Value Stream Mapping (VSM) to align the economic and environmental aspects of production processes. They described their tool as environmental value stream mapping (EVSM) and used it to map water usage in the alcohol and sugar industry. Faulkner and Badurdeen (2014) advanced VSM further to develop Sustainable-VSM which takes into account the environmental as well as societal aspects of manufacturing.

3.4 Six Sigma

In the mid-1980s while working for Motorola, Bill Smith developed an approach to quality management using scientific and statistical methods that proved to be very effective in terms of cost savings and increasing customer satisfaction (Bendell, 2006). The term Six Sigma originated from the statistical modelling of processes and is now adopted by thousands of organisations in many different business sectors (Brady et al.,

2006). Although, Six Sigma is heavily based on statistical methods for quality control, the technique has grown to become a comprehensive approach to process improvement and long-term business strategy (Arnheiter and Maleyeff, 2005). Tjahjono et al. (2010) viewed Six Sigma in four forms: a) a set of statistical tools; b) an operational philosophy of management; c) a business culture; and d) an analysis methodology. Linderman et al. (2003) provide the following broad definition:

> "Six Sigma is an organised and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates."

Brady et al. (2006) viewed this definition as "unnecessarily vague" and considered it essential to include that:

> "The Six Sigma method for completed projects includes as its phases either: Define, Measure, Analyse, Improve, and Control (DMAIC) for process improvement, or Define, Measure, Analyse, Design, and Verify (DMADV) for new product and service development"

Indeed, the DMAIC cycle (Figure 10) is the main methodology used in Six Sigma as it links various tools and techniques in a sequential manner (Antony et al., 2005). It is also the standardised process that brings a diverse team together (Pande et al., 2002). Many studies have reported successful implementations of Six Sigma projects in manufacturing using the DMAIC approach. Most of these projects aimed at optimising operational performance and achieving cost savings. However, Six Sigma can also optimise environmental performance. Lucato et al. (2015) introduced environmental considerations into the Six Sigma technique by proposing a procedure to incorporate environmental variables into the DMAIC process as a way to increase the eco-efficiency level of firms.

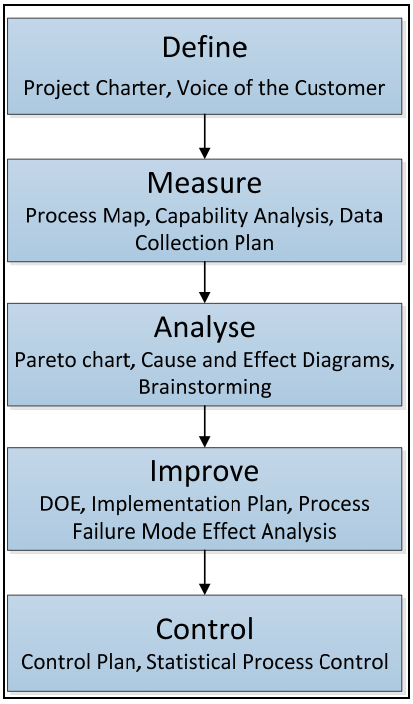

Figure 10: DMAIC process of Six Sigma and some of its tools

Research has shown that Six Sigma has a positive impact on sustainability. Calia et al. (2009) analysed 2096 pollution prevention projects and concluded that implementing Six Sigma significantly improved the environmental performance. TheyCalia et al. (2009)Calia et al. (2009)Calia et al. (2009)Calia et al. (2009) linked this success to Six Sigma's ability to boost the organisation's capabilities in data-based project management. Moreover, learning and knowledge sharing is a central focus in Six Sigma, where capability levels are divided into 'master black belt', 'black belt' and 'green belt' in cross-functional teams. The cross-functional team is the main driver in Six Sigma projects as it increases the skills and knowledge available and improves learning within the project (Arumugam et al., 2016).

3.5 Lean Six Sigma (LSS)

In an effort to increase the efficiency of manufacturing operations, many companies have developed integrated management systems to reduce waste and the probability of error (Welford and Gouldson, 1993). Lean has been combined with various systems and techniques, since "any concept that provides customer value can be in line with a lean strategy" (Bhamu and Sangwan, 2014). The combination of Lean with Six Sigma has been extensively researched and practiced. Arnheiter and Maleyeff (2005) pointed out that implementing Lean or Six Sigma alone might reach a point of 'diminishing

returns', as further improvements become hard to generate and, thus, companies embark on combining the two systems for continuous improvements. The integration of Lean thinking and Six Sigma to achieve process improvement is not widely covered in the literature in terms of a "common model, theoretical compatibility or mutual method" (Bendell, 2006). However, a single standardised approach might be unnecessary as research has shown that the benefits of combining Lean and Six Sigma can be achieved without one (Assarlind, 2013). However, the Six Sigma problem solving approach (DMAIC) that includes Lean tools is frequently used for frameworks to implement LSS (Furterer and Elshennawy, 2005, Kumar et al., 2006, Thomas et al., 2008).

Moreover, Six Sigma is thought to be a good methodology providing Lean thinking with the necessary tools to solve specific problems (Pepper and Spedding, 2010, Assarlind, 2013). In addition, merging the two can overcome the difficulty of creating an on-going culture of continuous improvement, which is difficult to achieve and maintain using only one of these approaches (Pepper and Spedding, 2010, Assarlind, 2013). Another area of benefits is that while Lean identifies standardisation, Six Sigma works on identifying variations from the proposed standard, which in itself does not completely focus on customer requirements if not supported by lean thinking (Pepper and Spedding, 2010). Yang et al. (2011) conclude that "It is important for manufacturing firms to implement both lean manufacturing and environmental management practices in ways to enjoy eco-advantage through improvements in environmental performance". Welford and Gouldson (1993) affirm that there are clear parallels between these systems (Lean and Six Sigma) in pursuing quality and environmental management. LSS has been viewed as a major part of the solution to sustainability as it can enhance not only the economic dimension of business but the social and environmental dimensions as well (Cherrafi et al., 2016). LSS combines the benefits of Lean and Six Sigma earlier described. There is clear evidence for its rising popularity amongst practitioners and researchers.

3.5.1 LSS success factors

There has been a large number of studies looking into the critical success factors (CSFs) of implementing Six Sigma and Lean as separate management systems or combined as LSS. Näslund (2008) argues that the CSFs for both systems are similar

in general and include "the importance of a vision and strategy, top management support and commitment and the importance of communication and information". Coronado and Antony (2002) gathered the key ingredients for implementing LSS from the existing literature and presented them as follows:

i. Top management involvement and commitment

   Resources and training for LSS requires top management involvement and continuous support. In most success stories, such as Motorola and GE, CEOs lead the LSS initiative and support it throughout the process of change.

ii. Cultural change

   The culture in LSS is based on openness and collaboration between people at different levels and in different departments. It also puts greater emphasis on customer satisfaction and the overall approach to projects. Another important feature of the LSS culture is the level of employee involvement. This makes LSS different from traditional process management, and thus the issue of cultural change should be addressed to eliminate any resistance to change.

iii. Communication

   As employee involvement is central to the success of LSS, a communication plan is important to involve all employees in the company. Communication between different departments should also be improved beyond traditional management communication.

iv. Organisational infrastructure

   The infrastructure of the organisation should support the requirements of LSS. Communication and training are amongst the requirements that need to be in place for LSS to succeed.

v. Training

   Training is a crucial factor in the success of LSS. The basic 'yellow' and 'green' belts should be used to train staff to take on projects and to progress to 'black' and ultimately 'master black' belts. Continuous training ensures the availability of skilled employees for improvement projects and to ensure that as many people as possible in the company are aware of the value of LSS.

vi. Linking LSS to business strategy

As discussed earlier, Six Sigma and Lean have grown to become business philosophies that reach all levels of a business. Using LSS as only a set of tools without linkage to business strategy limits its potential.

vii. Linking LSS to customers

The primary focus of LSS is customer satisfaction. Practitioners of LSS should make sure that this aim is not superseded by other goals such as cost savings.

viii. Linking LSS to human resources

Recruitment, training, employee support, employee empowerment and involvement are all important aspects of human resource management that should be adapted to provide the support needed for the implementation of LSS.

ix. Linking LSS to suppliers

Sharing best practice with suppliers can deliver substantial benefits from LSS as improvement projects may extend beyond a company's own operations.

x. Understanding tools and techniques within LSS

The choice of tools and techniques within LSS differs from one project to another as there is no standard set of tools for the different phases of the DMAIC process. Good understanding of the tools available and how to use them is important for the success of LSS projects.

xi. Project management skills

Basic project management skills are essential to lead teams within LSS. These skills should be taught in parallel with LSS training programme.

xii. Project prioritisation and selection

Implementing LSS can reveal many opportunities for improvement. Selecting projects that will have the biggest impact, whether it is cost saving or quality improvement, or any other, is important to ensure gradual and continuous success.

3.6 Life Cycle Assessment (LCA)

Moving towards sustainable production requires product developers, consumers and decision makers to consider the up-stream and down-stream impact of products. The full life-cycles of products must be taken into account. The typical stages of LCA span from the extraction of raw materials to the disposal or recycle of a product (cradle-to-grave) (Pennington et al., 2007). Life-cycle assessment (LCA) is an important

approach to evaluating the environmental impact of manufacturing processes and products. The 'cradle to grave' approach of LCA extends the evaluation beyond a company's boundaries to cover the whole supply chain (Matos and Hall, 2007), and thus provides a better perspective for decision makers. The International Organisation for Standardisation (ISO) has set the ISO 14040 series to standardise the methodology of LCA, which has made it a widely used tool for assessing the environmental impact of products and processes (Kaebernick et al., 2003).

3.6.1 The four phases of LCA studies

According to ISO14040, LCA has four phases as shown in Figure 11. The first phase is goal and scope definition where the objectives are clearly stated. The systems' boundaries, such as the stages of the life-cycle to be included, and depth of data is also determined. The goals of LCA can be one or more of the following (EPA, 2006):

- To support broad environmental assessments.
- To establish baseline information for a process.
- To rank the relative contribution of individual steps or processes.
- To identify gaps in data.
- To support public policy.
- To support product certification.
- To provide information and direction to decision-makers. For example, comparing products.
- To guide product and process development.

Rebitzer et al. (2004) identified two categories of LCA goals:

- Attributional LCA describes a product system and its environmental exchanges.
- Consequential LCA describes how the system's environmental exchanges might be affected as a consequence of introducing changes.

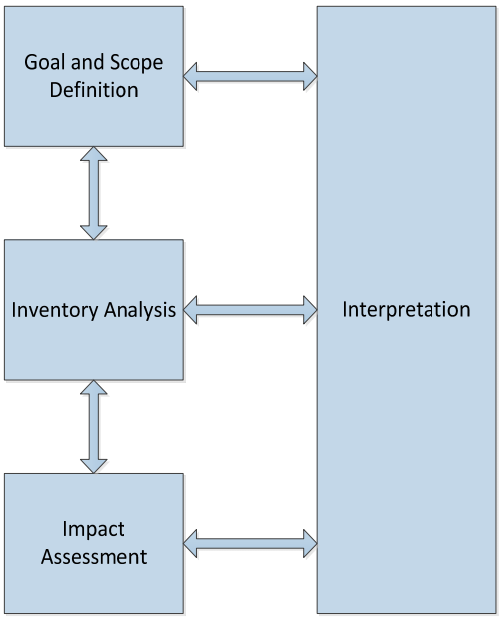

Figure 11: ISO 14040 Framework for LCA. Source (Rebitzer et al., 2004)

Once the goal and scope are defined, the second phase of LCA, inventory analysis, starts by collecting data on raw materials and emissions that occur at each production step. Databases have been created by various organisations to provide data such as resource consumption, waste and emissions. This second phase provides huge amounts of detailed data where understanding its environmental relevance may be unclear. Thus, the third phase, impact assessment, translates this information by characterising it in different environmental impact categories such as land use or climate change. The significance of the data's impact may still not be clear, however. Therefore, LCA compares the impacts of the product system identified to a reference system, such as the impact caused by a human individual in one year. This step provides a better view of the results and is called normalisation. The aim of normalisation is typically two-fold (Finnveden et al., 2002):

- To place impact assessment results into a broader context, and
- To adjust the results so that they are presented in standard dimensions.

Grouping and weighting are then used to sort the data and weighting factors are applied according to the importance of the area of protection, such as global warming, The goals of LCA and stakeholders values influence the weights associated with different impact categories. Thus, weightings should be clearly documented, as this process remains a controversial part of LCA (EPA, 2006, Pennington et al., 2004).

The final phase of an LCA study is interpretation. In this phase, an evaluation of the whole process is conducted to link the various phases in order to achieve the goals of the study. The ISO has defined the following two objectives of life-cycle interpretation (EPA, 2006):

- To analyse results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA, and to report the results of the life-cycle interpretation in a transparent manner.
- To provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with its goals and scope.

The World Trade Organisation (WTO) uses the ISO 14040 standards to distinguish between environmentally justified policies and those that constitute non-tariff trade barriers which, therefore, violate the General Agreement on Tariffs and Trade (GATT). This reliance on ISO 14040 by the WTO has given LCA potential trade implications (Hertwich et al., 2000), which has also promoted its use.

A company can find ways to influence change outside its boundaries at any stage of the product's life cycle once a LCA study has been conducted. There are many ways for this to be achieved. For example, the design could be changed to reduce the impact of materials extraction, or instructions provided for consumers to reduce the impact of the product's usage. Recycling is another key for manufacturing to reduce the impact on the environment and therefore its use should be strengthen.

3.6.2 Seeing the whole with LCA

LSS accounts only for what is perceived to be waste within the company's boundaries. It is argued that, to use resources and time to merely tackle waste within these boundaries is perhaps not the best way to improve environmental performance over the span of the product's life cycle. For example, if money is allocated to mitigating the wastage of water, the stage of the life-cycle at which water is wasted the most should be defined. A good case in point is the case study of a pair of Levi's jeans (Camp et al., 2010). It was found that over the entire life-cycle of a pair of jeans, 45% of the water consumed is associated with washing during the use stage. As a result, the company paid attention to this stage, where large and potentially inexpensive improvements could be made. In Levi's case, for instance, less frequent cold washing

is recommended to consumers according to the product's label. Generally, in many cases when LCA is applied, the impact within a company's boundaries is often found to be insignificant when compared to the impact during the whole-life cycle (see examples from (UNEP and SETAC, 2016).

While LCA has been used successfully and standardised internationally by the ISO, there are still barriers that constrain a wider implementation of the technique. Pennington et al. (2007) classified these barriers as demand-related and supply-related barriers. On the demand side, they argued that there is a need for greater awareness of the benefits of LCA and the use of related tools such as environmental product declarations (EPDs) should be encouraged in support of business-to-business communication and eco-labels for business-to-consumer communication. On the supply side, a wealth of methods and data are available. However, the problems of their complexity and the dependency on experts to conduct LCA studies need to be addressed. This is particularly important for life-cycle thinking to "become better accepted and more efficiently integrated into public decision making" (Pennington et al., 2007)

3.6.3 Simplified LCA

As indicated above, for manufacturers to make a greater impact on the product life-cycle as a whole, the role of LCA is crucial. However, a LCA that includes detailed information and follows the ISO 14001 standard for comparison purposes can be expensive and time consuming. Rebitzer et al. (2004) argue that, for many applications, the time taken for and costs of a detailed LCA study may be judged not incommensurate with the possible benefits. A full LCA has also been described as a methodology that is beyond the capacity of most potential users (Weitz et al., 1999). Rebitzer et al. (2004) assert that these limitations are particularly acute in contexts where rapid decisions are required, such as during a design for environment (DfE) process or when a rough first overview of a system's impact is needed in order to decide on further investigation. Therefore, in order to provide efficient and reliable support for decisions in a relatively brief period of time and to avoid the complexity of LCA studies in situations where resources and time are limited, organisations should conduct less detailed studies that are described as screening LCA (Fleischer and Schmidt, 1997), simplified LCA (Rebitzer et al., 2004) or streamlined LCA (Weitz

et al., 1999, Yilmaz et al., 2015). The decision concerning the suitability of a simplified LCA depends on the goal and scope of the study (Rebitzer et al., 2004). Weitz et al. (1999) identified the primary considerations for a simplified LCA in the goal and scope definition phase, as shown in Table 4.

Table 4. Primary considerations for simplifying LCA in the goal and scope definition phase. Source (Weitz et al.,1999)

Goal and scope considerations	More opportunity for streamlining	Mid-point	Less opportunity for streamlining
How will results be used?	Scoping, screening, identify hot spots	Estimate relative difference	Marketing, labeling, public policy
Is there a dominant life-cycle stage?	Very dominant	Somewhat dominant	No dominant stage
Who is the study's audience?	Internal	Internal and external	External
What is the threshold for uncertainty?	High uncertainty	Moderate	Low uncertainty
To what extent are recycled/reused materials used?	Recycled/reused materials	Virgin and reused materials	Virgin and recycled materials
How narrowly is the product defined?	Generic product	Product type	Specific product
How much is already known about the product?	High knowledge of all life-cycle stages	High knowledge of some life-cycle stages	Low knowledge of all life-cycle stages

Studies conducted using streamlined LCAs have shown their advantages. Ingwersen et al. (2012) used it in a university to compare the environmental impact of printed annual reports against reports distributed via the internet. They concluded that it is an approach that can provide a grounding for environmental decision making within a reasonable time period and cost while maintaining sufficient accuracy for guiding purchasing or product decisions. Goglio and Owende (2009) used a screening LCA to study the environmental impacts of two small scale generators. Their study produced information that allowed important improvements to the design to be made. Yilmaz et al. (2015) have also chosen a streamlined LCA over a full LCA to evaluate best available techniques for iron foundries.

3.7 Environmental Strategy

Another important aspect of the present research is focused on strategy formulation. The subject of manufacturing strategy is therefore reviewed in order to identify most appropriate theory and practices. The work of Dangayach and Deshmukh (2001) provides a comprehensive review of the status of the literature on manufacturing strategy. According to their findings, the literature on environmental strategy is poor and no defined principles or frameworks are available to guide practitioners through the process of linking environmental practices to business strategy. Addressing this gap in the literature is one of the objectives of this research project, whereby an approach which can be used to formulate a robust environmental strategy is proposed.

Businesses often consider environmental issues as a challenge to comply with regulations or as a marketing and public relations concern (Raiborn et al., 2013). However, this attitude is changing as more companies are now linking such issues with business strategy (Dittmar, 2010, cited Raiborn et al., 2013). Manufacturing businesses in particular are more concerned about environmental issues due to the high energy consumption, waste and emissions involved in manufacturing processes. Considering the environment when formulating manufacturing strategy thus seems to be necessary.

Skinner (1969) defines manufacturing strategy as an approach to exploiting certain properties of the manufacturing function as a competitive weapon. Many leading authors as reviewed by Dangayach and Deshmukh (2001) define manufacturing strategy as an approach to coordinate operational capabilities and for the whole

business to meet market requirements. In general, in any complex activity, such as in business, there are often a number of plans in place designed to achieve many goals. Different departments and teams would implement different plans to reach these goals, which makes the whole system very complicated. So, for the whole system to work effectively, these plans must work in harmony to support each other and to ensure that conflicts are minimised. The coordination of these plans with a master plan can be described as a strategy. The proposal to apply LSS and LCA methodologies to achieve sustainable manufacturing is a case in point of multiple plans that require strategic coordination.

Hill (1997) emphasises the need for a well-defined strategy by showing the problem of having multiple functions within a company working without proper integration. He argues that: "Lacking essential integration, the result is a compilation of distinct, functional strategies which sit side by side, layer on layer in the same corporate binder. Integration is not provided if, in fact, it was ever intended"

An important lesson in manufacturing strategy is that operational effectiveness in terms of quality, cost, speed and flexibility does not necessarily deliver business success. On the contrary, it might be draining resources without delivering tangible benefits for the business (Skinner, 1969, Porter, 1979). Skinner (1969), who was a pioneer of manufacturing strategy, stressed the importance of strategy for manufacturing businesses to move away from the traditional thinking of production managers, where manufacturing works in isolation from the rest of the business according to criteria that might not be required for competitiveness in the first place.

Two principle tasks of manufacturing strategy have been identified (Hill, 1997). The first is to manage the set of tasks and responsibilities related to operations. The second is to provide support for chosen markets by prioritising investments and developments within operations. Hill (1997) defines three levels of strategy:

- Corporate level strategy concerns the market for the company as a whole. It decides what markets and what sectors to target and prioritise resource allocation and investments.
- Business level strategy is needed if a company has more than one business and is formulated for each part of the business to define priorities and the level of competition allowed.

- Functional or departmental level strategy is implemented to ensure that different functions are in line with the business strategy for the intended markets. It concerns the management of daily requirements, 'make or buy' decisions and process improvements.

The aim of manufacturing strategy's has always been to achieve a fit between marketing and manufacturing decisions (Dasilveira, 2005). In SM, companies should develop their manufacturing strategies to satisfy all stakeholders concerned with sustainability including customers, the local community and government regulators. In particular, manufacturing strategy must give regard to the environment and perform operations in an eco-friendly manner (Dangayach and Deshmukh, 2001).

By applying the general principles of manufacturing strategy, it is possible to build up a picture of how to formulate an environmental strategy that improves a company's environmental performance and also improves, or at least does not affect, its business performance.

An important tool for environmental strategy is environmental management system (EMS) which is implemented to achieve environmental sustainability. It seeks to optimise the ecological performance of the entire corporate system (Yang et al., 2010). Implementing an EMS requires large investments of financial capital, knowledge, and managerial time (Atkin et al. 2012). Therefore, any effort and resources dedicated to tackle environmental issues should be managed according to a well-defined strategy that supports corporate strategy and optimises the use of the allocated resources.

The basic elements of an EMS are described in the ISO14001 standards (Atkin et al., 2012), which were introduced to standardize and promote EMS. Although the ISO standard is voluntary, it is an effective tool to promote environmental practices. According to business leaders from the World Business Council for Sustainable Development (WBCSD), voluntary certification such as ISO 14000, initiatives by companies dominant in the supply chain, investor pressure and a company's genuine self-interest in the environment can give better results than direct governmental regulation (Andrews et al., 2006). The following benefits and motivations from ISO 14001 have been proposed in the literature (Nunhes et al., 2016):

- Resources are saved and internal efficiency improved through the reduction of pollution and adhering to laws and regulations.
- Improvements in marketplace acceptance and the enhancement of corporate image and reputation.
- Enabling the participation of companies in public service in countries where the law only requires the participation of companies to be certified according to environmental standards.

Drawing from the previous discussion on manufacturing strategy, it is argued that strategic thinking is lacking in environmental sustainability. Table 5 shows how the principles of manufacturing strategy can be applied when formulating environmental strategy.

Table 5. Principals of manufacturing strategy extended to environmental Strategy

Manufacturing Strategy	Environmental Strategy
Operational efficiency is not strategy	Waste elimination is not strategy
Routine decisions that seem logical might take the company to a non-competitive position.	Routine decisions that seem to tackle environmental issues might not be the best ones for the environment and the company. A view of the whole life-cycle is missing.
Integration of different systems is required	Integration of different systems is required

In manufacturing, for example, what appear to be routine manufacturing decisions often come to limit the company's strategic options, leading it along with facilities, equipment, control systems and personnel to a non-competitive position (Skinner, 1969). Similarly, without using an environmental strategy, many environment-related activities might not assist in maintaining the company's competitive advantage. Bendell (2006) argues that the "naïve" elimination of all waste using Lean techniques might lack focus and may itself be a wasted effort.

3.8 Systems Integration

The subject of systems integrations is relevant to this research as it can be used to link LSS and LCA. Karapetrovic and Willborn (1998b) define a system as "a complex of

interrelated processes and resources that create products and other outputs to achieve some objective". Examples of systems within a manufacturing company are shown in Figure 12. Even though an attempt at systems integration may look at integrating different management systems within an organisation, the same thinking can be applied to integrate a management system such as LSS with an assessment tool such as LCA. This integration is required because the two processes influence the internal decisions made in each. Karapetrovic and Willborn (1998b), Karapetrovic and Willborn (1998a) assert that "sound partnership comes with a proper linkage of business systems and will result in the continuous improvement of the systems performance".

In their review of integrated management systems, Nunhes et al. (2016) found that, companies engaged in sustainability, although having many certified management systems, often do not integrate corporate sustainability into their management systems. Systems integration is an important concept for efforts to integrate LSS and LCA because the two techniques belong to different systems within the company; usually the quality management system and the environmental management system. According to Karapetrovic and Willborn (1998a), the benefits of such integration include:

- Improved technology development and transfer.
- Improved joint operational performance.
- Improved internal management methods and cross-functional teamwork.
- Higher staff motivation and fewer inter-functional conflicts.
- Multiple audits can be reduced and streamlined.
- Enhanced confidence of customers and positive market/community image.
- Reduced costs and more efficient re-engineering.

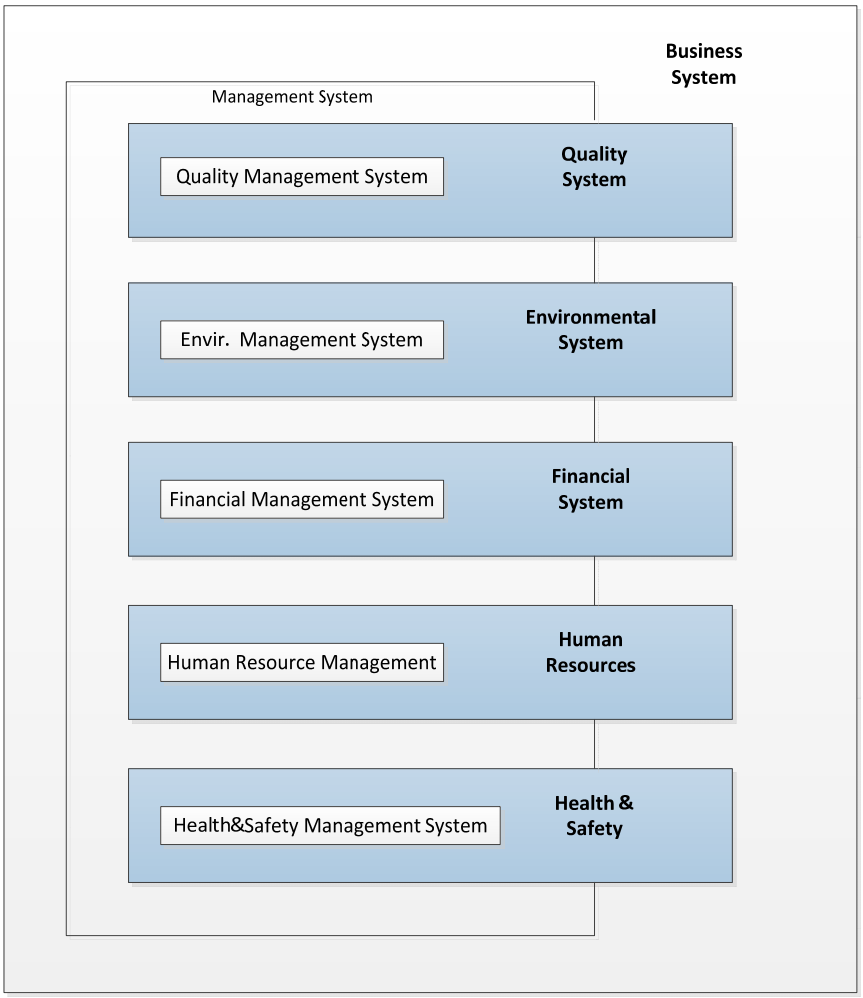

Figure 12. Systems within a manufacturing company.
(Source: Karapetrovic and Willborn, 1998a)

The success of systems integration depends on critical success factors. Almeida et al. (2012) identified these factors as top management commitment, training, financial resources, human resources, and employee motivation and involvement. To further illustrate the importance of systems integration, the following example can be cited:

Levi Strauss & Co., the global manufacturer of Levi's jeans, has for years worked on improving efficiency and reducing the impact of their operations on the environment. Given that jeans production consumes enormous amounts of water (about 1,914 litre per pair of jeans), the company invested heavily in water recycling even beyond legal requirements due to its ethical beliefs. However, the company realised only after conducting a LCA study that the biggest impact of water in the life-cycle of the product is during the consumer's use stage (45% water and 58% energy). The company reacted to this new insight by directing customers in product instructions to use a fast cold

wash, and also hinting in better advertising that washing once a month is sufficient for durable jeans. Management also realised that some of the waste reduction investment could have been better devoted to other environmental projects (Camp et al., 2010).

