CRANFIELD UNIVERSITY

MOUSTAFA ELNADI

# AN INNOVATIVE FRAMEWORK FOR IMPLEMENTING LEAN PRINCIPLES IN PRODUCT- SERVICE SYSTEM

SCHOOL OF APPLIED SCIENCE

PhD THESIS
Academic Year: 2011 - 2014

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This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

## ABSTRACT

The aim of this research project is to develop an innovative framework to implement lean principles in Product-Service System (PSS) with the capability of assessing the leanness level of the services offering process. The framework comprises three implementation phases namely: assessment of the current state, developing a future state, and stabilising the new way of operations. Additionally, the framework covers the enablers, factors, and appropriate lean tools required for the successful implementation of lean practices in Product-Service System (PSS), as well as, the challenges that may obstacle the implementation process. The proposed framework has integrated an assessment model that provides a quantifiable measure of the leanness level of Product-Service System (PSS).

Five main enablers and thirty three factors emerging from these main enablers deemed to be critical for the successful implementation of lean practices in Product-Service System (PSS). Moreover, a series of eight inhibitors appeared to block the implementation process.

The Product-Service System leanness assessment model was developed upon three main levels, namely: enablers, criteria, and attributes. The first level contains five enablers. These enablers are supplier relationship, management leanness, workforce leanness, process excellence, and customer relationship. In the second level there are twenty one criteria such as: supplier delivery, culture of management and process optimisation. Finally, the third level consists of seventy three attributes. By using multi-grade fuzzy approach the PSS leanness index was computed and areas for further improvement were identified.

A combination of research methodology approaches has been employed in this research. Firstly, an extensive literature review related to lean and PSS was conducted. Secondly, the qualitative approach and the case study were selected as an appropriate methodology for this research, using semi-structured and structured interview techniques to gather the required data from experts who are involved in lean projects in their companies. Finally, validation of the results was carried out using real life industrial case studies and experts judgment.

Case studies demonstrate that the framework provides guidelines for manufacturing companies that aim to implement lean principles in Product-Service System (PSS). The framework enables manufacturing companies to better satisfy their customers' needs through responding quickly to their changing demands; to improve the service offering process through reducing the creation of wastes and non-value added activities; and to improve competitiveness through increasing customers' value. Additionally, the PSS leanness index is useful for improving the service offering process. The index provides manufacturing companies with a real insight into the leanness level of their service offering, as well as, it provides managers with a quantifiable measure of how lean their PSS is. The index identifies the gap between the current state and the future state and this helps in determining areas for further improvement.

**Keywords:**

Product-Service System, Leanness, Assessment, Fuzzy logic, Enablers, Challenges.

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Last, but not least, I would like to dedicate this thesis to the spirit of my beloved Brother Mohamed Elnadi who has been and always will be my best friend.

**MOUSTAFA ELNADI**

# LIST OF PUBLICATIONS

## Journal Papers

1. Elnadi, M. and Shehab, E. (2014), "A Multiple-Case Assessment of Product-Service System Leanness in UK Manufacturing Companies", *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, In Press. DOI: 10.1177/0954405414555561

2. Elnadi, M. and Shehab, E. (2014), "Main Enablers and Factors for Successful Implementation of Lean Principles in Product-Service Systems". *International Journal of Agile Systems and Management,* (Accepted)

3. Elnadi, M. and Shehab, E. (2014), "An Innovative Model for Assessing Product-Service System Leanness", *International Journal Operations and Production Management*, (Submitted)

## Conference Papers

1. Elnadi, M. and Shehab, E. (2014), "A conceptual model for evaluating Product-Service System leanness in UK manufacturing companies", *the 3rd International Through-life Engineering Services Conference (TESConf 2014),Cranfield University, Cranfield, UK, 04-05 November 2014, pp 281-286.*

2. Elnadi, M. and Shehab, E. (2014), "Critical Success Factors for Lean Implementation in Product-Service Systems", *the 12th International Conference on Manufacturing Research (ICMR 2014), Southampton Solent University, UK, 9-11 September 2014, pp 221-226.*

3. Saad, N., Al-Ashaab, A., Shehab, E. and Elnadi., M (2014), "Developing a Methodology of a New A3 Thinking Approach for Product Design Problem Solving", *the 12th International Conference on Manufacturing Research (ICMR 2014), Southampton Solent University, UK, 9-11 September 2014, pp 21-26.*

4. Elnadi, M., Shehab, E., and Peppard, J. (2013) "challenges of lean thinking application in product-service system" *Proceedings of The 11th International Conference on Manufacturing Research (ICMR 2013), Cranfield University, Cranfield, UK, 19-20 September 2013, pp 461-466.*

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6. Elnadi, M., Shehab, E., and Peppard, J. (2012) "Product-Service System in the Egyptian Manufacturing Sector: Issues and Challenges" *Proceedings of The 10th International Conference on Manufacturing Research (ICMR 2012), Aston University, Birmingham, UK, 11-13 September 2012, pp 391-396.*

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| 5s | Sort, Set, Shine, Standardise, Sustain |
| AHP | Analytical Hierarchy Process |
| ANP | Analytical Network Process |
| BB | Black Belt |
| CSFs | Critical Success Factors |
| DFLSS | Design for lean six sigma |
| DMAIC | Define, Measure, Analyse, Improve, Control |
| EEPS | Eco-Efficient Producer Services |
| FMEA | Failure Mode and Effects Analysis |
| GB | Green Belt |
| IT | Information Technology |
| JIT | Just-In-Time |
| KPI | Key performance Indicator |
| LSS | Lean Six Sigma |
| MBB | Master Black Belt |
| PDSA | Plan, Do, Study, and Act |
| PSS | Product-Service System |
| SE | Service Engineering |
| SMED | Single Minute Exchange of Die |
| SMEs | Small and medium-sized enterprises |
| TPM | Total Productive Maintenance |

| | |
|---|---|
| TPS | Toyota Production System |
| TQM | Total Quality management |
| VOC | Voice of the customer |
| VSM | Value stream mapping |
| WIP | Work in process |

# CHAPTER 1

# 1 INTRODUCTION

## 1.1 Research Background

In the manufacturing industry, the importance of services is growing and the trend of servitization of products is obvious. Often, 65-75% of the employees in a traditional manufacturing enterprise perform ‘service sector’ roles. These roles range from production-related activities such as research, logistics, planning and maintenance, to product and process design. General support services are also required, such as accounting, finance, law, and personnel (Mont, 2002). Thus, there is a tendency now in manufacturing industries to use services to add value to customers, enhance their competitiveness and provide new business opportunities. One of the initiatives that reflect this new trend is Product-Service System (PSS).

Product-Service System (PSS) appeared for the first time in 1976 (Wang et al., 2011) and the first formal definition of PSS was published by Goedkoop et al., in 1999. The concept of PSS is originating from the Scandinavians (Goedkoop et al., 1999; Lamvit, 2001; Mont, 2000, 2004) and focuses in delivering value in use via the combination of products and services (Baines et al., 2007).

PSS can be defined as a mix of tangible products and intangible services, designed and combined to be competitive, satisfy customer needs and have lower environmental impact (Mont 2001, Tukker and Tischner 2006, Maussang et al., 2009). Baines et al., (2007) mentioned that the main idea beyond PSS is the 'sale of use' rather than the 'sale of the product'. Thus, customers pay for using the product rather than its purchase. PSS aims to combine the tangible product with the intangible service elements and create a system that can satisfy customers need in a better way (Doultsinou et al., 2009). Many companies successfully applied PSS. For example, Rolls-Royce offers 'Total Care Package' and 'Power by the Hour' rather than selling the engine. Also, Toyota offers 'Do not buy a forklift' to their customers. Moreover, Xerox offers their customers a fixed price per copy not to buy the machine (Wang et al., 2011). Due to the possible benefits gained by implementing PSS, many researchers from different background have investigated the implementation of this new industrial trend. Many terminologies have been proposed to describe this new industrial trend such as functional sales, service engineering, functional products, and servitization.

Lean manufacturing was developed from the Toyota Production System (TPS) with the aim of the continuous identification and elimination of waste from manufacturing processes (Serrano et al., 2008; Womak and Jones, 1996). Lean is most frequently associated with the elimination of seven types of wastes namely, overproduction, over processing, waiting, transportation, defects, inventory and storage (Shah and Ward, 2007). Many researchers and authors have studied lean manufacturing and they have viewed it from different angle. There are many formal definitions of lean manufacturing. Liker and Wu (2000) defined it as a philosophy of manufacturing that focuses on delivering the highest quality product on time and at the lowest cost. Shah and Ward (2007) defined it as "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability". The idea beyond lean is to minimise waste and non-value-added activities or steps, and improve the value-added activities or steps (Womack and Jones, 1996). The goal of lean manufacturing is to reduce waste in terms of human effort, inventory, time to market, and manufacturing space, and to become highly responsive to customer demand while producing world-class quality products in the most efficient and economic manner (Singh et al., 2006). Thus, lean is about delivering the most value from the customers' perspective while consuming the fewest resources. By implementing lean principles, companies can achieve many results, including: higher quality products and services, increased market share, revenue growth, higher productivity, better customer focus, and faster response to changing market conditions (Radnor et al., 2006).

In recent years, it was found that lean has been widely applied in both the manufacturing and the non-manufacturing sectors. Womack and Miller (2005) stated that lean is not a manufacturing tactic only, but a management strategy that is applicable to all organisations because it improves business processes. Non-manufacturing sectors that have applied lean include for instance, insurance companies (Swank, 2003), NHS (Esain et al., 2008), and universities (Balzer, 2010; Radnor and Bucci, 2011). Lean implementation includes a wide variety of management practices that can be implemented in the manufacturing and the non-manufacturing sectors. Some of these practices are: (1) Total Quality Management (TQM); (2) Just-In-Time (JIT); (3) Total Productive Maintenance (TPM); (4) Kaizen and (5) Value Stream Mapping (VSM) (Shah and Ward, 2007; Narasimhan et al., 2006; Camacho-Minano et al., 2013). However, the implementation of lean practices in the manufacturing and the non-manufacturing sectors is growing; few companies are successful in their implementation process (Baker, 2002; Tracey and Flinchbaugh, 2006). There are many lean implementation obstacles and many companies have great difficulty in implementing lean principles.

Since lean principles are applicable to any process, then lean principles can be applied in the service offering process that the PSS provider uses to deliver services to customers as presented in Figure 1.1. The implementation of lean principles in Product-Service System (PSS) is essential for adding value to customers by providing services with higher quality and lower leads time via using fewer, but right resources.

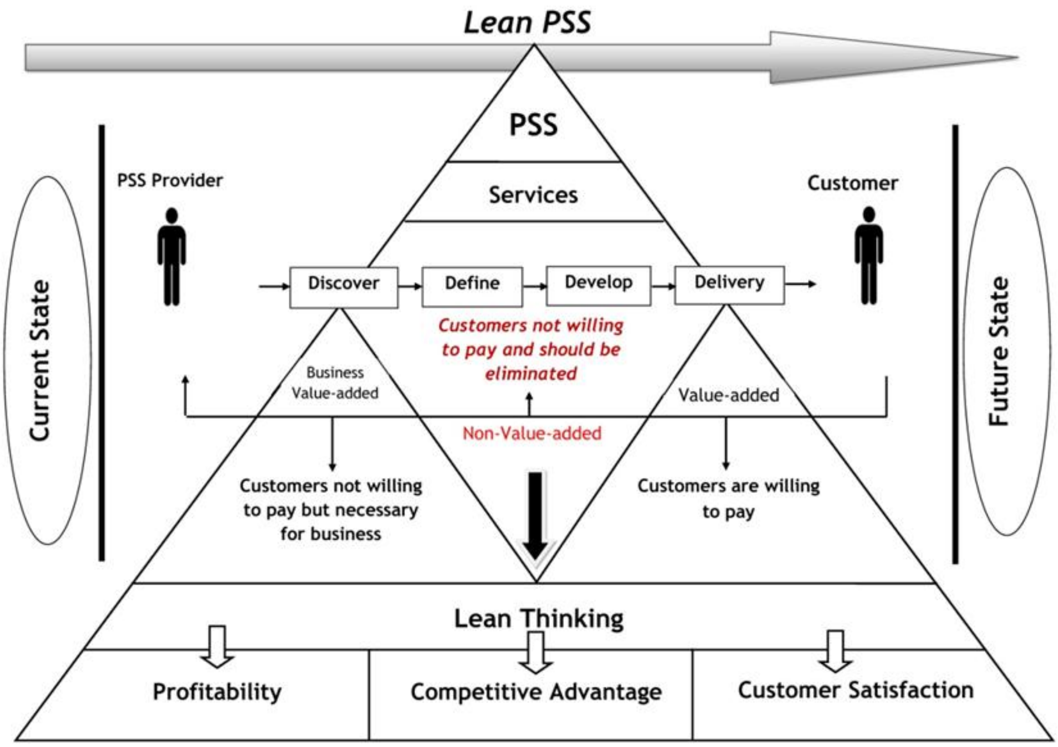



**Figure 1.1 Lean PSS**

The main idea beyond lean Product-Service System (PSS) is the removal of wastes from the service offering process by distinguishing value-added activities or steps from non-value-added activities or steps. Lean PSS can be defined as the application of lean principles to the service offering processes that PSS providers use (Elnadi et al., 2012). Lean PSS emphasises understanding customer value and focuses on the service offering processes to provide the perfect value to the customer through a perfect value creation process that has the minimum waste. Through the implementation of lean practices in the service offering process, manufacturing companies will be able to respond to changing customer desires with high variety, high quality, low cost product and service mix; and with very fast throughput times.

The status of lean PSS implementation can be measured by PSS leanness. Elnadi and Shehab (2014a, b) defined Product-Service System (PSS) leanness as “the degree of the adoption and implementation of the lean principles in the process of providing services to customers”. PSS leanness can be used as assessment parameter to measure the lean status of the process of providing services to customers (Elnadi and Shehab, 2014a, b). PSS leanness answers the questions of: how lean the service offering process is and how lean the service offering process should be.

## 1.2 Research Motivation

In today’s competitive market, manufacturing companies are more focused on the improvement of core competitiveness. Manufacturing companies try to improve and develop their ability for competition through modern manufacturing initiatives and from these initiatives are lean manufacturing and Product-Service System (PSS). Lean and PSS can lead to dematerialisation through reducing the creation of wastes and the consumption of raw materials; improving customers’ satisfaction by meeting customers’ needs better and improving competitiveness through increasing customers’ value (Elnadi and Shehab, 2014b). Thus, an important motivation of this research relates to its ambition to combine lean practices and PSS.

Although the concept of lean has been applied in both the manufacturing and non-manufacturing sectors, Liker and Rother (2011) found that about two percent of companies with a lean program have achieved the expected results. Additionally, Baker (2002) reported that the success percentage of UK organisations on lean implementation is less than 10%. Tracey and Flinchbaugh (2006) stated that while ‘going lean’ may be a powerful means to improve a business, too few organisations are able to successfully do so.

Therefore, the implementation of lean can be considered difficult and challenging and few companies succeed in their lean journey. To avoid mistakes in lean implementation, there is a need to define a well-planned framework for the successful lean implementation. While many attempts have been made to create a useful framework for lean implementation in the manufacturing sector and the non-manufacturing sector, none of the existing frameworks have tried to develop a framework for implementing lean in Product-Service System (PSS). The lack of previous studies that examined the implementation of lean practices in PSS is another reason for conducting this research. This is associated with lack of existing research that examines and investigates the enablers, challenges, and tools of implementing lean practices in PSS.

Moreover, most of the previous studies focused on how to make a manufacturing or a non-manufacturing process or a system leaner by implementing lean principles, tools, and techniques. Few attempts were made to precisely define leanness in the context of assessing lean status, although the leanness measurement gains importance as it indicates the leanness performance of the organisation. Little effort made on: how to make the service offering process leaner, determining how lean the service offering process is, determining how lean the service offering process should be, and determining how to achieve the desired leanness level in the service offering process. This presents another motivation for conducting this research. Under these circumstances, the aim of this research project is to develop an innovative framework to implement lean principles in Product-Service System (PSS) with the capability of assessing the leanness level of the services offering process.

## 1.3 Research Scope

The outcome of this research can be used by large manufacturing companies that apply Product-Service System and keen to implement lean practices in the service offering process. The outcome of this research has the capability of identifying the phases and tasks required for the successful implementation of lean practices in the services offering process. The research offers a description of what these phases entail, and a guideline for the sequence in which these phases should be implemented. It also emphasises what must be done to recognise the desired benefits within short time and ensures continuous improvement. In addition, the study covers the enablers, factors, and lean tools required for the successful implementation of lean in PSS, as well as, all the challenges that may obstacle the implementation process. Moreover, the research project has integrated an assessment model that provides a quantifiable measure of the PSS leanness level.

Although the scope of this research is limited to large manufacturing companies that apply PSS and implement lean principles or keen to implement lean principles, the concept of PSS leanness measurement can possibly be applied to other circumstances. Potential extensions of the research scope include non-manufacturing sectors. The way and cost to adapt and implement the proposed assessment model in these circumstances is beyond the current research.

## 1.4 Aim and Objectives

The aim of this research is to develop an innovative framework to implement lean principles in Product-Service System (PSS) with the capability of assessing the leanness level of the services offering process.

The main objectives of the research are to:

1 Understand the current industrial practices and state of the art in Product-Service System (PSS) and lean.
2 Determine the key challenges of implementing lean practices in Product-Service System (PSS).
3 Develop a framework for the implementation of lean principles in Product-Service System (PSS).
4 Identify the main enablers and factors that enable manufacturing companies to implement lean practices in Product-Service System (PSS).
5 Specify the most appropriate lean tools that can be used to implement lean principles in Product-Service System (PSS).
6 Develop a model to assess Product-Service System (PSS) leanness and provide leanness index for the service offering process.
7 Validate the research results through case studies and experts judgement.

## 1.5 The Collaborating Organisations

Three large UK manufacturing companies participated in this research. All of these companies have applied PSS successfully and keen to implement lean practices. Due to confidentiality agreements, the companies name will not be disclosed and will be referred as company (A), company (B) and company (C). The following presents a brief summary about each company.

Company (A) is a document management company that produces and sells portfolio of offerings such as: colour and black-and-white printing, publishing systems, multifunction devices, photocopiers, fax machines, and related consulting services. Company (A) started its quality journey in the early 90s and in 2003 six sigma and lean were integrated and driven as a company strategy. Improvement processes, tools and techniques were deployed across the company and cantered on improving business processes to create a higher level of customer satisfaction, quality and productivity.

Company (B) is a specialist train manufacturers that provides a comprehensive range of design, manufacturing, operating and maintenance service for the rail transport. Company (B) develops and markets the most complete range of systems, equipment and services in the railway sector, including rolling stock, infrastructure and signalling equipment, as well as maintenance operations. The company started its lean journey in 2006. The company deployed the lean concept throughout the whole company via a policy deployment process. The company uses a wide variety of lean tools and techniques including Kaizen, 5s, daily management process, standard work, visual control, Key Performance Indicators (KPIs) and daily accountability process.

Company (C) is specialised in manufacturing commercial heavy vehicles. The Company offers customers comprehensive services in one stop shopping such as, service and repair contracts, fleet management, tailor made financing, leasing and insurance, flexible rental options and many other tailored services. Company (C) still in the early stage of lean implementation.

## 1.6 Thesis structure

This section presents the structure of this thesis. The thesis is divided into seven chapters as presented in Figure 1.2.The contents of each chapter are given below.

Chapter 1 outlines the fundamental research issue. Research background, motivation, scope, collaborating organisations and aim and objectives of this study are clearly mentioned in this chapter.

In Chapter 2, a structured account of existing literature is critically analysed. The two key areas covered in this literature review are Product-Service System (PSS) and lean. The objective is to provide a better understanding about the state of the art in these areas and identify any existing research gap.

Chapter 3 presents the research methodology developed to achieve the research aim and objectives. An analysis of the possible approaches and strategies to design this research was carried out, and the justification of the methodology selected is presented.

Chapter 4 reviews a number of relevant lean implementation frameworks, as well as, the current lean practices in three UK manufacturing companies. Later in this chapter, the author presents the proposed lean Product-Service System implementation framework along with a description of the main phases and steps of the framework.

In Chapter 5, the main factors and enablers for the successful lean implementation in the service offering process are presented, along with the challenges that hinder manufacturing companies to implement lean practices in Product-Service System (PSS). Additionally in the chapter, the most appropriate lean tools that can be used to implement lean practices in the service offering process are discussed. Later in this chapter the findings achieved are validated through experts' judgement.

Chapter 6 presents the development of the lean product-Service System assessment (PSS) model, along with the calculation of the Product-Service System leanness index for three UK manufacturing companies. Finally in this chapter the assessment model and the calculated indices are validated.

Finally, in Chapter 7 the work of this thesis is synthesised and the implications of the research findings are discussed. The main research contributions are stated, along with the limitations and the future research directions. Lastly, the overall conclusions are presented, demonstrating how the aim and the objectives have been achieved.

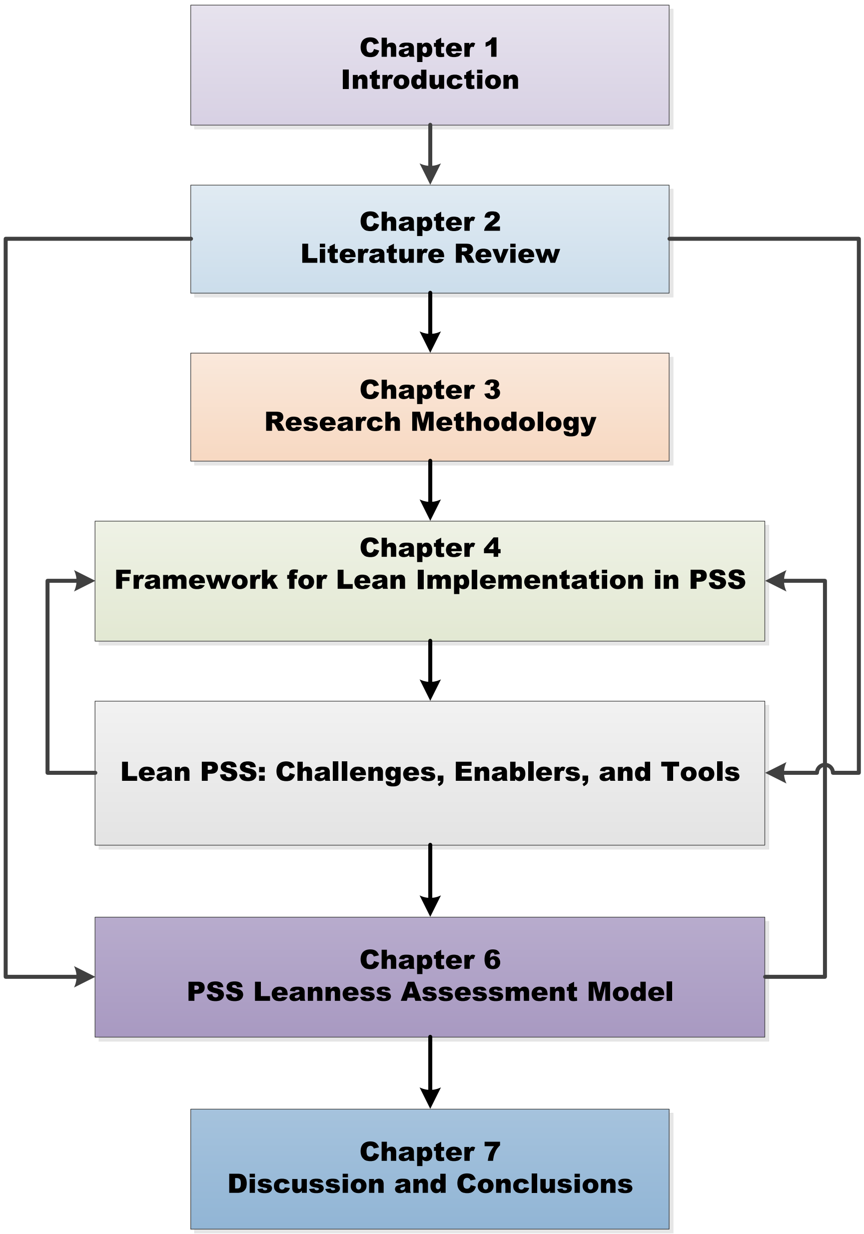



**Figure 1.2 Thesis Structure**

## 1.7 Chapter Summary

The aim of this chapter was to outline the fundamental research issues. To accomplish this aim, the research background has been first introduced. A quick review of Product-Service System (PSS) and lean journey has been provided initially, as well as, the implementation of lean in Product-Service System (PSS). Also, brief overview of the collaborating organisations was presented. The research motivation and research scope are also discussed. Accordingly, the research aim, objectives, and an overview of the thesis structure have also been given. This had to be outlined prior to the commencement of the next chapter which will present an analysis of the literature review.

# CHAPTER 2

## 2 LITERATURE REVIEW

In chapter 1, the research area and the aim of this study were presented. Chapter 2 focuses on the analysis and the synthesis of two main bodies of extant literature which are positioned at the centre of this thesis, namely, Product-Service System (PSS) and lean.

The aim of this chapter is to provide a better understanding about the state of the art in the areas of Product-Service System (PSS) and lean, as well as, identifying any existing research gap. In order to successfully achieve the aim of this chapter, this chapter is organised as presented in Figure 1.1.

Section 2.1 focuses on exploring the concept of Product-Service system (PSS). Section 2.2, is devoted to investigating the concept of lean. The research gap analysis is presented in Section 2.3. Finally, the chapter summary is presented in Section 2.4.

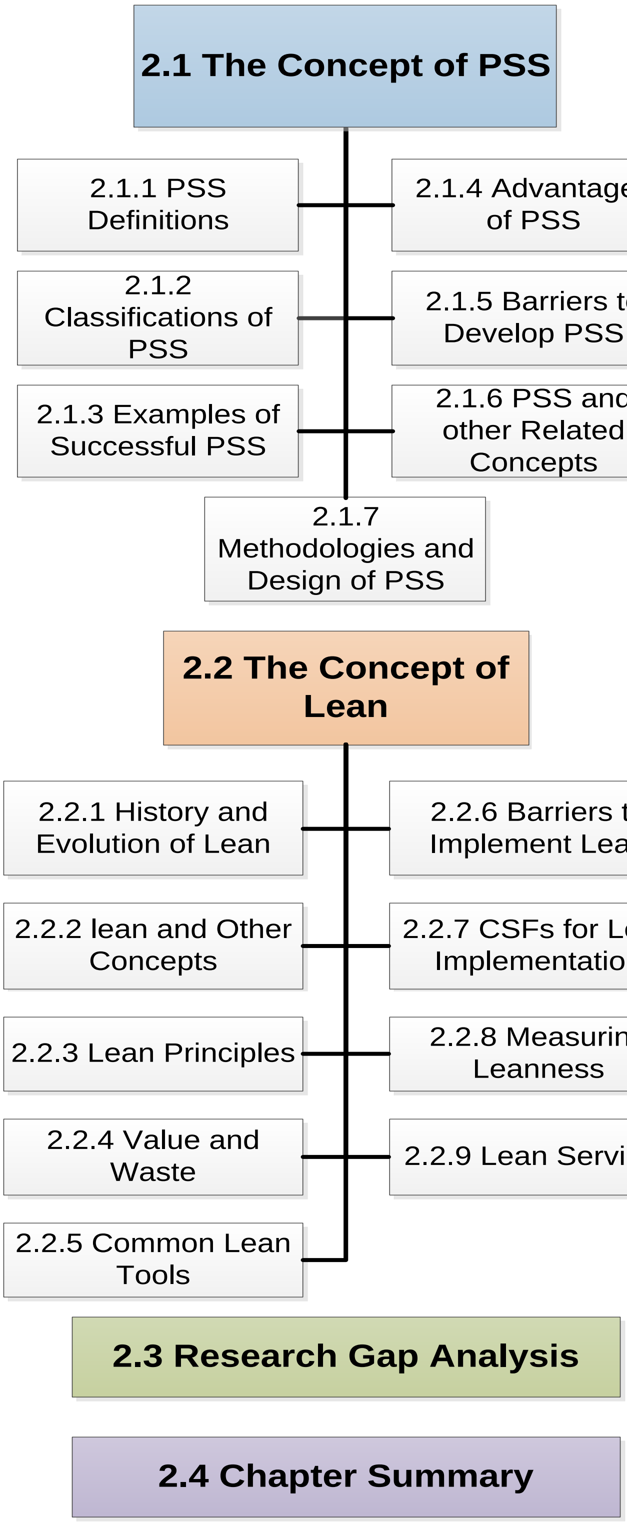



**Figure 2.1 Structure of the Literature Review**

PSS: Product-Service System, CSFs: Critical Success Factors

## 2.1 The Concept of Product-Service System (PSS)

Serious changes in recent years affected economies especially in the UK and the US. These changes shifted their economies towards the service industry. In the UK from 1950 to 1990 manufacture employment decreased from 35% to 20%, while the employment in services increased from 32% to 75%. The case is similar in the US where manufacture employment decrease from 25% to 15% and service employment increased from 40% to 62% (Roy, 2000). Selling products in some industries is considered as an old business model and it is more desirable to sell integrated solutions.

Now, manufacturers have turned to provide solutions including tangible products and intangible services to customers instead of providing a single product. Integrated solution can be considered as a combination of products and services customised for a set of customers that allows customers to achieve better outcomes than the sum of the individual components (Sawhney, 2006). Many researchers from different backgrounds have started to investigate, analyse and describe this new trend. An example that presents this industrial shift is the application of the Product-Service System (PSS) concept. The concept of PSS appeared in the late 1990’s in the Scandinavians with the aim of improving sustainability and reducing the consumption of materials (Goedkoop et al., 1999; Lamvik, 2001; Mont, 2004).

### 2.1.1 Product-Service System Definition

The original ideas of PSS appeared in 1976 (Stahel and Reday-Mulvey, 1981). The first article on PSS published in 1999 (Goedkoop et al., 1999). The earliest definition of PSS was “a marketable set of products and services capable of jointly fulfilling a users’ need” (Goedkoop et al., 1999). The product to service ratio can vary, either in terms of function fulfilment or economic value (Mont, 2002).

The basic elements that form PSS are: product, service, networks of players, supporting infrastructure, competitiveness, customer needs satisfaction and lower environmental impact (Goedkoop et al., 1999). Since then, the concept of PSS has been openly discussed in the literature for over a decade and many definitions were created by many researchers according to their background. However, there is no one publicly accepted uniform definition of PSS. Some of the recognised definitions of PSS are presented in Table 2.1

**Table 2.1 Definitions of PSS**

| Author | PSS Definition |
|---|---|
| **Goedkoop et al., 1999** | "A marketable set of products and services capable of jointly fulfilling a user's need" |
| **Mont, 2001** | "A system of products, services, networks of actors and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and has a lower environmental impact than traditional business models" |
| **Brandstotter et al., 2003** | "A PSS consists of tangible products and intangible services, designed and combined so that they are jointly capable of fulfilling specific customer needs. Additionally PSS tries to reach the goals of sustainable development" |
| **Manzini and Vezzoli, 2003** | "An innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client demands" |
| **Tukker and Tischner, 2004** | "A value proposition that consists of a mix of tangible products and intangible service designed and combined so that they are jointly capable of fulfilling integrated, final customers' needs. PSS: the product-service including the network and infrastructure needed to 'produce' a product-service" |
| **Wong, 2004** | "A solution offered for sale that involves both a product and a service element, to deliver the required functionality" |
| **ELMA, 2005** | "A system of products, services, supporting networks and infrastructure that is designed to be competitive, satisfying customer needs, & having lower environmental impact than traditional business models" |
| **Baines et al., 2007** | "PSS is an integrated combination of products and services that delivers value in use" |

In summary, most of the definitions cover the key elements that form the concept of PSS namely, product, service, network partners, supporting infrastructure, fulfilling customer needs, generating customer satisfaction, creating competitiveness, and producing less environmental impact. The basic two common pillars in all of the previous definitions are: (a) products and services that jointly can satisfy customers' needs, and (b) innovation involved in how the needs are satisfied. From the previous definitions the following can be concluded:

- The elements of PSS are product, services, supporting networks and infrastructure.
- PSS aims to achieve competitiveness for producers, satisfy customer needs and maximising customer value, and have a lower environmental impact than traditional business model. PSS can lower the environmental impact through: closing material cycles, reducing consumption via alternative scenarios of product use, increasing overall resource productivity and dematerialisation of PSS and providing system solutions seeking the perfection in integrating system elements along with improving resource.
- For consumers: PSS means a shift from buying products to buying services that satisfy their needs with the minimum environmental impact.
- For producers and service providers: PSS mean a higher degree of responsibility for the product's full life cycle, the early involvement of consumers in the design of the PSS, and design of the closed-loop system.

In this research, the definition of Product-Service System (PSS) proposed by Baines et al., (2007) will be adopted: "PSS is an integrated combination of products and services that delivers value in use".

### 2.1.2 Classifications of PSS

Various classifications of PSS have been proposed (Goedkoop et al., 1999; Mont, 2001; Wong, 2004; Tukker, 2004; Baines et al., 2007). However, no standard classification yet exists. The most commonly used PSS classification is based on two parameters: the distribution of property rights and the degree of interaction between actors. This classification divides PSS into: product-oriented PSS, use-oriented PSS, and result-oriented PSS (Tukker and Tischner, 2006; Baines et al., 2007; Sakao et al., 2009; Yang et al., 2009). Figure 2.2 shows how PSS can be divided into three main PSS categories (product-oriented, use-oriented, and result-oriented) and the eight basic subcategories that are discussed in this section.

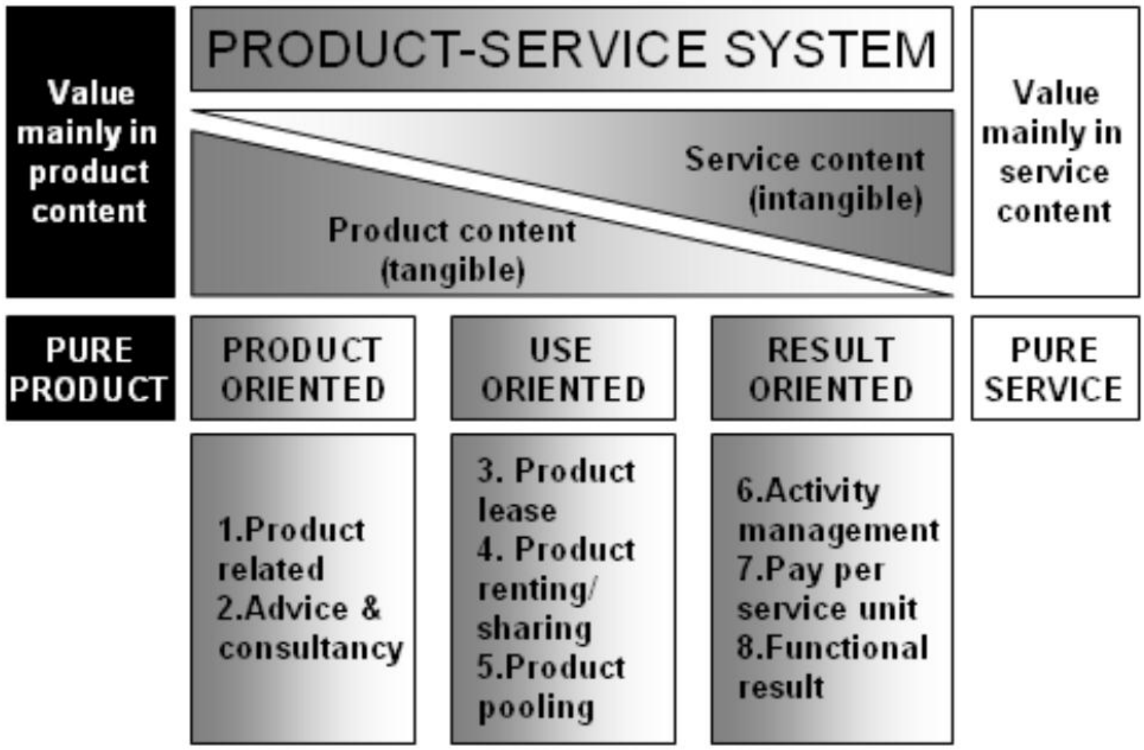



**Figure 2.2 Main categories and subcategories of PSS (Tukker, 2004)**

### 2.1.2.1 Product-Oriented PSS

Product-oriented PSS is the traditional sale of a product, but additional services are provided to customers. These services include maintenance, warranty, repair, distribution, installation, recycling, re-use, and helping customers optimise the application of a product through training and consulting. The main feature of this type is that the product is owned by the consumer, and services delivered are attached to the product itself (Tukker, 2003). In this type, the product is considered as a mean to deliver services. Two types of product-oriented PSS have been identified as:

- Product-related services: The provider not only sells a product, but also offers services related to that product such as warranty, maintenance, monitoring, repair, and upgrades and recycling.
- Advice and consultancy: in relation to the product sold, the provider gives advice on its most efficient use such as training, advice on the organizational structure of the team using the product, or optimising utilisation.

#### 2.1.2.2 Use-oriented PSS

In use-oriented PSS, the traditional product still plays a central role, but the business model is not geared towards selling products. The focus is on the sale of the use or the availability of the product through activities like leasing or sharing. The main feature of this type is that the provider or the supplier no longer sells the product, but only its usage and functions (Tukker, 2003). Also, the ownership of the product is retained by the supplier or the provider and customers pay for a specific use of products and services. In other words, the use of product is sold, not the product (Tukker and Tischner, 2006). Three types of use-oriented PSS have been identified as:

- Product lease: the product does not shift in ownership. The provider has the ownership and is also responsible for maintenance, repair, upgrading during a given period of time. The lessee pays a regular fee for the use of the product and has an exclusive access to it.
- Product renting or sharing: the same as product leasing but the main difference is that the user does not have unlimited and individual access, others can use the product at other times. The same product is sequentially used by different users
- Product pooling: this greatly resembles product renting or sharing. However there is a simultaneous use of the product (customers can use this product virtually on-demand).

#### 2.1.2.3 Result-oriented PSS

Result-oriented PSS focuses on selling the functionality, capability or end results instead of a product. The main feature of this type is that the supplier or the provider owns the products and is responsible for its conditions. In result-oriented PSS the customer pays only for the provision of agreed results. The provider guarantees the satisfaction of customer needs, regardless of tangible products (Tukker and Tischner, 2006). For example, a user that pays for clean clothes rather than buying a washer machine or paying to use one (Roy, 2000). Three types of result-oriented PSS have been identified as:

- Activity management/outsourcing: in this type a part of an activity of a company is outsourced to a third party. Examples: the outsourcing of catering and office cleaning.
- Pay per service unit: the customer pays for either the time a product is used or for each service unit provided by that product. In other words, the customer payment is made in accordance with the level of use.
- Functional result: in this type the provider agrees with the client the delivery of a result. The provider is completely free as to how to deliver the result. Examples: companies who offer to deliver a specified pleasant climate in offices rather than gas or cooling equipment or companies who promise farmers a maximum harvest loss rather than selling pesticides.