3.9 Main Findings and Literature Gaps

The research gaps that have been identified during the literature review were discussed in the first chapter. Existing knowledge from the literature has provided the study with important frameworks and concepts that can be used to improve the proposal of the integrating of LSS and LCA. The first finding from the review is that environmental sustainability is growing in importance and its benefits are leading more manufacturers to adopt SM. This illustrates that the topic chosen in this research relates to a pressing issue for manufacturers as they transform to SM. Other important findings from the literature review include the following:

1. Lean has evolved to Green Lean, which adds green waste to the classic production waste.
2. While the DAMIC cycle is a standard approach in Six Sigma projects, the integration of Lean and Six Sigma does not yet have a standard framework.
3. LCA has a standard framework as described by ISO 14001.
4. A streamlined (simplified) LCA is appropriate for the framework to be proposed in this study as it provides efficient and reliable decision support in a relatively brief period of time and avoids the complexity of full LCA studies in situations where resources and time are limited.
5. An environmental strategy is important for integrating LSS and LCA in order to ensure that the two techniques do not work in isolation or conflict. The environmental strategy will oversee the information and activities of LSS and LCA for coordination and to make sure that all activities are market-driven.
6. Market requirements are important for the proposed framework's design for two reasons. Firstly, market requirements have been found to be an important driver of SM. Secondly, market requirements should be the prime consideration when formulating strategy, as suggested by the manufacturing strategy literature.
7. Employee involvement, communication and top management commitment are critical success factors for LSS and systems integration.

3.10 Summary

This chapter has provided a detailed review of the scientific literature in the area of sustainable manufacturing. The drivers of SM were presented and emphasis was put on three drivers: supply chain pressure, market pressure, and competitiveness. These drivers were considered most important and relevant to the proposed framework. The review of SM drivers answered the fourth research question: what is the current strength of the drivers of SM? This is further examined in the empirical study in chapter 5.

The literature concerning LSS and LCA was reviewed to identify how they can be best utilised in SM. The review revealed that Lean has evolved to Green Lean which adds environmental concepts to the original production principles. The review also showed that a full LCA can be complicated and beyond the reach of many users; therefore, a simplified form of LCA, known as streamlined LCA, will be adopted for the purpose of developing the proposed framework. These findings partially answer the third research question: what adjustments to LSS and LCA are required to enable the framework?

Strategy and systems integration were also reviewed as important concepts for the proposed framework. These concepts are complementary and aim for total integration of and harmony between different functions within an organisation. The chapter ended with a summary of the main findings that will be used to develop the proposed framework.

The existing literature does not cover the integration of LSS and LCA, thus more data is required to answer all the research questions. To that end, the next two chapters describe the process of collecting primary data and the analysis.

CHAPTER 4. DATA COLLECTION

The present study's strategy, as described in Chapter 2, is to collect data from various sources to assess the framework proposed in this study from various perspectives in order to develop it accordingly. Primary data is required to fill in gaps in knowledge because the existing literature could not provide answers to some of the research questions. Surveys of academics and industry leaders, and semi-structured interviews were conducted to collect primary data. This chapter outlines the process of undertaking the data collection.

4.1 Survey of Academics

As part of the research design, the views and thoughts of academic researchers in the field of sustainable manufacturing were sought. A survey was conducted with the main aim of gaining insight from academics on the proposed integration of LSS and LCA and also to examine the validity of some aspects of this study.

4.1.1 Defining the population

The survey was aimed at UK-based researchers who work at universities and research centres. A search was conducted to identify organisations within the UK that engage in and promote research into sustainable development. Variations of keywords were used to identify contacts, such as 'sustainable manufacturing group ac.uk', 'sustainable manufacturing centre', 'sustainable manufacturing research UK', 'university staff sustainable manufacturing UK', 'university staff sustainable life cycle', and other combinations of search terms. Table 6 shows the institutions identified and the number of researchers working there. A total of 151 researchers were identified.

4.1.2 Selecting the sample

Due to the multidisciplinary nature of sustainability research, and also to ensure the validity of responses, it was important to target the questionnaire at individuals who have the necessary knowledge and understanding of the concepts involved in this study. Therefore, potential sample was narrowed down to include only those whose background, qualifications and experience relate to manufacturing and operations management. This filtering step reduced the total number of targeted participants to a total of 78 researchers. Invitations to take part in the survey were sent to the targeted

researchers and were followed by two reminders at two-weekly interval, which resulted in a total of 22 responses. The sample is fairly representative as it represents 28% of the targeted population. The sample is also stratified, which means that it gives a fair representation of different layers of the population, including professors (13%), those with doctorates (32%) and PhD researchers (55%).

Table 6. Identified institutions that conduct research on sustainability

Institution	Number of researchers
Engineering and Physical Science Research Council EPSRC, Centre for Industrial Sustainability	50
Sustainable Materials and Manufacturing Research Group (Warwick University)	13
Sustainable Business Initiative (University of Edinburgh)	7
Centre for Engineering Sustainability (University of Liverpool)	13
The Centre for Sustainable Manufacturing and Reuse/Recycling Technologies (SMART) (Loughborough University)	7
Newcastle Institute for Research on Sustainability (Newcastle University)	20
Bradford Centre for Sustainable Environments (Bradford University)	16
Sustainable Energy Research Team (University of Bath)	15
Independent researchers	10
Total	151

4.1.3 Designing the questionnaire

The first consideration in designing the questionnaire was to keep it simple and short so as to increase the response rate. The sequence of questions progressed from simple to more detailed questions. For clarity and simplicity, the majority of questions were provided with optional answers with a four-point Likert scale from “very low” to “very high”. This was intended to encourage participation, as ticking a preferred answer is easier and quicker. Room for comments was also provided with each question to obtain qualitative comments. The final question is the only entirely qualitative question, with no optional answers. Such qualitative questions provide valuable qualitative insights; however, they have an associated risk of being skipped and, if over-used, respondent might not complete the questionnaire. Therefore, only one qualitative question was used. A pilot questionnaire was sent to three researchers

whose comments were used to improve the wording of questions. The questions and their associated options are shown in Appendix A.

4.1.4 Administering the questionnaire

The choice of an internet-based questionnaire was considered the most suitable method to administer the questionnaire because the target population can all be contacted directly via email, which is faster and more reliable than other methods such as fax or post. SurveyMonkey, which is free online survey software, was used for the purpose of administering the questionnaire. After receiving responses from the three pilot respondents, the modified questionnaire was sent to the targeted population. Twelve participants responded within the first week, and the rest responded after the first reminder. The second reminder did not yield any further responses. Appendix A shows a sample response for the questionnaire.

4.2 Survey of Industry

As discussed in the methodology section in Chapter 2, the second phase of the research involves collecting empirical data from manufacturing industry by conducting a questionnaire survey. Empirical evidence was important for this research to progress further and verify the information gained from the literature review and the survey of academia and also to obtain new data related to the design of the framework. The data collected was intended to provide the following information:

- To investigate the state of sustainability in the view of the participants and the potential for the proposed framework to improve it (discussed in section 5.2).
- To identify the factors that underlie the drivers of sustainable manufacturing according to the sample (discussed in section 5.3).
- To assess the readiness of SMEs to implement the framework (discussed in section 5.4).
- To identify the general characteristics of sustainable manufacturing (discussed in section 5.1).

The present author has gained knowledge about conducting surveys mostly from the literature. However, learning by doing was achieved by conducting the survey of academics discussed earlier, which improved the author's experience and skills

needed for undertaking survey research. The following sections, therefore, discuss in more detail the following survey elements.

4.2.1 Defining the population

The focus of this study has been on manufacturing industry from the outset, due to the fact that the topics, concepts and methods under investigation are strongly related to and practiced in manufacturing. Therefore, the target population would naturally be manufacturing companies. This target was narrowed down to include UK manufacturers who the author could more easily reach, since the research project was limited in terms of time and budget.

The questionnaire was targeted at only one individual in a company who holds the position of production, quality or general manager. Although this affected the design of the questions in terms of depth, and also increased the possibility of "subjective bias due to an individual's unique prospective and limited access to information" (Boyer and Verma, 2000), this was unavoidable because the response rate would significantly drop if multiple individuals in the same company were targeted. Nevertheless, this limitation helped in assessing the state of communication between departments based on the knowledge of the respondent about other departments. In other words, if the respondent was a production manager who skipped general questions about other departments, such as questions about the market conditions or whether or not the company had conducted life-cycle assessment, this would indicate a possible problem of internal communication.

4.2.2 Selecting the sample

The sample was selected randomly in order to ensure better representation of the population. Random sampling also ensures that the sample has the same composition and characteristics as the population it is drawn from. For these reasons, random sampling is considered to be the best technique in selecting a representative sample (Kothari, 2004).

The questions were targeted at production, quality or general managers at plant level. Although those at corporate level may have a more holistic view of the firm's plants and may provide more information, plant level staff may also be appropriate for operations management studies concerning strategy (Flynn et al., 1990). For example,

the Minnesota-Iowa State research on World Class Manufacturing (WCM) used the plant as the level of analysis, eventhough WCM is a strategic approach, because many of WCM initiatives involving measurable improvements occur at the plant level (Flynn et al., 1990)

To identify target companies, general information about manufacturing companies published by trade associations such as the British Engineering Manufacturers' Association (BEMA), Federation of Environmental Trade Associations (FETA), Engineering Employers Federation (EEF), and others, was used to produce a list of targets. Non-manufacturing companies were systematically excluded from the search results. To find specific information about the production/quality/operations managers in target companies, a search was conducted by making phone calls and sending emails to readily available company general email addresses, such as sales@, enquiries@ and info@. Sending emails to these addresses produced no feedback, whereas phone calls to enquire about the contact information of managers usually faced the obstacle of company policy not to transfer calls unless the manager's name is known to the caller. To overcome this obstacle, LinkedIn, which is a business and employment-oriented social networking service, was used to obtain the names of managers in the targeted companies. The names obtained allowed for calls to be transferred to managers who were then invited to take part in the questionnaire survey. LinkedIn was also used to contact potential respondents directly by making contact requests; none of which, however, was accepted by the targeted participants.

4.2.3 Designing the questionnaire

The questionnaire was designed to cover four areas of interest to this study to provide information about various activities within the business. These four areas are:

- Market conditions
- Development investments
- Operations management and
- Environmental practices.

For each area investigated, questions were developed based on the literature and the objectives of the study. Questions for the first and third areas were largely adapted from questions used in the International Manufacturing Strategy Survey (IMSS, 2011).

Meanwhile those for the second area consisted of a single question about the size of annual investments in developing: (a) product related R&D; (b) processes and equipment; (c) staff training and education; and (d) environmental programmes. The fourth area was covered by questions about environmental practices such as the availability of an Environmental Management System (EMS). The questions covering this area were all developed by the author due to the lack of coverage in the literature.

Another consideration of the survey design was to promote participation by means of shortening the length of the questionnaire. According to Frohlich (2002), an important principle of survey design is that, in general, the shorter the questionnaire the better. While the questions addressed the marketing, finance and operations departments as mentioned earlier, the questionnaire was targeted at one individual, either the production, quality, or general manager.

The design of the questionnaire also considered the drivers of SM that were discussed in section 3.2. Previous studies that have looked into the drivers of SM have mostly relied on direct questions to collect data and to prioritise the drivers (Zhu et al., 2007 and, Mittal and Sangwan, 2015). In this study, however, a different design was adopted in which participants were asked about factors that underlie the drivers rather than the drivers themselves. The benefits of this design are twofold.

Firstly, it reduces bias since companies tend to overstate their efforts and interest in sustainability. Walker et al. (2008) pointed out that companies often do not change their practices, but merely advertise that they do so. Raiborn et al. (2013) also indicated that management exaggerate when reporting their environmental performance. To avoid this, direct questions about the drivers were not included in the questionnaire.

Secondly, multi-item constructs increase content validity and enhance confidence in the results. Malhotra and Grover (1998) reasoned that single-item questions have "considerable measurement error" and thus they encourage the development of multi-item constructs using a framework such as that shown in Figure 13. If respondents were asked, for example, a direct question, such as 'From 1 to 10, how healthy is your lifestyle? The answers would not provide accurate information. Instead, forming a construct that measures various aspects of a healthy lifestyle would provide more accurate information. Such a construct might include items such as 'How often do you exercise?', 'How many hours of sleep do you have?', and 'What is your diet like?.

Similarly, to evaluate a driver such as 'supply chain pressure', multiple questions about different aspects of the supply chain should be investigated. This may include items such as supply chain integration, importance of environmental products to suppliers and bargaining power of suppliers, and then data from these items can be accumulate to measure the driver supply chain pressure. In statistics, this is described as a construct or multi-item scale.

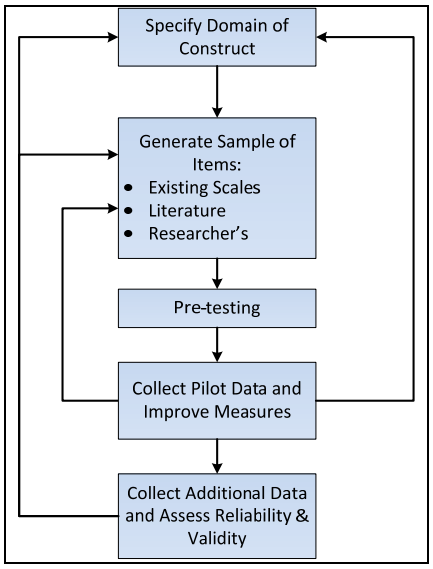

Figure 13. Framework for developing measurement scales.
Adapted from Malhotra (1998)

The final version of the questionnaire included nine questions that were arranged under five headings as shown in Appendix B. The pilot study with the first three respondents indicated that the time it took to finish the questionnaire was about thirteen minutes.

4.2.4 Administering the questionnaire

A total of 151 direct emails of company managers were collected. The emails were used to send an invitation that included a link to the questionnaire in SurveyMonkey. Only 2 responded to the questionnaire, despite a reminder being sent. Follow-up phone calls to 23 managers produced another 8 responses. Due to the very low response rate to the questionnaire, the techniques recommended by Frohlich (2002) for increasing the response rate were adopted as shown in Table 7. This study found that the most effective technique is seeking third-party sponsorship and endorsements from individuals that the participants respect as this "significantly boosts the study's creditability" Frohlich (2002). In this view, seeking help was sought from an academic

member of the university sponsoring this project who has wide personal connections in the local manufacturing industry. This academic colleague agreed to help and sent an invitation to 100 persons, out of which 26 responded within a week, which increased the total sample size to 36. While a sample of 36 is small and the results obtained from it cannot be generalised to the whole population, the aim of the survey in this exploratory study was to explore a new phenomenon rather than generalising to a larger population (Kothari, 2004).

Table 7: Techniques for improving response rates. Source (Frohlich, 2002)

Technique	Definition	Why used?
Pre-notice (or covering latter)	Brief advance letter to generate early interest	Manager knows about the survey what the survey is about, and understands its importance
Sponsorship	Endorsement of survey by third party and/or use of their logo on the survey	Builds credibility for the study, shows who else is interested in the results
Multiple mailings (reminders)	Multiple waves of mailings, usually 2–3 waves with covering letters and extra surveys and/or increasingly firm reminder letters	Most managers have good-will but are busy, shows the study is important. Replaces lost/misplaced surveys
Results	Offered in the covering letter to provide a copy of the results	
Subject interest	Channelling the survey to the most appropriate/interested managers	Gets the survey to the manager most likely to respond, who is often the most qualified person to respond too
Formatting	Carefully spaced questions and survey laid-out to look easy to do; most interesting questions first	Trick is getting managers to start filling out a survey—once started they usually complete it
Pre-tested survey	A pilot to improve readability, question order, and remove ambiguous questions	If managers do not find it clear or get frustrated while completing the survey they will stop
Existing scales	Using, where possible, reliable scales and therefore having to ask fewer questions	Reduces the survey's length and makes it easier for mangers to complete the instrument

The issue of low response rates however, is affecting surveys in many fields (Voogt and Saris, 2005). This trend has also been noted in operations management (OM) survey research. Frohlich (2002) found that the average response rate in OM studies published in the period 1989-2000 was 32% and this could have declined in the subsequent years. Low response rates have been attributed largely to employees having less free time for reasons such as workforce downsizing that makes jobs more labour-intensive. Frohlich (2002) added that consultants have "inundated (and burnt-out) many of the same managers that we target with their non-scientific research and benchmarking surveys". A review of the literature illustrated the suitability of conducting research based on low numbers of participants. For instance, in research on empirical research methods in operations management, (Flynn et al., 1990) cited questionnaire-based survey studies published in the OM literature that had response rates as low as 10% to 20% with samples as low as 6, 8, 12, 18 and 20 companies. Other recent studies that have been published in reputable journals have also been based on low numbers of cases and response rates; for example, 57 cases and 39% response rate (Jayaram et al., 1999), and 38 cases and 20% response rate in (Wright et al., 1999).

4.3 Interviews

The second phase of the research design involves conducting interviews to explore SM further using a qualitative lens. This section describes the process of conducting semi-structured interviews to collect the qualitative data required. Based on the findings from the analysis of the questionnaires and the parallel literature review, it emerged that three areas require further investigation:

1. The influence of the various drivers of sustainable manufacturing.
2. How internal communication between departments is achieved.
3. How Lean, Six Sigma, and LCA are implemented and managed.

The investigation was not limited to the above areas because, due to the nature of semi-structured interviews, the open-ended conversation exposed areas of interest that the researcher did not plan to explore. The first area requires further investigation due to the importance of drivers in implementing the proposed framework. The second area emerged from the analysis of the quantitative data where the results showed signs of poor communication between departments that could negatively affect SM in general

and the implementation of the framework in particular. It was also important to explore the integration of LSS and LCA because it is not covered in the literature and was not addressed in the questionnaire.

4.3.1 Selection of participants

The interviews were initially targeted at companies that responded to the survey of industry. Some information was already known about these companies which made the selection of interviewees more focused. In addition, selecting from these participants increased the possibility of accepting the interview invitation. The following list describes the characteristics of the companies that were targeted in descending order of priority:

- A company that meets the requirements of SM as discussed in section 5.2.2.
- A company employing LSS and which has conducted a LCA study.
- A company employing LSS and has an Environmental Management System.
- A company employing LSS.
- A company employing Lean tools and techniques.

This type of sampling is described as purposive sampling, in which participants are selected according to "predetermined criteria relevant to a particular research objective" (Guest et al., 2006). The selection process was based on the data collected from the survey, which produced a list of eight companies that represent a stratified purposive sample. The invitation to interview, however, was accepted by only four companies. To determine whether or not four cases are satisfactory for this research, the following section discusses the number of interviews required in research projects.

4.3.2 Determining the number of interviews required

The number of participants that is required in qualitative research is determined by the concept of 'saturation'. The saturation point is the level at which more interviews do not produce new information, but rather a repetition of the same data or codes (Mason, 2010). The saturation point is determined by the researcher who, parallel to conducting interviews, observes the point of diminishing returns. Creswell (2013) stated that the number of interviews needed to reach the saturation point also depends on the qualitative design being used (e.g., case study or field study), and he found from experience and a review of many qualitative research studies that it is likely for:

> "narrative research to include one or two individuals; phenomenology to typically range from three to ten; grounded theory, twenty to thirty; ethnography to examine one single culture-sharing group with numerous artifacts, interviews, and observations; and case studies to include about four to five cases." Creswell (2013)

Along the same lines, a study by Mason (2010) examined 560 PhD theses and found that the number of interviews depended on the type of research, as shown in Table 8.

Table 8: Number of interviews conducted in PhD Studies. Adapted from (Mason, 2010)

Type of Study	No. of PhD studies	Range		Measures of central dispersion	
		High	Low	Mean	St. Dev.
Action research	28	67	3	23	18.4
Case study	179	95	1	36	21.1
Collaborative research	2	25	5	15	14.1
Content analysis	42	70	2	28	14.7
Grounded theory	174	87	4	32	16.6
Life history	35	62	1	23	16.1
Phenomenology	25	89	7	25	19.9

Based on the preceding discussion and because this research is phenomenological research to explore a phenomenon, the interviewing process started with the four companies who accepted the invitation, as this number seemed adequate. However, in parallel to conducting the interviews, a search for more participants from outside the initial list commenced in order to increase the sample as an extra measure to ensure that saturation would be reached. As a result, three more interviews were obtained, making a total of seven interviews. The saturation point, however, was reached after the first four interviews. Table 9 shows some information about the participants.

Table 9: Information about the interview participants.

Participant	Size	Certificates	Management systems	Business activities	Type
P1	Large	ISO 9001/14001, EMAS	LSS	Spare parts manufacturer and distributor	Face to face
P2	SME	HACCP	Lean	Food and beverage manufacturer	Skype
P3	SME	ISO9001	LSS, LCA	Chemicals production	Skype
P4	Large	ISO 9001/14001/, BS OHSAS18001, EMAS	LSS, LCA	Valve/pump/controller manufacturer (oil&gas)	Face to face
P5	SME			Packaging	Face to face
P6	SME			Metal formations	Face to face
P7	SME	ISO9001	Lean	Hydraulic equipment repair and manufacturer	Face to face

4.3.3 Interview protocol

Creswell (2013) suggested developing a protocol for conducting interviews to ensure that standard procedures are used from one interview to another. The following components constituted the interview protocol of this study:

- A thank-you statement for accepting the invitation to the interview.
- A consent form to be signed by the interviewee. The form used is the standard university document to consent to audio-taping. The form assures the participant of confidentiality and the right to withdraw from the study at any time.
- A verbal introduction to the study and its objectives is given.
- The questions.
- Note-taking.
- A final thank-you statement to acknowledge the time the interviewee has spent.

The consent form, invite, a brief introduction and interview questions are shown in appendix C.

4.3.4 Data management

Data from the interviews was collected in three forms: i) audio recordings of three interviewees, ii) notes taken during the interviews, and iii) notes about the interviewees who have LinkedIn accounts. Collecting information about the experience and interests of participants from LinkedIn was important to focus the questions on areas relevant to the interviewee's experience.

A common practice in the analysis of interview data is to transcribe the audio-tape records to use the text in the analysis. The general benefits of transcription have been reported as a process that brings the researcher close to the data and which ensures reliability (Halcomb and Davidson, 2006). A noticeable benefit of transcribing audio data is that transcribed texts could be entered into data analysis software such as NVivo to manage a large number of interviews. However, transcription involves significant costs in terms of time, and physical and human resources (Halcomb and Davidson, 2006). The average time it takes to transcribe a taped interview lasting one hour is reported to be 6-10 hours by a fast typist (Saunders et al., 2009). Transcribing has also been described by Gilbert (1993) as not only lengthy but also a complex process.

The author has weighed the downsides of transcription against its potential benefits and decided that transcriping the recordings was not necessary. Reliability can be maintained by means of selective transcribing as recommended by Saunders (2009). Halcomb and Davidson (2006) supported the view that transcribing is not always necessary and proposed a method to manage and analyse qualitative data without it. Their method is adopted in this study by taking the following steps:

Step 1: Audio-taping of interview and concurrent note-taking

Out of the seven interviews conducted, audio-taping was done successfully in three using a Dictaphone. Two Internet interviews were conducted using the video chat application Skype where recording was not made. For the two remaining interviews, the researcher felt that the participants did not wish to be recorded, and so no recording took place to allow for a comfortable conversation. However, whether recording took place or not, concurrent note-taking was done in all interviews with more intensity in cases where recording was not possible.

Step 2: Reflective journalizing immediately after an interview

This step involved a reflection on the notes taken hastily during the interview in order to expand on and clarify them. This task was done immediately after the end of an interview and was particularly important with interviews where audio-taping was not done.

Step 3: Listening to the audio-tape and amending/revising field notes and observations

In the three cases where audio-taping was conducted, the audio-tapes were reviewed to expand on the notes. As the extended notes represented the raw data on which the analysis would be performed, the audio-tapes were listened to several times so as to produce an accurate reflection of the interaction between the researcher and the interviewees. After obtaining data from the interviews, the following step involved the analysis of this data, which is discussed in the next chapter in section 5.5.

4.4 Summary

This chapter has introduced the process of collecting data using two questionnaire surveys and semi-structured interviews. The two questionnaire surveys followed the same procedure of defining the targeted population, then selecting the sample, and finally designing and administering the questionnaires. The first questionnaire was sent to academics who were conducting research into SM to explore their views on the proposal of this study. The second questionnaire was sent to companies in the UK to collect empirical data that will be used to test various aspects of SM in industry.

The process of conducting semi-structured interviews was also discussed in this chapter, including a discussion on what number of interviews was acceptable for this type of research. It was concluded that the number of interviews depends on the principle of saturation and can only be determined by the researcher during data collection. The next chapter presents the data collected and its analysis.

CHAPTER 5. DATA ANALYSIS

The data collected was used to assess the framework's applicability to industry and various aspects related to its design. This chapter describes the process of analysing the data and presents the findings that emerged during the process.

5.1 Descriptive Statistics

Data analysis started with descriptive statistics to compare and describe variables numerically (Saunders et al., 2009). Diagrams and summary tables are used to explore the data. The measure used to describe the central tendency of data is the mean (M), and the measure used to describe how the data are dispersed around the central tendency is the standard deviation (σ).

5.1.1 Survey of academics

The questionnaire answers were coded and entered into the statistical analysis software SPSS to obtain descriptive statistics. Content analysis and reflections on qualitative data was also used to draw conclusions from the comments and notes participants provided.

5.1.1.1 Research topics and motives

Firstly, the questionnaire was intended to discover the most researched areas in sustainable manufacturing within the sample population. The question was worded as follows: "What is your area of interest/more relevant to your research?" Four areas of research were given as choices with a 4 grade Likert scale. Figure 14 shows the distribution of the answers. It was expected that researchers would cover various areas of sustainability due to the multidisciplinary nature of the subject. Life cycle assessment seems to be a hot topic as it is the area currently most researched, scoring a mean = 3.00. This indicates that there is a wide recognition of the potential of LCA in sustainable manufacturing. However, quality systems such as Lean and Six Sigma seem to be falling out of favour in achieving sustainable manufacturing, with the latter scoring a low average of M= 1.81. It can be argued that this lack of focus on quality systems represents a misjudgement of the importance of the ability of these systems to improve the environmental performance of manufacturing businesses.