As presented in Figure 2.3, product-oriented PSS aims to provide more products than services and the customer's value is based mainly on the ownership of the product. On the other hand, both use-oriented PSS and result-oriented PSS promote the utility and the sale of use not the sale of product i.e. customers value is based on the service not the product. A summary of the three types of PSS with examples are shown in Table 2.2

**Table 2.2 Classification and Examples of PSS**
**(Hockerts and Weaver, 2002)**

| | **Definition** | **Examples** |
|---|---|---|
| **Product-oriented** | Provides additional services to sold products | Consultation, maintenance, disposal, take-back, financing schemes |
| **Use-oriented** | The use of products is sold, not products | Product renting and leasing, sharing and pooling |
| **Result-oriented** | The provider, regardless of material products, guarantees satisfaction of customer needs | Least cost planning, facility management services |

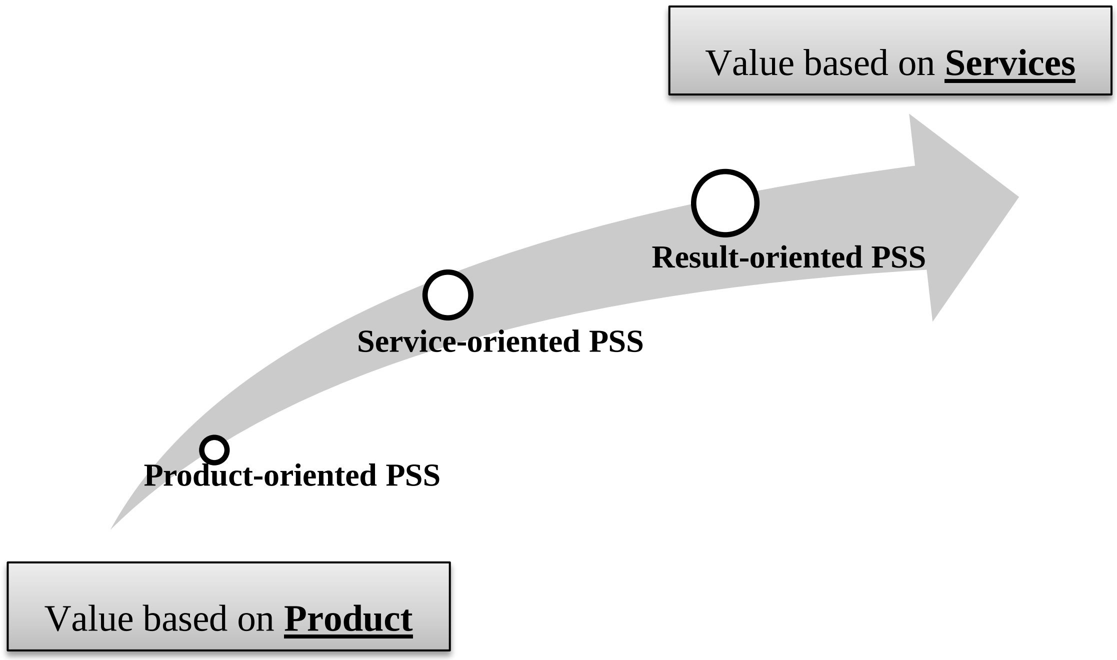



**Figure 2.3 The evolution of PSS**
**(Wang et al., 2011)**

This section discussed the most common categories and subcategories of PSS. There are there main categories of PSS; these categories are product-oriented PSS, service-oriented PSS and finally result-oriented PSS. Also, the differences among these categories have been highlighted in this section. The next section, will present some real examples of companies that have successfully applied PSS.

### 2.1.3 Real Life Examples of Successful PSS

Many companies successfully applied PSS for example, Rolls-Royce offers 'Total Care Package' and 'Power by the Hour' rather than selling the engine. Toyota offers 'Do not buy a forklift' to their customers, also Xerox offers their customers a documentation management business model instead of owing their machines (Wang et al., 2011). This section gives some examples of companies that have successfully implemented the concept of PSS. These examples are presented in Table 2.3

**Table 2.3 Examples of Successful PSS**
**(Baines et al., 2007)**

| Organization | Description |
|---|---|
| **Rolls-Royce** | The concept of Total-Care where customers lease the product for an agreed period of time within which Rolls-Royce is responsible for the full maintenance of the product. |
| **Xerox International** | Products are sold guaranteeing fixed price per copy from products/processes designed for remanufacturing. |
| **Parkersell (UK)** | Parkersell developed a product service integrated lighting system solution for Sainsbury's more efficient in life cycle costing and environmental improvement |
| **Castrol Inc.(USA)** | Lubricant service packages reducing lubricant consumption. Profit from cost saving not consumption |
| **Eastern Energy (UK)** | Not just energy but energy management, consumption and process monitoring and utility awareness and training. |
| **Electrolux (Sweden)** | Selling washing function instead of the washing machine. Initial fee then pay per wash from remotely monitored energy efficient machine and launderette system solutions including maintenance, repair and finance services. |
| **Mobility (Switzerland)** | Vehicle sharing group – 1400 cars, 850 locations, 350 communities. Costs less than 1500€/yr. |
| **Car-a-Car, Green Wheels, StattAuto** | Car renting and vehicle sharing group |
| **Gambro** | Medical equipment is offered on a pay-per-use basis to doctors. |

### 2.1.4 Advantages of PSS

There are a wide range of benefits of PSS. According to Mont (2002), the concept might be beneficial for manufacturing and service companies, government, consumers, and the environment. PSS can be seen as a win-win solutions, winning for the producers/providers, the users and the environment. This section presents the benefits of PSS for companies, customers, and the environment.

#### 2.1.4.1 For Manufacturers

The benefits gained by companies from applying PSS result from the potential of higher operating efficiencies and improved strategic positioning.

1. Higher Operating Efficiency

A shift to PSS can result in a situation where a company continues to make a profit and at the same time reduces the environmental impact of resources consumed. Manufacturers can make more profits, if they can meet the same demand by providing a less resource intensive product and related service mix. PSS motivate manufacturers to repeatedly provide the same service to different customers, so they will be more able to maximise their profit. Moreover, applying PSS provides manufacturers with the possibility of the repeat usage of a product in the form of renting, leasing and pooling through increasing the frequency of utilising of the products by selling it many times in comparison to a pure product offering where products are sold once only. Thus, allowing the products to be used more intensively. Additionally, since the ownership stays with the manufacturer, there will possibly be a lower cost of spear parts, profitable after-sale services, reduced waste and efficient use of equipment (Baines et al., 2007).

Cost savings for manufacturers result from reduced quantities of the used materials and reduced costs from the extended responsibility for the product throughout its use and disposal. Maussang et al., (2009) mentioned that PSS can lead to dematerialisation and creation of sustainable products through decreasing the creation of wastes and the consumption of raw materials. Furthermore, closing product cycle allows companies to have a constant flow of raw materials, which can be used for further production. Having a secondary source of raw materials directly from the market can be especially profitable when there are strong fluctuations in raw material prices. Cook et al., (2006) pointed that PSS can provide an opportunity to improve the productivity of resources through dematerialisation.

2. Improved Strategic Positioning

Applying PSS can put companies in a better strategic position (Mont, 2002; Cook et al., 2006; Tukker and Tischner, 2006) because of the potential added value perceived by customers. Delivering product service mix enable manufacturers to improve their position in the value chain, improve customer value, obtain more stable cash flow, and improve their innovation potential (Tukker and Tischner 2006; Baines et al., 2007; Wang et al., 2011). These benefits can be identified as:

- New market development, through a differentiated product with a customised service element which is difficult to imitate (Ang et al., 2010)
- Increased flexibility to respond more rapidly to the changing consumer demands and market. Also, services could guarantee manufacturers a steady income level especially when facing a global or regional financial crisis (Wang et al., 2011).
- Long term customer relationships. Many companies indicated that establishing longer relations with customers is a very appealing feature of PSS, as the sale transaction no longer ends when the product is delivered to the customer. Signing a contract provides producers with an idea about the period of time that the customer will be in touch with the company. The upgrading or maintenance service provides an opportunity to contact the customer and to provide updated information about the company's offers. This will lead to stronger company-customer relationships, improved customer satisfaction and enhanced customer loyalty.
- Improved corporate identity through a better implementation of its social and environmental responsibility. Implementing PSS leads to a reduction in the use of raw materials, reduction in energy consumption, reduction in the volume of products produced, less generation of waste and less dependency on material offers to satisfy needs (Mont, 2002; Tukker and Tischner, 2004; Cook et al., 2006). So, companies will be able to show their care of the social and environmental aspects.
- Competitiveness and new ways of profit generation. In the case of function selling, the product prices competition is shifting towards competition of functions. In functional selling, product and raw materials prices do not play such as a decisive role as traditional selling. Under these circumstances, the pressure for finding the balance between quality and price is shifted towards price of function and it becomes an incentive for the producer to manufacture durable and high quality products that ensure function provision to the customer. In business-to-business context, manufacturers receive customised and integrated services from suppliers and this by turn help manufacturers to focus more on their own core business.

#### 2.1.4.2 For Customers

For customers, the supplier or the provider will be responsible for all the administrative and the monitoring tasks (Baines et al., 2007). Also, the responsibility of product for its whole lifecycle will be shifted to the supplier or the provider. Furthermore, customers will receive greater variety of service offers, maintenance and repair services, and payment schemes. Moreover, customers will contribute to a less pollution consumption.

#### 2.1.4.3 For Environment

PSS also have a positive environmental impact (Tukker and Tischner, 2004). By applying PSS, there will be an opportunity that the total amount of consumed products will be reduced in comparison to the traditional selling. Therefore, less waste will be generated, less raw materials and energy will be consumed and less dependency on material offers to satisfy needs (Mont, 2002; Tukker and Tischner, 2004; Cook et al., 2006).

This section discussed the benefits that can be gained from applying PSS for manufacturers, customers, environment and government. In the next section the drivers and barriers to develop PSS will be discussed.

### 2.1.5 Drivers and Barriers to develop PSS

Despite the various benefits that can be achieved from PSS as discussed in the previous section, some barriers to the development of PSS will be described in this section. Mont (2002) stated some drivers and barriers in the development of PSS. These drivers and barriers are presented in Table 2.4

**Table 2.4 Drivers and Barriers to the Development of PSS (Mont, 2002)**

| | **Internal** | **External** |
|---|---|---|
| **Drivers** | • Possible financial savings and revenues<br>• Top management commitment<br>• Risk reduction<br>• New possible sources of resources<br>• Environment | • Legislation<br>• New opportunities to growth<br>• Competence |
| **Barriers** | • Organisational resistance<br>• Have to manage financial uncertainties<br>• Problems to balance environmental goals with customer satisfaction<br>• Prevention of diversification | • Relations along the value chain<br>• Difficulties to gain public acceptance<br>• High labour prices<br>• Lack of demand for this kind of solutions |

### 2.1.5.1 Barriers to Develop PSS

The main barriers to develop PSS can be identified in the following points:

A. The cultural shift necessary for the user to value “having a need or want met in a sustainable way” as opposed to “owning the product”. One of the most important barriers is the customers’ acceptance of the loss of property.

B. The availability of advanced technological information and knowledge to produce a socially and economically viable PSS.

C. The difficulty of quantifying the savings arising from PSS in economic and environmental terms, in order to market the innovation to stakeholders both inside and outside the company.

D. Longer relationship between manufacturers, suppliers and customers in comparison to the traditional selling, may result in high level of interdependence.

E. Lack of knowledge and experience in terms of: service design methods and tools (there will be a need to align product and service design with the design of offerings), new tools that companies can use to assess and implement PSS, and service management systems

F. Businesses may perceive the risks of:

- Conflict with existing internal procedures and tools (accounting and reporting methods)
- Product ownership and promised availability
- Service being easily replicated by a competitor (more easily than a physical product)
- Partnerships interdependence leading to reduced control of core competencies and reducing the influence of business decisions.
- Uncertainty entailed, due to managing tangibles and intangibles at the same time.
- Multiple and varying demands.
- Increased reliance on suppliers or provider in the business-to-business context

G. Lack of external infrastructure and technologies (product collection, remanufacturing or recycling).

#### 2.1.5.2 Drivers to develop PSS

According to Mont (2002), there are a number of forces that trigger the introduction and development of PSS. One of the forces is increasing environmental awareness. Increasing environmental awareness of the general public and society resulted in more stringent regulation, a change in its focus from process to product orientation, as well as, increasing the number of stakeholders that are concerned with the environment and putting their demands on producers. All this resulted in increasing pressure on companies to improve the environmental performance of their operational activities, products and services. The second driver is related to market drivers. Development and standardisation of technology lead to increasing difficulties with product differentiation on the market, which leads to fierce price competition resulting eventually in low profit margins in many industry branches. So, some companies have tried to find ways to diversify their product offers and deliver unique functions or services to customers. Furthermore, deregulation and globalisation lead to an increasing number of new players on the market and fiercer competition. According to companies, it is not enough to compete based on product quality and the increasing efficiency of the operational and production processes.

Companies are competing for the customer. They are building direct customer relations, intensifying contacts or increasing contact frequency with the customer, all with the purpose of creating added value for customers.

The need to protect the market share via discouraging newcomers by increasing the quality level throughout the supply chain is considered one of the possible drivers for companies to find new opportunities for improvement of the quality of their offers.

The last driver is increasing time of product development. Shorter product life cycles and increasing time for product development lead to a situation where companies need to come up with new offers on the market all the time, meaning that there is a lack of time for designing and developing rally innovative products that are competitive. Companies proposed some solutions for reducing the time to market through diversification of the product offer on the market by the provision of value added services, which might require less time to develop.

### 2.1.6 PSS and other Related Concepts

This section provides a brief explanation of some concepts that are relating to PSS. Many researchers created different terminologies that have different emphases relating to the concept of PSS such as: servitisation, functional sales, functional product, service engineering, and eco-efficient producer services (EEPS).

The first term, servitisation was introduced by Vandermerwe and Rada (1988). They defined servitisation as “a strategy in which companies offer their products as part of a package which includes services, support, self-service and knowledge”. Also, Robinson et al., (2002) defined servitisation as “a concept which goes beyond the traditional approach of providing additional services but considers the total offer to the customer as an integrated bundle consisting of both the goods and the services”. The second term is functional sales. Functional sales emphasis on the change from traditional product selling to more service oriented product sales. Functional sales focuses on offering the functional solutions, which consists of a combination of systems, physical products and services, from a lifecycle perspective that are able to fulfill a defined customer need (Sundin and Bras, 2005). Table 2.5 highlights the differences between functional sales and traditional sales.

Functional sale is a business model in which a unit of transaction is a function of a product, not the product per se. In functional sales customers pay per function.

The third concept is functional products, also known as ‘total care products’, are “products that comprise combinations of ‘hard’ and ‘soft’ elements. Typically, they are described as comprising hardware combined with a service support system” (Alonso-Rasgado and Thompson, 2006).

The fourth concept is service engineering. Sakao and Shimomura (2007) defined service engineering (SE) as “a discipline to increase the value of artefacts and to decrease the load on the environment by reasons of focusing service”. Service engineering focuses on improving the efficiency and the quality of service creation, service delivery, as well as, service consumption (Sakao and Shimomura, 2007; Tomiyama, 2001).

The fifth and last term, is eco-efficient producer services (EEPS). Eco-efficient producer services (EEPS) can be defined as “services which improve the eco-efficiency of business customer activities. This can be done directly by replacing an alternative product–service mix or indirectly by influencing customer activities to become more eco-efficient” (Bartolomeo et al., 2003). According to Brezet et al., (2001), the concept of eco-efficient services has a minimum environmental impact in addition to; it creates the maximum added value for customers. The name comes from the belief that the services are more environmentally sound.

From all these previous concepts and definitions a number of common elements can be identified. The first common element is the emphasis on satisfying customers changing needs. The second element is the combination of a product and service mix in the offering. The third is that the new combination of products and services creates a different type of offering which is not like adding some services to the existing product. The final common element among the previous concepts is the long-term orientation of these types of offerings.

**Table 2.5 Functional sales Vs. Traditional sales (Mont, 2004)**

| Traditional sales | Functional sales |
|---|---|
| New products are sold | The function is sold; therefore the sold products are not necessarily new as long as they fulfil the agreed function |
| Ownership is transferred to the customer | Ownership is retained with producer/retailer |
| Consumption unit is purchased at once. Function stays the same throughout the product life cycle | Consumption unit can be changed (keeping, adjusting or upgrading the function) |
| Length of contract between producer and customer is limited to sales process | length of contract between producer and customer is determined in the negotiation process and can be continuous or discontinuous (in periods) |
| Purchase on approval – product testing is done at the point of sale | Product testing is done at the point of service. Consumers can try and test the product before they lease or rent it |
| A fix warranty period agreed in advance | the function is guaranteed throughout the service period |
| Producer’s involvement is limited to warranty period. Over the life of the product support is provided by organisations that have no relations with the producer | Support from a network of companies that are brought together by the producer so the producer is involved over the entire time of value provision, but the customer is supported by a network of companies |
| Initial investment can be considerable | No initial investment, the use costs are spread over the use time |
| Consumables are purchased separately | Consumables are supplied by the provider in accordance with the contract and the defined function |
| No information regarding the life cycle cost of product ownership | Clear information regarding the total cost of function or service |
| Linear material flow and business arrangements | May stimulate circular material flow |

### 2.1.7 Methodologies and Design of PSS

This section provides a brief introduction to the previous research works specific to the tools and methodologies of PSS. PSS design requires the shifting of product design and service design to product service system design. This shift posed a new challenge for many designers and inspired new research in this area (Manzini and Vezzoli, 2003; Morelli, 2003; Maussang et al., 2009). The development of PSS differs from physical product development because the service element in the PSS introduces new variables such as: time, interaction between people, social habits and culture background, and so on (Morelli, 2006).

According to Maussang et al., (2009), there are many elements that can influence the design and the development of PSS. These elements include for example: partners and organisation of the enterprise, benefits for customers and providers, elements of solutions, environmental and social consideration, easiness of use, and so on. Bey and McAloone (2006) pointed out that, in order to design a PSS properly, designers need to have a full view of the product in terms of the product lifecycle and all the stakeholders. Additionally, Mont (2002) and Wong (2004) mentioned that regulatory support and the presence of appropriate incentive structures and environmental regulations are also important in the design and development of PSS. Moreover, Manzini (2003) mentioned that designing a new service in PSS should be able to link the technology to the social and cultural dimensions. Thus, PSS design demands that service and product must be developed in one coordinated development process in order to avoid insufficient consideration of the mutual influences of products and services (Wang et al., 2011).

There are a variety of PSS methodologies found in the literature. The Methodology for Product Service System (the MEPSS project founded by European Commission under the 5th Framework Programme), developed a toolkit that enables the industry to develop PSS. According to MEPSS (2004) toolkit, there are four groups of methods and tools for developing and designing PSS. These four groups are: dynamic system analysis, PSS design (selection, design and development of PSS business model), sustainability assessment of PSS business, and market acceptance. The MEPSS toolkit is available via a handbook (MEPSS, 2004) and on the website http://www.mepss.nl.

Luiten et al., (2001) introduced the sustainable PSS methodology using Kathalys method. The Kathalys method is a five step-phased approach with guidelines for future exploration to implementing new sustainable products and services. These five phases are: future exploration, system design, product/service specification, drawing in detail and testing, and finally, implementation. Fujimoto et al., (2003) present a life cycle simulation of the developed service-oriented business using consumer facsimile machines as an example of "service-oriented products". The proposed service-oriented products will provide various services to customers. Additionally, they argued that with the service-oriented product, it will be easy to control quality, cost, as well as, delivery of the recycling systems and integrate recycling systems into manufacturing systems. Maxwell and Van der Vorst (2003) developed a method for effective sustainable product and/or service development (SPSD) in industry. The method is designed to provide pragmatic guidance to business and industry for developing sustainable products and services, as well as, incorporating this approach within existing corporate strategy, cleaner production, and product development systems. Also, Mont (2004) presented a step-by-step PSS methodology based on Deming cycle. Alonso-Rasgado and Thompson (2006) proposed a total care design process to develop innovative offerings consisting of hardware and services integrated to provide complete functional performance. Moreover, Aurich et al., (2006) mentioned that technical services such as maintenance, retrofitting, refurbishing or user training are a kind of PSS and should be taken into account in designing a PSS. They introduced a lifecycle oriented method for systematic design of technical services based on its modularisation and integrated it with the existing product design process to design a technical PSS. On the same time, Morelli (2006) introduced a combination of techniques that can be used by PSS designers. He used techniques such as Integration definition for functional modelling (IDEF0), Scenarios and use cases, and service blueprinting. The use of such techniques in design discipline would: provide an accurate representation of logical, time related and physical connections between various phases and components of a system, define requirements and structure of a PSS, and finally present and blueprint a PSS. Based on product lifecycle and Six Sigma Zhao et al., (2008) developed flow of service design. This developed flow is divided into four stages: service requirement analysis, service design, service machining, and service maintenance. By this flow product lifecycle data could be contacted and feedback manufacturing and maintenance information to the service design process.

Maussang et al., (2009) used the FAST diagram (Functional Analysis System technique) to realise the deployment of functions, use the functional block diagram to model and analyse a PSS structure.

Shimomura et al., (2009) integrated the design of services and products and proposed a method called extended 'service blueprint' for designing service activity and product concurrently and collaboratively to maximise customers' value. Yang et al., (2009) stated that current methods and tools related to PSS are mainly concerned with general PSS and service design, which cannot assist manufacturers of consumer products to implement and realise PSS solutions. They presented a methodology for the realisation of product-oriented and use-oriented PSS for consumer products through the use of product lifecycle data. They used service enabler to capture data of product lifecycle and deal with the issue of actively utilising product lifecycle data in creation and delivery of effective services during a product's lifecycle. Finally, Vijaykumar et al., (2013) developed a capability-based PSS design framework. The proposed framework is structured into 10 steps, these steps are: understanding customers' needs, identifying existing capabilities and resources of the customer, identify current status of products and services, identify new design required to satisfy needs at every level, identify conditions and consequences of each design, identify additional capabilities required to develop new design, understand and specify the responsibilities of the stakeholders, group different combinations of designs to satisfy customer needs, evaluation of the cost and functional performance of the grouped designs, and finally, representation of the chosen design.

Wang et al., (2011) classified existing methodologies for PSS design into three main groups:

- The first group is trying to upgrade the development and management of physical products and provide a modified product which is easy to be serviced and this group includes studies conducted by (Fujimoto et al., 2003; Yang et al., 2009; Xing and Luong, 2009)
- The second group is aiming for an inclusion service operation into product development and providing product-service solutions and this group includes

studies conducted by (Maxwell and Van der Vorst ,2003; Zhao et al., 2008; Shimomura et al., 2009)

- The third group is trying to improve methods and tools of other science domains in order to develop PSS and this group includes studies conducted by (Morelli ,2006; Maussang et al., 2009; Vijaykumar et al., 2013).

## 2.2 The Concept of Lean

Lean manufacturing was developed from the Toyota Production System (TPS) and with the publication of the book *The Machine That Changed the World* by (Womack et al., 1990), lean manufacturing practices have found acceptance in many manufacturing operations over more traditional mass production techniques.

In fact numerous definitions and descriptions of lean exist. Many researchers and authors have studied lean manufacturing and they have viewed it from different angles. While many researchers and practitioners have studied lean manufacturing, it is difficult to find a concise definition which everyone agrees. The lack of a clear definition of lean has been mentioned by many authors. Karlsson and Alhstrom (1996), Shah and Ward (2007), Bayou and De Korvin (2008) mentioned that there is still not a precise and agreed upon way of defining lean.

Sohal (1996) described the lean production system as "a system that seeks to eliminate unnecessary processes, to align processes in a continuous flow and to use resources in order to solve problems in a never ending process". Liker (2004) defined lean as "a way of thinking that focuses on making the product flow through value-adding processes without interruption (one-piece flow), a 'pull' system that cascades back from customer demand by replenishing only what the next operation takes away at short intervals, and a culture in which everyone is striving continuously to improve". Shah and Ward (2007) defined it as "an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimizing supplier, customer, and internal variability".

According to Womak and Jones (1996), lean thinking is lean because it provides a way to do more and more with less and less - less human effort, less equipment, less time, and less space -while coming closer and closer to providing customers with exactly what they want.

The main idea beyond lean involves determining the value of any process by distinguishing value-added activities or steps from non-value-added activities or steps and eliminating wastes, so that every step adds value to the process to reduce costs, speed up cycle times and improve quality and reliability (Womack and Jones, 1996).

Lean is frequently associated with the elimination of seven types of wastes namely: overproduction, over processing, waiting, unnecessary transport, defects, excess movement and inventory (Shah and Ward, 2007).

Womack and Jones (1996) identified five lean principles that organisations should follow in order to become lean. These five principles are: (a) identification of customer value, (b) management of value stream, (c) developing a flow production, (d) using pull techniques, and (e) striving to perfection.

In recent years, it was found that lean has been widely applied in manufacturing sectors especially in the automotive industry where it started. But currently, because of the possible benefits gained by applying lean, the popularity of lean in the non-manufacturing sector is growing exponentially. Non-manufacturing sectors that have applied lean practices include for instance: insurance companies (Swank, 2003), NHS (Esain et al., 2008), and universities (Balzer, 2010; Radnor and Bucci, 2011). Womack and Miller (2005) stated that lean is not a manufacturing tactic only, but a management strategy that is applicable to all organisations because it has to do with improving processes.

Lean implementation includes a wide variety of management practices that can be implemented in manufacturing and non-manufacturing sectors. Some of these practices are: (1) Total Quality Management (TQM); (2) Just-In-Time (JIT); (3) Total Productive Maintenance (TPM); (4) Kaizen and (5) Value Stream Mapping (VSM) (Shah and Ward, 2003; Narasimhan et al., 2006; Camacho-Miñano et al., 2013).

### 2.2.1 History and Evolution of Lean

This section focuses on the history and evolution of lean, by tracing its development since the late 1940s to the present. This section starts by outlining the origin and gradual development of lean. Lean can be seen as one of the steps in the evolution from craft production, to mass production, to Just-in-Time, to lean.

#### 2.2.1.1 Craft Production

Craft production is the process of manufacturing by hand or without the aid of tools. The craft production is characterised by the use of craft-based skills in small-scale factories and its ability to produce customised products. Products produced by the craft production system were seen to be of high quality and refinement (Adebayo-Williams, 2013). Craft production was a common method of manufacturing in the pre-industrialised world. During this era the production costs were very high and did not get smaller with a bigger production volume. Craft production was very common in the pre-industrialised era especially in the automobile sector. But, this system was inadequate to manage high demand where very high qualified workers were spending a long time to produce a single vehicle and this has affected prices and annual production rate of vehicles (Womack et al., 1990). According to Womack et al., (1990), craft production had the following characteristics: a workforce that was highly skilled in design, machine operations, and fitting, the use of general-purpose machine tools, and a very low production volume.

#### 2.2.1.2 Mass Production

The time of traditional craft production was over. The industry was looking for more efficient and effective ways of producing goods. In 1908, Henry Ford started one of the considered greatest achievements in human history, since then known as mass production. Mass production is the production of large amounts of standardised products, especially on assembly lines. Elements of mass production are presented in Figure 2.4

Replacing craft production, mass production dramatically lowered manufacturing costs and time for most products in all types of industries. By using the mass production system, Ford Motor Company was able to reduce the hours it took to assemble a Model T car from the initial 14hours to 1hour 33minutes. This lowered the overall cost of each car and enabled Ford to reduce the selling price of the Model T (Hounshell, 1985). Ford was among the first industrialists to recognise that price is related to volume. Mass production system was characterised by the use of: assembly line that defines the progression of work, division of labour to break the production process into separate tasks performed by specialists or craftsmen, precision tooling to provide mechanical leverage in the assembly line, standardisation, and finally mass demand. Over the years, customers need changed and the market required more product variety and the mass production was unable to meet the market new requirements.  However the advantages gained from mass production, it is considered inflexible way of production, because it is difficult to alter a design or production process after a production line is implemented. Also, all products produced on one production line will be identical or very similar, and introducing variety to satisfy individual tastes is not easy.

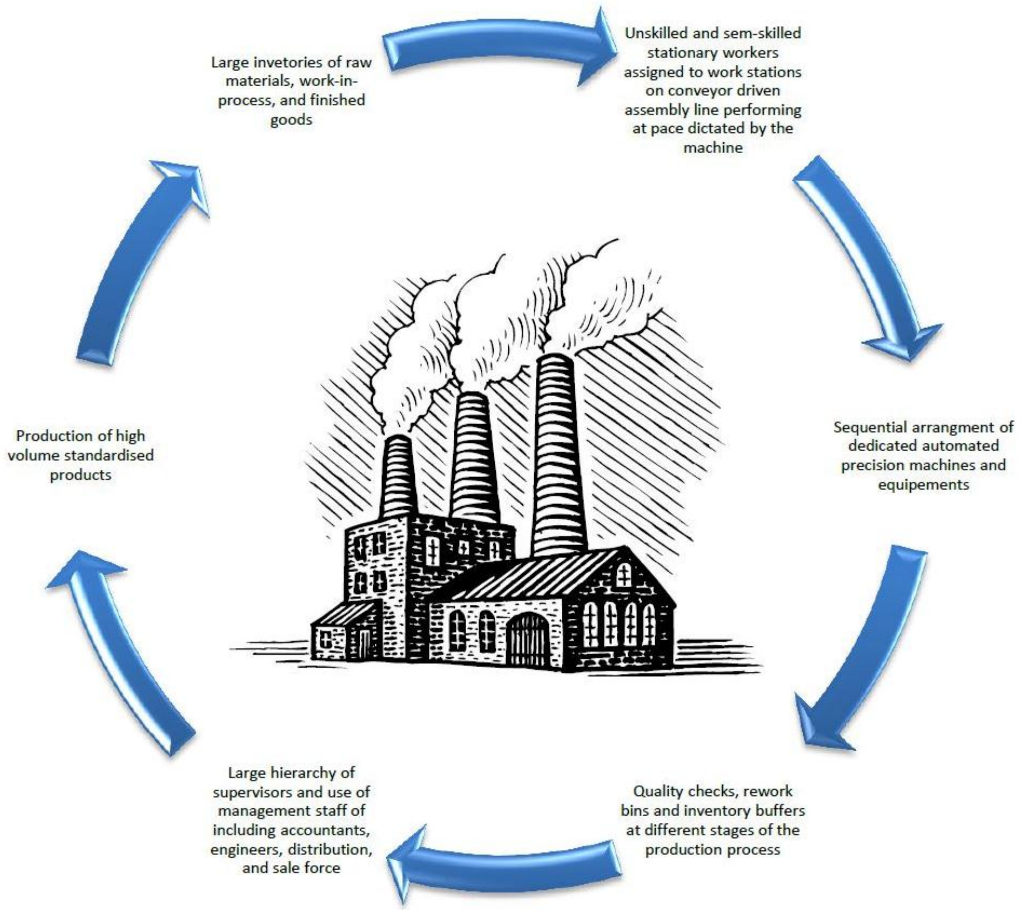



**Figure 2.4 Elements of Mass Production System (Adebayo-Williams, 2013)**

#### 2.2.1.3 Toyota Production System (TPS)

The Toyota Motor Company is credited with initiating the next production paradigm shift, originally referred to as the "Toyota Production System" (TPS) which has come to be known as "lean production". Toyota developed its TPS to overcome the challenges faced by the company after the World War II, these challenges include: stiff competition from European and American counterparts, inability to make huge investments, a small and fragmented domestic market, small and depleted workforce, and finally, lack of resources (Ohno, 1988). TPS was developed to survive with minimum amount of resources.

The limited availability of resources made all mistakes unaffordable, and reducing wastes in the shop floor became the mission of survival (Ohno, 1988). Mass production system was not the ideal production system in the Japanese economy (Womack et al., 1990). Toyota Company then went onto developing the now popular Toyota Production System (TPS). According to (Ohno, 1988), Toyota Production System's main outcomes are:

- To increase product efficiency by consistently and thoroughly eliminating waste,
- To provide customers with the highest quality products, at lowest possible cost, in a timely manner with the shortest possible lead times, and finally
- To give the company flexibility to respond to the changes in the market.

Toyota does not view lean as a collection of tools, but as a reduction of three types of wastes: Muda (non-value adding work), Muri (overburden), and Mura (unevenness) (Hines and Lethbridge, 2008). The challenge was how to design a new production system that could simultaneously provide a greater variety of low cost and high quality products to meet diverse and varying customer needs. As a result the lean production system emerged.

Figure 2.5 presents the Toyota Production System House.The TPS assumes that all processes are stable and therefore under control. There are two main pillars of the system. These two pillars are still at the heart of Toyota's stated vision and philosophy. The first pillar of the system is Just-In-Time (JIT). JIT refers to having only what is needed when it is needed without any waste. This enhances efficiency and enables quick responses to change (Ohno, 1988). Jidoka (Build in quality) is the second pillar of the system. Jidoka is a Japanese word that means autonomation, or automation with a human touch. Jidoka refers to the ability of production lines to be stopped in the event of such problems as equipment malfunctions, quality problems or work being late either using machines which have the ability to sense abnormalities or using workers who push a line-stop button (Miltenburg, 2001). The notion of automation with a 'human touch' refers to the critical role of an employee in any process, for example, to stop the process for immediate resolution of problems. The aim of TPS is to produce products in the highest quality, with the lowest possible cost and shortest lead time.

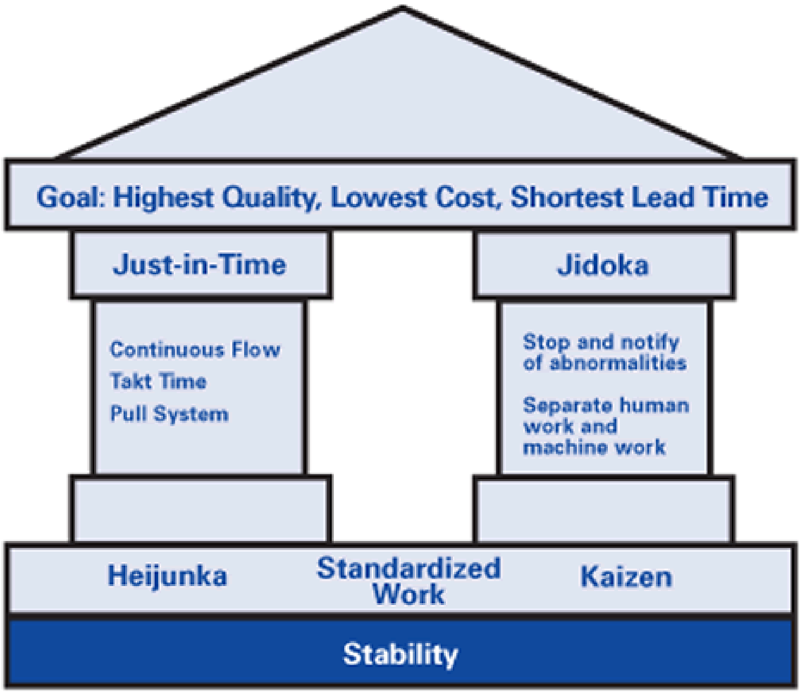
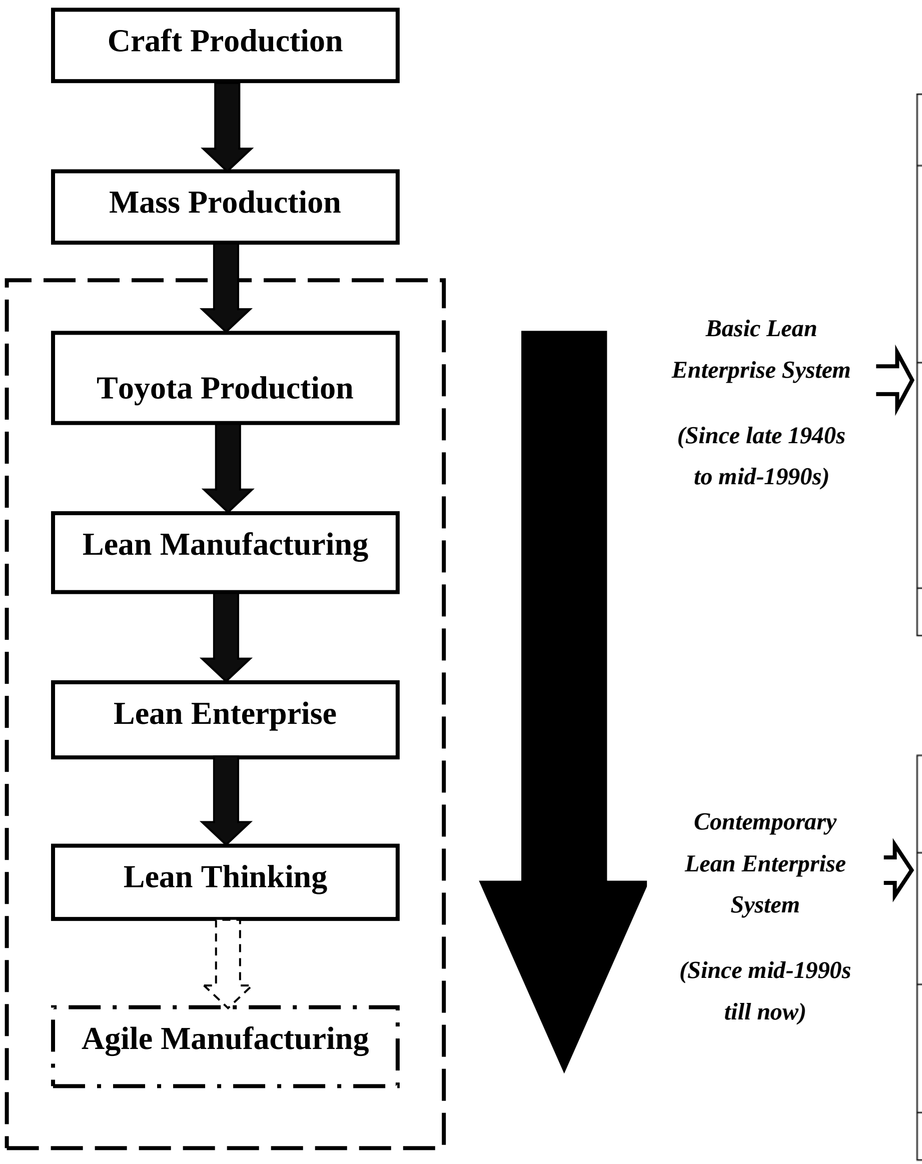



**Figure 2.5 The house of TPS**
**(Liker, 2004)**

This section discussed the critical phases in the evolution of lean from craft production, through mass production till the introduction of Toyota production system and lean manufacturing, these phases are summarised in Figure 2.6




| | |
|---|---|
| ***Goal*** | • Deliver value to customers<br>• Increase production efficiency and profitability |
| ***Core Principles*** | • Deliver customer-pulled value<br>• Eliminate waste<br>• Crate JIT production system<br>• Perfect quality<br>• Continuous flow<br>• Continuous improvement |
| ***Implementation*** | • Specify value as defined by the end customer<br>• Identify the value stream to eliminate all non-value-adding activities<br>• Make the value adding steps for the specific products flow continuously<br>• Let the customers pull value from the enterprise<br>• Pursue perfection through continuous improvement |
| ***Mode of Change*** | Continuous incremental change |

| | |
|---|---|
| ***Goal*** | Create and deliver value to multiple enterprise stakeholders<br>Build dynamic network-wide capabilities for sustained competitive advantage |
| ***Core principles*** | • Adopt holistic view of the end-to-end networked enterprise<br>• Define value exchanges among stakeholders<br>• Eliminate waste<br>• Culture of continuous improvement |
| ***Implementation*** | • Purse enterprise transformation by adopting a holistic enterprise perspective, Lean principles, conceptual frame works, methods and tools<br>• Plan and implement enterprise transformation |
| ***Mode of change*** | • Systemic evolutionary change |



**Figure 2.6 History and Evolution of Lean**

### 2.2.2 Lean and Other Concepts

During the last decades, different quality management concepts, including Total Quality Management (TQM), Six Sigma and lean, have been applied by many different organisations. The purpose of this section is to describe each concept as presented in Table 2.6

**Table 2.6 Comparing TQM, Six Sigma and Lean (Andersson et al., 2006)**

| **Concept** | **TQM** | **Six Sigma** | **Lean** |
|---|---|---|---|
| **Origin** | The quality evolution in Japan | The quality evolution in Japan and Motorola | The quality evolution in Japan and Toyota |
| **Theory** | Focus on customers | No defects | Remove waste |
| **Process view** | Improve and uniform processes | Reduce variation and improve processes | Improve flow in processes |
| **Approach** | Let everybody be committed | Project management | Project management |
| **Methodologies** | PDCA | DMAIC | Principles: value, value stream, flow, pull and perfection |
| **Tools** | Analytical and statistical tools | Advanced statistical tools | Analytical tools |
| **Primary effects** | Increase customer satisfaction | Saves money | Reduced lead time |
| **Secondary effects** | Achieves customer loyalty and improves performance | Achieves business goals and improves financial performance | Reduces inventory, increases productivity and customer satisfaction |
| **Criticism** | No tangible improvements, resource-demanding, unclear notion | Dose not involve everybody, does not improve customer satisfaction, does not have a system view | Reduces flexibility, causes congestion in the supply chain, not applicable in all industries |

#### 2.2.2.1 Total Quality Management (TQM)

Quality has been an important issue for organisations for many years. The early focus on quality evolved from inspection to quality control and later to quality assurance (Dale et al., 2013). During the 1990s, Total Quality Management (TQM) emerged as a common term among organisations to reflect a style of management that gives everyone in an organisation responsibility for delivering quality to the customer. According to Yusof and Aspinwall (2000), TQM can be considered as a continuously evolving management system consisting of values, methodologies and tools, aiming to increase external and internal customer satisfaction with a reduced amount of resources. Dahlgaard and Dahlgaard-Park (2006) defined TQM as a corporate culture characterised by increased customer satisfaction through continuous improvement, in which all employees in the firm actively participate.