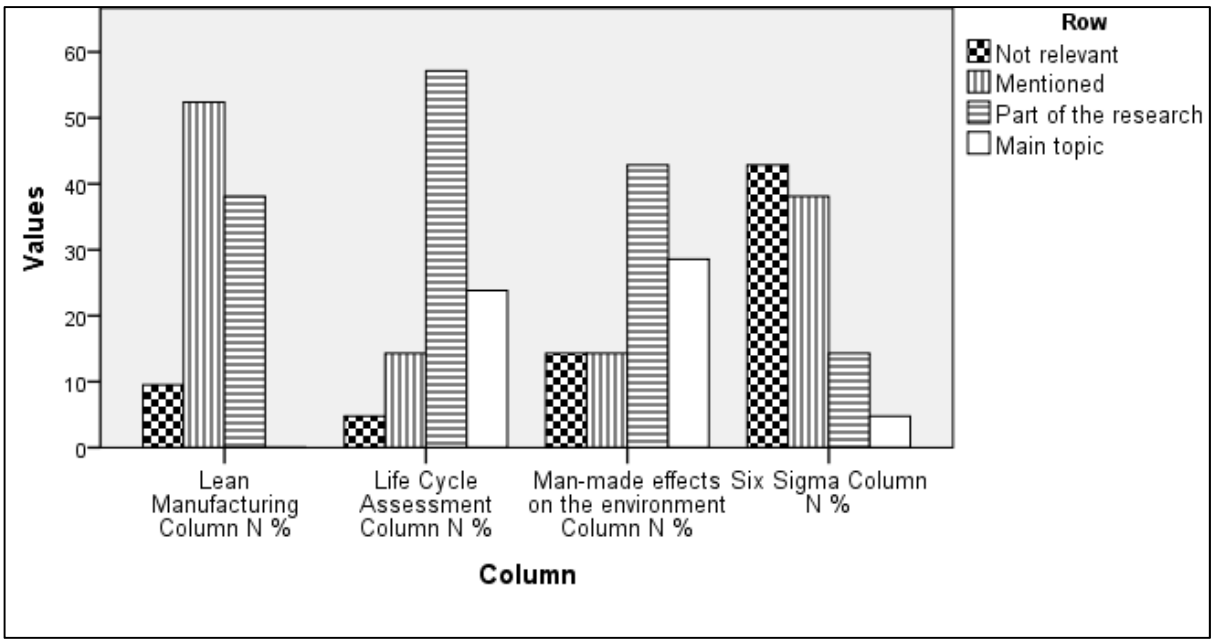

Figure 14: Interest in different research areas within SM.

The motives for conducting research on sustainability have been assessed by the second question. Five main motives have been identified from the literature: resource scarcity (e.g water, energy, land, etc); global warming and pollution; protecting ecological systems and biodiversity; social issues related to manufacturing; and keeping up with business requirements. The highest rated of these motives as seen in Table 10 are resource scarcity and global warming, which represent the general purpose of sustainability. However, business survival is also a large motivator for researchers, as one-third of respondents rated it as a 'high' motive.

Table 10: Different motives for researching in sustainability.

Scale	Resource scarcity	Global warming and pollution	Protecting the ecological system and biodiversity	Social issues related to manufacturing	To keep up with business requirements
Very low	0.0%	0.0%	0.0%	0.0%	9.5%
Low	9.1%	9.1%	13.6%	31.8%	19.0%
Medium	27.3%	31.8%	50.0%	36.4%	38.1%
High	63.6%	59.1%	36.4%	31.8%	33.3%
Mean	3.55	3.50	3.23	3.00	2.95

To further explore this motive, the third question was designed to find out about the preferred business approaches amongst the following options:

- Manufacturers should keep their focus on operational effectiveness. It is still early for change.
- Manufacturers should start a gradual change to new technologies to spread the investment over time.
- Manufacturers should wait until it is mandatory to change (e.g government regulations, market requirements, etc) even if it is more expensive to do so.

The majority of participants preferred to adopt a middle point approach of gradually shifting to sustainability, which is rated as 'high' by 91% of researchers. One participant commented that "*The best thing for the government to do would be to set a gradually increasing tariff for oil prices*". On the other hand, the survival-minded business strategy of focusing on operational effectiveness and the view to just comply with the law are not highly recommended and endorsed by 20% and 10% of respondents respectively.

A fourth approach that was suggested by a participant is to swiftly change to sustainability. He argued that:

"*Don't understand your low/medium etc. Manufacturers should be pushing HARD and NOW*"

Although this approach is regarded as "expensive" and "does not appear to be reasonable" by both supporters and opponents of sustainability (Hayward, 2009, Stavins, 2009), it exemplifies how clearly some researchers view, and strongly feel about, environmental problems.

5.1.1.2 Integration of Lean and Six Sigma

As mentioned in the literature review in section 3.5, the integration of Lean and Six Sigma is not fully developed, as there is no common model or general agreement on how to achieve this. Hence, the fourth question was designed to explore this area by evaluating the views of studies that looked at merging Lean manufacturing and Six Sigma and to describe them as either:

- Beneficial, with Six Sigma being the main strategy and Lean as a tool.

- Beneficial, with Lean being the main strategy and Six Sigma as a tool.
- No need for a standardized approach. A company could apply a combination of both as appropriate.

These three options were evaluated by respondents as shown in Figure 15. Views varied between researchers on the integration of the two methodologies, with the majority (44.62%) stating that a standard approach is not always necessary and the two techniques can be integrated according to a company's specific requirements. One participant pointed out that "*I have seen companies do both in the pharmaceutical sector. It depends on the setting e.g. packaging (lean), product formulation (six sigma)*".

Further analysis to examine relationships between variables using inferential tests was conducted to find the relationship between the choices participants made and the topics of their research. It was expected that those with Lean as their main research topic would chose it as the main strategy, and vice versa if Six Sigma was the main topic. Additionally, the relationship between the choices made and the academic level of the respondents was also tested. The test used to measure these relationships is the Spearman's Correlation test. The results of the test revealed that the choices in Figure 15 are not affected by the researchers' main topics being Lean or Six Sigma. This indicates that the choices were not influenced by bias towards a preferred technique but rather that they were determined by the experience of the researchers. On the other hand, the results reveal that there is a strong positive relationship between the variables 'No need for a standardised approach' and the academic level of researcher ($r = .535$, $N = 15$, $p = .04$). This indicates that higher level researchers tended to not emphasise one technique over another and suggests that a combination of both techniques can be applied as appropriate to the setting. These results echo those commonly found in the literature that no standard approach to combining Lean and Six Sigma is necessary.

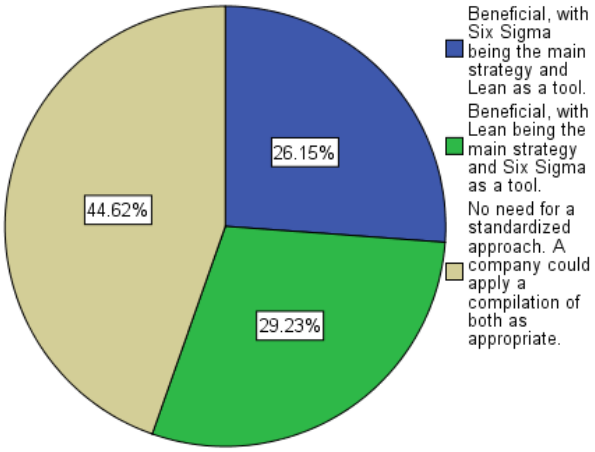

Figure 15: Preferred approach to combining Lean and Six Sigma

5.1.1.3 LCA's impact on operations

The influence that LCA has on manufacturing operations has been evaluated in the questionnaire to gauge how efficiently life cycle assessment studies can influence changes in product and process design, choice of material, and employees' thinking and involvement. While the influence in the first three areas is widely reported in the literature, the influence of LCA on employees' thinking and involvement is rarely mentioned. The reason for this is that LCA has always been reported as merely a tool that provides environmental information for management. There has been no attempt to link LCA to other management techniques. In this respect, there was a general agreement amongst participants that the influance of LCA on employees' thinking and involvement is low (M=2.64, σ=1.049) compared to the influence it has on the other areas as seen in Table 11.

Table 11: LCA's influence on different areas.

Variable	N	Mean	Std. Deviation
LCA influences product design	22	3.45	.671
LCA influences process design	22	3.23	.752
LCA influences material choice	22	3.55	.596
Employees' thinking and involvement	22	2.64	1.049

5.1.1.4 Implementing LSS prior to conducting LCA

Another objective of the survey was to assess the need to implement LSS prior to conducting LCA for the three potential benefits that LSS provides:

- Major waste elimination, so that LCA provides clear-cut improvements.
- Supply chain integration, thus enhancing the quality and benefits of LCA.
- People's commitment to support LCA and apply its recommendations.

The above potential benefits were presented to respondents for evaluating along with a fourth statement that LSS is not needed prior to LCA because it provides no benefits to it. Table 12 shows the response patterns where supply chain integration is considered a particularly important benefit of LSS (M=3.05, σ=0.621). However, 45.45% of participants still viewed LCA as an independent tool that does not require LSS to be effective. Some participants provided important comments including the following:

- "*This* [LSS needed prior to LCA] *is very product specific. Over the lifecycle of products such as energy using products the impact from the manufacturing stage is likely to be so small that lean measure may contribute very little, however for parts that are benign in use the contribution will be greater and will therefore be more highly valued.*"

- "*I don't see Lean as an antecedent to LCA. I would look at a company's environmental management capabilities before looking to extend Lean practices to include environmental impacts, or conducting any LCA activities.*"

- "*as I understand it, lean does not address end-of-life issues or [the] use phase of a product*"

Nonetheless, the above comments of those who viewed LSS as not needed prior to LCA include the words "before looking to <u>extend Lean</u>", "lean measure <u>may contribute</u>" (emphasis added), which implies that there could be still benefits from using LSS prior to LCA. With regards to the last respondent's comment, it is true that Lean does not, in terms of direct impact, address the use stage, or any stages other than the manufacturing stage for that matter; however, its influence on employee

involvement and on supply chain integration makes it important if a holistic environmental strategy is to be achieved rather than the result from LCA not being implemented.

Table 12: Potential benefits of applying LSS prior to LCA

Variables	N	Mean	Std. Deviation
It eliminates waste, thus gives LCA more potential.	19	2.79	.787
It improves the supply chain integration, thus enhancing the credibility and benefits of LCA	19	3.05	.621
It ensures people's commitment to apply LCA recommendations.	19	2.68	.749
No, it is not needed; Lean does not add much to what LCA can illustrate.	22	2.27	1.162

5.1.1.5 Correlations between variables

The Spearman's correlation test was used to explore other general characteristics of research on sustainability. The characteristics were drawn from the test resuls as shown in Table 13, which shows the statistically significant correlations between variables. These correlations indicate that:

- Six Sigma and Lean are positively related fields of study. This means that researchers who focus on Lean also focus on Six Sigma. This confirms that academia is aligned with industry in the direction of integrating Lean and Six Sigma.
- Lean and LCA's ability to improve employee involvement are negatively correlated. Researchers for whom Lean is a large part of their research recognise that LCA is weak in this area.
- There is a strong positive relationship between LSS and its perceived influence on supply chain integration and people's commitment.
- There is a positive relationship between LCA and its influence on process design and material choice.

Table 13: Correlation between variables

Variable		1	2	3	4	5	6	7	8	9
		Lean	LCA	Six Sigma	LCA influence product design	LCA influence process design	LCA influence material choice	LCA improves Employ. Involvement	LSS improves sup. chain integrat.	LSS ensures people's commit.
1	r	1	-.376	.566**	.026	-.088	.314	-.534*	.513*	.255
	Sig.		.102	.007	.913	.706	.166	.013	.025	.293
2	r		1	-.420	.262	.496*	.454*	.197	-.462	-.390
	Sig.			.065	.252	.022	.039	.392	.053	.110
3	r			1	-.047	.235	.078	-.432	.777**	.484*
	Sig.				.840	.306	.736	.050	.000	.036
4	r				1	.487*	.265	.282	-.080	.261
	Sig.					.022	.234	.204	.745	.280
5	r					1	.504*	.122	.218	.071
	Sig.						.017	.589	.369	.773
6	r						1	.010	.079	-.213
	Sig.							.964	.749	.381
7	r							1	-.416	-.295
	Sig.								.077	.220
8	r								1	.598**
	Sig.									.007
9	r									1
	Sig.									

r = correlation coefficient which takes a range of values from -1 to +1
Sig.= significance of the correlation at the 0.01 or 0.05 levels
** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The questionnaire at the end attempts to gather more insights by including a qualitative question that asks respondents to provide suggestions about the integration of LSS and LCA to improve SM. Although this question was skipped by the majority of respondents (72.7%), valuable insights were obtained from those who answered the

question. Reflection on these answers produced three main themes in these suggestions:

Avoidance of complications: this category includes suggestions that facilitate the integration of LSS and LCA, including simplifying LCA since full LCA studies are too detailed for LSS integration, and a sequential use of the techniques such as LCA/LSS/LCA to avoid complications.

Early application: using LCA early in the design stage allows for continuous improvements by LSS afterwards.

Extending to the supply chain: LCA will identify hotspots outside of the focal company, and so plans to extend LSS to the supply chain are essential for integration.

The first suggestion, to simplify LCA, has been discussed in section 3.6.3 in the literature review as an important enabler for integration. The reiteration of this by survey respondents signifies its importance for the framework. On the other hand, the suggestion of applying the techniques in a sequential manner is not what the framework is intended to achieve. A sequential application might limit the interaction between the two systems. In addition, integration must be designed to guide projects in designing new products and processes, as well as projects for improving existing products and processes. While sequential application might do well in the first, it is not practical for the second. This also applies to the suggestion of early application at the design stage. While this is desired, integration should be researched after the design stage in existing projects.

5.1.2 Evaluation of the industry questionnaire

As described in Chapter 4. the questionnaire for industry was larger and more detailed than the questionnaire for academia. This section presents an evaluation of the questionnaire data including an assessment of the level of engagement and concentration given to the responses, statistical tests to check the reliability of the constructs, and finally, the validity of the questionnaire is discussed.

5.1.2.1 Completion rates and engagement

As discussed in the previous chapter, the questionnaire was designed to collect information about four areas: marketing, investment, operations, and environmental

activities. Since the questions target production or quality managers, it was expected that participants would skip some questions that did not directly relate to their department. However, if internal communication between departments was well established, participants would be able to provide answers as all of the questions are general in nature (this is discussed further in section 4.3.3). The analysis revealed that 86% of the market-related items were answered, while 62% of the investment related items were answered. The other two groups of questions which covered operational and environmental activities were 66% and 62% completed respectively. This pattern of skipping items in the questionnaire shows that the longer the questionnaire, the less interesting it may become to participants who might then skip more items or completely stop. There is no rule in statistics that determines a minimum level of answers to make a complete response, and it is up to the researcher to include or exclude incomplete responses by judging the usefulness of data in these responses. In this survey, given that the questionnaire covers various areas, the above response rates seemed reasonable and thus no responses were excluded.

Another consideration when assessing the questionnaire was to check the level of engagement by respondents. If a respondent is not engaged, they may provide random answers to complete the questionnaire faster. Some questions were designed, therefore, to enable a consistency check. This has been done by comparing questions that should have comparable answers. If the respondent provides a notable level of inconsistency in their answers, their responses will be considered inappropriate for inclusion in the analysis. A consistency check for the questions in Table 14 was conducted for each individual response, and no noteworthy conflicts were found in the answers provided and thus no responses were omitted for failing the consistency check. This indicates that the questionnaire design is appropriate in length and structure in such a way that sustains the engagement of the respondents.

Table 14: Comparing questions to check response consistency

Question	Comparable question	Inconsistency alert
Q5: Indicate the level of implementation of the following programme (in the last three years): • Lean Manufacturing • Six Sigma	Q6: Which of the following techniques have you practiced in your company:-Lean tools.-Six Sigma, management and statistical tools-Other quality management tools?	If high level of implementation was indicated in Q5 and no evidence to support it in Q6
Q5: Indicate the level of implementation of the following programme (in the last three years): Supply Chain Integration	Q9.3: Do you do any decision making/joint efforts related to environmental issues with your suppliers and customers?	If a yes answer was provided for Q9.3, and a low level was chosen for Q5
Q7: Please describe the following:(Please provide your answer in relation to your main product) The complexity of the bill of materials (BOM) of your main product.	Q7: Please describe the following:(Please provide your answer in relation to your main product) Process steps required to finish the job.	If a significant difference is found in the answers to these two questions because if the BOM is complex, many process steps will be required.
Q3: What is the importance of the following attributes to win orders from your major customers? More environmentally-friendly products and processes	Q4: What is the annual expenditure as a percentage of total sales in Environmental Sustainability Q9.2 Do you have an Environmental Management System (EMS) in place?	If the answers to these three questions are conflicting.

5.1.2.2 Reliability

The questionnaire was also evaluated in terms of the reliability of its constructs. Bolarinwa (2015) describe this process as internal consistency reliability. As explained in section 4.2.3, a construct is a collection of variables that are correlated in a meaningful way and are measuring the same thing. “In statistical terms, the usual way to look at reliability is based on the idea that individual items (or sets of items) should produce results consistent with the overall questionnaire” (Field, 2009).

To test the reliability of the questionnaire, Cronbach’s Alpha which is a common internal consistency test was used (Bolarinwa, 2015). Field (2009) suggests dividing the questionnaire to measure different constructs separately, and states that an

acceptable level of alpha is above 0.7. While the questionnaire includes several constructs, the reliability test was applied on the two main constructs, which relate to the environment and operations. The operations construct consists of the following items:

- Level of implementation of Lean.
- Delivery speed and reliability.
- Level of implementation of Six Sigma.
- Workers' motivation and satisfaction.
- Product quality.
- Labour productivity.
- Investment in improving processes and equipment.

The reliability test for this construct produced a very low level of alpha at .287 (it is a common practice in statistics to drop the leading zero if the value cannot be greater than 1) which is way below the cut-off value of .7 and indicates that the measures are inconsistent. In a perfect scenario (alpha = 1), all items will measure in the same direction, all increasing together or decreasing together, as illustrated in Figure 16. To find out which items are holding down the level of alpha, each item was checked in terms of correlation with the total score. A correlation is a measure of the strength of the association between variables, which could be positive, negative or no correlation. For example, there is a positive correlation between Lean and quality if the company advances its Lean implementation and product quality increases as a result, as shown in Figure 16.

The correlation analysis of the operations construct revealed a negative correlation for the investment item, which is causing the overall low level of Cronbach's alpha. By deleting this item, a high level alpha of .821 was obtained, which indicates that the investment item needs to be investigated. One would logically expect that values of this variable would increase with those of other items. So as investment increases, other operations variables increase with it. However, this is not the case in this construct. The reason for this could be that the respondents did not provide accurate information in answering investment-related questions or, perhaps, companies are finding ways to improve their operational performance without investing much in new equipment. Toyota is a case in point where productivity was increased sharply by

rearranging the shop floor and applying tools such as 5S and cell-layout without making significant capital investment (Womack et al., 1990).

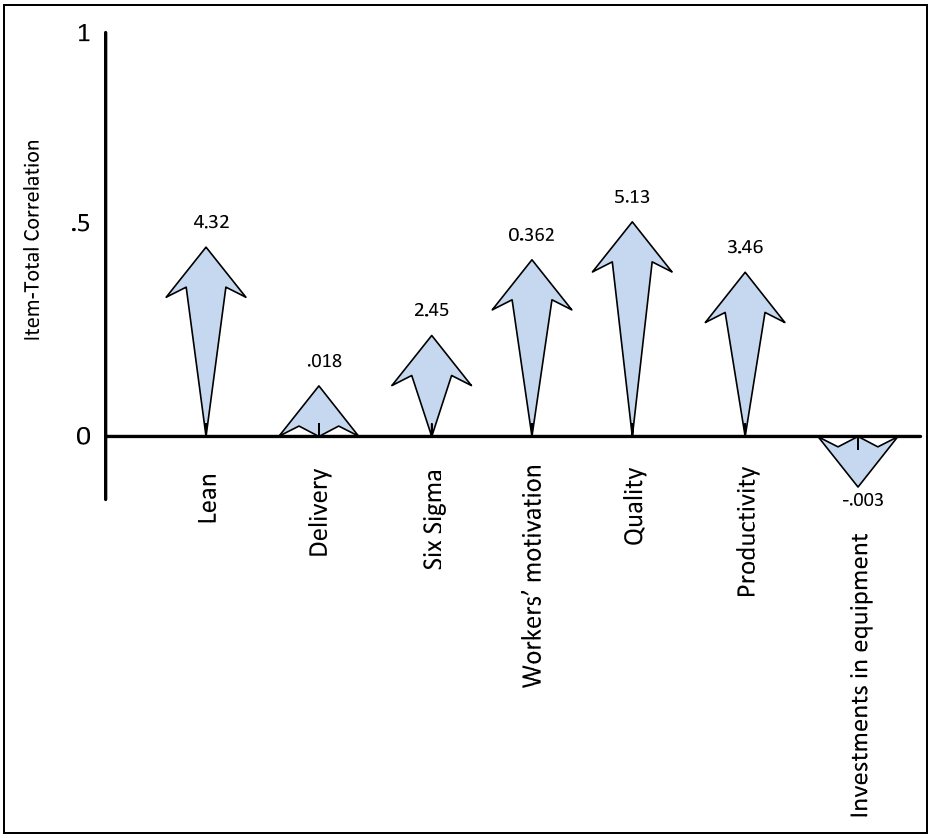

Figure 16: Items within the operations construct measure in the same direction except for one item

The second construct that was tested for reliability was the environment, which includes the following items:

- Material, water and energy consumption.
- Having an EMS.
- Waste and pollution emissions.
- Investment in environmental programmes.
- Certificates acquired (such as ISO 14000).

The alpha obtained for this construct was also very low at .149. The item that had the most undesirable impact on the value of alpha was 'investment in environmental programmes'. Deleting this item increased the level of alpha to .423, which is still unacceptably low. The item of 'having an environmental management system' also

affected the alpha value and deleting it increased the level of alpha to .611 which can be accepted as reliable since the number of items in the construct is relatively low and the average correlation between items is respectable at .407 (Field, 2009). The results of this reliability test suggest that companies engage in waste, energy, and emissions reductions without necessarily making large investments or creating an EMS. This result is in line with the result of the reliability test of the operations construct where investment was a problematic variable. It seems likely that most companies pursue improvement programmes that do not require large capital investments.

5.1.2.3 Questionnaire validity

The validity of the questionnaire as a measuring instrument needs to be evaluated in terms of the extent to which it provides adequate coverage of the topic under study. Kothari (2004) and others describe this as content validity and asserts that there is no numerical way to express it. A panel of experts was used to confirm whether or not the questionnaire design is valid for addressing the problem under study. In this case, the supervisory team checked the instrument and confirmed its validity.

5.1.3 Survey of industry, descriptive statistics

As with the survey of academia, the answers to this survey were collected and coded to be entered into SPSS to perform the analysis. Descriptive statistics as well as inferential statistics comparing groups and exploring relationships were used to draw useful conclusions from the data. This section presents the descriptive statistics of the data.

5.1.3.1 Company size and industry

Companies from eight industries participated to the questionnaire (Figure 17). One company from the service sector was included in the survey because it is a consultancy that provides services to manufacturing companies. This company was requested to provide average answers that represented its clients. The sizes of participating companies are small (19.4%), medium (36.1%) and large companies (44.4 %). Although the majority of participants were in large companies, the completion rates of the questionnaire are lowest for this group. On the other hand, respondents from small companies answered all of the questions. This suggests that factors that hinder participation, such as free time and confidentiality, affect small companies less than larger companies.

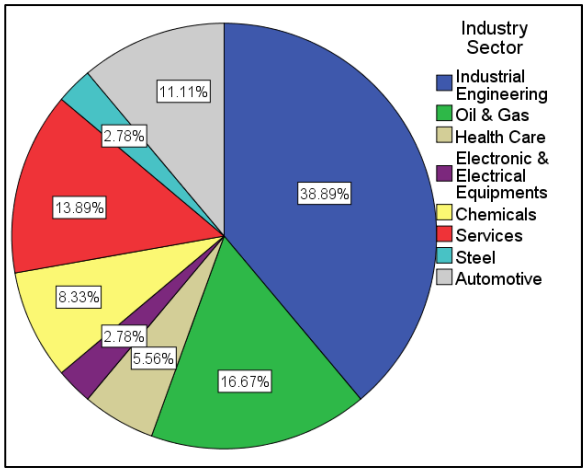

Figure 17: Industry sectors of the sample population

5.1.3.2 Competitive priorities

The most important competitive priorities are similar in SMEs and large companies with the exception that large companies prioritise environmental issues more than SMEs do. It is notable that large companies regard environmental protection as being as important as quality and production reliability. This trend has been observed in the literature review where large companies are reported to give more consideration to environmental issues (IMSS, 2011). Tables 15 and 16 show the average scores for the 5 competitive priorities. One might expect price to be one of the top priorities for both large companies and SMEs. In developed countries such as the UK, however, price is not so important due to the strength and stability of the economy. This finding is consistent with the findings of a larger international survey (IMSS, 2011) where it was found that the importance of a lower selling price is lowest among companies in Northern Europe and highest in Eastern Europe and South and Central America.

Table 15: Competitive priorities. Average scores by large companies.

	Importance of price to win orders	Importance of Quality to win orders	Importance of faster and reliable deliveries to win orders	Importance of a wider product range to win orders	Importance of environmentaly-friendly products to win orders
Mean	3.33	4.67	4.42	3.67	4.08
Minimum	1	3	3	1	2
Maximum	5	5	5	5	5

Table 16: Competitive priorities. Average scores by SMEs.

	Importance of price to win orders	Importance of Quality to win orders	Importance of faster and reliable deliveries to win orders	Importance of a wider product range to win orders	Importance of environmentaly-friendly products to win orders
Mean	3.58	4.32	4.47	3.21	2.74
Minimum	1	1	3	1	1
Maximum	5	5	5	5	5

5.1.3.3 Investment

With regards to the size of investment that companies make for improvement purposes, companies invest most in product-related R&D (M=8.25%), followed by investments in upgrading process equipment (6.29%), whereas the smallest investments are in environmental improvements (2.97%). The size of these investments is evidently influenced by the competitive priorities of the sample companies who, nevertheless, still allocate less funds in tackling environmental issues despite it being considered not an important competitive advantage. The role of the proposed framework in this thesis is important in this respect, as it seeks to make better use of lower funding to create a greater impact on other lifecycle stages.

5.1.3.4 Operations management programmes

Lean and Six Sigma as programmes adopted to improve manufacturing functions are widely implemented on average (M=3.13 and 2.38 respectively), although there are significant differences between industry sectors. For example, the steel and chemicals industries indicated a low level of implementation of both Lean and Six Sigma, whereas in automotive and industrial engineering Lean and Six Sigma are highly implemented. The other programmes that affect manufacturing functions are the level of supply chain integration, the power given to employees, and how involved the operations department is in forming company strategy. The latter is very important, as has been discussed in the literature review. Table 17 shows the average scores for each variable.

Table 17: Level of implementation of programmes related to manufacturing functions.

Variable	Minimum	Maximum	Mean	Std. Deviation
Level of implementation of lean manufacturing	1	5	3.13	1.486
Level of implementation of Six Sigma	1	5	2.38	1.408
Operations Departments involvement in forming company strategy	1	5	3.54	1.215
Level of power given to employees	1	5	3.76	1.091
Level of supply chain integration	1	5	3.32	1.282

The aforementioned variables concerning competitive priorities, investment, and improvement programmes have a direct effect on the performance of a company. The questionnaire evaluates how performance has changed in terms of various performance indicators as shown in Figure 18. The bar chart shows that, while the production indicators of quality, productivity, speed, and supply chain integration have shown improvements on average, the environmental indicators of energy consumption, material waste, and pollution emissions have on average remained unchanged. This can be attributed to a lack of strategy to improve environmental performance.

5.1.3.5 Environmental activities and LCA

When asked about the environmental activities that the companies perform, participants provided answers ranging from low level activities such as abiding by the law and energy saving to more advanced activities such as implementing a green philosophy and promotional activities such as green days which are important for employee engagement. This type of advanced activities, however, is not common in the sample population (8%).

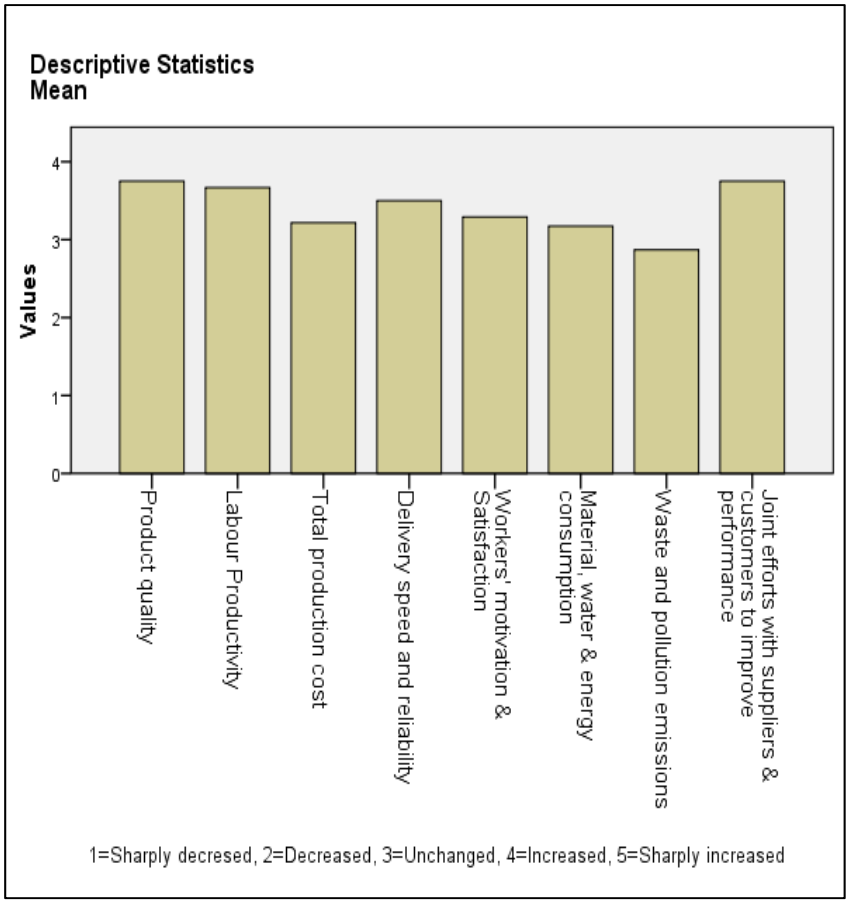

Figure 18: Performance changes over the last 2-3 years

The use of LCA amongst the participating companies was found not to depend on neither company size nor industry sector. The missing answers for the variable 'have you conducted LCA' is noticeable. 44% did not provide a yes or no answer to this question, which implies that either participants were not sure if LCA was performed in the company, or they were oblivious of LCA. The present author speculates that the first reason is more likely to be due to weak internal communication between departments. Meanwhile, 50% of participants stated that their companies conducted LCA. The accuracy of this percentage is uncertain, as there are no other studies that have surveyed the use of LCA in the UK to verify this finding. In Sweden, for example, data is available about the application of LCA where the rate of application has increased from 15% in 2002 to 32% in 2010 (Gluch et al., 2014). On the other hand, the application of environmental management systems (EMS) by 62% of the sample appears to be more common than the application of LCA. One of the main reasons

cited for not implementing EMS is the associated cost and the fact that it requires dedicated employees.

The questionnaire has also attempted to assess the complexity of the bill-of-materials (BOM) as an important factor in conducting LCA studies. The data shows that, on average, the BOMs in the sample population are very complex (M=4.21) and the average number of process steps for making products was high (M=4.17). The high means of these two variables are important reasons for hesitation in conducting LCAs because LCA studies are very complicated for complex products. Other important variables that relate to LCA are the percentages of total costs representing direct and indirect materials. The higher the level of percentages of these two variables, the more urgent is the elimination of waste. Waste to be eliminated can be identified by LSS in the company and LCA in the supply chain. The data shows that the average percentages of direct and indirect materials is 55-75%, and 7-12% respectively. The reduction of waste in both types of material could provide substantial savings.

5.1.3.6 Other characteristics of SM

In addition to the previous findings, the analysis also provided empirical support to some characteristics of SM, including:

- Lower selling price is very important if the customer is an SMEs, and is less important for a large company. 17% of respondents who supplied large companies stated that price is not important at all.
- The importance of fast and reliable delivery is equally important to win orders from all types of customers.
- Manufacturing a wide product range is very important when customers are distributors or end users.
- The importance of environmentally friendly products is not significant to 80% of companies if the customer is an SME. The importance of this varies if the customer is a large company, where 22% consider it as not important, 22% neutral and 56% as very important. Meanwhile 75% of companies whose customers are end users reported that environmentally friendly products are very important.

5.2 Assessment of the Current Status of Sustainable Manufacturing

Often companies claim to be sustainable in a case of rhetoric rather than reality. Mission statements and PR would refer to the hot topics in their business, whether this is the environment, society or anything that concerns stakeholders, and promise to work on them and deliver solutions. Raiborn et al. (2013) point out that "a gap often exists between the rhetoric espoused by companies and the reality of their actions". Even if there is an effort and sincere intention to be environmentally sustainable, companies might fall short in the requirements that need to be fulfilled to become truly sustainable. This section presents a review of the four stages in transforming to sustainable manufacturing as described in the literature. The requirements of the second stage are brought into focus as they are related to the proposed framework. The section concludes with a statistical analysis of the data to test whether companies in the sample population satisfy these requirements.

5.2.1 Stages to transform to true sustainability

In the last decade, as the number of companies practicing or considering sustainability have grown rapidly, researchers started to look at identifying the stages of transforming to sustainability to provide a road map for implementation. These stages also provide a good measure of the level of sustainability in an organization. Zadek (2004) identified these stages as: defensive, compliance, managerial, strategic, and civil. Wirtenberg et al. (2007) presented the stages of transforming to a sustainable company as: (i) Foundation: participating in strategy formulation and Involving top management. (ii) Traction: system alignment and managing change. (iii) "Integration": holistic integration and broad stakeholder engagement. Lavery and Pennell (2012) proposed an approach to progress through the stages of sustainability using a transformation road map. They suggest starting with "Prepare" where targets are set and policies developed, then moving to the "Design" stage where production efficiency and process design are reconsidered to find opportunities for sustainable practices. Finally, moving to the "Enable" stage to develop best practice-sharing process and establish measurements and metrics. Kashmanian et al. (2011) drew from these views and from personal experience to describe the stages of sustainability as the elements of a corporate sustainability strategy grouped as follows:

1. Set a strategic direction to align the company's sustainability and business strategies.
2. Improve operational performance to align the company's management systems and environmental performance strategies.
3. Improve value chain performance to recognise the extent of the company's environmental footprint and therefore the extent of its sustainability strategy
4. Relate effectively to internal and external stakeholders to recognise that the company's sustainability strategy will benefit from not being exclusively internal.

The above review indicates that there is a mutual agreement amongst scholars that an internal rearrangement and alignment of management systems is a fundamental stage of a successful transformation to sustainability. However, prior research does not provide in-depth information as to how each stage should be approached in terms of what management systems need to be used and how to align them. The proposed framework of this research addresses this gap in knowledge. The framework proposes utilising LSS and LCA for sustainable manufacturing and provides a systematic alignment between the two techniques to improve operational performance and environmental performance concurrently.

5.2.2 Requirements of the second stage

The second stage of Kashmanian et al.'s (2011) corporate sustainability strategy is the focus of this study. They described four essential requirements to formulate a strategy. These requirements are investigated in this research to justify the need for the framework and ultimately improve it. These requirements along with Kashmanian et al.'s view are as follows:

1. Enhance awareness and engage employees
   Employees should be aware of the company's quest for sustainability through training and information sharing.
2. Develop metrics for sustainability
   Sustainability should be measurable so that progress can be monitored and assessed. Kashmanian et al. suggested LCA as a tool that can be used to set targets and focus attention.
3. Facilitate information exchange between corporate management and facilities

Communication between corporate management, who provide resources and general direction, and the facilities which implement environmental programmes should be improved to include sustainability information.

4. Establish facility sustainability standards

   Creating a sustainability standard that applies to all facilities is important for benchmarking and communication with top management. An environmental management system (EMS) is introduced to regulate and standardise environmental activities based on the ISO14001 standard.

5.2.3 Assessment of sustainability in the sample companies

No prior study has attempted to empirically assess the requirements of the second stage in companies adopting environmental sustainability. The sample was therefore evaluated to find out how the companies meet the above requirements. To establish the measure, each requirement was linked to a corresponding question in the questionnaire as follow:

- **Enhance awareness and engage employees.** This was addressed in the questionnaire using three items that measure the level of a) knowledge and involvement of employees, b) employee satisfaction, and c) promotional activities such as green-days and cycle-to-work.
- **Develop metrics for sustainability.** This was addressed by a single item: a question asking whether or not the company conducted a LCA study.
- **Facilitate information exchange between corporate management and facilities.** A general observation of missing answers and comments from participants were used to evaluate this point.
- **Establish facility sustainability standards.** A single item was considered sufficient to measure this point and that is 'do you have an EMS in place?'

5.2.4 Findings

A company that is considered to meet the requirements of the second stage, and hence be truly sustainable, should have a total score of more than 22. This score is calculated as shown in Table 18.

Table 18: Calculating the score for meeting sustainability requirements.

Variable	Type of measure	Range	Minimum accepted	Weight	Points
Knowledge and involvement of employees	Likert scale	1-5	4	1	1
Employee satisfaction	Likert scale	1-5	4	1	1
Environmental activities for employees	Likert scale	1-5	4	1	1
LCA is conducted	Yes/no	0-1	1	9	9
Good Internal communication	Yes/no	0-1	1	6	6
EMS implemented	Yes/no	0-1	1	4	4
					∑= 22

It can be argued that the four requirements differ in terms of importance when attempting to approach the second stage. In this respect, because this area has not previously been researched, the following perspective is suggested on how to prioritise them:

1. A company starts first with encouraging wider employee engagement that would provide further support for sustainability through the sharing of ideas and commitment.
2. Establishing good internal communication between departments which ensures that knowledge flows between different areas in the business such as marketing, manufacturing, legal and finance. This knowledge will be the foundation of an LCA study that can influence decision making. It will also lay the foundation for a company-wide EMS.
3. Implementing an EMS ensures that information is documented in a standardised manner. The EMS also monitors plans, resources, and training to continuously improve sustainability.
4. An LCA study is conducted.

The variables in Table 19 are given different weights according to their importance. The weights of the three variables related to employees engagement is 1 point for each

variable, which gives a total weight of employee engagement of 3 points. A maximum weight of 9 points is assigned to the LCA variable. The variables of good internal communication and the implementation of an EMS are weighted at 6 and 4 respectively.

A company that is considered to be in compliance with the requirements of the second stage should score a minimum of 22 points according to Table 19. Scoring less than 22 indicates either deficiencies in the approach to sustainability or no commitment to sustainability at all. The results show that the average score obtained by participating companies was low (M=14.62, σ=6.38). Only 6 out of the 36 companies (16.6%) fulfilled the requirements of the second stage of sustainability (2 large, 2 medium and 2 small companies) as shown in Figure 19. The percentage of only 16.6% of companies meeting these requirements is very low considering that:

- 70% stated that environmentally friendly products are important to win orders.
- 16.6% spend more than 5% of annual expenditure on environmental improvements.
- 34.3% have implemented an EMS.
- 25.7% have conducted LCA to assess environmental impacts.

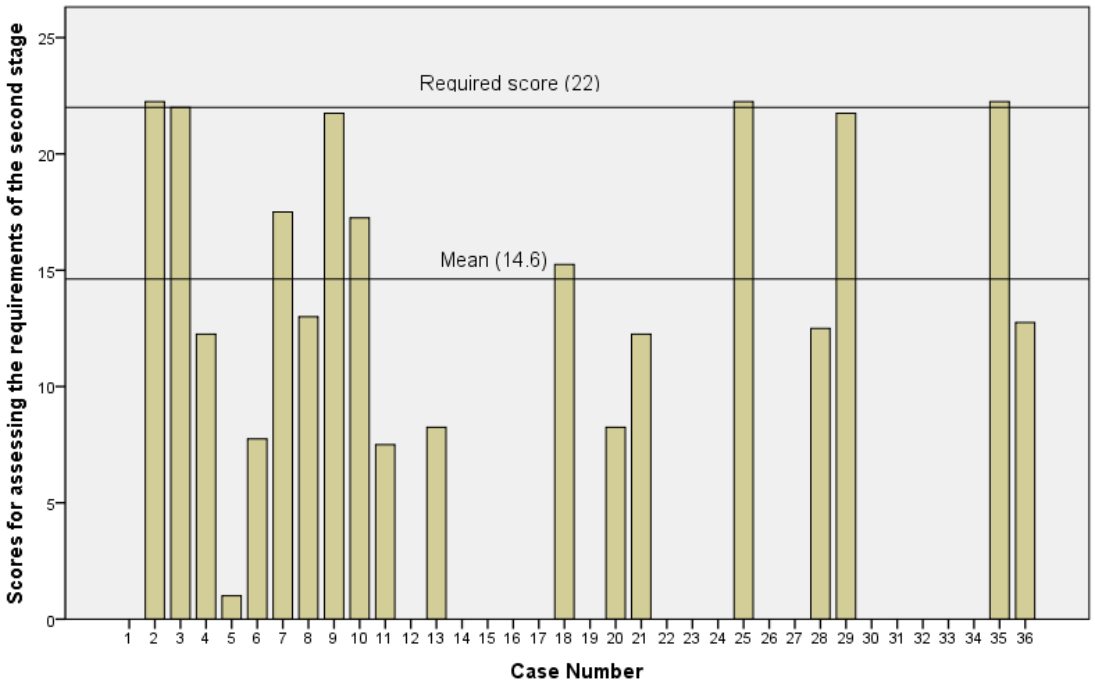

Figure 19: Scores obtained by participants in the assessment of the second stage

From the above results it is evident that manufacturers recognise the importance of sustainability and make considerable efforts to achieve it by allocating financial resources and implementing the appropriate techniques to evaluate their environmental impact. However, the outcome of these efforts is poor considering that 37.1% reported unchanged or increased material, water and energy consumption, and 25% reported unchanged or increased waste and pollution emissions in the last 2-3 years. The efforts made and resources allocated by manufacturers are not efficient because the requirements for true sustainability are not met, and although the right techniques, such as an EMS, are used and resources are allocated, strategic thinking to align systems and meet all of the requirements is missing. This state of flawed sustainability misleads companies and their stakeholders into thinking that they are on the sustainability track while in fact they are not, which consequently results in wasted effort and an opportunity lost.

5.2.5 Summary of the assessment of sustainable manufacturing

Section 5.2 and its subsections began with the argument that companies are claiming to be on track for the sustainability journey while in fact they do not fulfil the requirements of true sustainability. The journey to sustainability involves four stages. Each stage has a set of requirements that have been outlined in the literature and are discussed in this section. Particular focus is given to the requirements of the second stage because this stage relates to the proposal of this research, which is to align the company's management systems and environmental performance strategies.

The data collected from the questionnaire have been analysed to assess the sample of companies tested in terms of compliance with the requirements of the second stage. It was found that the majority of companies in the sample do not fulfil these requirements. The analysis also revealed that considerable efforts are made by companies to be environmentally sustainable by means of using tools such as LCA, EMS, and promoting environmental activities. However, the outcome of these efforts is not efficient.

The results provide strong support to the first and second hypotheses of this research, and justify the need to apply the proposed framework in manufacturing in order to fully comply with the requirements of the second stage.

5.3 Assessment of the Factors That Underlie the Drivers of SM

The drivers of sustainable manufacturing have been extensively researched in the literature. Section 3.2 in the literature review covers the important drivers of SM. The current section, however, goes beyond the drivers themselves to explore the factors that underlie each driver. For example, customer demand is a driver that depends on factors such as the importance of environmentally-friendly products to win orders and the bargaining power of customers. In other words, the strength of customer demand depends on the cumulative strength of its underlying factors. A thorough understanding of these factors can provide information to advance the field of environmental management. In this section, ten factors that underlie five drivers are analysed. The purpose of this analysis is to link the important drivers and their underlying factors to the framework.

5.3.1 The factors

The data available from the survey is limited and allows only for the study of ten factors that support five drivers. Studying the effect of all drivers was not the main focus of the survey design. Instead, it focused on factors that relate directly to the framework proposed in this research. Drivers such as regulations and public pressure are beyond the scope of this study.

The drivers and their supporting factors that were analysed are shown in Table 19. Lean and Six Sigma can be considered as underlying factors that support more than one driver such as competitiveness and cost savings. Similarly the factor company size plays an important role in many drivers. The success of SM depends on this drivers, which in turn depend on the factors that determine their strength. As mentioned in the third chapter, the review of the literature on SM did not produce a single study analysing these factors.

Table 19: Factors under study and the drivers they support.

Driver	The ten underling factors
Customer demand	1. Market competition 2. Market concentration 3. Importance of environment.-friendly products 4. Bargaining power of customers 5. Company size
Organizational resources	6. Spending on envi. programs * . Company size
Cost savings	7. Lean Manufacturing 8. Six Sigma
Competitiveness	*. Lean Manufacturing *. Six Sigma
Supply chain pressure	9. Level of supply chain integration 10. Bargaining power of suppliers *. Company size

* Some factors support more than one driver

5.3.2 Ranking the factors

In statistical process control, variation signals an opportunity for improvements (Oakland, 2008). The priority given to actions to achieve these improvements starts with problems that cause large variations and then moves on to problems that cause smaller variations. If the same principle is applied to the variation within a sample population, opportunities for improvement will arise by reducing the causes of that variation. For example, if companies differ significantly in their level of implementation of Six Sigma. This management technique should be investigated to find out why it is not a standard practice. This will reveal possible opportunities to expand the application of Six Sigma. This shows that variation is a window onto opportunity. Finding the cause of differences between companies in the same manufacturing industry in areas such as operations management and environmental management, could reveal opportunities for improvement.

The aim of this section, however, is not to explore opportunities, but rather to put a set of opportunities (variables) to the test to find out how much they vary in order to ultimately produce a list of priorities where it is more important to investigate large

variations. In this case, the ten factors identified in the previous section will be tested so as to rank them as factors in terms of the opportunities they represent.

5.3.3 Analysis and Findings

To prioritise the factors categorised as supporters of SM drivers, principal component analysis (PCA) was used. PCA is a technique for identifying groups or clusters of variables (Field, 2009). In a large set of data, PCA is typically used for data reduction by means of finding groups of variables that explain most of the variation in a sample. The test splits the variables into a number of components (groups of variables) based on the interrelationships between these variables.

PCA also determines the importance of each component/group based on the percentage of variance it explains. The loading of variables on each of the components will determine the ranking of the factors under investigation. A simple example would be a study of first year pupils at local schools. Much information can be gathered, including height, age, family size, distance to home, and much more. A long list of the different characteristics of each pupil can be created. However, many of the characteristics may measure similar features, and so will be redundant. Therefore, PCA finds the characteristics which can be used to summarise the list of variables, puts them in groups (components) and shows each group's share in the total variation.

However, the goal of using PCA here is not to summarize a large number of variables. The test will rather be used to rank the factors under study based on the total variance they represent. A typical application of PCA requires a large sample size to improve the accuracy of the results. However, the technique is applied in this study only to illustrate a logical approach to identifying variation and to providing a ranking order of a set of variables; the accuracy of the outcome is not a major concern at this stage. The steps that were followed to rank the factors are illustrated in Figure 20. The analysis was performed using the statistical software SPSS. The Kaiser-Meyer-Olkin (KMO) test shows if the data allows for identifying patterns of correlations between variables. KMO=0 indicates diffusion in the pattern of correlations, hence PCA is not suitable, whereas a value of KMO close to 1 indicates that the correlations are clustered in a way that allows for components to be identified (Field, 2009).

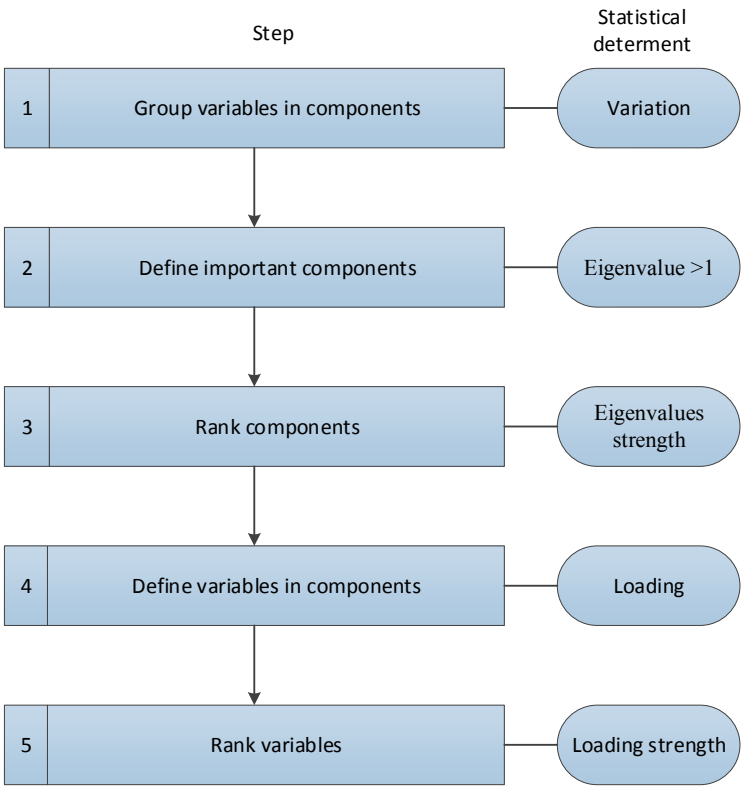

Figure 20: Steps undertaken to rank the factors

The results of the KMO test confirmed that the available sample is adequate for conducting PCA, as it exceeded the cut-off value of 0.5 (KMO=0.601) with a significance of less than 0.05 (Sig.=0.003). PCA revealed the presence of four components with eigenvalues exceeding 1. These groups are arranged according to the percentage of variance they explain, as shown in Table 21. This means that in our sample, the variables under study have been grouped in components, four of which are significant with eigenvalues of more than 1. These four components represent %79.8 of the total variation in the sample. Table 22 shows the strong loadings of each of the variables on the different components.

Based on the information in Table 20, a ranking order of the components is obtained. The following step is to determine which variables each component is made of. To improve the interpretation of the results, rotation is used. Rotation maximizes the loading of each variable on one of the principal components while minimizing the loading on all other components, which makes it easier to observe the variables that relate to each component (Field, 2009). Varimax with Kaiser Normalization is the default rotation method in SPSS. According to their component's contribution and

their loading on these components, the variables are presented in Table 22 where each component is assessed in terms of correlation with the variables it contains. Therefore, the factors in Table 21 are ranked according to their importance.

Table 20: Total variance explained.

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	3.488	34.876	34.876
2	1.885	18.855	53.731
3	1.593	15.931	69.662
4	1.014	10.135	79.797
5	.588	5.879	85.677
6	.447	4.470	90.147
7	.392	3.920	94.066
8	.319	3.189	97.255
9	.159	1.592	98.848
10	.115	1.152	100.000
Extraction Method: Principal Component Analysis.			

Table 21: Factor ranking from the Rotated Component Matrix.

Factors	Component			
	1	2	3	4
Level of implementation of Six Sigma	**.875**	.222	.200	.163
Level of supply chain integration	**.847**	-.112	.203	.101
Level of implementation of lean manufacturing	**.792**	.213	-.179	.076
Market competition level	-.084	**.919**	.217	.005
Importance of environmentally-friendly products to win orders	.192	**.864**	-.193	-.026
Size of business	.434	**.632**	.413	-.004
Market concentration	.134	.119	**.910**	.058
Spending on environmental improvements	.279	.034	-.236	**.816**
Bargaining power of customers	-.343	-.129	.431	**.648**
Bargaining power of suppliers	.368	.029	.411	**.646**
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.[a]				
Rotation converged in 8 iterations. Strong loading is presented in bold font				

Opportunities for improvement lie where there is a significant difference between companies in the sample. In Table 20, the significant differences are represented by four components, which counted for 79.79% of the total variance. In studies that rank SM drivers, participants are asked to rank the drivers as a single variable, which results in an incomplete understanding of SM. It is observed from the results of this study that fragmenting the SM drivers into their underling factors provides a better picture of the factors' significance, whereas in typical SM studies the importance of underling factors is overlooked.

The results show that the first component consists largely of items that relate to process management and managing the supply chain. This suggests that companies vary significantly in their performance in these areas. In the context of SM, the application of Six Sigma is ranked first, meaning that there is no consistency in the use of Six Sigma amongst companies. Given that variation signals an opportunity, a priority should be given to investigating the reasons why Six Sigma is not a standard application in the quest for SM. Sequentially, the investigation moves to the other factors to find more opportunities.

The analysis presented provides the level of detail needed for guiding research projects to give focus and direction to efforts to improve SM. It can also be used by government departments that work on promoting SM within a region or an industry to identify improvement opportunities. According to the current findings, for example, governments should facilitate access to training in Six Sigma and Lean as a first step in promoting sustainability. Large companies with many factories can also benefit from knowing the source of variations in performance between their factories and could work on reducing these variations by means of benchmarking. In the case of a single company, prioritizing the factors provides more detail for analytic tools such as SWOT rather than merely prioritizing the drivers.

5.3.4 Using the findings to develop the framework and wider application

There is evidence to show that the interest in sustainability is still not a top priority amongst manufacturers. As mentioned in the literature review, the findings of large

surveys show that prime focus of manufacturers is on operational competitiveness in terms of quality, speed, cost and flexibility (IMSS, 2011). The findings of the current study confirm the importance of operational effectiveness because the top ranked factors were found to be Six Sigma, supply chain integration, and Lean. Therefore, operational effectiveness should be central to any improvement programmes, whether this is related to environmental, social, or any other improvements. The findings described in this section sections support the idea that, for manufacturers to be involved in sustainability, operational techniques must be enhanced and built upon. This supports the fourth hypothesis in the present study that LSS is a fundamental requirement for SM. To this end, the framework emphasises starting with LSS to ensure that manufacturers commit to sustainability.

The influence of markets on the formulation of strategy was discussed in the literature review, which outlines how the market for sustainability is growing and affecting manufacturing. The findings of the preceding analysis support previous research in that the market is a main driver for sustainability because market-related factors gained high rankings.

The findings, along with the literature review, suggest that including market requirements in the framework is an essential addition that has the benefit of making the environmental strategy relevant to the business environment. This will also make the framework more appealing to strategy developers who realise that the market is the main determinant of manufacturing strategy (Hill and Hill, 2009, Hill, 1997, Skinner, 1980, Skinner, 1969)

As the analysis above was conducted at a level of detail deeper than the common identification of sustainability drivers, the information obtained by analysing the factors underlying those drivers can be very useful in the creation of advanced predictive/optimising algorithms that must include many variables. Algorithms are widely used in marketing to predict customer behaviour and to fine-tune the company's strategy accordingly (Reeves, 2015). Similarly, an algorithm that uses the factors mentioned in the preceding analysis can be more accurate than just using a handful of abstract drivers as its input variables.

5.4 Assessment of SMEs

This section aims to find out if SMEs satisfy the requirements of and have the capabilities to adopt the proposed integration of LSS and LCA for improving their environmental performance. In general, large companies are leading innovation in operations and environmental management and are assumed to have the ability to implement the framework. Most of the significant developments in manufacturing originated in large companies and then spread to SMEs and other sectors. Mass production, Lean, and Six Sigma are some of numerous examples of management techniques that were invented in large companies. This is mainly due to the capabilities and resources that large companies can afford. In addition, experience from trial and error that large companies acquire over time is not available for SMEs who have relatively short lifetimes. However, due to the importance of SMEs in the world economy and for the environment, the proposed framework needs to be assessed, and modified if necessary, to be applicable to SMEs. SMEs are different from large companies in many characteristics, and what works in large companies might not work, or may need to be modified, for SMEs. Kumar et al. (2011) criticised the implicit assumption that "organisational theories, models and conceptual frameworks developed in large organisations were relevant and directly applicable to SMEs". Their research found that what is required is a "tailor-made" implementation framework for SMEs. Therefore, assessing the proposed framework in terms of its suitability for SMEs was deemed necessary.