The evolution of TQM was started as a result of consumers demand for greater value in terms of quality and relative factors such as on-time delivery at reduced prices. This notion therefore encouraged several manufacturing firms into restructuring their business processes with the aim of achieving competitive advantage, flexibility and higher productivity (Vonderembse et al., 1996).

According to Harris (1995), the basic concepts of TQM are:

- Customer satisfaction: identify internal and external customers of the organisation and measure customer satisfaction periodically
- Continuous improvement: continuously improve the production system for good quality through quality improvement teams and establish a reward and recognition system based on teams’ achievement
- Total quality control: eliminate quality inspectors. Measure quality through workers i.e. from their feedback. Establish statistical quality control at every step of the manufacturing process
- Training: develop a training program to regularly update the skills of the managerial and non-managerial employees who are involved in manufacturing

One of the most common tools used in TQM is improvement cycle. The improvement cycle is used to improve business and is composed of four stages: plan, do, study and act (PDSA) (Andersson et al., 2006).

**2.2.2.2 Six Sigma**

Six sigma was first introduced in the mid-1980s at Motorola. Six sigma is a well-established approach that seeks to identify and eliminate defects, mistakes or failures in business processes or systems by focusing on those performance characteristics that are of critical importance to customers (Snee, 2004). Six sigma can be viewed from two different angles. The first one is the statistical angle. From the statistical angle, six sigma can be defined as having less than 3.4 defects per million opportunities or a success rate of 99.9997% where sigma is a term used to present the variation about the process average (Antony and Banuelas, 2002). Thus, six sigma represents the application of probability theory to manage and control the quality of processes. Six sigma can be used to measure how many defects occurred in a process and figure out how to eliminate them and get as close to 'zero defects' as possible. It is aimed at achieving virtually defect free operations.

The second one is the business angle. From the business angle, six sigma can be defined as a business strategy used to improve business profitability, to improve the effectiveness and efficiency of all operations to meet or exceed customers' needs and expectations (Antony and Banuelas, 2001). The applications of the six sigma methods allowed many organisations to sustain their competitive advantage by integrating their knowledge of the process with statistics, engineering, and project management.

According to Antony et al., (2005) and Goh and Xie (2004), six-sigma uses (DMAIC) methodology to solve the problem and improve the overall performance. The DMAIC methodology includes five steps. These steps are as follows:

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

- Measure - Identify the key factors that have the most influence on the process, and decide upon how to measure them.
- Analyse - Analyse the collected data and process mapping of the current state should be analysed in order to determine root causes of the variation and opportunity for improvement.
- Improve - Design and implement the most effective solution. Cost-benefit analysis should be used to identify the best solution.
- Control - Results should be evaluated and assessed to ensure that any cause of the problems has been removed and any variations from the designed state were corrected

#### 2.2.2.3 Agile Manufacturing

Agile manufacturing can be defined as the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer designed products and service (Cho et al., 1996). Vokurka and Fliedner (1998) stated that agility is the ability to successfully produce and market a broad range of low cost, high quality products with short lead times in varying lot sizes, which provide enhanced value to individual customers through customisation. Rigby., et al (2000) defined agility as the ability of an organisation to thrive in a constantly changing, unpredictable business environment. As mentioned by Ramasesh (2001), the term agility refers to the ability of an organisation to develop and exploit its capabilities to successfully compete in an uncertain and unpredictable business environment. Sharifi and Zhang (2001) observed that the concept of agility comprises two main factors: (a) responding to changes (expected or unexpected) in a proper ways and due time, (b) exploiting changes and taking advantage of changes as opportunities.

Agile manufacturing is all about the ability to respond to shifting customer demands quickly. Agile manufacturers design their production processes in ways that can be changed rapidly, using existing equipment, tools, labour and raw materials to create new or custom products on the fly. As an example, an agile car manufacturing plant will have the ability to use its existing infrastructure to manufacture new vehicle models without significant capital investment. According to Yusuf and Adeleye

(2002), there are four principles support agile manufacturing. These principles include: (a) customer enrichment through one-of-a-kind products at the cost of mass production, (b) organising to master change by competing from multiple fronts with reconfigurable resources, (c) intra and inter-enterprise cooperation, and (d) leveraging of organisational knowledge by means of advanced technologies. The ultimate goal of agile manufacturing is develop capabilities for managing continuous change in customer requirements as a routine, and be able to produce ‘anything, in any volume, at anytime, anywhere and anyhow’ (Fitzgerald, 1995).

According to Krishnamurthy and Yauch (2007) and Inman et al., (2011), there are three general positions with respect to lean and agile: those who believe that they are mutually exclusive or distinct concepts that cannot co-exist, those who believe that they are mutually supportive strategies, and those who believe that lean must be a precursor to agility. Table 2.7 presents the differences between lean and agile manufacturing.

### 2.2.3 Lean Principles

Womak and Jones (1996) defined five principles of lean in their book ‘Lean Thinking’. These five principles are considered the most widely cited in the academic literature. Womack and Jones (1996) summarised these five principles of lean as: (a) specify value by specific product, (b) identify the value stream for each product, (c) make value-flow without interruptions, (d) let the customer pull value from the producer, and (e) pursue perfection. Womak and Jones asserted that through understanding these principles and applying them all together, organisations can successfully implement lean. This section provides an explanation of the five lean principles.

**Table 2.7 Differences Between Lean and Agile Manufacturing (Yusuf and Adeleye, 2002)**

| Factor | Lean | Agile |
|---|---|---|
| 1. Market conditions | Fairly stable market, suitable for sequential customisation of product families | Turbulent market, most suitable for parallel customisation as market demands vary randomly |
| 2. Competitive objective | Productive efficiency through continuous improvement in resource and process usage | Customer enrichment through timely mobilisation of enterprise-wide competencies |
| 3. Core capability | Multi-skilled workers, who constantly retool flexible machines for JIT deliveries | Knowledge workers who manipulate intelligent machines to quickly replicate custom solutions |
| 4. Management style | Paternalistic management – longer time contractual obligations with stakeholders | Laissez faire management of professionals engaged in open sharing through virtual technology |
| 5. Operations control | JIT, TQM and TPM all focused on smooth and frugal process and resource flow | Specific tools yet to emerge but there is increasing focus on virtual concurrent engineering |
| 6. IT architecture | EDI based technologies used widely to transmit operational and contractual data | Client server technologies employed for virtual design, engineering and manufacture |
| 7. Logistics | A hierarchy of distributors and suppliers put on master servant long-term contacts | Virtual sharing of manufacturing knowledge via ad hoc supplier, customer and competitor networks |
| 8. Work organisation | Process based work teams who meet frequently discuss quality and efficiency | Virtual work teams with boundary-spanning concept to cash |
| 9. Machine characteristics | Simple machines which are continually retooled by multi-skilled operatives | Programmable machines which are continually reprogrammed by knowledge workers |
| 10. Nature of automation | Repetitive automation, applied to linear flow transfer batch processes | Re-programmable automation applied to the manufacture of intelligent one-of-a kind products |
| 11. Core training requirements | Cross-training in preventative maintenance and operations before and after own station | Specialist training in system monitoring/analysis as well as applications software |
| 12. Overriding limitation | A fragile balance of inventories, capacity and relationships, not robust against shocks | In adequate attention to internal factors, and absence of implementation methodologies |

#### 2.2.3.1 Identification of customer value

The first principle of lean is to specify value from the perspective of the end customer. The critical starting point for lean implementation is value. Value can only be defined by the end customer (Womack and Jones, 1996). Customer value can be defined as how the customer perceives the product or service offered by the organisation. Every feature of a product or service not required by the customer is waste. It is important to accurately identify value in order to eliminate waste. The outcome of specifying value may lead a company to reinvent itself for its customers.

#### 2.2.3.2 Management of value stream

The second principle of lean is to identify all steps in the value stream of a product or service and if possible, eliminate all those steps which do not create value for the customer. Value stream is the set of all specific processes and actions required to bring a specific product or service to the customer. By defining the entire value stream all the non-value added activities and wastes can be eliminated (Womack and Jones, 1996). It is necessary to understand all process activities and then optimise the value stream in regard to the customer, so each activity adds value to the customer.

#### 2.2.3.3 Developing flow production

After specifying value and identifying the value stream, the third principle is getting the activities that are value adding to flow without interruptions. Creating a flow in the process enables organisations to discover problems and also to take quick corrective actions. Also, continuous flow reduces the lead-time, processing time, and overall production costs.

#### 2.2.3.4 Using pull techniques

“Pull in simplest terms means that no one upstream should produce a good or service until the customer downstream asks for it” (Womack and Jones, 1996). As the product flows out the organisation, there must be a customer that needs it or there will be excess product in the marketplace that eventually gets pushed on potential customers. Pull is described as not allowing a product to proceed to the next step unless the downstream customer requires it. In short, pull is accurately responding to the demand of the customer.

#### 2.2.3.5 Strive to perfection

After value specification, value stream analysis, elimination of waste, and creation of flow, the fifth principle of lean aims to restart this process again. This principle reminds the company to never stop improving on the lean principles. Perfection is the complete elimination of waste. At this point every activity creates value for the customer.

As the customer's requirements change, modifications in value specification will be required along with re-identifying the value stream that must flow and pull properly.

### 2.2.4 Value and Waste

As discussed in the previous section, the most important aspects of lean implementation are identifying value and eliminating wastes or non-value-added activities. Therefore, this section will provide an explanation of both value and waste.

#### 2.2.4.1 Value

The term value is very subjective and its meaning differ from one person to another, this section provides some definitions of the terms value. Zeithaml (1988) defined value as consumer's overall assessment of the utility of a product based on perceptions of what is received and what is given. Monroe (1990) stated that buyers' perceptions of value represent a trade-off between quality or benefits they perceive in the product relative to the sacrifice they perceive by paying the price. Gale and Wood (1994) defined value as market perceived quality adjusted for the relative price of your product. Therefore, the meaning of value can vary from customer to customer as follows:

- First: ‘value is low price’. For those customers, lowest price is the best.
- Second: ‘value is whatever I want in a product or service’. This focuses on benefits, not price.
- Third: ‘value is the quality I get for what I pay’. Here expectations are directly linked to price-pay more expect more.

- Fourth: ‘value is what I get for what I give’ all benefits against all sacrifices, not just money.

In sum, value can be defined as getting the exact product or service that you require, in the right quantity, at the right time, with perfect quality of course, and at the right price (Bicheno, 2008).

#### 2.2.4.2 Waste

Waste is any activity or step in a process for which the customer is not willing to pay. Such steps not only add to the time but also the cost of the process. There are broadly three types of activities in a process (Womack and Jones, 1996; Sarkar, 2007):

- Value-added steps/activities are those activities for which the customer is willing to pay. These steps help to bring about a transformation in the product or service being provided by the organisation and add a feature or trait that the customer values and is willing to pay for.
- Business-value-added steps/activities (necessary non-value adding) are those activities in a process for which the customer is not willing to pay but that cannot be avoided. They necessarily need to be present in the process and cannot be eliminated from the process. They are also called necessary non-value-add. The Japanese call them type I muda (waste). (e.g., preparing financial reports, maintaining human resources records, and ordering business supplies).
- Non-value-added steps/activities are those activities in a process for which the customer are not willing to pay and can be avoided. The focus should be to eliminate these activities and steps. The Japanese call them type II muda.

Lean is frequently associated with the elimination of seven types of wastes namely: overproduction, over processing, waiting, unnecessary transport, defects, excess movement and inventory (Shah and Ward, 2007).

**1. The waste of overproduction**

The waste of overproduction means processing more or sooner than required, i.e. making too much, too early or just-in-case. The aim should be to make or do or serve exactly what is required, no more and no less, just in time and with perfect quality. Overproduction discourages a smooth flow of goods or services, also leads directly to excessive lead time. As a result defects may not be detected early, products may deteriorate, and the chance of defects increases. (Bicheno, 2008)

**2. The waste of waiting**

Waste of waiting refers to individuals and items being idle between operations or it is any delay between one activity and another. Waiting is the enemy of smooth flow (Bicheno, 2008).This unused time adds no profit and actually costs the company money due to employee wages.

**3. The waste of unnecessary motions**

Waste of motion is the movement of individuals that is unnecessary for successfully completing a job in a process (Sarkar, 2007). Motion waste is the pointless movement of various employees, raw materials, or machines from one place to another.

**4. The waste of transporting**

Waste of transporting refers to movement of materials, which is more than just time in processing (Sarkar, 2007). This type of waste means having too many transports for a certain material or work in progress transportation. It also includes product deterioration or damage which occurs during transports and the prolonged transport times, in which there is not profit.

**5. The waste of processing (Inappropriate processing)**

Trying to add more value to goods or services than what the customer wants to pay for it. Also, inappropriate processing refers to a process that cannot help but make defect (Bicheno, 2008).

**6. The waste of unnecessary inventory**

This is when there are items or supplies in the process in excess of what is required for single-piece flow. Inventory is the enemy of quality and productivity. This is because inventory tends to increase lead time and prevents rapid identification of problems. There are three types of inventory: raw materials, work in process, and end item (Bicheno, 2008; Sarkar, 2007). All unnecessary inventories should be removed in order to reduce the costs.

**7. The waste of defects**

This refers to waste that occurs due to errors and not getting an item or product right the first time out in a process. Due to the errors, the item or the product needs to be reworked. Failure or defect may be internal failure (rework, delay) and external failure (including warranty, repairs, but also possible lost custom). Table 2.8 demonstrates a summary of the seven wastes associated with lean.

### 2.2.5 Common Lean Tools and Techniques

To achieve the desired goals of implementing lean, a variety of tools and techniques can be used. If these tools and techniques are used appropriately, they can help in eliminating waste, better inventory control, better product quality and better overall operational procedures (Womack et al., 1990). However, there is no single source for lean tools and techniques that drives a company to a successful implementation (Hobbs, 2003). Each organisation must deal with its own problems and processes and select the tools and techniques that suit its processes and operations. Lean tools and techniques are not discrete; some tools overlap and support each other. This section presents some of the lean tools and techniques as explained in Table 2.9 from a variety of sources.

#### 2.2.5.1 5S

5s is a concept which originated from 5 Japanese words that starts with ‘S’ Seiri, Seiton, Seiso, Seiketsu and Shitsuke. These words translated into English to: Sort, Set, Shine, Standardise and Sustain (Chapman, 2005). The purpose of the 5s is to create and maintain an organised, clean, safe, and high performance work place. Therefore, implementing 5s eliminates waste that results from a poorly organised work area. This tool is a systematic way to improve the workplace and processes. The 5s are described as:

Sorting – This is the first step, which involves sorting out what is needed at the workplace in order to carry out work. Sort is clearly distinguishing what is needed or not needed among the tools, supplies and other materials.

**Table 2.8 Summary of the Seven Types of Waste**

| Waste | Description | Lead to | | |
|---|---|---|---|---|
| **1. Overproduction** | Producing too much or too soon, resulting in poor flow of information or goods and excess inventory | → | • Costs money<br>• Consumes resource ahead of plan<br>• Creates inventory | • Hides inventory/defect problems<br>• Space utilisation |
| **2. Defects** | Frequent errors in paperwork, product quality problems, or poor delivery performance | → | • Adds costs<br>• It interrupts the scheduled<br>• It consumes resources | • It creates paper work<br>• Reduces customer confidence |
| **3. Unnecessary inventory** | Excessive storage and delay of information or products, resulting in excessive cost and poor customer service | → | • Adds cost<br>• Extra storage space required<br>• Extra resource to manage | • Hides shortages & defects<br>• Can become damaged<br>• Shelf life expires |
| **4. Inappropriate processing** | Going about work processes using the wrong set of tools, procedures or systems, often when a simpler approach may be more effective | → | • It consumes resource<br>• It increases production time | • It's work above and beyond specification |
| **5. Transportation** | Excessive movement of people, information or goods resulting in wasted time, effort and cost | → | • Increases production time<br>• It consumes resource & floor space<br>• Poor communication<br>• | • Increases work in progress<br>• Potential damage to products |
| **6. Waiting** | Long periods of inactivity for people, information or goods, resulting in poor flow and long lead times | → | • Stop/start production<br>• Poor workflow continuity<br>• Causes bottlenecks | • Long lead times<br>• Failed delivery dates |
| **7. Unnecessary motion** | Poor workplace organization, resulting in poor ergonomics, example: excessive bending or stretching and frequently lost items | → | • It interrupts production flow<br>• Increases production time | • Can cause injury |

Set – The second step is setting everything in order. “A place for everything and everything is in its place” (Chapman, 2005). Set is arranging needed items so that they are readily accessible and labelled so that anyone can find them.

Shine – This step focuses on neatness. Shine means keeping work area cleaned and in an orderly condition during working hours. All staffs are encouraged to routinely clean their work space. Bicheno (2000) reasoned that the “simple fact is that the cleaner or tidier a location is, the easier it is to see if something is out of place”.

Standardise – Standardise means defining what the normal condition of the work area. The method of how to carry out the work, the equipment and anything related to the organisation must be standard and made assessable and recognisable throughout the organisation.

Sustain – The final step is to ensure that the four earlier steps become the norm of working in the organisation.

#### 2.2.5.2 Kaizen (Continuous Improvement)

Kaizen is a Japanese word that stands for “Kai” (means “change”) and “Zen” (means “for the good”). Kaizen means continuous improvement. Kaizen is a systematic approach where employees work together proactively to achieve regular, incremental improvements in the manufacturing process (Furterer, 2009). It is a method for accelerating the pace of process improvements. The foundation of kaizen consists of five elements, namely: teamwork, personal discipline, improved morale, quality circles and suggestions for improvement.

#### 2.2.5.3 Just- in- Time (JIT)

JIT is closely associated with lean implementation. JIT refers to the production of goods and services to meet customer demand exactly, in time and in the right quality and quantity (Hutchins, 1999). The customer is the final purchaser of the product or another process further along the production line. JIT is closely related to pull systems. JIT attempts to minimise inventories, work-in-progress, and poor scheduling of parts delivered.

#### 2.2.5.4 Value Stream Mapping (VSM)

Value stream is all the processes involved to produce a product or service to the customer from designing, receiving orders, production till delivering products. Value stream mapping (VSM) is a process mapping method to document the current and future states of the information and material flows in a value stream, from customer to supplier (Rother and Shook, 2003). VSM helps in creating an “As-Is” version to visualise the improvement opportunities and also helps in creating “Should-Be” version. Therefore, VSM exposes waste in the current processes and provides a roadmap for improvement through the future state.