5.4.1 Findings

To support the claims of the previous discussion that the framework is suitable for all company sizes, and SMEs in particular, empirical evidence is required to support qualitatively induced claims. Therefore, an evaluation of the sample of companies in this study is conducted in three main areas. First, the level of compliance with the requirements of sustainability (discussed in section 4.3) is checked in large companies and SMEs. The second test was run to check if operational and environmental performance is affected by company size. The third test looks into the readiness to use the framework.

(1) Satisfying sustainability requirements

The six companies that scored more than 22 points in the assessment of sustainability, as found in section 5.3, are two small, two medium-sized and two large companies. This was the first indicator that company size has no effect on satisfying the requirements of true sustainability. Both small and medium-size companies meet the requirements of sustainability and, thus show that the requirements are attainable by SMEs.

(2) Operational and environmental performance

This test is run as more results were needed to compare SMEs and large companies. Scores were computed for each company in the sample to measure the operational and environmental performance. Table 22 shows the average scores obtained by large, medium and small companies. On average, the scores obtained by SMEs are very close in operations to the scores of large companies, and scores are similar in environmental performance, which indicates that there is no difference between large companies and SMEs.

Table 22: Scores obtained by companies of different sizes in operational and environmental performance.

Construct	Company Size	Mean	σ	Min	Max
Operations	Small	18.86	5.113	13	28
	Medium	19.22	4.494	12	28
	Large	20.86	5.273	14	29
	Total	19.61	4.774	12	29
Environment	Small	15.33	2.066	12	18
	Medium	15.00	3.018	12	22
	Large	15.00	4.147	10	20
	Total	15.09	3.006	10	22

(3) Readiness of SMEs to use the framework

The framework requires the use of Lean, Six Sigma, and LCA. A company is considered to have complete readiness for the framework that is being designed if this

company already applies these techniques. This criteria will be used to compare the three sizes of companies.

A one-way analysis of variance (ANOVA) test was conducted to examine whether or not there are statistically significant differences between companies of different sizes in relation to the individual items for Lean, Six Sigma and LCA. A one-way ANOVA test looks at the variability amongst group means and compares it to the variability within each variable. The descriptive statistics in Table 23 show in the mean column that large companies have on average higher levels of implementation of Lean and Six Sigma which is expected and conforms to other findings in the literature.

Table 23: Descriptive statistics of the level of application of Lean, Six Sigma, and LCA.

Co Size		N	Mean	Std. Dev	Std. Error	95% Confidence Interval for Mean		Min	Max
						Lower Bound	Upper Bound		
Level of implementation of lean manufacturing	Small	7	2.71	1.496	.565	1.33	4.10	1	5
	Med	10	3.00	1.491	.471	1.93	4.07	1	5
	Large	6	3.83	1.472	.601	2.29	5.38	1	5
	Total	23	3.13	1.486	.310	2.49	3.77	1	5
Level of implementation of Six Sigma	Small	7	1.57	.787	.297	.84	2.30	1	3
	Med	10	2.40	1.506	.476	1.32	3.48	1	5
	Large	7	3.14	1.464	.553	1.79	4.50	1	5
	Total	24	2.38	1.408	.287	1.78	2.97	1	5
Company has conducted life cycle assessment	Small	5	.60	.548	.245	-.08	1.28	0	1
	Med	10	.40	.516	.163	.03	.77	0	1
	Large	5	.60	.548	.245	-.08	1.28	0	1
	Total	20	.50	.513	.115	.26	.74	0	1

To determine if these differences are statistically significant, the ANOVA results in Table 24 are examined. The significance values (in the Sig. column) need to be less

than 0.05 for a conclusion to be drawn that there is a significant difference between the groups. From Table 24, this condition is not met and therefore it can be concluded that there are no statistically significant differences between small, medium-sized, and large companies in their level of implementation of Lean, Six Sigma and LCA as determined by a one-way ANOVA test that yielded the following results:

- The level of implementation of Lean ($F(2,20) = 0.982$, $p = .392$)
- The level of implementation of Six Sigma ($F(2,21) = 2.458$, $p = .110$)
- The use of LCA ($F(2,17) = 0.354$, $p = .707$)

Table 24: ANOVA test results.

		Sum of Squares	df	Mean Square	F	Sig.
The level of implementation of lean manufacturing	Between Groups	4.347	2	2.173	.982	.392
	Within Groups	44.262	20	2.213		
	Total	48.609	22			
The level of implementation of Six Sigma	Between Groups	8.654	2	4.327	2.458	.110
	Within Groups	36.971	21	1.761		
	Total	45.625	23			
Company conducted Life Cycle Assessment	Between Groups	.200	2	.100	.354	.707
	Within Groups	4.800	17	.282		
	Total	5.000	19			

To explain further these results, in assessing the variable 'Lean', the mean score for each company size was calculated and found to be different for the three company sizes (2.71, 3.00 and 3.83). The degrees of freedom (df) (one less than the total sample size (N – 1)) and the mean square of each group were then used to calculate the F-ratio, which is a measure of the ratio of systematic variation to unsystematic variation (Field, 2009). It was found that the F-ratio ($F=0.982$) with 2 and 20 degrees of freedom (2,20) is not significant as Sig.>.05. In other words, it may be first thought that different company sizes differ in their use of 'Lean' because they have different mean

scores (2.71, 3.00 and 3.83), but then the test reveals that the variation within each group is such that the differences are not strong enough to be considered significant.

5.4.2 Summary of the assessment of the framework's suitability for SMEs

Section 5.4 attempts to evaluate the framework in terms of its suitability for all different company sizes. A review of the importance of SMEs was outlined to justify the need for this assessment. At first, a qualitative evaluation of some characteristics of SMEs (leadership, strategy, and management style) was conducted and related to the design of the framework. Quantitative evaluation was also performed by running three tests that looked into the following:

- **Satisfying sustainability requirements**: The test found no difference according to company size with regard to meeting the sustainability requirements that the framework addresses.
- **Operational and environmental performance**: The test found that the environmental performance of SMEs is similar to that of large companies. This means that SMEs are ready for sustainability just as much as large companies.
- **Readiness to implement the framework**: The test found that SMEs, just like large companies, have the required Lean, Six Sigma, and LCA techniques needed to implement the framework.

These findings demonstrate that company size is not an obstacle to designing the proposed framework, as SMEs, just like large companies, can achieve the sustainability requirements and implement the required techniques.

5.5 Interview Data Analysis

An understanding of how the proposed framework can be improved has so far been developed through the analysis of quantitative data. This section presents the analysis of the qualitative data that was collected using semi-structured interviews and the comments from the questionnaires as described in Chapter 4.

By the end of data collection, a preliminary analysis was already building up from the previous steps of conducting the interviews. As stated by Saunders et al. (2009), the interactive nature of data collection, note-taking and analysis, allows important

themes, patterns and relationships to be recognised as data is being collected. A more thorough examination and reflection, however, is then conducted than in the preliminary examination of data carried out during data collection. The audio recordings and notes were reviewed several times due to the richness of information obtained. The data collected was closely studied to identify the main themes communicated in the interviews. Themes are frequent expressions, behaviour, or observations that the researcher finds in the data. Themes can also be described as "codes", "categories", "labels", or "incidents" (Ryan and Bernard, 2003). Themes in this study were identified using two approaches as shown in Figure 21 and discussed in the following sections.

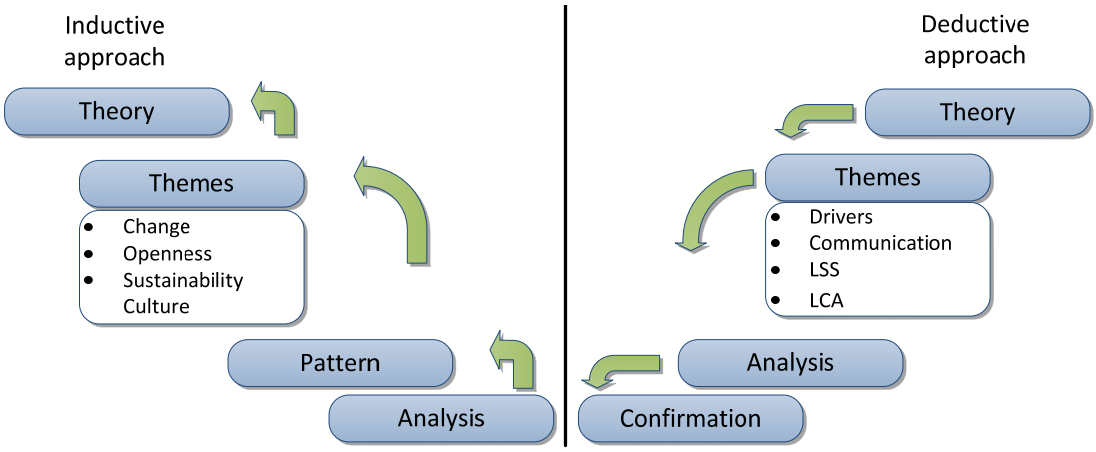

Figure 21: Themes identified using inductive and deductive approaches

5.5.1 Themes identified using the deductive approach

In this approach, the researcher identified the expected themes based on the literature review and the findings from the two questionnaires. These themes were intended to be investigated and were considered in the design of the interview questions. The themes identified using this approach are:

5.5.1.1 Drivers

The driver that seemed most dominant is cost savings. Two main phrases were repeatedly referred to by participants: energy saving and waste reduction. On almost all occasions when participants were asked about environmental activities, they described environmental activities and eventually linked these to cost savings. For example, when asked about environmental activities, two participants answered as follows:

"*there is also steam recapture, so if you have a look if you go along this industrial estate for example, you've got a lot of chimneys kicking off a lot of steam, just wasted steam, so we've got a new system now to recycle this steam back into the factory to power process*"

"*once a customer goes along, it does some sort of energy management or something that is environmentally friendly, they realise that it's something good for their business, once they're on board with it, once they've done one project. At the minute a lot of companies are changing to LEDs, the lights of the building, you won't believe how much money is spent on just lighting in factories because they've got to be lit 24 hours a day because people've got to see*"

The researcher mentioned to one participant that some of their activities were more about cost saving than protecting the environment. The participant responded by saying that: "*cost and environmental impacts are very related, aren't they?, I think there will always be cost analysis to any programme*"

Government regulations were repeatedly mentioned by participants who were not engaged in sustainability. Two large companies and one SME who were already engaged in sustainability viewed regulations as standards that they havd gone beyond. Whereas the other four SMEs were still in the compliance phase and were largely driven by government regulations. In general, government regulations did not represent a challenge to the participants, which suggests that the government's enforcement of environmental sustainability is a gradual process so that industries are not negatively affected.

Another important driver that was mentioned by participants is customer/market demand. One of the participants, a manufacturer and supplier to a large number of manufacturers in the engineering industry, estimated that 20% of manufacturers are currently active in environmental sustainability, while another 20% have the capabilities to engage but are not fully committed. The rest, he argued, are oblivious of sustainability. Another participant stated that the efforts of his company to go beyond the regulations are all customer-driven. Other participants reported that customer demand is a driver that comes after cost savings or government regulations.

In terms of barriers to sustainability, budget seemed to be the biggest obstacle for all participants. They stated that company departments often place environmental activities and improvements further down the list of priorities when they plan their annual budgets. Because budgets are tight in the first place, due to "*small engineering companies having a tough time*" according to a participant, environmental improvements are not accomplished and the budget is blamed. One participant suggested a solution for this problem arguing that instead of allocating, for example, a £1,000,000 budget for each department, 2-5% should be withheld and used by a dedicated team or department for environmental improvements. An illustration of the participant's drawing when he was explaining his point is shown in Figure 22.

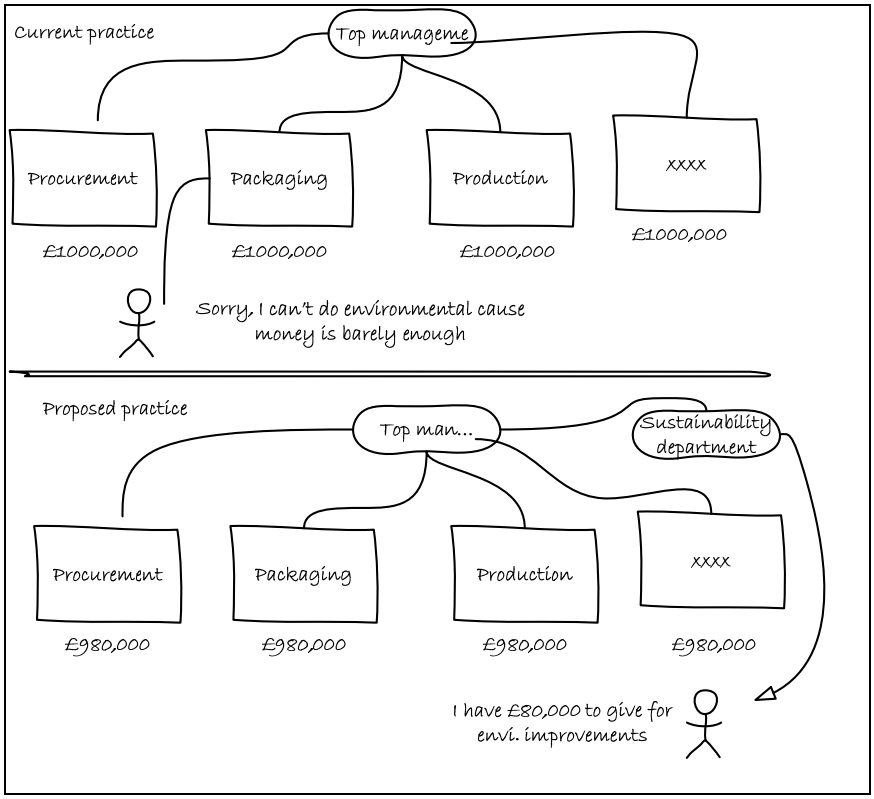

Figure 22: Sketch by a participant showing an approach to solving the budget problem.

5.5.1.2 Communication

The literature review suggested that vertical communication between different levels of management and horizontal communication between departments should be established and should include sustainability information. In the survey of industry, the results suggested that internal communication might be weak in manufacturing. However, in the interviews, participants reported various measures used to improve communication between different areas within the company; for instance, by informal

communication, regular meetings and cross-referencing of emails to keep all departments informed of any changes or improvements. However, a participant admitted that electronic communication is not as effective as verbal discussions. Communication with the wider workforce about environmental activities is achieved by workplace posters, training and, most importantly according to participants, by promotional activities such as cycle-to-work, recycling, and green days.

SMEs reported communication as a strength due to the small number of people and the relatively simple management structure. However, environmental sustainability appeared not to be well communicated if top management was not driving it. The use of cross-functional teams as an approach to solving problems and improving communication between departments was reported by companies that used Six Sigma. Companies that did not use Six Sigma reported that there is "*no need for that* [team formation]" or "*we work as a big team anyway*"

5.5.1.3 Integration of Lean and Six Sigma

Questions were asked to investigate the integration of Lean and Six Sigma, in order to test the conflicting views obtained from the literature review and the survey of academia where some authors and participants viewed Lean and Six Sigma as complementary or independent. In the interviews there were no reports of conflict between the two techniques and there were two approaches used to apply them in practice:

1. Tools from both techniques are selected as appropriate to the needs of the business without the need for emphasising one technique over another. This approach is found to be suitable for companies who require a "bespoke" system. One participant commented that: "*Lean was developed in Toyota, and Six Sigma in Siemens, but we're not Toyota nor Siemens, so we cherry-pick what works for us and develop our own system*". This approach was also reported in one of the questionnaire responses where the participant stated that "*Using Hoshin Kanri to define the true north of the business, we find that all the other tools such as six sigma and lean mould in to allow all of them to be used as one*."

2. Simple Lean tools are used first to start a momentum and then extend gradually to include advanced tools from Six Sigma. This approach has been reported to have twofold benefits. Firstly, it is appropriate in getting people to buy-in to change and, secondly, the gradual change facilitates learning and continuous improvement. The two participating companies who followed this approach have two features in common; they both have a small product range, and both are largely focused on manufacturing compared to other participants who provide services and distribution in addition to manufacturing.

5.5.1.4 LCA

Discussion about life cycle assessment was poor even in companies where the technique was adopted. In one case, a respondent from a large company, who holds the position of continuous improvement (CI) manager and was knowledgeable about all aspects of the business, provided little information about an LCA study taking place in his company in terms of its goal and scope. Another SME respondent was aware of the technique and said that his company had conducted a LCA study. However he too could not provide useful information. This lack of knowledge about LCA is an indicator of the low popularity of the technique and the lack of communication between production departments and the LCA team. Most participants argued that LCA is "*maybe not important for us now*" and "*it needs someone to do it*". The CI manager pointed out that the LCA in his company had started a year ago and was not finished.

5.5.2 Themes identified using the inductive approach

In this approach, the data was explored to find themes other than those predetermined by the researcher. Using this approach is important to eliminate any bias that may result from the researcher's focus on predetermined aspects of the data. The following are the themes that were found in the data:

5.5.2.1 Change towards sustainability

Clear evidence appeared to indicate that change from traditional manufacturing to SM has been taking place in the last 3-4 years in particular. There was a clear pattern of participants mentioning that there has been a "*fast growing*" demand and that "*people* [customers] *are buying into the idea* [sustainability] *more than before*". In one of the interviews, the participant invited to the meeting an apprentice who had spent the last

three years moving between different departments and the shop floor to gain comprehensive knowledge of the business. An informal conversation with this apprentice revealed that sustainability has been an important part of his learning journey. Other participants who were not yet engaged in sustainability did observe it in their supply chain and their industry; one stated that he regularly read case studies on EPA because sustainability is "*becoming more important*".

5.5.2.2 Openness

One common theme arose in all interviews; that regardless of the topic discussed, the researcher observed openness and truthfulness by the interviewees. None of the interviewees exaggerated the environmental efforts of their companies. On the contrary, interviewees openly discussed and admitted their shortcomings and failings in tackling environmental issues. The literature review and the questionnaire findings indicated that companies usually exaggerate their environmental performance for publicity purposes. However, this was not the case in the interviews probably because the conversations were confidential. One of the interviewed companies whose environmental efforts were significant, did not in fact mention most of its activities on its website, which indicates that they are not PR-driven. This finding contradicts the findings of the questionnaire where it was noted that participants overstated their environmental efforts. The nature of the interaction in the interview setting seems to allow for more honest and open conversation. Therefore, the researcher found the interviews to be more important in terms of data reliability than published company reports and questionnaires where the topic of environmental sustainability is concerned.

5.5.2.3 Sustainability culture

The interview design included some final questions about the environmental activities that participants did on a personal level. For instance "Do you personally do any environmentally friendly activities?" The aim of the questions was to contrast the seriousness of the interview with more friendly questions that allowed for informal conversation afterwards and, in addition, to gain more insight into individual perspectives.

In light of the personal questions, a new theme emerged in observing a pattern of words such as "right" and "wrong", indicating the presence of principles due to some

aspects of culture. In general, respondents seemed to be willing to perform environmental activities on a personal level, and some were very passionate about them, if their company was engaged in sustainability. One respondent put it as follow: "*I have a 14 year-old-son and I would like him to find the world as good as I found* it", which shows a commitment to protecting the environment in both personal and professional life. To put it in another way, there appeared to be a strong connection between the person's interest in the environment and the company's environmental activities, because those who worked in environmentally active companies seemed to care more about the environment even on a personal level.

The mutual influence between the company and its personnel depends on the level of the individual concerned. This point was elaborated on by one of the respondents who promoted sustainability in his supply chain as a parts supplier (large company). He referred to his observations to explain that:

"*it* [interest in sustainability] *depends on the job role and the level of the person you're speaking to, so if you're speaking to an engineer, not interested. They're generally interested in making sure the machine's running longer, less downtime, less maintenance. If you're speaking to procurement, again, not interested, procurement teams and directors are only interested in the cost of a product…. , but as you go higher, that's site directors, finance directors, the're really keen on it* [sustainability]…. , *if you look at finance directors, strangely enough, they are one of the main drivers for environmental projects….*"

The strong influence of top management was repeatedly mentioned in the interviews as a main creator of a culture of sustainability in the company. Figure 23 gives an illustration of the mutual influence between the culture of the company and different levels of people as derived from the interviews.

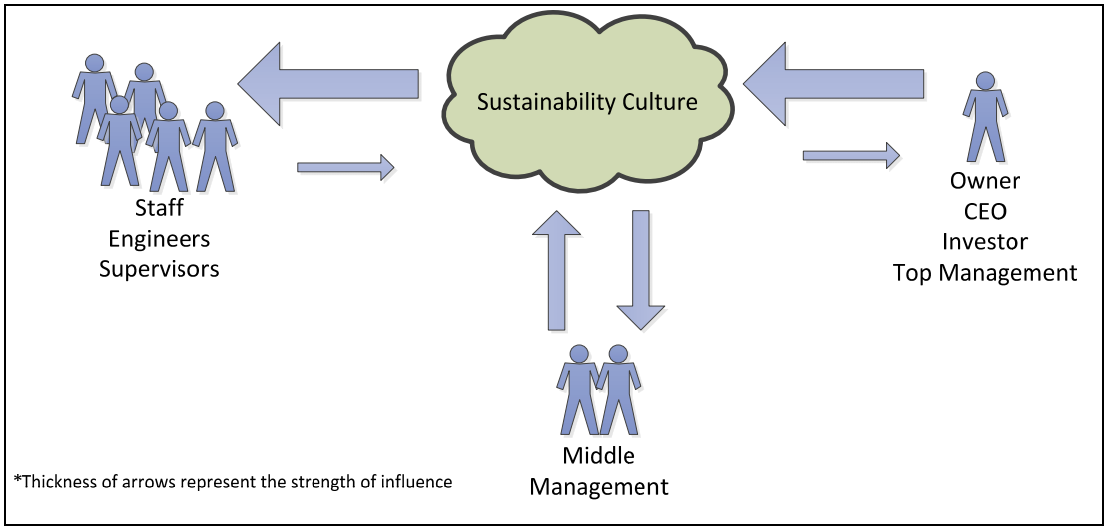

Figure 23: Mutual influence between sustainability culture and people in different positions

5.5.3 Summary of findings from the interviews

The previous section described the data collection and analysis from seven semi-structured interviews. Several findings emerged throughout the analysis process and are summarised in this section.

The themes identified using the deductive approach were previously examined in the literature review and survey questionnaires. Triangulation with these methods confirmed previous findings as follows:

- Cost savings, competitiveness, and market demand are the main drivers for sustainability in companies that have moved beyond regulatory compliance.
- The integration of Lean and Six Sigma is not carried out using a standard approach. The two techniques are integrated according to the company's own requirements and capabilities.
- LCA is still not popular in industry and amongst operations managers and, when it is conducted, operations managers are not well informed about the process and results. This supports the third hypothesis of this research that states that there is lack of communication between LSS and LCA, and they are not strategically linked.

Findings that emerged using the inductive approach provided a wider perspective concerning SM. The main finding was that the influence of people at different levels

of an organisation is necessary to create a culture that supports SM. Creating this culture is important to the success of sustainability programmes.

Another finding from the inductive approach was the openness observed by the interviewees. Although this does not relate directly to the process of improving the framework, it remains an important finding in terms of improving research methodology, because it indicates that interviews are more suitable than surveys in exploring sensitive business aspects that can affect the public profile of an organisation, such as the case with environmental sustainability.

5.6 Summary

This chapter has presented the analysis that was performed on the data collected by the surveys and the interviews. Quantitative data analysis started with descriptive statistics for both questionnaires and then expanded to include inferential statistics. An evaluation of the survey of industry was conducted and it was found that the questionnaire design achieved acceptable levels of engagement, reliability and validity.

To justify the need for conducting this research, an assessment of the current state of SM was performed. The results indicated that sustainability as recommended by prior research is achieved by only 16.6% of the sample of companies. This study's proposal (the framework) will be designed to provide an action plan to cover those recommendations.

Analysis was also performed to assess the strength of the drivers of SM by evaluating the factors that underlie them rather than evaluating the drivers themselves directly. This approach has many benefits and potential applications. In this study, the assessment results will be used to improve the framework.

The chapter also presented the qualitative analysis on the data from the interviews. The findings of this analysis validated previous findings through triangulation with the results of the literature review, the survey of academia, and the survey of industry. The qualitative analysis provided a greater understanding of the phenomenon and added a dimension of human experience to the data collected using other methods.

CHAPTER 6. DISCUSSION ON THE PROPOSED FRAMEWORK, VALIDITY AND THOUGHT EXPERIMENTS

This study began with a proposal for integrating LSS and LCA to achieve SM. An initial proposal for a framework to achieve this goal was presented in Chapter 2 in Figure 5. The aim of the study was to develop this framework based on the existing body of knowledge, and by collecting and analysing primary data. This chapter describes how the initial framework was developed based on the findings from the literature review and the data analysis.

6.1 The proposed Framework for Integrating LSS and LCA

The framework has been developed from an unspecific proposal into a framework that captures the relevant concepts and theory from the literature and builds on the results accumulated from the questionnaires and interviews. The result is a framework that enables manufacturers to be sustainable by achieving a strategic fit across the activities of LSS and LCA. The elements that were discussed in the previous section are put together to form the framework, as seen in Figure 24.

Although the framework is expected to bring tangible and intangible benefits when implemented, the main concern of manufacturers has always been the costs associated with new programmes. For example, the analysis has shown that companies pursue improvement programmes that do not require large capital investment (section 5.1.2.2). Therefore, particular attention was given to the cost of implementation by using LSS, which is a popular technique and is very likely to already exist in the company. In addition, a streamlined LCA was chosen as an alternative to full LCA to reduce time and cost. The following sections discuss how the framework can be implemented, and what factors will facilitate its success.

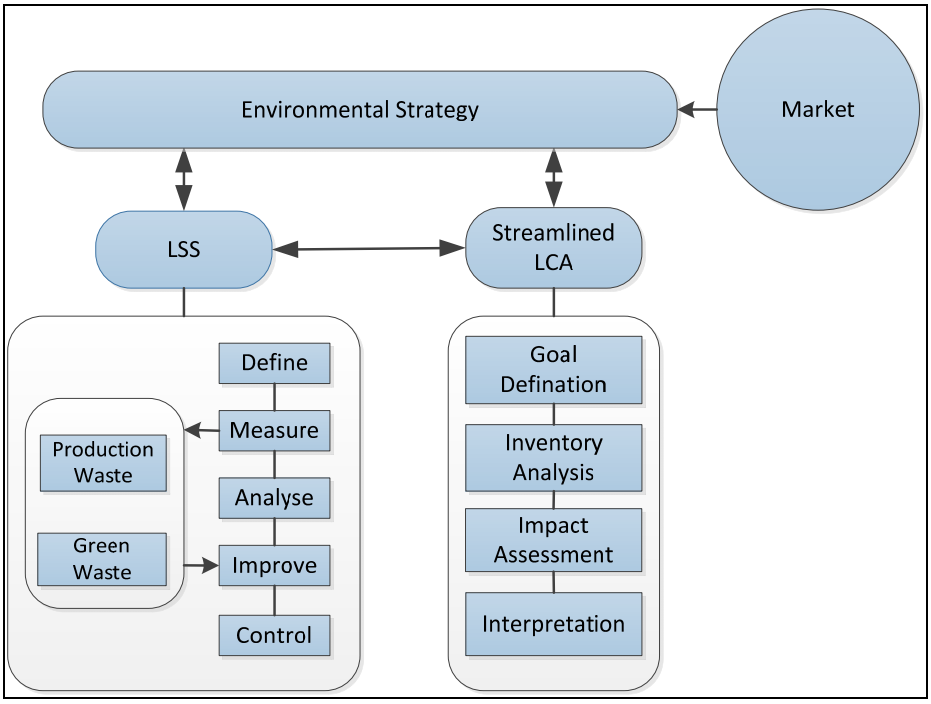

Figure 24: The proposed framework to integrate LSS and LCA in an environmental strategy to deliver market requirements

The framework was designed based on the findings on Lean Six Sigma, Life Cycle Assessment, and the importance of strategy and the market. The following three sections describe how each of these three framework components was formed.