#### 2.2.5.5 Root Cause Analysis (5 Whys)

5 whys and cause-and-effect diagram are powerful tools to generate the root causes of the problem. They are used for discovering all the possible causes for a particular effect. The major purpose of the cause and effect diagram is to act as a first step in problem solving by generating a comprehensive list of possible causes (Furterer, 2009). Cause and effect diagram can lead to immediate identification of major causes and point to the potential remedial actions. Preparing a cause and effect diagram will lead to greater understanding of the problem (George et al., 2005).

#### 2.2.5.6 Poka-Yoke (Error Proofing)

Poka-yoke is a Japanese word that stands for mistake proofing. Poka-yoke technique is the art of preventing defects in products by correcting or raising alarm on different human errors or machine defects as they occur. Poka-yoke performs a detective function, eliminating defects in the process as early as possible (Fisher, 1999).

#### 2.2.5.7 Standardised Work

Standardised work is one of the most powerful but least used lean tools. Standardised work ensures that each job is organised and is carried out in the most effective manner (Bicheno, 2008). Standardised work is a management driven way of controlling the work of the workers. Standardised work attempts to eliminate waste by consistently applying best practices, and form a baseline for future improvement activities.  Experts decide in advance how a job should be done, how long it should take, and how problems are to be handled (Furterer, 2009). As the standard is improved, the new standard becomes the baseline for further improvements, and so on. Improving standardized work is a never-ending process (George et al., 2005).

#### 2.2.5.8 Key Performance Indicators (KPIs)

KPIs are metrics designed to track and encourage progress towards critical goals of the organisation. Strongly promoted KPIs can be extremely powerful drivers of behaviour. The best manufacturing KPIs are those that aligned with top-level strategic goals, effective at exposing and qualifying waste, and readily influenced by employees so they can drive results (Furterer, 2009).

#### 2.2.5.9 Visual Management

Visual management is providing and maintaining selected information in a visual, graphic form. It can involve production work planned by the day or week, work centre status, departmental goals, or other information (Parry and Turner, 2006). Visual management makes the state and the condition of the manufacturing processes easily accessible and very clear to everyone. Therefore, visual management helps people understand complex information at a glance, reduces waste by communicating effectively, and encourages collaborating among a team because everyone can see what everyone else is working on (Koning et al., 2006).

#### 2.2.5.10 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a holistic approach to maintenance that focuses on proactive and preventive maintenance to maximise the operational time of equipment. The idea behind TPM is that of having zero tolerance at breakdowns, as well as, defects. TPM blurs the distinction between maintenance and production by placing a strong emphasis on empowering operators to help maintain their equipment (Nakajima, 1988).

#### 2.2.5.11 Policy Deployment

Policy deployment is the process of ensuring that the company objectives are effectively deployed throughout the whole organisation. Through policy deployment, the company objectives should be cascaded and translated into: departmental objectives, team objectives, and individual objectives. Policy deployment provides the framework that links every employee's worked the top level strategy (Hines et al., 2004).

### 2.2.5.12 Takt Time

Takt time is defined as the maximum time of a single component allowed to produce a product so as to meet customer demand. It is calculated by dividing the available production time by number of products demanded by customers (Sarkar, 2007).

**Table 2.9 Common Lean Tools[1]**

| Lean Tool | Description | Benefits |
|---|---|---|
| **5S** | Organise the work area:<br>Sort (eliminate what is not needed)<br>Set in order (organise remaining items)<br>Shine (clean and inspect work areas)<br>Standardised (write standards to conduct the work)<br>Sustain (regularly apply the standards) | Eliminate waste that results from a poorly organised work area |
| **Kaizen (Continuous Improvement)** | A strategy where employees work together proactively to achieve regular, incremental improvements in the manufacturing process | Combines the collective talents of a company to create an engine for continually eliminating waste from manufacturing processes |
| **Just in Time (JIT)** | Pull parts through production based on customer demand instead of pushing parts through production based on projected demand | Highly effective in reducing inventory levels. Improves cash flow and reduces space requirements |
| **Value Stream Mapping** | A tool used to visually map the flow of production. Shows the current and future state of processes in a way that highlights opportunities for improvement | Exposes waste in the current processes and provides a roadmap for improvement through the future state |
| **Root Cause Analysis** | A problem solving methodology that focuses on | Helps to ensure that a problem is truly eliminated by |

[1] **(Source: http://www.leanproduction.com/)**

| Lean Tool | Description | Benefits |
|---|---|---|
| | resolving the underlying problem instead of applying quick fixes that only treat immediate symptoms of the problem | applying corrective action to the "root cause" of the problem |
| **Poka-Yoke (Error Proofing)** | Design error detection and prevention into production processes with the goal of achieving zero defects | It is difficult (and expensive) to find all defects through inspection, and correcting defects typically gets significantly more expensive at each stage of production |
| **Standardised Work** | Documented procedures for manufacturing that capture best practices | Eliminates waste by consistently applying best practices.<br>Forms a baseline for future improvement activities. |
| **Key Performance Indicator (KPI)** | Metrics designed to track and encourage progress towards critical goals of the organisation. | The best manufacturing KPIs:<br>Are aligned with top-level strategic goals (thus helping to achieve those goals)<br>Are effective at exposing and quantifying waste<br>Are readily influenced by plant floor employees |
| **Visual Management** | Visual indicators, displays and controls used throughout manufacturing plants to improve communication of information | Makes the state and condition of manufacturing processes easily accessible and very clear to everyone |
| **Total Productive Maintenance (TPM)** | A holistic approach to maintenance that focuses on proactive and preventative maintenance to maximise the operational time of equipment. | Creates a shared responsibility for equipment that encourages greater involvement by plant floor workers |
| **Policy Deployment** | Align the goals of the company (Strategy), with the plans of middle management (Tactics) and the work performed on the plant floor (Action) | Ensures that progress towards strategic goals is consistent and thorough eliminating the waste that comes from poor communication and inconsistent direction |

### 2.2.6 Barriers to Implement Lean

Changing an organisation from old habits into new one is difficult. Many organisations have failed in their lean transformation due to a variety of reasons. The implementation of lean within organisations is perceived to attract enormous challenges (Achanga et al., 2006; Aurelio et al., 2011). Bhasin and Burcher (2006) stated that although lean manufacturing has a lot of benefits, its implementation in the organisation faces many different challenges. Barker (1996) and Barker and Barber (1997) mentioned that less than 10% of the overall UK companies have yet to accomplish successful lean implementation within their premises. This section addresses some of the barriers and challenges that impede the organisation to adopt lean.

#### 2.2.6.1 Insufficient financial resources

For the successful implementation of lean, there is a need for change in the structure, habits, and performance evaluation system (Mirzaei, 2011). Lean cannot be simply applied in existing organisation without any changes and be expected to generate the desired return. According to Gautam and Singh (2008), Browning and Heath (2009), and Mirzaei (2011), lean implementation may be associated with extra implementation cost and investment in manufacturing and assembly facilities, as well as, changes in maintenance system. Shah and Ward (2003) stated that resource limitations have a great impact when applying lean. Financial inability is considered one of the challenges for the successful implementation of lean. Organisations will require a bulk of money to pay for consultants, training employees to understand lean tools and techniques.

#### 2.2.6.2 Misapplication and misunderstanding of lean

The current Toyota Production System has been in existence since 1945, it has had many years of development to where it is now. But, due to the competitive nature of the current manufacturing market, most manufacturers usually apply lean practices in rush. The focus on efficiency gains have led to a number of partial implementations of lean as companies managers have attempted to replicate the success of other without understanding the principles of lean. Pavanasker et al., (2003) stated that misapplication and misunderstanding of lean practices by manufacturers resulted in many failures, where most of them look for immediate results and impacts. According to Grove et al., (2010), there are critical determinants that need to be put in place before organisations can start the implementation of lean. The top of the requirements are the tools and techniques, these tools and techniques are usually used for a quick fix and achieving short term results and benefit. But the successful lean implementation requires all of the tasks from the bottom to the top to be accomplished. Hence, to achieve successful implementation and subsequent adoption of the lean concept, all the factors must be facilitated concurrently as displayed in Figure 2.7

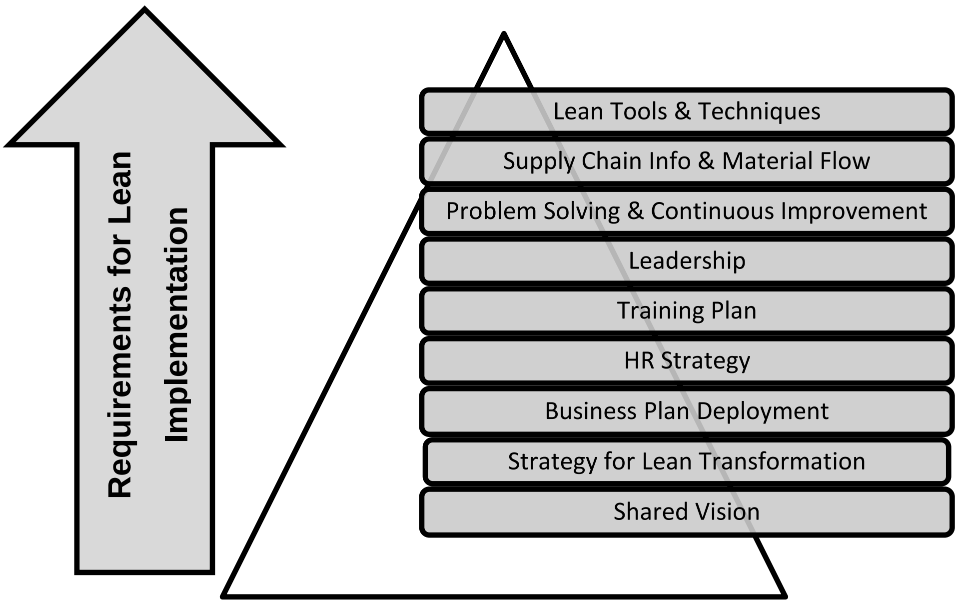



**Figure 2.7 Requirement for Lean implementation**

### 2.2.6.3 Employee involvement

Employees are the tools that can be used to implement any new business changes. They can either accelerate these changes or hinder them. Without the support and participation of employees all the lean efforts will be useless. The application and successful adoption of lean can only be sustained in a smooth and structured manner, when the employees are involved. Radnor et al., (2006) reported that workforce that are willing to accept lean initiatives, is one of the key factors for the successful lean implementation. Employees should be engaged in the improvement process from very early stages to become more committed and motivated.

Implementing lean requires hiring the right number of employees, with the right skills, that work safely and productively without errors (Harris, 2007).

#### 2.2.6.4 Lack of supportive culture

Underlying every lean failure is the fundamental issue of corporate culture and change management (Parks, 2002; Mann, 2010). Successful lean implementation is associated with adopting the culture of continuous improvement and waste elimination across all areas of the business (Bhasin and Burcher, 2006). Organisational culture is an essential element in lean implementation process and high performing companies are those with a culture of sustainable and proactive improvement effort (Achanga et al., 2006). Organisational culture is the personality of an organisation; it includes the organisation's expectations, experiences, philosophy, and values that hold it together. Organisational culture is based on shared attitudes, beliefs, customs, and written and unwritten rules that have been developed over time (Buhler, 2007).

According to Bhasin (2011), 80 % of becoming lean is related to culture issues. Organizational culture facilitates the integration of individual learning by influencing the organizations' ability to learn, share information and make decisions. Changes of mind-set gives people an aim in their working life and have the potential to change attitudes, so that the employees begin to think differently and are more willing to contribute to company's improvement initiatives.

#### 2.2.6.5 Lack of management commitment

Narang (2008) and Brown et al., (2006), emphasised that the lean is not just a toolkit which is used to reduce the costs and inventories, or about removing wastes and enhancing productivity. Nevertheless, lean is about human resources, leadership, management, and culture. To succeed in lean implementation, a committed management is crucial. One of the key reasons of the failure of any change efforts is the lack of management commitment. All managers at all levels should be convinced that lean is the right path for organisational development. Senior management need to show full commitment and belief in lean, as well as, they should provide the required support, resources, budget and investment to their employees (Randor et al., 2006). Moreover, managers should act as leaders to establish the necessary conditions for effective lean implementation communicate the importance and benefits of implementing lean practices, crate a sustainable motivation among employees. The role of leader is vital when implementing lean initiatives. Womack and Jones (1996) mentioned that for successful lean transformation, a company will need:

- Someone that deeply understands lean techniques (lean specialist).
- Someone who can be the champion and solve all the challenges arose during the implementation process.
- Someone who is committed to lean.

#### 2.2.6.6 Poor communication

A successful lean implementation is influenced by how the company will effectively communicate with those affected by the new way of doing the business (Worley and Doolen, 2005). For companies to success in their lean implementation process, managers need to convey the benefits of lean, as well as, how the implementation will take place to all the members of the company (Mathaisel, 2005). Good communication plan is vital to involve everyone in the implementation process to get them committed and to identify how the implementation of lean will affect their work.

#### 2.2.6.7 Lack of training

Training is one of the most important factors that contribute to the success of lean implementation. Successful lean implementation requires a deep understanding of its principles and practices and the implementation process will be facilitated with extensive training at all levels. Training should focus on changing employees' beliefs and attitude (Bozdogan et al., 2000). Training will help all the members of the organisation to fully understand the concept of lean and how it will be applied. Training is crucial for organisational development and success. Training will result in increasing productivity, quality, profitability, and team spirit, as well as, improving and organisational culture. Lean training may include: lean skills for leaders, and other training on lean tools and techniques such as: process mapping, value steam mapping, and project management. A lean workforce should have the right skills to be able to implement the new way of doing their work.

#### 2.2.6.8 Complexity of lean implementation process

One difficulty with lean implementation is that the complexity of the new approach. Lean implementation is a complex process that requires a proper plan prior to its implementation. Womack et al., (1990) stated that the application of lean should take a sequential path. It first requires changing employees' attitudes toward quality, then the establishment of flow with only value-added operations, and the implementation of lean tools and techniques. If managers use a few of the basic lean tools only to pick their anticipated faults, a quick fix approach, the real potential for dramatic and continuous improvement is usually lost (Achanga et al., 2006).This indicates that the complexity of lean implementation should be taken into consideration. Furthermore, lean is constant, long term and a never-ending process (Frigo, 2003). Implementing lean requires a long-term commitment, a minimum time frame of five years of an average sized company (Womack et al., 1990).

### 2.2.7 Critical Success Factors for Implementing Lean Practices

Critical success factors (CSFs) can be defined as "the limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organisation" (Rockart, 1979). Also, Boynton and Zmud (1984) defined CSFs as "those few things that must go well to ensure success". Activities associated with CSFs must be performed at the highest possible level of excellence to achieve the intended overall objectives. If these objectives are not achieved, the application program will lead to failure.

Several authors stressed on the importance of examining and investigating such key factors that considered critical for the successful implementation of any new improvement initiatives such as; lean and lean six sigma. Various studies have been conducted to identify the significant factors that are necessary for the successful implementation of lean in the manufacturing sector and the non-manufacturing sector.

In the manufacturing sector, Crute et al., (2003) identified the factors that affect lean implementation in two plants in the aerospace industry. They have claimed that there are five main factors that affect lean implementation in the aerospace industry. Also, by examining lean implementation in ten UK SMEs, Achanga et al., (2006) demonstrated the necessary factors for the successful implementation of lean in SMEs. Furthermore, Rich and Bateman (2003) conducted a study within 21 companies to determine the inhibitors and enablers of process improvement activities.

In the non-manufacturing sector, there are some exiting researches carried out to determine the CSFs for the successful implementation of lean. Suárez-Barraza and Ramis-Pujol (2010) examined the implementation of lean-kaizen in the human resource service process in the Mexican public service organisation. They clarified the key factors that are necessary for the successful implementation of lean in the Mexican public service organisation. In addition to Suárez-Barraza and Ramis-Pujol, Pedersen and Huniche (2011) examined the CSFs for implementing lean practices in the Danish public sector. Also, in a study conducted in the IT service sector by Kundu and Manohar (2012), the CSFs for the successful lean implementation have been identified. Beside all the previous research that have carried out to determine CSFs for implementing lean in both the manufacturing sector and the non-manufacturing sector, many other researchers have emphasised on the CSFs of implementing lean six sigma in manufacturing and non-manufacturing sectors. Authors that have examined the implementation of lean six sigma include Henderson and Evans (2000), Coronado and Antony (2002), Kwak and Anbari (2006), Antony et al., (2007), Chakrabarty and Tan (2007), Antony and Desai (2009), and Jeyaraman and Teo (2010). All these researchers examined and identified the CSFs for implementing lean six sigma and six sigma in either the manufacturing sector or the non-manufacturing sector. The literature review yielded just over 20 papers that discussed the CSFs for implementing lean and lean six sigma in the manufacturing sector and the non-manufacturing sector. Table 2.10 summarises all the CSFs identified by previous researchers and the important of each factor.

### 2.2.8 Measuring Leanness

In spite of the vast research published on lean manufacturing and lean service, the concept remains immature for two reasons: (1) it lacks a general accepted definition; (2) it lacks a holistic and unifying measure. Therefore, it becomes necessary for successful lean implementation to develop a standard measure to assess the effectiveness and efficiency of lean implementation and lean practices (Bayou and De Korvin, 2008; Pakdil and Leonard, 2014).

**Table 2.10 CSFs for Lean implementation**

| Number | Critical success factor | Frequency |
|---|---|---|
| 1 | Management commitment & leadership | 19 |
| 2 | Culture issues | 11 |
| 3 | Training | 10 |
| 4 | Assessment and evaluation | 5 |
| 5 | Customers' relationship | 5 |
| 6 | Financial capabilities | 5 |
| 7 | Understanding of process | 3 |
| 8 | Suppliers' relationship | 2 |

(**Source:** Crute et al., 2003; Achanga et al., 2006; Rich and Bateman,2003; Suárez-Barraza and Ramis-Pujol, 2010; Pedersen and Huniche, 2011; Kundu and Manohar, 2012; Henderson and Evans, 2000; Coronado and Antony, 2002; Kwak and Anbari, 2006; Antony et al., 2007; Chakrabarty and Tan, 2007; Antony and Desai, 2009; Jeyaraman and Teo, 2010)

If lean is the aim, then it is necessary to use performance measures that promote lean behaviour. Measurement of lean status will facilitate the implementation process (Haque and Moore, 2004).

Assessment is essential to identify both the deficiencies and progress of lean concept within firms, because leanness is a process, a journey, not an end state and if you cannot measure it, you cannot manage it (Pakdil and Leonard, 2014).

The term leanness has been used by several researchers while discussing on lean manufacturing. However, the perceptions of leanness found in the literatures differ from one author to another. The definition of leanness was not stated explicitly. Few attempts were made to precisely define leanness in the context of assessing lean status. Leanness refers to the degree of the adoption and implementation of lean philosophy in the organisation (Wong et al., 2014). Comm and Mathaisel (2005) described leanness as a relative measure of whether a company is "Lean" or not. Bayou and De Korvin (2008) described manufacturing leanness as a strategy to incur less input to better achieve the organisation's goals through producing better output. Vinodh and Chintha (2011) defined leanness as the performance measure of lean practices. The leanness measurement gains importance as it indicates the leanness performance of the organisation.

Several researchers examined the leanness status in manufacturing and non-manufacturing sectors. This section presents previous studies conducted to evaluate and assess lean implementation in both manufacturing and non-manufacturing sectors.