6.2 Lean Six Sigma

The literature review showed that combining Lean and Six Sigma as LSS is a technique for which there is no standard framework in the academic literature, and it is implemented in industry using nonstandard approaches depending on company-specific requirements. However, the Six Sigma problem-solving approach DMAIC, which includes Lean tools, has frequently been used in frameworks to implement LSS (Furterer and Elshennawy, 2005, Kumar et al., 2006, Thomas et al., 2008). On the other hand, the literature on Lean has shown that it has evolved to include green waste to address the impact on the environment.

The results of the survey of academia (in section 5.1.1) confirmed the views expressed in the literature that no standard approach to combining Lean and Six Sigma is required. This has been emphasised in particular by senior researchers in the survey. The results of the survey of industry emphasised the importance of both Lean and Six

Sigma to SM (sections 5.2 and 5.3), and it was empirically confirmed that LSS is attainable by both SMEs and large companies (section 5.4.4). In addition, the two approaches to LSS identified from the analysis of interview data require no standard framework and this supports the findings of the other research methods used (section 5.5.1.3). Based on these findings about LSS, the initial framework is improved by presenting it as shown in Figure 25.

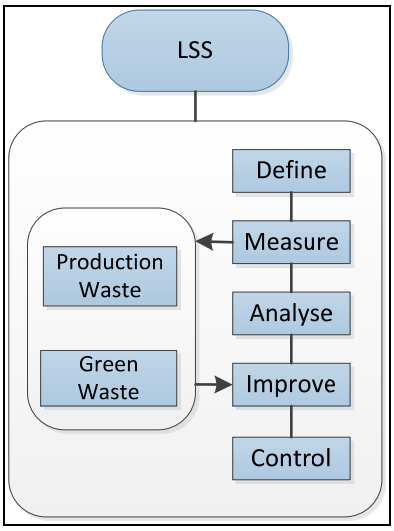

Figure 25: LSS Framework

6.3 Life Cycle Assessment

Data from the questionnaires and the interviews about LCA was not detailed due to the technique's low popularity. The main reason for LCA's low acceptance amongst manufacturers is its complexity, an issue that has been reported in the literature (Weitz et al., 1999, Rebitzer et al., 2004, Yilmaz et al., 2015), and supported by the findings of this research (section 5.5.1.4). Details of LCA are lacking even in companies where the technique is applied. This is due to the fact that most participants in this study were production and quality managers who were not involved in conducting LCA, and information sharing between production departments and those conducting LCA is weak (sections 5.2.4 and 5.5.1.4). However, a wealth of information about LCA was obtained from the literature, as prior research has extensively reviewed and improved the technique. Furthermore, LCA has an ISO standard framework that is viewed by researchers and practitioners as the only accepted approach to conducting LCA studies.

The literature was also the source of ideas for the present research to explore ways of simplifying LCA so that it can be adopted by a larger number of manufacturers, which will ensure that the proposed framework can also be adopted. In this regard, streamlined LCA was found to be a suitable method for the design of the framework, as it supports rapid decision making and reduces the complexity of a full LCA. These are important features for a successful implementation of the proposed framework. Figure 26 shows the standard LCA framework that can be incorporated in the framework.

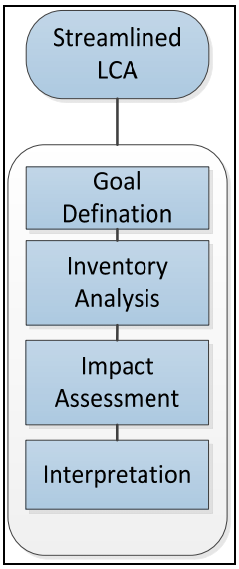

Figure 26: LCA framework

6.4 Environmental Strategy and the Market

Evidence from all data sources suggests that integrating LSS and LCA requires a strategy that coordinates the integration and ensures that the outcome is in line with a company's objectives. Lessons learned from the literature on manufacturing strategies show that integration is beneficial because linking LSS and LCA reveals opportunities for improvement that cannot be realised if the two methods are implemented in isolation (Hill, 1997, Dangayach and Deshmukh, 2001). Previous research has also shown that companies engaged in sustainability initiatives often fail to integrate corporate sustainability into their management systems (Nunhes et al., 2016). Moreover, setting a strategic direction to align the company's sustainability and business strategies has been viewed as a crucial requirement for sustainability (Kashmanian et al., 2011, Nunhes et al., 2016).

The results from the questionnaires and interviews indicate that a well-defined strategy to improve environmental performance might be missing. It was found that companies make efforts and allocate resources to environmental improvements, but their efforts appear to be not well-coordinated because their outcomes are not optimal. For example, the results showed that while production indicators such as productivity have shown improvements on average, the environmental indicators of energy consumption, material waste, and pollution emissions have remained unchanged or increased (section 5.2.3.4). Companies also fail to succeed in sustainability because of the lack of effective communication between those implementing LSS and LCA, which can be achieved by setting an environmental strategy (section 5.2.4).

On the other hand, the importance of making market requirements as the main drive for the strategy has been discussed in the literature (Hill, 1997, Dasilveira, 2005). It was stated that a successful strategy should be a strategy that delivers market requirements rather than a strategy that focuses on operational improvements. The literature review also showed that the market for sustainability is growing and having an impact on manufacturing (Welford and Gouldson, 1993, Department for Business Innovation and Skills, 2012, infoDev, 2014). The empirical results confirm the importance of the market as one of the main drivers for sustainability, as market-related factors scored high in the ranking of factors (section 5.3.2). Additionally, interview participants regarded market requirements as an important reason for engaging in sustainability (section 5.5.1.1). These results, along with the literature review, suggest that including market requirements in the framework is important to make the environmental strategy market-driven. Figure 27 gives an illustration of environmental strategy and market forces as will be added to the framework.

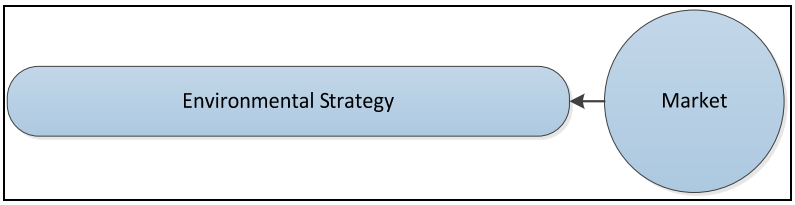

Figure 27: Environmental strategy based on the requirements of the market

6.5 Framework Implementation

The framework was designed for the purpose of linking LSS and LCA, as there is no existing research in this direction. Furthermore, empirical evidence has shown that linking the two techniques in practice is not common. This research focused on those responsible for executing LSS (the quality or production department) and found that, even in companies where LSS and LCA are implemented, LSS practitioners often do not participate in LCA studies, and the results of these studies are not directly communicated to them. The role of the framework is to provide an approach which would solve this problem. This section presents a proposed implementation process for the framework as shown in Figure 28. However, there are other possible ways to implement the framework, as the process may vary according to the company's resources and whether it already has LSS, LCA, or both. The steps of the suggested implementation in Figure 28 are outlined next.

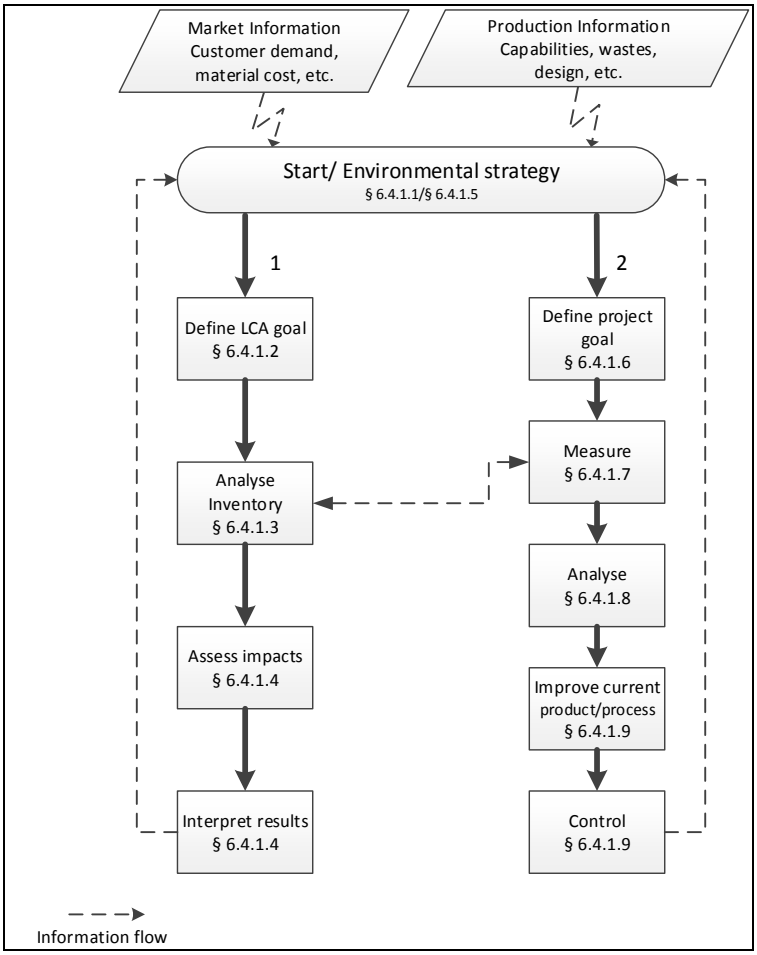

Figure 28: Proposed process for implementing the framework and reference to the section number (§) of each step.

Start/environmental strategy

A company starts by formulating a provisional environmental strategy based on information from the market and production processes. The team responsible for formulating this strategy is cross-functional so as to ensure that all departments are involved in the programme. Market information includes an assessment of the requirements of a company's specific market and its position in that market. In addition to environmental considerations, the environmental strategy should consider all factors that affect its market. A PESTLE (political, economic, social, technological, legal, and environmental) analysis is conducted to consider all market factors (Srdjevic et al., 2012) so that the environmental strategy is not isolated from corporate strategy. Production information includes the capabilities of the production function. A SWOT (strength-weakness-opportunities-threats) analysis is performed to determine how the production functions can achieve market requirements, and how they can be modified if currently incapable of this. The environmental strategy then proceeds to collect information about the impacts of the company's products on all life cycle stages by conducting a streamlined LCA study as discussed in subsequent steps. Engaging wider staff should also be considered early on in this phase to gain support for sustainability through idea sharing and commitment (Cassell et al., 2006).

The environmental strategy should address the requirements for sustainable manufacturing in the order that was suggested in section 5.2.4 as follows:

1. Encouraging wider employee engagement that would provide further support for sustainability through the sharing of ideas and commitment.
2. Establishing good internal communication between departments which ensures that knowledge flows between different areas in the business such as marketing, manufacturing, legal and finance. This knowledge will be the foundation of an LCA study that can influence decision making. It will also lay the foundation for a company-wide EMS.
3. Implementing an EMS ensures that information is documented in a standardised manner. The EMS also monitors plans, resources, and training to continuously improve sustainability.
4. An LCA study is conducted as outlined in the following susections.

LCA goal and scope definition

General guidelines for conducting an LCA are given in the ISO 14040 standards. In the first phase, the goal of the LCA study is determined based on information from the environmental strategy that defines the type of information needed to support decision making. For example, this can be information about water consumption in a market concerned about water supply, or information about gas emissions in a market concerned about pollution. An LCA study can have more than one goal. It can, for instance, seek to guide new product development to evaluate energy efficiency and CO2 emissions, and simultaneously prepare for product certification. The specificity of data should be determined at this phase to allow for a reliable streamlined study that is not as complicated and time-consuming as a detailed LCA (Weitz et al., 1999, Goglio and Owende, 2009).

The scope of the study is also determined in this phase. The stages of the lifecycle are normally materials extraction, manufacturing, use, and disposal, and these are all typically included in the LCA study. However, a company might decide to limit the focus on some stages that it considers more important or has detailed environmental data about. The scope of the study defines the system boundaries, which are determined to include some of the lifecycle stages in detail and information is acquired about the other stages outside the system boundaries from environmental databases such as Ecoinvent, as shown in Figure 29.

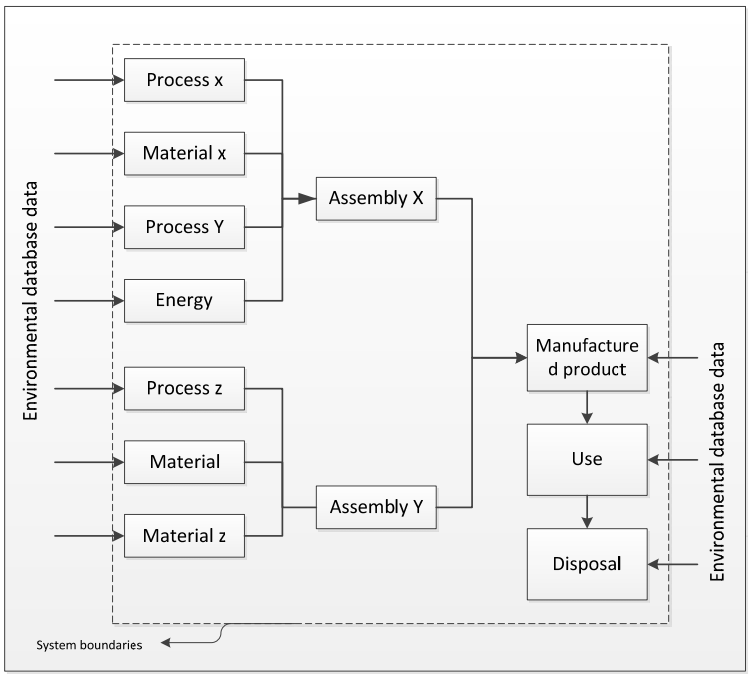

Figure 29: System boundaries showing processes to be detailed in the study.

Inventory analysis

The lifecycle inventory is quantified in this phase. This includes energy, raw material requirements, and waste and emissions for the entire lifecycle of a product. Data about processes within the system's boundaries is collected. This data can be obtained from upgraded LSS tools that include environmental measures as shown by the information arrow in Figure 29. Depending on the scope of the study, the data in this phase is gathered for all stages of the lifecycle, or alternatively is obtained from existing datasets or other similar studies. Supply chain integration is important to facilitate data collection from companies in the supply chain. Data from the manufacturing stage can be obtained from meter readings from equipment, laboratory tests and equipment specifications. Data from the use and disposal stages can be obtained using customer surveys to find, for example, how many times the product is used and how it is disposed of.

Impact assessment and interpretation

The impact assessment phase of LCA categorises the large amount of data collected in the previous phase into impact categories such as land use, human health and global warming. Thus, it is possible to compare the different types of waste and emissions by

comparing their impacts in different categories. The final task of LCA is to evaluate the results and relate them to the purpose of the study in the interpretation phase, which also checks the data in the previous phases to make adjustments to the study and produce a final report for the environmental strategy.

Amended environmental strategy

The environmental strategy can now be amended based on the information from the LCA study. The next step is to undertake an LSS project to evaluate the current state of the production functions and propose improvements to move to a future state.

Define

The goal of the define phase of the LSS's DMAIC process is to define the problem and the benefits expected in light of what the environmental strategy has provided. The cross-functional team is required to undertake the project with roles and responsibilities clearly outlined in this phase.

Measure

The current state is evaluated in this phase. A typical LSS would use tools such as Value Stream Mapping (VSM) and Just-In-Time (JIT) (Pepper and Spedding, 2010). However, the framework requires tools that consider environmental impacts so that the measure stage can feed data into the inventory analysis of the LCA study. Tools such as Environmental Value Stream Mapping (EVSM) have been developed for this purpose (Torres Jr et al., 2009, Faulkner and Badurdeen, 2014). Other tools such as JIT can be altered to consider road congestion and CO2 emissions (Cusumano, 1994). Upgrading the tools of the measure phase to include environmental measures would stream information to the inventory analysis of LCA, which is beneficial for the company as time and resources are not wasted on doing the same task twice.

Analyse

This phase of the project analyses the data collected in the previous stage. Statistical analysis is performed to explore the problem in detail and to identify variables that cause variations in the process. Variables that are related to environmental performance would be considered alongside typical production variables. For example, a typical LSS would focus its analysis on bottlenecks to improve throughput,

but in this framework the environmental strategy sets guidance to also consider areas of significant environmental impact. Moreover, the typical cost-benefit analysis that estimates the benefits and costs of proposed improvements should be modified to include environmental impacts. The company's allocated budget for environmental improvements should be used to offset the costs of environmental improvements in the cost-benefit analysis.

Improve and control

The goal of these two phases is to implement improvements to the current state and activate control plans to document procedures and ensure that the improvements are sustainable. The documentation procedure to be adopted should follow the ISO14000 standards for environmental management systems. Karapetrovic and Willborn (1998a) suggest that an integrated system of ISO9000 and ISO14000 (EMS) is required to meet the requirements of both systems with less time, effort, and conflict.

The present study argues that LSS is important to support the implementation of LCA recommendations, and this support can be achieved by means of actions that ensure that the LCA findings are addressed in the improve and control stages. Incorporating environmental education into the LSS training programme is an example of how LSS can support LCA. Measures that statistically monitor the impact of improvements in economic and environmental performance should be implemented in the control phase so as to constantly feed information to the environmental strategy. The process shown in Figure 28 is iterated in a continuous cycle that improves the environmental strategy based on new information from the market, production department, LSS, and LCA.

6.6 Critical success factors for the framework

This section provides a summary of the critical success factors (CSFs) that need to be considered in order to maximise the benefits of implementing the framework. Understanding CSFs is important for this study and has been an important area of research in project management in general (Fortune and White, 2006). This framework's CSFs are similar to those for LSS, which have been discussed in section 3.5.1, and also similar to the CSFs for systems integration (section 3.8). This similarity is due to the fact that the framework as a whole is a management approach that has the same features as its components.

The factors that support the drivers of SM which have been discussed in section 5.3 are important CSFs for the framework and include:

- Implementation of Six Sigma
- Implementation of Lean
- Supply chain integration
- Market demand for environmental products
- Budget for environmental improvements

The budget, top management support, skilled staff are factors that the framework takes into consideration. For example, the budget to implement the framework is minimised by incorporating an existing LSS and using a streamlined LCA that does not require expertise and management resources. The analysis of data reveals that the CSFs that affect the implementation of the framework are similar in SMEs and large companies (section 5.4). The important CSFs that emerged during the analysis are:

- Cross-functional teams

  The role of a cross-functional team in implementing the framework is critical, as it will bring expertise and information from different departments. Team members are also expected to report back to their departments to ensure that communication between different departments is effective. This is very important because the problem of information sharing was evident in both the questionnaire and interview data where participants' knowledge of other departments was weak.

- Communication to stakeholders

  Communication with employees about the company's environmental impact and plans to address it brings new ideas and ensures employee commitment in support of such plans. The training and education programmes of LSS should integrate environmental education. In addition, communication to suppliers, customers, and other stakeholders can enhance environmental efforts through participation. For example, one of the companies that participated in the interviews is making considerable effort to improve its environmental performance. However, these efforts are not reflected in the company's

website. When the researcher discussed the importance of communication with stakeholders, the interviewee agreed that their programme should have been presented on the website and he would raise the point to top management to consider.

6.7 Validity of the Framework

A validity assessment is required in order to determine how well the framework would meet the purpose that it was designed for. Validity is different from testing in that it is an assessment of the assumptions, concepts, and data used to build a model, for logical consistency, and the review is aided by input from experts knowledgeable in real world situations (Balci, 2001). Whereas testing is a real-life implementation of the framework in order to determine whether or not the actual outcomes and the predicted outcomes are the same. According to Kumar (2011), validity is determined without directly confirming knowledge. Confirming knowledge is achieved by testing in a case study implementation. Testing of the framework in case studies is beyond the scope of this study due to time constraints, and testing in a single case study might not be sufficient to demonstrate the various potential benefits of the framework. This section's objective is, therefore, to present the methods that were used to assess the validity of the framework. Validity assessment is related to internal validity and external validity. Internal validity refers to the consistency between methods that achieve the research goals, while external validity relates to the generalisability and acceptability of findings to people other than the researcher (Vladimirova, 2012). The validity of the framework was assessed using four methods as outlined in the following sections.

6.7.1Triangulation

Triangulation is considered to be a means to assess the internal validity of findings in mixed-methods research (Saunders et al., 2009). Triangulation is a validity procedure where researchers search for convergence among multiple and different sources of information (Creswell and Miller, 2000). An examination of the evidence from the different data sources used in this study has built a coherent justification for the framework and supported its internal validity. The literature review, the questionnaire survey of academics, the questionnaire to industry, and the interviews have all been used to assess various aspects of the study in different dimensions and the results were

mostly found to cross-validate each other. In addition, appropriate samples and statistical tests were used in the quantitative approach to increas confidence in the framework's validity (Morse et al., 2002). Figure 30 shows how the different methods of data collection support each other's main findings.

Method \ Findings	No standard framework for LSS	Streamlined LCA is appropriate	Strategy is required	Market driven strategy	SM drivers	LSS and LCA complement each other	CSFs
Literature Review	+	+	+	+	+	+	+
Survey-Academics	+	+				+	
Survey-Industry			+	+	+	+	+
Interviews	+			+			+

Figure 30: Triangulation findings supported by different methods of data collection.

6.7.2 Panel of experts

Authors of research methods frequently recommend the use of a panel of experts to maximize the validity of research (Davis et al., 2007). This approach was used to find out expert opinions of and feedback about the framework. Three experts in Six Sigma and Lean, and one expert in LCA were interviewed to discuss how the framework was developed and how it can be used. The interview with the experts was unstructured and revolved around:

- The importance of the framework to manufacturing.
- The importance of the components of the framework; LSS, LCA, strategy, and market to achieve SM.
- The implementation process of the framework.

A meeting with the three experts in Lean and Six Sigma was conducted first. The LCA expert was sent an email that introduced the framework prior to a telephone discussion in which feedback was provided. While the four experts gave positive feedback on the framework in terms of its potential benefits and coverage of an area that is under-

investigated, they gave useful comments on how it could be improved. The experts were satisfied with the logic of developing the framework based on existing concepts. One particularly useful piece of feedback was the suggestion that the process of implementing the framework should be clearly explained. This feedback was addressed in section 6.4.1.

The LCA expert is a member of a large project that is promoting LCA studies in large manufacturers such as Land Rover and Jaguar. He has also given a positive feedback on the framework and has stated that the project he is involved in actually promotes involving all departments in LCA studies. The motive for this, he elaborated, is to get more staff involved and to obtain detailed data from different functions within the company, which is one of the framework's goals.

6.7.3 Follow-up discussions

This approach is recommended by Creswell (2013) for the assessment of the external validity of research findings. Lincoln and Guba (1985) described this method as "member checking", referring to participants of a study as members of it, and considered it as a very important technique for establishing validity. To this end, a follow-up discussion was conducted with managers who had participated in both the questionnaires and interviews in the present study. The two participants are industry experts in production management and have good knowledge of environmental requirements and practices in their industry. The feedback from the two participants was obtained by telephone conversations that followed email invitations. The framework and a brief description of how it was developed and how it can be implemented were given in the email. The industry experts evaluated the framework from a different perspective than that of the academic experts. The industry experts' inquiries were mostly about resources for implementing the framework. Both of the industry experts agreed that the budgets and human resources required could be inexpensive if the framework utilised existing resources and only a few adjustments were made to include environmental measures. The two experts also agreed that production managers should be aware of the environmental impacts through out the lifecycle of a product, and should be involved if the company has plans to reduce these impacts. With regards to LCA, one expert was satisfied with using a streamlined LCA, while the other argued that a full detailed LCA could be better as the extra detail can

be used later. He used building a ‘motorway’ as an example of how infrastructure should be built to accommodate future expansions. While this is a valid point, the choice of a full LCA or streamlined LCA depends on the company’s capabilities, and whether or not the LCA study has other purposes, such as obtaining environmental certification. However, the framework is proposed with streamlined LCA so that it can appeal to a wide range of potential users.

6.7.4 Peer review

Creswell (2013) applies this method to establish the validity of qualitative research. Receiving feedback from peers is an advantageous method that has been applied throughout the course of this study by means of publications, seminar presentations and informal discussions with fellow researchers. The framework and other parts of this study have been published in three international conferences and a journal (Fargani et al., 2014, 2015, 2016, 2017). Discussions with the audience in conferences after presentations have also been a valuable method to check the validity of the framework. The peer reviews provided valuable feedback and indicated that the validity of the framework is strong in terms of its purpose, findings, and design.

The methods discussed above for assessing the validity of the framework are summarised in the map shown in Figure 31.

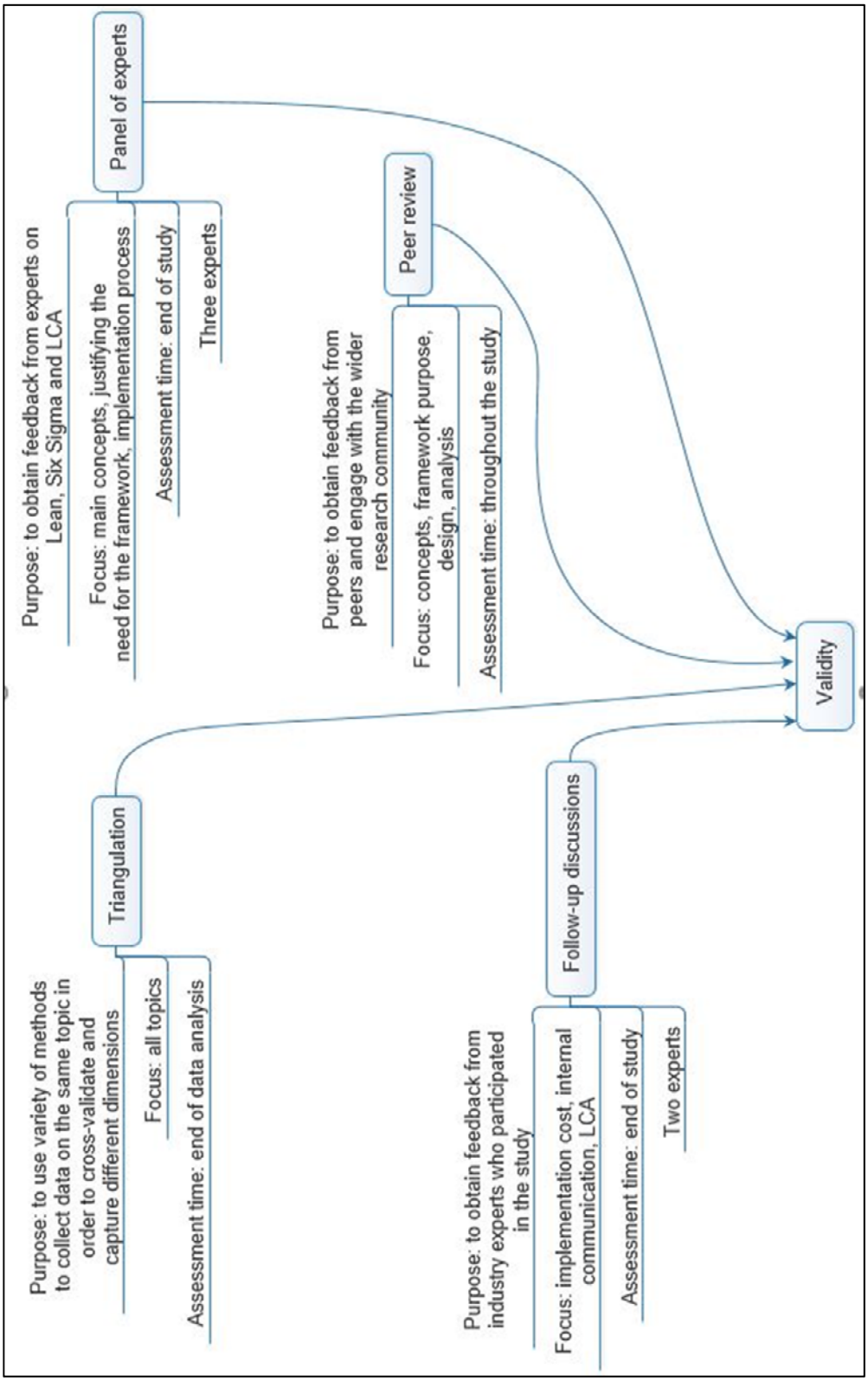

Figure 31: Methods used for validity assessment.

6.8 Thought Experiments

Researchers seek to evaluate new ideas, options, and management models prior to actual implementation to prove the value of their research and demonstrate its readiness for real life applications. For this purpose, the use of simulation is a very popular method of inquiry in operations management research (Montazer et al., 2003). The following sections discuss the issues associated with simulation and then suggest 'thought experiments' as a possible alternative to demonstrate the feasibility of the proposed framework. Three thought experiments are then presented to demonstrate how the proposed framework can achieve the purpose it was designed for.

6.8.1 Issues of simulation

According to Dooley (2001), simulation is a method that can be used to prove the existence of a possible solution to a problem. Simulation in the context of business and social sciences applications refers to "the operation of a numerical model that represents the structure of a dynamic process" (Kothari, 2004), and it is a powerful method to assess proposals such as frameworks, models, and designs. Simulation has been widely used in research. For example, Ignall et al. (1978) showed how simulations of a city's fire and police operations have been used to develop and test simple analytic models. Therefore, a simulation can be viewed as an experiment with a model or a framework, manipulating its variables in order to prove it usefulness. However, a key obstacle for the present study to use simulation is obtaining valid source information for the key elements of the framework, including qualitative data, because the latter may increase the complexity of the simulation and make it very fragile and possibly misleading (Luna-Reyes and Andersen, 2003). The present study is partly qualitative and excluding qualitative data to conduct a simulation would undermine the validity of the results. This issue has been discussed by Davis et al. (2007) who argued that simulation "either replicates the obvious or strips away so much realism that it is simply too inaccurate to yield valid theoretical insights"

Another issue with simulations is that they do not appeal to managers. This issue has been highlighted by many researchers such as Meredith et al. (1989), who noted that in operations management (OM) research:

> "OM researchers addressing the problems of production and productivity through the now-standard quantitative modeling

> paradigm were more and more simply talking among themselves. Managers looked at this 'research' and found that they could neither understand the solutions being proposed nor the problems OM researchers thought they were addressing." (Meredith et al., 1989)

The above discussion indicates that alternative methods are required to communicate with managers more effectively.

6.8.2 Thought experiments as an alternative method

An alternative research method that is more appealing to managers is required in order to convey research findings to industry more effectively. This alternative needs to have the following features that are not found in simulation:

- It should make communicating the results and benefits of the framework easier.
- It should not require extensive resources, especially time.
- It should apply to a wide range of companies and not be limited to a single case.

A research method that meets the above requirements is thought experiments. According to Brown and Fehige (2016), a thought experiment "considers some hypothesis, theory, or principle for the purpose of thinking through its consequences", and is most often "communicated in narrative form". Thought experiments are perceived by many philosophers to be the use of hypothetical scenarios to help understand the way things actually are (Kennard, 2015).

Thought experiments have been used in research in many fields, including philosophy, physics, and economies. Famous examples of thought experiments include Einstein's elevator, the Laffer curve and Searle's Chinese room. Searle's Chinese room, for instance, is a thought experiment that was put forward by Searle (1980) to illustrate that artificial intelligence cannot function like human brains. Searle imagined that he is locked in a room alone and given a batch of Chinese stories (a language he does not understand), and an English translation (his first language). He is also given a batch of rules in English to correlate with the Chinese symbols. Using what he has, he can receive Chinese questions about the stories, translate them, and use the correlation

rules to provide answers in Chinese. To those outside the room, it would seem as if Searle totally understands Chinese because he gets questions in Chinese about stories in Chinese and provides correct answers also in Chinese. Searle argues that the translations and rules he is given are similar to computer programs that have a specific function and in no way could these programs understand the content beyond the given rules.

The use of thought experiments in operations management research is rare. However, there seems to be mounting evidence that the method can be used in this field to test new concepts prior to real-life implementation in cases where time and cost are challenges. In fact, the use of thought experiments has a long history in strategic management research and practice, where it is described as scenario planning which is defined as a qualitative method during which:

> "Participants discuss current trends and future prospects arising in a firm's external environment. They create coherent stories about possible futures. Managers exercise their judgment by distilling the myriad possible future states of the world to the most plausible few. Through scenario planning, the contingencies, uncertainties, trends, and opportunities that are often unanticipated can be identified, evaluated and acted upon" (Miller and Waller, 2003)

Di Paolo et al. (2000) drew similarities between thought experiments and simulation models, arguing that even though thought experiments do not have new information fed into them, they are indirectly saying something about nature and have a historical role just like an empirical observation. The authors cite Kuhan's (1977) argument that these two similarities enable thought experiments to give "scientists access to information which is simultaneously at hand and yet somehow inaccessible". Along the same lines, El Skaf and Imbert (2013) illustrated that a thought experiment, a computer simulation, and an actual experiment can contribute to answering the same question. They described how the three methods were used with the same role at different periods of time to answer the same questions about the possibility of a physical Maxwellian demon. A computer simulation of a Maxwellian demon in 1992 and an experiment in 1997 reached the same conclusions as a thought experiment

conducted in 1912. Figure 32 shows how a thought experiment is similar to an actual experiment in physics, whereas in social sciences the equivalent to a thought experiment is not an experiment, but an empirical case study (Ylikoski, 2003).

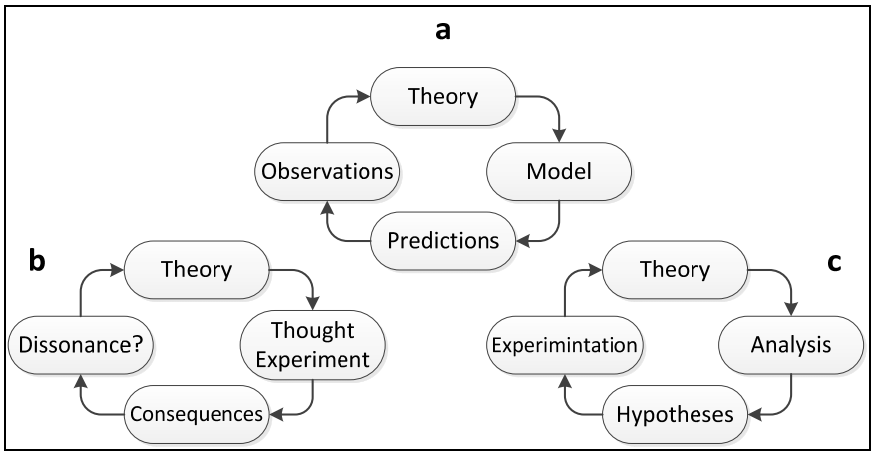

Figure 32: The thought experiment (b) and the physics model (c) can be understood as examples of a more general cycle of scientific inquiry (a). Source (Di Paolo et al., 2000)

In industry, thought experiments are already widely used by managers to create business models, generate ideas and make decisions (Baden-Fuller and Morgan, 2010). For example, Gordon Moore and Andy Grove (Brandenburger and Nalebuff, 1996) used a simple thought experiment to save the then-struggling Intel Corporation by posing a hypothetical question "If we got kicked out and the board brought in a new CEO, what do you think he would do?" Business consultants are also adopting thought experiments to deliver effective training to their clients. Author and consultant Scott (Scott, 2004), for example, urges clients to search within their minds and emphasises that the answers to most problems in a business are already in 'the room' in reference to the meeting room.

6.8.3 Thought experiments for assessing the validity of the framework

For the purpose of assessing the validity of the current study's proposed framework, three thought experiments are conducted to illustrate the potential benefits of implementing the framework. Most thought experiments provide a scenario and then discuss its implications and possible outcomes, which is similar to the general scientific inquiry method as shown in Figure 33. The same approach is used here to present the three experiments which firstly provide a scenario that resembles a real life situation in a manufacturing company and it describes typical business activities and

decisions. Then, the scenario is analysed to explore possible consequences that might unfold. Finally, it is assumed that the framework is implemented so as to explore what benefits it could bring to the company.

6.6.3.1 Scenario 1

Company X produces vacuum cleaners for the European market. It has been for the last two years investing in improving its production lines to reduce lead-time and improve the quality of vacuum model X100. Operations managers believed this would strengthen the company's competitive advantage in winning orders. Not fully aware of the serious implications of an EU directive for eco-design requirements issued in October 2009, management spent valuable time and money on the upgrading project, and when the EU made the directive law in July 2013 and put it into force in September 2014, the company realised it had made a serious mistake. This scenario was inspired by the enforcement of the EU's vacuum cleaner regulations as part of its plans to meet targets on energy efficiency (European Commision, 2013).

Analysis

The company in this scenario realised that the production lines of X100, which they had been improving, would produce vacuum cleaners which would not be accepted by the market. This means that the company would lose money in its investment and, more importantly, it could lose significant market share. In today's competitive markets, the company would very likely go out of business as a consequence of its mistaken decision to invest in the project.

Framework advantage

If communication between production managers, marketing managers, and top management had been better focused on environmental market requirements, the investment would have been better spent. By implementing the framework, the environmental strategy team would have monitored the requirements of the market, and the forthcoming regulations in this case, and passed the information through to LSS. Other departments would also be briefed by the cross-functional team about upcoming changes.

6.6.3.2 Scenario 2

Company Y is a huge producer of industrial cutting tools and is engaging in environmental activities to reduce pollutant emissions and improve the company's image. The production department has proposed an LSS improvement project that will reduce machining time to achieve the company's targets. As part of the LSS proposal, the material that makes the cutting tools will be changed to an alloy that is faster to machine, and hence reduce manufacturing time and power consumption will be reduced. Tests show that the proposed material takes more time than the original material to perform the same job, but customers would not notice the difference because the time increase for cutting is only 1%. Top management needs to make a decision whether or not to implement the LSS proposal.

Analysis

The LSS improvement project will very likely be approved because it delivers environmental improvements and keeps the same quality level for customer satisfaction. All input and other information indicates that this is the right decision considering that market requirements are met, cost savings are achieved, and emissions are reduced.

Framework advantage

Although the information seemed adequate for top management to take a decision, it is in fact not so, because it is considering only part of the whole picture. Had the framework been implemented, the decision-making process would be different since information from the LCA would be available and would look at other lifecycle stages. In the lifecycle use stage, the effect of the 1% time increase in cutting with the proposed tools would be investigated because it involves increases in the customer's machining and power consumption. Given that the company has a large number of customers, the overall increase in gas emissions could be significant. The LCA would evaluate the two alternatives (change to new material or not) in terms of gains and losses at the manufacturing stage and the consumption stage. This situation is a good example of problem shifting, where an improvement is made in one lifecycle stage at the expense of other stages. Company Y may choose to drop the LSS proposal based on the new data if it has a genuine interest in reducing its environmental impact.

6.6.3.3 Scenario 3

Company Z is a multinational company and an industry leader that is committed to sustainability. It decided to make improvements to one of its manufacturing plants. The plant's top management allocated a team to make production improvements by applying Lean and Six Sigma tools and techniques, and another team to recommend environmental improvements by conducting a detailed LCA. The plant's top management has also appointed staff to ensure that a strategy is in place so that the production developments are assessed by the LCA.

Analysis

All of the steps that Company Z is taking are well-planned and mostly conform to the framework. LSS and LCA are employed and a coordination strategy is in place to ensure that the two techniques are in harmony. In addition, market requirements would certainly be addressed by a well-informed company such as Z. Can the framework bring any benefits to this company?

Framework advantage

One of the framework's focuses is the concept of systems integration. While the LSS team are using different tools to measure different aspects of the plant's current state, the LCA team will also be collecting data about operations. In this instance, there will be a missed opportunity to save time and resources because each team is working independently and systems integration is not intended. The framework addresses this problem by using upgraded LSS tools that provide environmental measures such as EVSM as discussed in section 6.4.1.7.

The framework's main advantage is that it addresses weaknesses in the decision-making process, and also identifies opportunities for improvements. A summary of the three thought experiments is shown in Table 25.

Table 25: Summary of thought experiments.

Thought experiment	Company weakness	Benefits of the framework
Scenario 1	Unaware of environmental developments in the market, no LCA, no strategy, poor communication between departments	It provides updates on new regulations and strategy for addressing environmental requirements.
Scenario 2	No LCA information to make the right decision.	It provides lifecycle information at all stages to avoid problem shifting.
Scenario 3	Systems integration is not intended.	It promotes for systems integration and provides tools that link LSS and LCA.

6.9 Summary

This chapter has outlined how the design of the framework has developed from a simple proposal to a framework that captures the important concepts and requirements for achieving sustainable manufacturing. The knowledge gained from the literature review and the data collected from the questionnaires and interviews throughout the study has led to the development of the framework by including four main areas, which are LSS, LCA, environmental strategy and market. This was followed by proposing an implementation process and discussing the critical success factors for successful implementation.

The validity of the framework was also discussed in this chapter. It was assessed using the methods of triangulation, a panel of experts, follow-up discussions with participants, and peer reviews. The main goal of checking the validity was to ensure that the framework is fit for purpose. The discussion then progressed to demonstrating the readiness of the framework for real-life applications in order to prove the value of the current research. For this purpose, the use of thought experiments was proposed as an alternative to simulation. Thought experiments have been used for testing theory in many research fields. However, in operations management there is still a lack of application of the method despite its potential benefits. The approach of thought experiments was used because various limitations prohibited the use of case studies and simulations. In addition, thought experiments could be more effective in passing the knowledge to managers compared to simulation. The outcome of the three thought

experiments shows that the framework is a useful tool for decision making and environmental improvement.

CHAPTER 7. CONCLUSIONS AND FURTHER RESEARCH

The present study set out to support manufacturing companies in meeting the requirements of sustainable manufacturing, and it has identified LSS and LCA as appropriate management techniques to meet these requirements. It was found that these two techniques have often been used without reaping their full benefits because they were mostly applied in isolation, and this issue has not been addressed in the literature. This study therefore focused on developing a novel framework for integrating LSS and LCA. The framework was developed through a methodological investigation consisting of three phases.

- The first phase was an academic investigation based on a literature review and a survey of academics. This phase was designed to identify the main concepts and theories that are relevant to the objectives of the study.
- The second phase was an industrial field study that gathered data using a questionnaire survey and interviews. Throughout the first and second phase of the study, the framework was gradually developed.
- The final phase consisted of a validity assessment of the framework and an attempt to use thought experiments as an alternative to simulation to illustrate the benefits of implementing the framework in industry.

This final chapter summarises the answers to the research questions and the research contributions of this project. It then discusses possible implications and offers suggestion for possible directions for further research.

7.1 Summary of Answers to the Research Questions

The study has specified important questions that should be answered in order to achieve the goal of this thesis. The answers found to the research questions are summarised as follows:

Q1: How can LSS and LCA be integrated to achieve sustainable manufacturing?

The study has found that a successful integration of LSS and LCA requires a strategy to ensure that the two techniques do not work in isolation and that synergies are

maximised. The principles of systems integration are also important for coordinating management methods, cross-functional teamwork and reducing the cost of joint activities. The integration also requires a focus on market requirements as the main driver for the strategy. The results showed that the lack of the above-mentioned requirements for integrating LSS and LCA leads companies to fail in achieving SM. Therefore, a framework was developed to address this issue. Furthermore, it was found that linking the measure stage of LSS and the inventory analysis step of LCA is key to a successful integration of the two systems. It was suggested that upgrading LSS tools to include environmental measures could save effort and improve the outcomes of applying the framework.

Q2: What are the characteristics of a company that might benefit from the proposed integration?

The answer to this question was mainly addressed in assessing the suitability of the framework to SMEs as discussed in section 5.4. It was found that SMEs, just like large companies, can benefit from the integration of LSS and LCA as proposed in the framework. Other important characteristics of a company to benefit from the proposed integration include:

- A management board that supports environmental sustainability and is willing to accept and implement change to achieve it.
- Open communication between top-management, middle management, and employees, and also good communication between different departments.
- The availability of empowered cross-functional teams that have expertise in executing improvement projects.
- A market that values environmental sustainability and supports it.

These findings are similar to those in the literature that cover the company characteristics required for LSS, manufacturing strategy, and sustainability in general (Hill, 1997, Hitchens et al., 2003, Cassell et al., 2006, Lucato et al., 2015). However, the assessment of the framework's suitability for SMEs is unique because the framework is original to this study.

Q3: What adjustments to LSS and LCA are required to enable the framework to be implemented?

It was found that the complexity of LCA studies needs to be addressed in order to facilitate the implementation of the framework. Streamlined LCA was found to be a suitable alternative to a full LCA. Streamlined LCAs have been widely used to support decision-making in situations where resources and time are limited (Fleischer and Schmidt, 1997, Weitz et al., 1999, Rebitzer et al., 2004, Yilmaz et al., 2015). LSS, on the other hand, needs to be modified to include green waste, and LSS tools should also be modified to include environmental measures in order to facilitate the proposed integration. Research in this direction has been proposing and testing modified tools such as environmental value stream mapping (Rothenberg et al., 2001, Faulkner and Badurdeen, 2014, Lucato et al., 2015, Cherrafi et al., 2016) which can be used in the framework. The above-mentioned adjustments to LSS and LCA are important requirements for the framework.

Q4: What is the current strength of drivers for sustainable manufacturing?

The discussion in section 3.2 has shown that the drivers of sustainable manufacturing differ in terms of importance according to factors such as region and industry. Their importance has also been changing over time. For example, government regulations were the top driver for some time. However, other drivers such as customer demand and competitiveness are becoming more important. The findings from this study support those in the literature (Williamson et al., 2006, Zhu et al., 2007, Mittal and Sangwan, 2015) in that competitiveness and market pressure are important drivers. However, this study's attempt to answer this research question is incomplete, as the findings cannot be generalised to the wider population due to the sample size tested being small. Nonetheless, the findings extend prior knowledge in a unique way because the study took a different approach to the evaluation of SM drivers by considering the factors that underlie them rather than directly studying the drivers themselves.

7.2 Contribution to Knowledge

The outcome of this study, in general, is an enhanced understanding of how sustainable manufacturing can be achieved. The present study shows that the application of LSS and LCA is crucial and it has aimed to develop a framework to integrate these two techniques in order to achieve sustainability. The proposed framework summarises:

- A standardised approach to implementing LSS and LCA.
- The concepts that are essential for integrating LSS and LCA.
- The results of the data analysis providing an evaluation of the factors that affect the framework and tested its suitability for SMEs and large companies.

To achieve the integration of LSS and LCA, it was found that integration is not a straightforward process because the two techniques differ in their focus and scope. The concepts of strategy and systems integration were therefore introduced to make integration possible. It was also realised that integration's main drives should be market requirements because market survival is the primary focus for manufacturers. In addition to these main findings, the study uncovered other requirements that are important for the integration, including simplifying LCA, including green waste to LSS, the role of cross-functional teams and the importance of communication. All of these findings have led to the further development of the framework, which represent the main contribution to knowledge of this study because linking LSS and LCA has not been previously reported. Previous studies such as those by Zadek (2004) and Kashmanian et al. (2011) that attempted to guide the implementation of SM did not specify the techniques that should be utilised and only provided general recommendations. The information that the present study provides makes it an important addition to the development of research on SM because it specifies LSS and LCA as the techniques required and focuses on the interaction between them to provide a road-map for implementation.

In addition to the proposed framework, the study has attempted to address other gaps in the literature and has made the following contributions:

- The study has discussed how the framework can guide practitioners through the process of formulating an environmental strategy (section 6.4.1).
- The study has empirically tested a sample population in terms of meeting the requirements of sustainability as proposed by Kashmanian et al. (2011). It was found that companies often fail to achieve true SM despite the efforts made by some of these companies (section 5.2.4).
- The study has presented an analysis of the drivers of SM using an original technique that is different from the approach of the mainstream literature (Zhu and Sarkis, 2006, Zhu et al., 2007, Walker et al., 2008, Mittal and Sangwan,

2015). This has been achieved by analysing the factors that underlie the main drivers of SM rather than directly analysing the drivers themselves.

- The study has addressed the challenges facing SMEs in developing a competitive strategy as highlighted by Singh et al. (2008). The proposed framework has the potential to tackle these challenges, as discussed in section 5.4.3.2.
- The study has introduced thought experiments as a possible alternative to simulation, which is an under-utilised approach in operations management research.

The above contributions demonstrate the originality of the study as they match some of the possible ways for Ph.D. studies to be original, as described by Phillips et al. (2005) who point out that a study can be considered 'an original contribution to knowledge' in one of a number of possible ways.

7.3 Implications of the Study

The findings of the present study have been drawn from academic research and industry data, and thus hold implications for theory and practice. The findings and the proposed framework can be used for practical and theoretical purposes by the following groups,

7.3.1 Academics

Academics who are undertaking research in sustainable manufacturing could exploit the findings of this study and may consider the framework as an incremental improvement to the theory of environmental strategy, which is an area that requires more research. The present study has also provided an example of how studying the integration of different management tools has the potential to improve the performance of the overall system. This should motivate more research that focuses on the interactions between different management tools rather than studying these tools separately. In addition, this study has promoted an alternative approach to evaluating research in operations management through the use of thought experiments, an approach that is widely applied and accepted in other research fields. This may encourage the application of thought experiments when simulations and case studies are problematic.

7.3.2 Industry practitioners

The present study has addressed issues that are important to manufacturers who are embarking on sustainability initiatives. There is evidence that industry practitioners are using LSS and LCA in isolation without strategic integration, which often results in limiting the usefulness of both tools. The framework addresses this issue and provides a methodological approach to formulating an environmental strategy that practitioners can use as a guide. The framework considers market requirements and, thus, is more appealing to managers. The study has also pointed to areas that require particular attention based on data collected directly from industrial practitioners. Internal communication and the use of cross-functional teams are amongst the most important areas that practitioners need to address to achieve their environmental goals.

7.3.3 Policy makers

Manufacturing is very important to the success of the economy, and it is also critical to the success of sustainable development because it is a major contributor to emissions and resource consumption. This study can benefit policy makers in government and other bodies in two ways. Firstly, initiatives for promoting sustainability should focus on LSS as a launch pad for sustainability because manufacturers would buy into these initiatives more if they related to financial and operational performance. These initiatives would then promote the use of LCA to improve environmental performance. The framework can be used as a guide in such initiatives. The second benefit that this study provides to policy makers is that it supports the fact that environmental impacts occur inside and outside the company. Thus, a company's environmental performance should include the impacts of its products in all lifecycle stages and not only within the company's boundaries. This is very important for policy makers who intend to reward manufacturers who amend their choice of material and design to be environmentally friendly without directly gaining financial benefits.

7.4 Limitations and Direction for Further Research

The subject of sustainable manufacturing is extensive and multifaceted. The present study has focused on one dimension, which is environmental sustainability. There is a need for more research to link the social and economic dimensions of sustainability in a manner that provides practical solutions in addition to theoretical insights. The

answers found to the research questions in this study might not be complete and certainly require more investigation due to the limitations that were identified in Chapter 2, which include:

- Findings cannot be generalised due to the small sample size
- Participant commitment is not strong because all participants are volunteers and do not have an obligation towards the study.
- Single sources of information (only one respondent from each company) limit the reliability of data.
- Implementation of the framework could not be achieved.

In addition, the proposed framework in this study remains, as do all frameworks, a simplified and incomplete model of a more complex reality (Maxwell, 2005). Hence, further research is required to test it and improve it. A number of directions for future research can be suggested to proceed from this study, including:

- Conducting a questionnaire that includes more factors that underlie the drivers of sustainable manufacturing. The information obtained by analysing the factors underlying those drivers can be very useful in the creation of advanced predictive/optimising algorithms that require many prediction/optimisation variables in SM.
- Replicating this study with a larger sample size so that findings can be generalised to the whole manufacturing industry. A larger questionnaire survey should target more than one individual in a company to obtain accurate information and eliminate bias. In addition, conducting more interviews will provide more qualitative information to help improve the understanding of SM.
- Implementing the framework in multiple case studies to test it, improve it and analyse the factors that affect its outcome in each case study.
- The study has highlighted the need to include environmental measures in LSS tools to support the inventory analysis step of LCA. Although there has already been a growing number of studies in this area of research, most studies have only focused on improving value stream mapping. It is recommended that this area of research expands to include environmental considerations in more LSS tools such as just-in-time and statistical analysis.

- The study has focused on environmental sustainability throughout its course. Including social sustainability to the framework can be a promising suggestion and, hence, should be explored.

7.5 Closing Remarks

With the increasing pressure on companies to consider the requirements of sustainability, it should be realised that there is no single management tool that can provide all the solutions to the economic, environmental and social dimensions of sustainability, and thus the integration of different management tools that address different aspects of sustainability should be investigated. In the present study, the focus has been on the environmental dimension of sustainability, and the management tools that were considered relevant were LSS and LCA. It was found that the chance to integrate these two management tools to improve environmental performances is often missed. Companies either do not look beyond their direct environmental impacts or attempt to look at the impact of the lifecycle but do not follow this with appropriate actions to address it.

Finally, despite the view that manufacturers are mostly interested in profit and engage in sustainability because of pressure, the researcher has observed a profound interest by practitioners in protecting the environment. The role of research, such as that presented in this thesis, is to provide these practitioners with the management tools to support them in protecting the environment without compromising market survival. This has been the main motivation for this study and it is hoped that it will encourage future research to follow in this direction.

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Appendix A – Survey of Academics and a Sample Response

Questionnaire for the Assessment of Sutainable Manufacturing

About the Questionnaire

This questionnaire is prepared to assist in a PhD research titled "A theoretical Frame Work to Implement Lean Six Sigma and Life Cycle Assessment in Sustainable Manufacturing" All the data and entries of the respondent will not be disclosed under any circumstances.

All questions and statements can be graded by giving points to show the level of your attitude. 4 point means you strongly agree with the statement, whereas giving no points shows disagreement. Please feel free to comment and provide insights under each question.

Name;
……
……..
Organisation;
……
……..
Current research
interestst……
……
……
……..

What is your area of interest/more relevant to your research?	NOT RELVANT	ONLY MENTIONED	PART OF THE RESEARCH	Main Topic
Lean manufacturing				
Life Cycle Assessment (LCA)				
The environment				
Six Sigma				
Supply Chain management				

Comments:
……
……
……
……
……
.

What are your motives to develop environmental practices through research:	Points			
Resource scarcity (e.g water, oil, etc)	1	2	3	4
Global warming and pollution	1	2	3	4

Protecting the ecological system and biodiversity	1	2	3	4
Social issues	1	2	3	4
To keep up with business requirements (e.g regulations, customers' demand)	1	2	3	4

Comments:
……
……
……

Governments gradually increase the requirements for greener processes and products. Is it time for manufacturers to invest more in new technologies (e.g new material, renewable energy, etc.)	Points			
Manufacturers should keep their focus on operational effectiveness. It is still early for change.	1	2	3	4
Manufacturers should start a gradual change to new technologies to spread the investment over time.	1	2	3	4
They should wait until it is mandatory to change to new technologies (e.g government regulations, market requirements, etc) even if it is more expensive to do so.	1	2	3	4
Cannot generalise as this highly depends on the type of business.	1	2	3	4

Comments:
……
……
……

What are your views on research and studies merging Lean manufacturing and Six Sigma?	Points			
Beneficial, with Six Sigma being the dominant and Lean as an assistant	1	2	3	4
Beneficial, with Lean being the dominant and Six Sigma as an assistant	1	2	3	4
No more than a philosophical argument	1	2	3	4

Comments:
……
……
……

Lean manufacturing is needed prior to LCA because:	Points			
It eliminates waste, thus makes LCA more potential	1	2	3	4

It improves the supply chain integration, thus enhance the benefits of LCA	1	2	3	4
It ensures people's commitment to apply LCA recommendations	1	2	3	4
No, it is not needed, LCA can apply to mass manufacturers and still give clear results	1	2	3	4
	1	2	3	4

Comments:
……
……
……
……

Do you see any potential for improving the integration of Lean Six Sigma and LCA to enhance the sustainability of manufacturing firms?	Points			
	1	2	3	4
	1	2	3	4
	1	2	3	4
	1	2	3	4
	1	2	3	4

Comments:
……
……
……
……

Assessment of Sutainable Manufa...