**2.2.8.1 In the Manufacturing Sector**

Karlsson and Åhlström (1996) used a checklist to assess the extent of leanness in a mechanical and electronic office equipment industry. The checklist includes nine variables like: elimination of waste, continuous improvement, zero defects, JIT deliveries, pull of materials, multifunction teams, decentralisation, integration of functions, and vertical information system. The nine variables are developed to assess the changes toward lean production, and the degree of leanness assesses the adoption of lean production practices concerned with work organization in the production and operation function. Based on Karlsson and Åhlström variables, Soriano-Meier and Forrester (2002) developed a model to assess the leanness levels of 30 UK ceramic tableware manufacturers. The model consisted of nine groups of measurable determinates which focused on technical lean practices such as, waste elimination, continuous improvement, zero defects, JIT deliveries, pull of raw materials, multifunctional teams, decentralisation, integration of functions and the use of vertical information system as used by Karlsson and Åhlström (1996). The Lean Enterprise Self-Assessment Tool (LESAT) presented by Nightingale and Mize (2002) and applied in the aerospace industry. This tool used to evaluate three main processes: (a) Enterprise leadership processes; (b) Life-cycle processes; (c) Enabling infrastructure processes.  Also, Goodson (2002) evaluated manufacturing plants' leanness with a rapid plant assessment tool (RPA). He described his approach as rapid plant assessment (RPA). His tool used to indicate whether a factory is truly lean.  He developed a toolkit that measure (customer satisfaction, safety, cleanliness and order, visual management system, use of space, movement of materials, level of inventory, teamwork and motivation, supply chain integration, and commitment to quality). As an extension of the RPA tool Makui et al., (2014) introduced the Total Rapid Assessment (TRA) tool in order to evaluate lean implementation in manufacturing companies. The TRA is based on 15 assessment category. Shah and Ward (2007) developed an instrument for measuring lean practices. They listed 48 items which they argue were selected to present lean. Some of these measures related to suppliers and other measures related to customers involvement and the remaining address issues internal to the firm. Furthermore, Bayou and De Korvin (2008) developed a systematic measurement algorithm for lean assessment of manufacturing systems. They used the fuzzy-logic methodology since they believe that lean is a matter of degree. Bayou and De Korvin made a comparison between the leanness of General Motors and Ford Motor Company by using Honda Motor Company as a benchmark. They found that Ford's system is 17% leaner than General Motors' system over a period of three years. Bhasin (2011) used a total of 104 indices, which are grouped within 12 distinctive categories to measure the leanness of 20 manufacturing organisations in UK. Additionally, Vinodh and Chintha (2011) developed an index for measuring the leanness of an Indian electronics manufacturer. They developed a model consisting of three levels. The first level consists of five leanness enablers; the second level consists of 20 lean criteria, and the third level consists of several lean attributes. By using this model they have specified the degree of leanness and the areas for leanness improvements. Also Vimal and Vinodh (2013) used their previous system, but they have applied artificial neural network with fuzzy logic in the leanness assessment process. Pakdil and Leonard (2014) developed a tool called the Leanness Assessment Tool (LAT) to assess the effectiveness and efficiency of lean implementation throughout the entire organisation, using both quantitative and qualitative approaches. Pakdil and Leonard used eight quantitative performance dimensions: time effectiveness, quality, process, cost, human resources, delivery, customer and inventory. They also used five qualitative performance dimensions: quality, process, customer, human resources and delivery, with 51 evaluation items. Finally, Matawale et al., (2014) developed a quantitative analysis framework and simulation methodology to evaluate the existing leanness level in the production systems. This lean appraisement is based on generalised interval-valued (IV) trapezoidal fuzzy numbers set. Table 2.11 presents an overview of the instruments used in assessing lean in the manufacturing sector.

**Table 2.11 An Overview of Instruments for Assessing Lean Manufacturing (Adapted from Malmbrandt and Åhlström, 2013)**

| Author | Instrument | What is measured – type of items | Measurement of item | Intended user |
|---|---|---|---|---|
| **Karlsson and Åhlström (1996)** | Determinants of lean production assessment model | Elimination of waste, continuous improvement, zero defects, JIT, pull instead of push, multifunctional teams, decentralised responsibilities, integrated functions, vertical information systems, | Movement is assessed, the desired direction of the indicator, if moving in a lean direction | Researchers, but possible to use for self-assessment |
| **Soriano-Meier and Forrester (2002** | Managerial commitment to lean, leanness and performance model | Degree of adoption of lean principles (elimination of waste, continuous improvement, zero defects, JIT, pull of raw materials, multifunctional teams, decentralisation, integration of functions, vertical information systems), degree of commitment to lean programme (quality leadership, problem-solving teams, training, empowerment) | Seven-point Likert-type scale. 1 – no adoption, 4 – partial adoption, 7 – total adoption | Researchers |
| **Nightingale and Mize (2002)** | Lean enterprise self-assessment tool (LESAT) | Lean transformation/leadership: enterprise strategic planning, adopt lean paradigm, focus on the value stream, develop lean structure and behaviour, create and refine transformation plan, implement lean initiatives, focus on continuous improvement, manage supply chain, distribute and service product<br>Enabling infrastructure processes: lean organisational enablers, lean process | Specific capability levels have been developed for each indicator based on maturity metrics with generic definition of maturity levels | Assessment done by the company, analysis to be done by consultant |

| Author | Instrument | What is measured – type of items | Measurement of item | Intended user |
|---|---|---|---|---|
| | | enablers | | |
| **Goodson (2002)** | Rapid Plant Assessment (RPA) | Customer satisfaction, safety, cleanliness and order, visual management system, scheduling system, use of space, movement of materials, and product line flow, levels of inventory and WIP, teamwork and motivation, conditions and maintenance of equipment and instruments, management of complexity and variability, supply chain integration, commitment to quality | Six scale levels with scores for each: poor (1), below average (3), average (5), above average (7), excellent (9), best in class (11). In addition there is a questionnaire with 20 yes-or-no questions | Group of experts taking a plant tour |
| **Shah and ward (2007)** | Instrument for measuring variability reducing lean practices and underlying factors | Supplier related: supplier feedback, JIT delivery, developing suppliers<br>Customer related: involved customers<br>Internally related: pull, flow, low setup, controlled processes, productive maintenance, involved employees | Five-point Likert-type scale on the implementation of each lean practice.<br>1 – no implementation<br>2 – little implementation<br>3 – some implementation<br>4 – extensive implementation<br>5 – complete implementation | Researchers |
| **Bayou and De Korvin (2008** | systematic measurement algorithm | JIT, Kaizen, and quality control | Benchmark against<br>industry best practices<br>Organisations categorised as:<br>Lean, leaner, and leanest | Researchers |

| Author | Instrument | What is measured – type of items | Measurement of item | Intended user |
|---|---|---|---|---|
| **Bhasin (2011)** | Comprehensive lean audit to measure the leanness of a manufacturing firm | 12 main lean categories and 104 sub-categories.<br>Overall safety, cleanliness and order; production and operation flow; process and operations; visual management; quality designed into the product; continuous improvement; lean change strategy; lean sustainability; culture – employee oriented; organisational culture – organisational practices; lean treated as a business; lean philosophy | One to ten rate score | Researchers |
| **Vinodh and Chintha (2011)** | Leanness assessment | Five main lean enablers: management responsibility leanness, manufacturing management leanness, workforce leanness, technology leanness, manufacturing strategy leanness<br>20 lean criteria and 60 lean attributes | Five grade: 8 – 10: extremely lean; 6 – 8: lean; 4 – 6: generally lean; 2 – 4: not lean | Researchers and self-assessment |
| **Pakdil and Leonard (2014)** | Lean Assessment Tool (LAT) | Eight performance dimensions: time effectiveness. Quality, process, cost, human resources, delivery, customer and inventory.<br>51 evaluation items. | Quantitative and qualitative | Researchers |

### 2.2.8.2 In the Non-Manufacturing Sector

There are some existing instruments for evaluating leanness status. Kollberg et al., (2006) developed a model called “flow model”. This model used to explore lean thinking initiatives in the Swedish health care. The main focus of the model was not measuring lean, but to measure lead times and their improvement in health care. Also, Sánchez and Pérez (2004) assessed the changes towards leanness in services. Their model was implemented in Spanish service companies. Cuatrecasa (2004) assessed lean adoption in a hotel checkout service. Cuatrecasa (2004) established a methodology used in measuring the operations efficiency of the hotel checkout service. Moreover, Apte and Goh (2004) built a model for evaluating the performance of lean adoption in the insurance claims handling process. Moreover, Malmbrandt and Åhlström (2013) developed an instrument for assessing lean service adoption. This instrument contains 34 items that assess enablers of lean adoption, lean practices, and operational performance. Finally, Machado Guimarães and Crespo de Carvalho (2014) developed a framework called Healthcare Lean Assessment (HLA) framework. The HLA framework assesses three main dimensions: lean readiness or preconditions, lean hard and soft deployment and lean outcomes. The HLA used as an “as is” diagnosis tool, assessing whether each process should be improved, disrupted or eliminated and an on-going implementation assessment, as well, providing control measures and correction actions. Table 2.12 presents an overview of the instruments used in assessing lean in the non-manufacturing sector.

**Table 2.12 An Overview of Instruments for Assessing Lean Service**

| Author | Type of items | Measurement of item | Intended user |
|---|---|---|---|
| **Kollberg et al., (2006)** | Performance: lead time | Measuring lead time between specific points in the process | Permit self-assessment |
| **Sánchez and Pérez (2004)** | Practices: elimination of zero-value activities, continuous improvement, multifunctional teams, JIT delivery, suppliers' involvement, flexible information system.<br>Few performance items: WIP and inventory | No scales for assessing items were developed | No ready-to-use, instrument development only |
| **Cuatrecasa (2004)** | Performance: cycle time, inventory and productivity | Measurement of lead time, productivity and stock | Permit self-assessment |
| **Apte and Goh (2004)** | Performance: cycle time, productivity and quality | Measurement of lead time, productivity and quality | Permit self-assessment |
| **Malmbrandt and Åhlström (2013)** | 34 items that assess enablers of Lean adoption, Lean practices, and operational performance. | 5 levels: level 1 – no adoption, level 2 – general awareness, level 3 – systematic approach, level 4 – on-going refinement, level 5 – exceptional | Permit self-assessment |
| **Machado Guimarães and Crespo de Carvalho (2014)** | Three main dimensions: lean readiness or preconditions, lean hard and soft deployment and lean outcomes | Conceptual | No ready-to-use, instrument development only |

### 2.2.9 Lean Services

In recent years, it was found that lean has been widely applied in manufacturing sectors especially in the automotive industry where it started. But currently because of the possible benefits gained by applying lean, the popularity of lean in non-manufacturing sector is growing exponentially. Non-manufacturing sectors that have applied lean practices include for instance, insurance companies (Swank, 2003), NHS (Esain et al., 2008), and universities (Balzer, 2010; Radnor and Bucci, 2011).

Implementing lean in the service sector is essential for adding value to customers by providing services with higher quality and lower lead time via using fewer, but right resources. The main concept in lean services is the removal of wastes from service processes. Lean services can be defined as the application of lean manufacturing principles to service processes. Table 2.13 summarises previous researches conducted to implement lean in both the manufacturing and the non-manufacturing sectors.

Lean is a way to identify where the value is in the process, eliminate the waste within the process and create value to the customer. This concept shows that lean is applicable in any organisation, since the goal of organisation is to create value to end customer (Piercy and Rich, 2009). Womack and Miller (2005) stated that lean is not a manufacturing tactic only, but a management strategy that is applicable to all organisations because it has to do with improving processes. However, there is a long debate whether or not manufacturing and service operations can be managed based on the same concepts (Fitzsimmons and Fitzsimmons, 2008). Some authors stress the significance of distinctive service features like Grönroos (1990). He claimed that there are four basic characteristic that can used to identify services:

- Services are more intangible.
- Services are activities or a series of activities rather than things.
- Services are at least to some extent produced and consumed simultaneously.
- The customer participates in the production process at least to some extent.

Also, Schlesinger and Heskett (1991) argued that services are unique in terms of customer involvement and labour intensity.

On the other hand, Levitt (1972) claimed that "The managerial rationality embodied in the practical imagination we see exercised so, effectively everywhere in manufacturing can, given the effort, be applied with similarly munificent results in the service industries". Many authors agree with Levitt's opinion, who argued that the distinctive features of services should not be an excuse for avoiding manufacturing concepts as a means of increasing the efficiency of service operations. For example, Bowen and Youngdahl (1998) argued that lean ideas transfer well from manufacturing to services provided they were employed with minor alteration. Also, Allway and Corbett (2002) claimed that lean principles can be applied to many service sector firms, with equally the impressive results achieved in the manufacturing sector. Radnor et al., (2006) asserted that lean is transferable to the public sector and can be used to develop more seamless processes, improve flow, reduce waste and develop an understanding of customer value. Radnor et al., (2006) found that lean is a suitable methodology for improving performance and embedding a continuous improvement culture in the public sector. Similarly, Swank (2003), Piercy and Rich (2009), Delgado et al., (2010) confirmed that lean principles can be applied in services.

**Table 2.13 Previous Studies on Lean Implementation**

| Sector | Author | Summary |
|---|---|---|
| Manufacturing | Crute et al., 2003 | They examined the key drivers for lean implementation in aerospace. Also they examined the assumption that transferring the lean principles from the automotive industry to the aerospace industry may be difficult. They found that the problems of implementing lean within aerospace are not, necessarily, more difficult than that of implementing lean within high volume sectors, including automobiles. The challenges are different but not more difficult. |
| | Hunter et al., 2004 | They explained the methodologies used for the implementation of lean production in the furniture industry. He found that by applying the lean production on the furniture industry several gains can be achieved such as: improved quality, flexibility of processes, and cost reduction. |
| | Leitner, 2005 | He described the history and development of lean enterprise at the Boeing Company, also he explained the key environmental factors that helped lean succeed and demonstrated the tools and techniques used in applying lean. |
| | Hines et al., 2008 | He developed the road map for lean implementation for Cogent Power (Electrical Steel Production Company) through which it improved its competitiveness in the marketplace, lead to exponential sales Growth, and a culture of continuous improvement |
| | Wong et al., 2009 | The purpose of this study is to investigate the adoption of lean manufacturing in the electrical and electronics industry in Malaysia. They found that many companies in the electrical and electronics industry are committed to implement lean manufacturing. |
| *Note:* There are many case studies on the automotive industry in general and Toyota in particular for example: Cusumano 1985 and Fujimoto 1999 | | |

| Sector | Author | Summary |
|---|---|---|
| Service | Bowen and Youngdahl, 1998 | They discussed the implementation of lean principles in three different types of service industries (Taco Bell which is a fast food restaurant, Southwest Airlines, and Shouldice Hospital which is a private hospital). And they found that lean approach have a positive impact on the three organizations in terms of cost of operations, customer service focus, quality, competitive advantage, and processes. |
| | Goland et al. 1998 | They stated that by applying lean manufacturing techniques in areas such as check processing, credit application and approval, and call centres, a bank can decrease its efficiency ratio. |
| | Allway and Corbett, 2002 | They developed a model for lean implementation through which an insurance company successfully followed. By applying their model the insurance company has generated positive results. |
| | Swank, 2003 | He argued that insurance companies like Jefferson Pilot Financial JPF can benefit from lean production because its operations involved the processing of an almost tangible “service product”. Like an automobile on the assembly line, an insurance policy goes through a series of processes, from initial application to underwriting, or risk assessment, to policy insurance. With each step, value is added to the work in progress- just as a car. By applying lean impressive results were achieved: labour costs were reduced, the average time from receipt of an application to issuance of a policy was halved, and the rate of reissue due to error was decreased. |
| | Piercy and Rich, 2009 | They assessed the suitability of lean production methods in three financial-services companies (a bank and two insurance companies), the case of call centre. They claimed the suitability of basic lean methodologies such as identifying value, process mapping and problem solving for the pure service context; also they recorded significant improvements in quality and costs. |
| | Julien and Tjahjono, 2009 | They introduced lean principles to a safari park in Buckinghamshire, UK. The lean principles enabled the park to increase profits through eliminating waste and improving the efficiency of key processes whilst concurrently increasing customer satisfaction. |
| | Staats and Upton, 2009 | They investigated the implementation of a lean production system at an Indian software service firm. They found that lean projects perform better than non-lean projects in the sample they used. They argued that the implementation of lean principles resulted in improved operational performance. |
| | Delgado et al., 2010 | They reported the results of a financial service organization (GE Money Portugal) which begun the implementation of Lean Six Sigma ten years ago, in the pursuit of service excellence. The following benefits were highlighted: decrease in the operational costs, increase in productivity, improvement of the processes, and improving revenue by increasing customer satisfaction and by servicing more customers. |
| | Laureani and Antony, 2010 | They examined the impact of applying Lean Six Sigma on HR function of a service industry corporation. They found that Lean Six Sigma can be used to improve administrative processes, such as HR where employees’ satisfaction increased, and employees’ turnover decreased. |

| Sector | Author | Summary |
|---|---|---|
| Public | Kim et al., 2006 | They believed that the healthcare sector can apply the lean approach like the manufacturing and service industries. According to their study the application of lean principles and methods could have a transformational effect on how health care is delivered, with the potential for great gains in quality, safety, efficiency, and appropriateness. |
| | Krings et al., 2006 | They argued that by applying the lean approach local government in Cincinnati (a city in state of Ohio) achieved millions of dollars of cost saving and greatly improved public service. |
| | Radnor et al., 2006 | They evaluated the application of lean principles in eight public sector organizations in Scotland. They found that there was a wide range of both tangible and intangible outcomes achieved by applying the lean principles, such as:<br>Improving customer waiting times<br>Improving service performance<br>Improving processing times<br>Better understanding of the needs of the customer<br>Support for the development of a culture of continuous improvement<br>Greater staff satisfaction and confidence in themselves and the organisation |
| | Esain et al., 2008 | They discussed the use of 5S as a tool for continuous improvement in a large NHS. They highlighted improved in the processes, performance, and customer satisfaction. |
| | Hines et al., 2008 | They explored how the lean principles can be successfully extended into the legal sector. By discussing the implementation of lean approach in two public sector cases from Portugal and Wales, they found that lean approach can be applied in the legal sector. |
| | Barraza et al., 2009 | They tried to found out how lean thinking can be applied in local councils in Spain. They found that the quality of public services provided by the councils and processes of the councils were improved, by applying some lean tools such as: 5S, gemba kaizen workshops, and process mapping, |
| | Zokaei et al., 2010 | They examined the application of lean thinking in public services, by measuring the performance of three public organizations (Neath Port Talbot County Borough Council, Blaenau Gwent County Borough Council, and Portsmouth City Council Housing Department) before and after applying lean. They found that the application of lean thinking has a positive impact on the performance of the three cases, but the impact differs from one case to another. |

| Sector | Author | Summary |
|---|---|---|
| Higher Education | Comm and Mathaisel, 2005 | They explored the application of lean concept to colleges and universities. By developing a qualitative questionnaire and providing it to 18 U.S public and private university representatives, they found that the lean approach will contribute to the sustainability of the universities through improving performance and reducing costs |
| | William, 2010 | In his book Lean Higher Education: Increasing the value and performance of university process, he developed a five-step model that can help colleges and universities to apply lean approach to better align their key processes to deliver value for all constituents. Also he provided proven methods for uncovering and eliminating activities that overburden staff yet contribute little or no added value to stakeholders. |
| | Barroso et al., 2010 | They focused on the application of lean principles in Higher Education Institutions, by examining lean implementation in seven universities in the USA. |
| | Radnor and Bucci ,2011 | They provided an analysis of lean implementation across business schools and universities in the UK. They used five case studies in their research (Cardiff University, Nottingham Business School, Portsmouth Business School, the university of St Andrews, and Warwick Business School). |

Somewhere in between the two previous points of view, there are some authors who suggested that services can benefit and gain the same advantages achieved through lean manufacturing, if the lean principles and tools are adapted and adjusted to cope with the organisational context. For example, Johnston (1994) and Ahlstrom (2004) claimed that the principles of lean manufacturing can be applicable in service operations, but with contingencies. Bicheno (2008) identified some factors that should be taken into account when implementing lean to service operations:

1. In service operations value creation depends largely on the customer's perception. Where some activities that might not seem value adding with regard to the service provider might be important for at least some customers (Ahlstrom, 2004).
2. Due to customer involvement and the intangible characteristic of services, many services providers face high level of variation of customer demand. While manufacturers offer a predefined set of products, service providers often have to deal with unexpected requests (Seddon, 2005). Bicheno (2008) claimed that service providers can deal with this issue by classifying customers based on their demand pattern and the frequency of a service request. So, service providers can anticipate their customers demand.
3. Employee empowerment is important in order to improve process resilience. Staff should be enabled to respond spontaneously and adequately to customers' demands and requirements. At the same time, there should be blueprints and guidelines to be followed by the staff members to perform their work.
4. As services are always made to order because that cannot be stored, the lean principle of pull has a different meaning. Pull in service operations means avoiding inventories of customers waiting for their services (Seddon, 2005)

Also, Bowen and Youngdahl (1998) proposed several characteristics of lean service as presented in Table 2.14

**Table 2.14 Lean Service Characteristic**
**(Bowen and Youngdahl, 1998)**

**Reduction of performance trade-offs**

- Operations goals of both internally-focused efficiency and customer-defined flexibility

**Flow production and JIT pull**

- Minimise set-up time allowing for smoother flow
- JIT levels of both input and output

**Value-chain orientation**

- Apply service blueprinting and value analysis to eliminate non-value added activities

**Increased customer focus and training**

- Involve the customer in the design of the service package
- Train employees in customer service skills and behaviours
- Train customers in how to contribute to quality service

**Employee empowerment**

- Invest significantly in employees (skills, teambuilding, participation)
- Empower employees to leverage customers' value equation (benefits divided by price and other costs)

Lean service is essential to add value to customers by providing services with higher quality and speed the process by using fewer, but right resources. Furthermore, there are many non-manufacturing sectors successfully applied lean and have achieved the desired outputs. The biggest challenge in implementing lean in the non-manufacturing sector is to know which of the lean tools and techniques to use and how to apply them effectively, and how to define waste and manage variability of customers' demands.