Summary | Design Survey | Collect Responses | Analyze Results

CURRENT VIEW

+ FILTER | + COMPARE | + SHOW

No rules applied

Rules allow you to FILTER, COMPARE and SHOW results to see trends and patterns. Learn more »

SAVED VIEWS (1)

Original View (No rules applied)

+ Save as...

EXPORTS

SHARED DATA

No shared data

Sharing allows you to share your survey results with others. You can share all data, a saved view, or a single question summary. Learn more »

Share All

RESPONDENTS: 22 of 22

Export All | Share All

Question Summaries | Data Trends | Individual Responses

Respondent #22

#22

COMPLETE

Edit | Delete | Export

Collector: New Email Invitation (Email)
Started: Wednesday, June 18, 2014 10:11:13 AM
Last Modified: Wednesday, June 18, 2014 10:41:01 AM
Time Spent: 00:29:48
Email: simon.roberts@cranfield.ac.uk
IP Address: 78.149.18.37

PAGE 1

Q1: What is your area of interest/more relevant to your research?

Lean manufacturing	Part of the research
Life Cycle Assessment (LCA)	Mentioned
Man-made effects on the environment	Main topic
Six Sigma	Mentioned

Q2: What are your motives to develop sustainable practices through research?

Resource scarcity (e.g water, energy, land, etc)	High
Global warming and pollution	High
Protecting the ecological system and biodiversity	High
Social issues related to manufacturing	Medium
To keep up with business requirements (e.g regulations, customers' demand)	Medium
Other (please specify)	Because I don't believe that excuses, such as "we don't have the cash", or "the payback period is too long" are valid anymore.

Q3: Governments gradually increase the requirements for greener processes and products. Is it time for manufacturers to invest more in new technologies? (e.g new material, renewable energy, etc.)

Manufacturers should keep their focus on operational effectiveness. It is still early for change.	Low
Manufacturers should start a gradual change to new technologies to spread the investment over time.	High
They should wait until it is mandatory to change to new technologies (e.g government regulations, market requirements, etc) even if it is more expensive to do so.	Very low
Comments	The best thing for the government to do would be to set a gradually increasing tariff for oil prices.

Q4: What are your views on research and studies on merging Lean manufacturing and Six Sigma?

Beneficial, with Six Sigma being the main strategy and Lean as a tool.	Medium
Beneficial, with Lean being the main strategy and Six Sigma as a tool.	Low
No need for a standardized approach. A company could apply a compilation of both as appropriate.	High
Other (please specify)	I have seen companies do both in the pharmaceutical sector. It depends on the setting e.g. packaging (lean), product formulation (six sigma)

Q5: How efficiently can Life Cycle Assessment (LCA) studies in manufacturing companies influence change in the following:

Product Design	High
Process Design	Medium
Material Choice	Medium
Employees' thinking and involvement	Low
Other (please specify)	For most companies, doing an LCA for all of their product range is prohibitively expensive. The amount of resource needed to execute an LCA makes me dubious about how "efficiently" it can influence change in anything. Most people who are well informed have a good idea of the 'hotspots' in manufacturing and supply chains and can start making changes before going through the whole process of an LCA.

Q6: Lean manufacturing could be needed prior to LCA because:

It eliminates waste, thus gives LCA more potential.	Medium
It improves the supply chain integration, thus enhance the credibility and benefits of LCA.	Medium
It ensures people's commitment to apply LCA recommendations.	Medium
No, it is not needed; Lean does not add much to what LCA can illustrate.	Medium
Others	I don't see Lean as an antecedent to LCA. I would look at a company's environmental management capabilities before looking to extend Lean practices to include environmental impacts, or conducting any LCA activities.

Q7: How do you suggest integrating Lean Six Sigma and LCA to improve sustainable manufacturing practices?

Some version of a streamlined LCA could be used to highlight areas for Lean Six Sigma improvements. Be aware that the results of an LCA could highlight areas in the supply chain that may need Lean Six Sigma expertise more than the focal company.

Appendix B – Survey of Industry and a Sample Response

Invite

Dear Sir/Madam,

I am a researcher at Northumbria University and currently conducting a survey on manufacturing businesses in the UK to explore the current practices of improving production and environmental performance.

You have been selected to be part of this project because you are the production manager of a manufacturing company who is a member of The Association of Ductwork Contractors and Allied Services (ADCAS)

I appreciate that this could be a busy time for you, but I hope that you will take just a little time to participate in this brief web survey

I expect that it should take you approximately 15 minutes to complete the questionnaire. But you do not have to complete it all at once.

Please link to: https://www.surveymonkey.com/s/N8TWV9L

This is very important for my work, and I would be very grateful if you could help!

All information that you provide will remain confidential. If you have any questions about this survey please feel free to contact me by telephone or email.

Thank you for your time.

Manufacturing & the Environment Survey

Summary → Design Survey → Collect Responses → Analyze Results

CURRENT VIEW

+ FILTER + COMPARE + SHOW

No rules applied

Rules allow you to **FILTER**, **COMPARE** and **SHOW** results to see trends and patterns. Learn more »

SAVED VIEWS (1)

Original View (No rules applied)

+ Save as...

EXPORTS

SHARED DATA

No shared data

Sharing allows you to share your survey results with others. You can share all data, a saved view, or a single question summary. Learn more »

Share All

RESPONDENTS: 36 of 36 Export All Share All

Question Summaries Data Trends **Individual Responses**

Respondent #2 All Pages

#2

COMPLETE Edit Delete Export

Collector: Email Invitation 2 (Email)
Started: Monday, November 24, 2014 10:24:48 AM
Last Modified: Monday, November 24, 2014 10:36:22 AM
Time Spent: 00:11:33
First Name: HEVAC
Email: sales@uk.ebmpapst.com
IP Address: 213.121.200.190

PAGE 2: General Information

Q1: Please provide the following information:

Name of the business unit	ebm-papst UK Ltd
Size of the business unit based on number of employees (1-49 Small, 49-249 Medium, over 249 Large)	Medium
Your Name (optional)	Dan Hopkins
Your Job title	Technical Manager
Description of the dominant activity (refers to the main activity the business relays on)	Fan supplier
Certificates the business acquires (e.g. ISO9000, ISO14000, EMAS)	ISO9001, ISO14001

PAGE 3: Market Conditions

Q2: How do you perceive the conditions in which your business operates with regards to:

Market Concentration (1) Few companies- (5) Many companies	4
Competition level (1) Very low - (5) Very high	4
Main customers (1) Small&Meduim Size Enterprises, (2)Large companies, (3) Government Units (4) End Users (5) Distributors	2, 3
Bargaining power of suppliers (1) Very low - (5) Very high	3
Bargining power of customers (1: Very low - 5: Very high)	4

Q3: What is the importance of the following attributes to win orders from your major customers?

Lower selling price	3
Better design and quality	Very important
Faster and more reliable deliveries	4

Wider product range	4
More environmentally-friendly products and processes	4

PAGE 4: Improvement Investments and Programs

Q4: For the following investments, what is the annual expenditure as a percentage of total sales?

(1) Product related Research & Development %	5%
(2) Improvement of Process Design and Equipments (e.g. changing manufacturing layout as in cellular manufacturing, Improving handling and storage, automation, acquiring hi-tec such as 3D printing, laser cutting, etc.) %	1%
(3) Workforce/staff Training and Education (e.g. safety awareness, advanced manufacturing techniques, etc.) %	1%
(4) Environmental Sustainability (Investments to reduce emissions /over consumption of water/energy etc., sustainability labeling, education specific to environmental awareness, etc.) %	1%

Q5: Indicate the level of implementation of the following programs (in the last three years):

Lean Manufacturing (cellular layout, one piece/small batch flow, Just-In-Time deliveries, Value Stream Mapping, etc.)	Very High
Six Sigma (utilizing the Define Measure Analyse Improve Control (DMAIC) cycle for projects, Six Sigma teams taking on projects, etc.)	Very Low
Operations Department's involvement in forming the company's marketing strategy.	Low
Knowledge & Involvement of employees (e.g. training, empowerment, encouraging solutions to work problems, incentives)	High
Supply Chain Integration (cooperation with suppliers and/or customers in training programs, R&D, Design, etc.)	Fair

PAGE 5: Description and performance of operations

Q6: Which of the following techniques have you practiced in your company:-Lean tools.-Six Sigma, management and statistical tools-Other quality management tools And what are the main synergies and conflicts if you have used more than one of theses techniques?

Respondent skipped this question

Q7: Please describe the following:(Please provide your answer in relation to your main product)

The complexity of the bill of materials (BOM) of your main product (1)very few part/one line BOM - (5)many parts/very complex BOM)	5
Direct material percentage of total cost, (1)1-20%, (2)20-40% (3)40-60% (4)60-80% (5) 80-99%)	3
Indirect material percentage of total cost, including energy and water (1)1-5%, (2)5-10% (3)10-15% (4)15-20% (5) 20-99%)	2
Process steps required to finish the job (1)very few steps - (5) a lot of steps	4

Q8: Please tick the appropriate scale to describe your manufacturing performance compared to 2-3 years ago in terms of:

Product Quality	Unchanged
Labour productivity	Increased
Total production costs	Decreased
Delivery speed and reliability	Unchanged
Workers' motivation, involvement & satisfaction	Increased
Materials, water & energy consumption (per unit)	Decreased
Waste & pollution emissions	Sharply decreased
Joint efforts with suppliers/customers to improve performance	Increased

PAGE 6: Environmental Sustainability

Q9: _

(1) What environmentally-friendly activities do you do?	Green Day initiative / Green Tech Philosophy
(2) Do you have an Environmental Management System (EMS) in place? if not, why?	Yes
(3) Do you do any decision making/joint efforts related to environmental issues with your suppliers and customers?	Yes
(4) Have you conducted a Life-Cycle-Assessment (LCA) to evaluate your products' impact on the environment?	Yes
(5) If LCA was conducted, what are the main findings from your prospective?	80% of the Life cost is the use phase (energy consumption)
(6) Was the Marketing Department involved in defining the goal of the LCA?	No
(7) Has the LCA study made you focus on specific wastes that were not considered before? Please specify.	Leaner production techniques, end of life recyclability

Appendix C – Interview Survey

Northumbria University
CEIS Research Ethics Sub-Committee
CONSENT FORM – C

Project Title: A Framework To Integrate Lean Six Sigma and Life-Cycle Assessment In Sustainable Manufacturing

Name of the Researcher: Haitem Fargani

Name of participant:

Participating Organisation:

I consent to take part in this project. ☐

I have had the project explained to me by the researcher/ consultants **and been given an information sheet**. I have read and understand the purpose of the study. ☐

I am willing to be interviewed. ☐

I understand and am happy that the discussions I will be involved in may be audio-taped and notes will be taken. ☐

I understand I can withdraw my consent at any time, without giving a reason and without prejudice. ☐

I know that my name and details will be kept confidential and will not appear in any printed documents. ☐

- The tapes and any personal information will be kept secure and confidential. They will be kept by the researcher/project consultants until the end of the project. They will then be disposed of in line with Northumbria University's retention policy.
- Anonymised summaries (if required) will be produced from the discussions to be used in the project report and in other publications. None of the participants will be identified in the project report or in other publications based on this project. Copies of any reports or publications will be available on request to participants.

Signed: **Date:**

Researcher: I confirm that I have explained the project to the participant and have given adequate time to answer any questions concerning it.

Signed: **Date:**

Invite

Dear Sir,

I would like to take this opportunity to thank you for participating in the first phase of our research on assessing the environmental impact of UK manufacturing. The findings from the 1st questionnaire have helped us to understand the importance of engaging sustainability in manufacturing.

Just a brief introduction of our research that the aim of this doctoral research is to develop a framework by integrating Lean and Six Sigma systems with an environmental impact assessment technique, namely Life Cycle Assessment (LCA). This would enable manufacturers to have a broader picture of assessing the environmental impacts as a result of reducing wastes and costs. The framework will also promote an optimum use of funds allocated to reduce the environmental impact and provide companies like yours with more information to support decision making.

In order to develop this framework, it is essential that I collect more information about your view and experience in addressing environmental issues within a manufacturing environment. The process of collecting further data to fulfil my research objectives will be through a short face-to-face interview with you. The questions I intend to cover are: (1) Sustainable Practices, (2) Internal Communication, (3) Lean Six Sigma and Life Cycle Assessment. The interview process will last around 45 minutes and all responses will be treated with the utmost confidence and no single set of responses will be identifiable.

Please let me know whether or not you accept my invitation. If you do accept, please let me knowthe most convenient time within the next two months so that I can schedule a meeting with you.

Thank you for your kind consideration and your support for my research.

Brief Introduction

Sustainable manufacturing has been defined as "*the set of technical and organisational solutions contributing to the development and implementation of innovative methods, practices and technologies, in the manufacturing field, for addressing the world-wide resources shortages, for mitigating the excess of environmental load and for enabling an environmentally benign lifecycle of products.*"

The aim of this doctoral research is to develop a framework combining Lean and Six Sigma systems with an impact assessment tool, namely Life Cycle Assessment (LCA). This would enable manufacturers to have a broader picture of environmental impacts while reducing wastes and costs. The framework will also promote optimum use of funds allocated to reduce the environmental impact. It will also provide more information to support decision making.

Environmentally-friendly practices

1) What Environmentally-friendly practices do your company do? (e.g. recycling, waste reduction, use of renewable energy)

2) What has been the company's motivation for wanting to consider the environment? What was the situation at the time? How was the change triggered? What happened? Can you prioritise the following motives?

- Consumer demand - Investors/shareholders requirements

- Government Legislations - Cost reduction - Leadership's personal interest

3) What was demanded of you to do as a (general/production/quality) manager? (e.g. waste reduction, energy consumption, emissions, recycling)

- What were the challenges you encountered? How would you rank these challenges in terms of importance for significant sustainability development? Please rank:
  -top management commitment, budget, technology and know-how, employees' involvement
- What is your current/next issue in the Sustainability journey that you have to tackle?
- How do you plan to resolve this issue?

4) Government regulations have been continuously introduced to address sustainability requirements. What were the regulation change that affected/challenged you the most?

5) Within the organisation, what or who promotes for sustainability? (e.g. new CEO or setting up a new sustainability department). What events took place to promote and increase awareness of sustainability?

6) Within your network of customers and suppliers, do you discuss environmentally-friendly activities? What conditions existed that supports sustainability (e.g. good communication and integration of the supply chain)?

7) What measures do the company use to assess the impact on the environment? Is there an Environmental Management System (EMS) in place? How effective EMS is? How much managerial time and effort does it require? Are you ISO14001 certified?

8) How do you involve employees in sustainability programs? Do you provide education/training/events?

Internal communication questions

9) How often are regular meetings held between departments?

10) Does your organization use cross-departmental teams for problem solving, system design, manufacturing and coordinating product lines?

11) Are there any permanent liaison positions within this organization, whose roles and responsibilities relate to coordinating manufacturing activities with other departments?

12) Is the co-ordination between departments (e.g. marketing, engineering, manufacturing) primarily by spontaneous contact between managers of the various departments?

Lean Six Sigma and Life Cycle Assessment questions

13) Has the company deployed Lean or Six Sigma techniques?

14) What belts of Six Sigma do you have in your company? In which departments? Please provide examples of wining Lean Six Sigma projects

15) If both techniques are used, can you describe the harmony and conflicts between them?

16) Have you conducted a LCA? Why (not)? What department was responsible for carrying out the study?

17) What was the impact of the LCA findings on your department and the company's strategy in general?

18) What training related to LSS and LCA do you provide? How often? How many persons for?

Questions about the respondent

19) How do you perceive sustainability? i.e., do you see it in your daily activities the same way you see quality and cost for example?

20) Do you do any environmently friendly activities on a personal level?

21) How are you updated about environmental issues in general? For example; requirements, changes to be made, etc.? what is your source of information?

Appendix D – Additional Statistical Results

Graph

Notes

Output Created		16-NOV-2016 15:08:36
Comments		
Input	Data	C:\Users\W13033664\Documents\Industry Survey.sav
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	N of Rows in Working Data File	36
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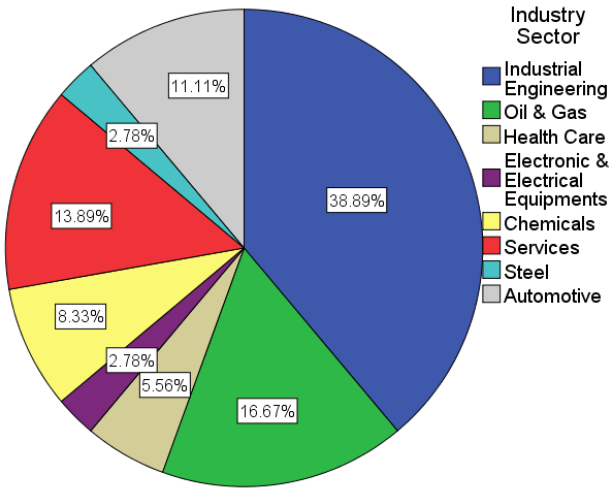
Resources	Processor Time	00:00:00.23
	Elapsed Time	00:00:00.22



Frequencies

Notes

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	Cases Used	Statistics are based on all cases with valid data.
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Statistics

Size of business

N	Valid	36
	Missing	0

Size of business

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Small	7	19.4	19.4	19.4
	Medium	13	36.1	36.1	55.6
	Large	16	44.4	44.4	100.0
	Total	36	100.0	100.0	

```
FREQUENCIES VARIABLES=Pric_2winOrdr Qlity_2winOrdr Dlivry_2winOrdr Rnge_2winOrdr
```

```
Envi_2winOrdr
  /STATISTICS=MEAN
  /ORDER=ANALYSIS.
```

Frequencies

Notes

Output Created		16-NOV-2016 15:30:27
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	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	36
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data.
Syntax		FREQUENCIES VARIABLES=Pric_2winOrdr Qlity_2winOrdr Dlivry_2winOrdr Rnge_2winOrdr Envi_2winOrdr /STATISTICS=MEAN /ORDER=ANALYSIS.
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.02

Statistics

		Importance of price to win orders	Importance of Quality to win orders	Importance of faster and reliable deliveries to win orders	Importance of a wider product range to win orders	Importance of environmentaly-friendly products to win orders
N	Valid	31	31	31	31	31
	Missing	5	5	5	5	5
Mean		3.48	4.45	4.45	3.39	3.26

Frequencies

Notes

Output Created		16-NOV-2016 15:50:34
Comments		
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	Active Dataset	DataSet1
	Filter	Cmpny_Size > 2 (FILTER)
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	16
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data.
Syntax		FREQUENCIES VARIABLES=Pric_2winOrdr Qlity_2winOrdr Dlivry_2winOrdr Rnge_2winOrdr Envi_2winOrdr /STATISTICS=MEAN /ORDER=ANALYSIS.
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.02

Statistics

		Importance of price to win orders	Importance of Quality to win orders	Importance of faster and reliable deliveries to win orders	Importance of a wider product range to win orders	Importance of environmentaly-friendly products to win orders
N	Valid	12	12	12	12	12
	Missing	4	4	4	4	4
Mean		3.33	4.67	4.42	3.67	4.08

Frequency Table

Frequencies

Notes

Output Created		16-NOV-2016 15:53:03
Comments		
Input	Data	C:\Users\W13033664\Documents\Industry Survey.sav
	Active Dataset	DataSet1
	Filter	Cmpny_Size <= 2 (FILTER)
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	20
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics are based on all cases with valid data.
Syntax		FREQUENCIES VARIABLES=Pric_2winOrdr Qlity_2winOrdr Dlivry_2winOrdr Rnge_2winOrdr Envi_2winOrdr /STATISTICS=MEAN /ORDER=ANALYSIS.
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.01

Statistics

		Importance of price to win orders	Importance of Quality to win orders	Importance of faster and reliable deliveries to win orders	Importance of a wider product range to win orders	Importance of environmentaly-friendly products to win orders
N	Valid	19	19	19	19	19
	Missing	1	1	1	1	1
Mean		3.58	4.32	4.47	3.21	2.74

Frequency Table

Descriptives

Notes

Output Created		16-NOV-2016 16:51:45
Comments		
Input	Data	C:\Users\W13033664\Documents\Industry Survey.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	36
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	All non-missing data are used.
Syntax		DESCRIPTIVES VARIABLES=Invst_RD Invst_Proces Invst_Training Invst_Envromnt /STATISTICS=MEAN STDDEV MIN MAX.
Resources	Processor Time	00:00:00.02
	Elapsed Time	00:00:00.06

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
%Spending on product related Research and Development %	21	.0	30.0	8.252	6.7177
%Spending on process and equipments %	20	1.0	25.0	6.290	6.0865
%Spending on staff training and education%	21	.0	10.0	3.381	2.7879
%Spending on environmental improvements%	21	.0	10.0	2.971	2.8700
Valid N (listwise)	20				

Descriptives

Notes

Output Created		16-NOV-2016 17:01:13
Comments		
Input	Data	C:\Users\W13033664\Documents\Industry Survey.sav
	Active Dataset	DataSet1
	Filter	Cmpny_Size <= 2 (FILTER)
	Weight	<none>

	Split File	<none>
	N of Rows in Working Data File	20
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	All non-missing data are used.
Syntax		DESCRIPTIVES VARIABLES=Invst_RD Invst_Proces Invst_Training Invst_Envromnt /STATISTICS=MEAN STDDEV MIN MAX.
Resources	Processor Time	00:00:00.03
	Elapsed Time	00:00:00.02

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
%Spending on product related Research and Development %	17	.0	30.0	7.959	6.6889
%Spending on process and equipments %	16	1.0	25.0	6.706	6.5793
%Spending on staff training and education%	17	.0	10.0	3.353	3.0040
%Spending on environmental improvements%	17	.0	10.0	2.906	3.1634
Valid N (listwise)	16				

```
DESCRIPTIVES VARIABLES=Lean SixSigma OpDep_MktStg Emply_involv SplChin_Intgr
  /STATISTICS=MEAN STDDEV MIN MAX.
```

Descriptives

Notes

Output Created		16-NOV-2016 17:24:10
Comments		
Input	Data	C:\Users\W13033664\Documents\Industry Survey.sav
	Active Dataset	DataSet1
	Filter	Cmpny_Size <= 2 (FILTER)

	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	20
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	All non-missing data are used.
Syntax		DESCRIPTIVES VARIABLES=Lean SixSigma OpDep_MktStg Emply_involv SplChin_Intgr /STATISTICS=MEAN STDDEV MIN MAX.
Resources	Processor Time	00:00:00.00
	Elapsed Time	00:00:00.01

Descriptives

Notes

Output Created		16-NOV-2016 17:34:10
Comments		
Input	Data	C:\Users\W13033664\Documents\Industry Survey.sav
	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	36
Missing Value Handling	Definition of Missing	User defined missing values are treated as missing.
	Cases Used	All non-missing data are used.
Syntax		DESCRIPTIVES VARIABLES=Lean SixSigma OpDep_MktStg Emply_involv SplChin_Intgr /STATISTICS=MEAN STDDEV MIN MAX.
Resources	Processor Time	00:00:00.03
	Elapsed Time	00:00:00.01

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
The level of implementation of lean manufacturing	23	1	5	3.13	1.486

The level of implementation of Six Sigma	24	1	5	2.38	1.408
Operations Department's involvement in forming the company's strategy	24	1	5	3.54	1.215
The level of power given to employees	25	1	5	3.76	1.091
The level of supply chain integration	25	1	5	3.32	1.282
Valid N (listwise)	23				

Crosstabs

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Industry Sector * The level of implementation of lean manufacturing	23	63.9%	13	36.1%	36	100.0%
Industry Sector * The level of implementation of Six Sigma	24	66.7%	12	33.3%	36	100.0%
Industry Sector * Operations Department's involvement in forming the company's strategy	24	66.7%	12	33.3%	36	100.0%
Industry Sector * The level of power given to employees	25	69.4%	11	30.6%	36	100.0%
Industry Sector * The level of supply chain integration	25	69.4%	11	30.6%	36	100.0%

Industry Sector * The level of implementation of lean manufacturing Crosstabulation

			The level of implementation of lean manufacturing	
			Very low	Low
Industry Sector	Industrial Engineering	Count	3	0
		% within Industry Sector	37.5%	0.0%

	Oil & Gas	Count	1	0
		% within Industry Sector	25.0%	0.0%
	Health Care	Count	0	0
		% within Industry Sector	0.0%	0.0%
	Electronic & Electrical Equipments	Count	0	0
		% within Industry Sector	0.0%	0.0%
	Chemicals	Count	0	1
		% within Industry Sector	0.0%	50.0%
	Services	Count	1	0
		% within Industry Sector	50.0%	0.0%
	Steel	Count	0	1
		% within Industry Sector	0.0%	100.0%
	Automotive	Count	0	1
		% within Industry Sector	0.0%	33.3%
Total		Count	5	3
		% within Industry Sector	21.7%	13.0%

Industry Sector * The level of implementation of lean manufacturing Crosstabulation

			The level of implementation of lean manufacturing	
			Not Sure	High
Industry Sector	Industrial Engineering	Count	2	0
		% within Industry Sector	25.0%	0.0%
	Oil & Gas	Count	0	3
		% within Industry Sector	0.0%	75.0%
	Health Care	Count	0	2
		% within Industry Sector	0.0%	100.0%
	Electronic & Electrical Equipments	Count	0	0
		% within Industry Sector	0.0%	0.0%
	Chemicals	Count	1	0
		% within Industry Sector	50.0%	0.0%
	Services	Count	1	0
		% within Industry Sector	50.0%	0.0%
	Steel	Count	0	0
		% within Industry Sector	0.0%	0.0%
	Automotive	Count	0	1
		% within Industry Sector	0.0%	33.3%
Total		Count	4	6
		% within Industry Sector	17.4%	26.1%

Reliability

Scale: ALL VARIABLES

Case Processing Summary

		N	%
Cases	Valid	18	51.4
	Excluded[a]	17	48.6
	Total	35	100.0

Reliability Statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.602	.682	4

Inter-Item Correlation Matrix

	Certificates the business acquire such as ISO9000 etc	Importance of environmentaly-friendly products to win orders	Comany has Environmental Management System	Company conducted Life Cycle Assessment
Certificates the business acquire such as ISO9000 etc	1.000	.432	.684	.073
Importance of environmentaly-friendly products to win orders	.432	1.000	.635	.018
Comany has Environmental Management System	.684	.635	1.000	.255
Company conducted Life Cycle Assessment	.073	.018	.255	1.000

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Squared Multiple Correlation
Certificates the business acquire such as ISO9000 etc	4.28	3.507	.525	.480
Importance of environmentaly-friendly products to win orders	2.50	1.676	.488	.426
Comany has Environmental Management System	5.11	3.634	.786	.654
Company conducted Life Cycle Assessment	5.28	4.918	.092	.119

Item-Total Statistics

	Cronbach's Alpha if Item Deleted
Certificates the business acquire such as ISO9000 etc	.447
Importance of environmentaly-friendly products to win orders	.596
Comany has Environmental Management System	.383
Company conducted Life Cycle Assessment	.678