## 2.3 Research Gap Analysis

From what has been exposed throughout this chapter, it can be concluded that manufacturing companies try to improve and develop their ability for competition through modern manufacturing initiatives and from these initiatives are lean manufacturing and Product-Service System (PSS). Lean and PSS can lead to dematerialisation through reducing the creation of wastes and the consumption of raw materials; improving customers' satisfaction by meeting customers' needs better; and improving competitiveness through increasing customers' value. Product-Service System (PSS) can be defined as an innovation strategy shifting the business focus from designing and selling physical products only, to selling a system of products and services which are jointly capable of fulfilling specific client demands. On the other hand, lean focuses on producing what is needed, when it is needed, with the minimum amount of wastes. Lean is not a manufacturing tactic only, lean applies in every business and every process because it improves business processes. Lean practices can be implemented in the process of providing services to customers. Lean PSS is the application of lean principles in the service offering processes that PSS providers use.

This literature review provided a better understanding about the state of art in PSS and lean. Most of the research described in the literature makes an attempt to implement lean practices and principles either in the manufacturing sector or in the non-manufacturing sector. The main observations identified by means of this literature are summarised as follows:

- The implementation of lean can be considered difficult and challenging and few companies succeed in their lean journey. For the successful lean implementation process, there is a need to define a well-planned framework that define and describe how lean principles can be applied to any process or system either in the manufacturing sector or non-manufacturing sector.

- The successful lean implementation is a complex process that requires a proper plan prior to its implementation. Therefore, it is important to outline the factors that perceived to be critical for the successful implementation of lean, as well as, the obstacles that may hinder the implementation process in the manufacturing and non-manufacturing sectors.

- Leanness measurement gains importance in both the manufacturing and the non-manufacturing sectors, as it indicates the leanness performance of the organisation.

The main research gaps identified by means of this literature review are summarised as follows:

- There is a lack of efforts conducted to precisely determine how lean principles can be implemented in PSS.
- While many attempts have been made to create a useful framework for the implementation of lean principles in the manufacturing sector and the non-manufacturing sector, none of them addressed the implementation of lean principles in PSS.
- Despite the much-acclaimed importance of the benefits of implementing lean in the manufacturing and non-manufacturing sectors, determinates of lean success and failure in PSS have not been investigated yet. It is important to outline the enablers, factors, challenges, and tools of implementing lean practices in PSS.
- Despite the vast research carried out either on lean manufacturing or lean service, the definition of leanness was not stated explicitly. Few attempts were made to precisely define leanness in the context of assessing lean status in the manufacturing and the non-manufacturing sectors, as well as, there is no structured tool that can be used to measure the degree of leanness in the service offering process.

## 2.4 Chapter Summary

In this chapter the literature associated with the context and research areas related to this study was reviewed, to reveal any research gaps and develop a better understanding of the area under investigation. The chapter was divided into three main parts. Part one focused on exploring the concept of Product-Service system (PSS) thus, this part was organised as follows:

In Section 2.1.1 the different definitions of PSS were presented. Then, in Section 2.1.2 the main categories and sub-categories of PSS were discussed. In Section 2.1.3 real examples were presented for companies from different industries that have successfully implemented PSS. In Section 2.1.4 and Section 2.1.5 the various benefits gained from implementing PSS and the key barriers to develop PSS were presented. In Section 2.1.6 the differences between PSS and other terminologies that are used interchangeably were presented. Finally, the design of PSS was presented in Section 2.1.7

The Second Part of this chapter was devoted to investigating the concept of lean and this Part was organised as follows:

Section 2.2.1 provided the origin of lean manufacturing. Then, in Section 2.2.2 a comparison between lean and other quality initiatives, such as: Total Quality Management (TQM), Six Sigma and agile manufacturing was conducted. Section 2.2.3 and Section 2.2.4 presented the lean principles, and provided insight into two main lean principles, namely: value and waste. After that, in Section 2.2.5 the available lean tools and techniques used were outlined. Moreover, Section 2.2.6 and Section 2.2.7 described the challenges associated with lean implementation, as well as, the critical factors required for the successful implementation of lean in the manufacturing sector and the non-manufacturing sector. Next, in Section 2.2.8 research work done in the area of evaluating and measuring leanness in both the manufacturing and the non-manufacturing sectors was discussed. Finally, in Section 2.2.9 research work done in the area of implanting lean in different sectors such as service, health care and education was discussed. In the third part of this chapter, the research gap analysis was presented.

# CHAPTER 3

## 3 RESEARCH METHODOLOGY

In the introductory chapter, the fundamental research issues have been outlined, along with an overview of the research aim and objectives. The relevant literature has been examined in chapter 2. Therefore, the aim of this chapter is to explain how the research was designed and present the research methodology followed. The justification of research methodology selected and rationale of their selection has been provided in detail. In Section 3.1, the different research approaches available regarding research purpose, application strategy and enquiry mode are presented and the most suitable for this research are selected. The main methods for data collection are also described in this section, together with the key threats to validity and generalisability, and how they can be mitigated. Section 3.2, provides the justification of research methodology selected and rationale of their selection. The proposed research methodology adopted is detailed, describing the three phases of this research in Section 3.3. Section 3.4 provides a summary of the chapter.

## 3.1 Research Methodology Development

This section presents the different research approaches that can be applied, and based on the research aim and context, a research strategy is selected. Subsequently, the issues related to the data collection techniques used are discussed. The research methodology development is presented in Figure 3.1.

### 3.1.1 Research Context

It is crucial to clarify the context of research in order to tailor an appropriate research methodology. This research is focused on the interaction between lean practices and Product-Service System (PSS), and in particular in the implementation of lean principles in the service offering process. PSS leanness can be defined as the degree of the adoption and implementation of lean principles in the process of providing services to customers. The main factors defining the context this research were the gaps identified within the overall domain of the study and the available industrial support to the researcher (collaborating organisations).

### 3.1.2 Philosophical Paradigms of Research

According to Easterby-Smith et al., (2012), the main philosophical positions underlie the designs of research. In other words, the philosophical factors affect the overall arrangements which enable satisfactory outcomes from research. Adoption of a certain philosophical position usually implies that the researcher will deploy methods that correspond with that position (Easterby-Smith et al., 2012; Van de Ven 2007). This philosophy constitutes the researcher's worldview (or paradigm).

A paradigm is "a set of beliefs about the world and about gaining knowledge that goes together to guide people's actions as to how they are going to go about doing their research" (Wilson, 2001). A paradigm is a belief system (or theory) that guides the way we do things, or more formally establishes a set of practices.

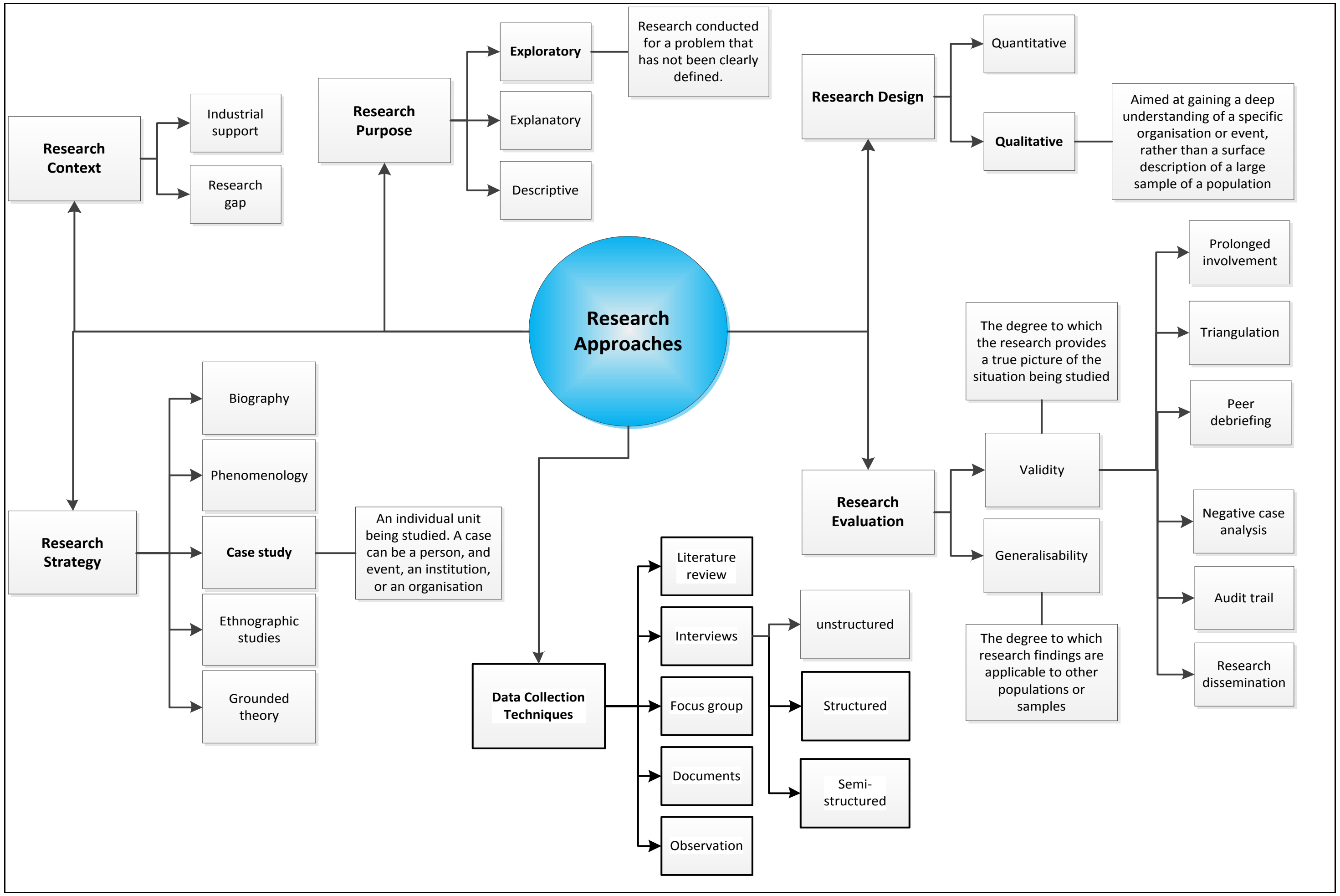



**Figure 3.1 Research Methodology Development**

Different philosophical paradigms have different views about assumptions that researchers make about the nature of the world or reality (ontology) and the set of assumptions about the best ways researchers can acquire knowledge about it (epistemology). According to Creswell (2003) and Lincoln et al., (2011), there are five alternative paradigms and each paradigm consists of four perspectives as presented in Table 3.1:

- Ontology refers to the belief about the nature of reality (what exists and is a view on the nature of reality) (Hart, 2010)
- Epistemology refers to the relationship between the researcher and the reality (types of knowledge that can be generated from an ontology) (Hart, 2010)
- Methodology refers to how you are going to use your way of thinking (your epistemology) to gain more knowledge about your reality (the rules governing the research enquiry) (Hart, 2010)
- Axiology refers to the goal of a particular worldviews (a set of morals or a set of ethics) (Hart, 2010).

According to Creswell (2003), the research design or research plan to conduct a research, involves the intersection of philosophy, strategies of inquiry, and specific methods as presented in Figure 3.2.

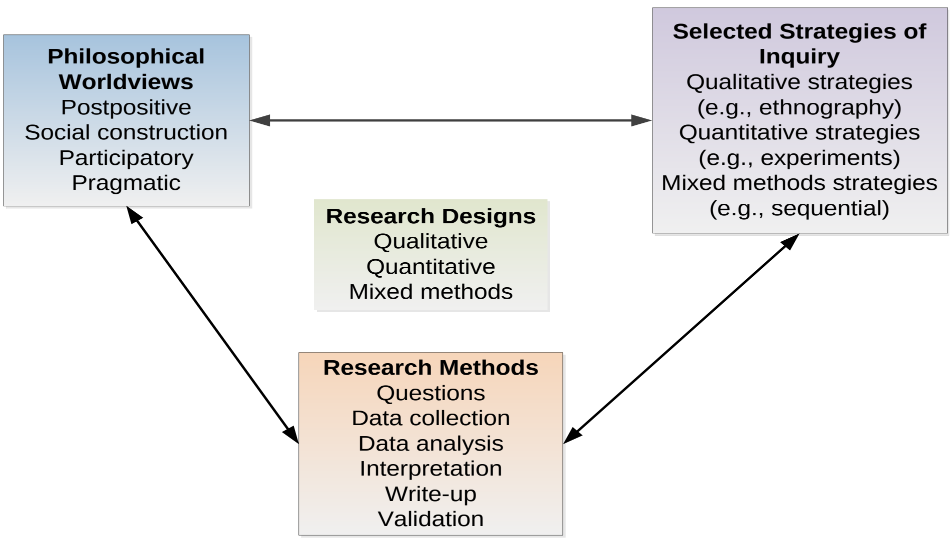



**Figure 3.2 A Framework for Research Design (Creswell, 2003)**

**Table 3.1 Basic Beliefs of Alternative Paradigms (Lincoln et al., 2011; Creswell, 2003)**

| | **Positivism** | **Critical Theory** | **Participatory** | **Pragmatism** | **Constructivism** |
|---|---|---|---|---|---|
| **Ontology** | Naïve realism – 'real' reality but apprehensible | Historical realism – virtual reality shaped by social, political, cultural, economic, ethnic and gender values; crystallised over time | Participative reality – subjective-objective reality, co-created by mind and given cosmos | Not committed to any theory of reality | Relativism –local and specific constructed realities |
| **Epistemology** | Dualist / objectivist; findings are true | Transactional / subjectivist; value mediated findings | Critical subjectivity in Participatory transactions with cosmos; extended epistemology of experiential, propositional and practical knowing; co-created findings | Truth is what works at the time and arises out of action, situations and consequences | Transactional / subjectivist; created findings |
| **Methodology** | Experimental / manipulative; verification of hypotheses; chiefly quantitative methods | Dialogic / dialectical | Political participation in collaborative action inquiry; primacy of the practical; use of language grounded in shared experiential context | Mixed methodologies that best meet a researcher's needs and purposes | Hermeneutical / dialectical |
| **Axiology** | Explanation: prediction and control | Critique and transformation; restitution and emancipation | Understanding and reconstruction; acknowledging that people are disenfranchised by power and authority | Application; finding the solution to problems | Understanding and reconstruction; aiming for consensus |

In accordance with the researcher philosophical beliefs and understanding, the researcher has chosen to adopt the philosophical stance of pragmatism. Pragmatism arises out of actions, situations, and consequences rather than antecedent conditions. Instead of focusing on methods, researchers emphasise the research problem and use all approaches available to understand the problem (Creswell, 2003). For pragmatists, research questions or objectives are at the centre of the inquiry. Also, inquiry is not a static concept but rather it has a dynamic and evolving nature and thus researchers need to acknowledge that the results of any research are always subject to further justification and inquiry (Dewey, 1938).

Creswell (2003) and Morgan (2007) stated the features of pragmatism as:

- Pragmatism is not committed to any one system of philosophy and reality.
- Individual researchers have a freedom of choice. In this way, researchers are free to choose the methods, techniques, and procedures of research that best meet their needs and purposes.
- Pragmatists do not see the world as an absolute unity.
- The pragmatist researchers look to the what and how to research, based on the intended consequences – where they want to go with it.
- Pragmatists agree that research always occurs in social, historical, political, and other context.
- Pragmatism opens the door to multiple methods, different worldviews, and different assumptions, as well as, different forms of data collection and analysis.

In selecting a research design, the researcher employs primarily qualitative methods to explore the phenomena of lean in Product-Service System (PSS) and combines this qualitative data with quantitative methods to identify the relative importance of the enablers, challenges, and tools of implementing lean in PSS, as well as, developing an index to measure the leanness degree of the service offering process.

### 3.1.3 Research Purpose

The purpose of the research needs to be understood, since it will aid clarifying which research strategy is the most appropriate for the nature of the research. According to Robson (2011), the purpose of a research can be exploratory, descriptive, and explanatory.

Exploratory research structures and identifies new problems. This type of research is particularly used in little-understood situations. Descriptive research portrays systematically an accurate profile of persons, events or situations. Finally, Explanatory research seeks an explanation of a situation or problem, clarifying how and why there is a relationship between two aspects of a phenomenon or situation. According to Robson (2011), the characteristics of each category are shown in Table 3.2.

**Table 3.2 Categories of Research Purpose**

| Category | Characteristics |
|---|---|
| **Exploratory** | • To find out what is happening, particularly in little understood situations<br>• To seek new insights<br>• To ask questions<br>• To assess phenomena in a new light<br>• To generate ideas and hypotheses for future research<br>• Almost exclusively of flexible design (qualitative) |
| **Descriptive** | • To portray an accurate profile of persons, events or situations<br>• Requires extensive previous knowledge of situations etc.<br>• To be researched or described, so that the author knows the appropriate aspects on which to gather information<br>• May be flexible and/or fixed design (qualitative or quantitative) |
| **Explanatory** | • Seeks an explanation of a situation or problem, traditionally, but not necessarily in the form of causal relationships<br>• To explain patterns relating to the phenomenon being researched<br>• To identify relationships between aspects of the phenomenon<br>• May be of flexible and/or fixed design (qualitative or quantitative) |

### 3.1.4 Research Design

A research approach is a discipline within which knowledge is acquired by different research methods. There are two distinct approaches to research design from the viewpoint of the inquiry mode: quantitative and qualitative (Gummesson, 2000). Quantitative and qualitative designs are also referred to as fixed or flexible designs (Johnson and Harris, 2002; Robson, 2011).

A quantitative approach is typically used when the phenomena object of the study can be quantified (Robson, 2011). A quantitative approach always involves the numerical analysis of data and places emphasis on the measurement and analysis of causal relationships between variables (Johnson and Harris, 2002). This approach falls under the fixed design perspective because of the use of a controlled environment. In the quantitative research, the researcher has both the environment and the experimental conditions under control, so that the influence is minimised on the research findings (Robson, 2011). Examples of quantitative methods include laboratory experiments, formal methods and numerical methods, such as mathematical modelling (Myers and Avison, 2002). The main strengths and weaknesses of the quantitative research are shown in Table 3.3.

**Table 3.3 Quantitative Research: Strengths and Weaknesses**

| | **Strengths** | **Weaknesses** |
|---|---|---|
| **Quantitative Approach** | • Results are replicable<br>• Results are verifiable<br>• Illustrates casual effects<br>• Less time for research setting<br>• Precise measurements<br>• Allows statistical comparison | • Removed from everyday life<br>• Limited research studies<br>• Costly<br>• Difficult to respond to environmental forces<br>• Dose not account for people's unique experiences<br>• Lacks flexibility |

Cresswell (1998) described qualitative research as: "an inquiry process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyses words, reports detailed views of informants, and conducts the study in a natural setting". Qualitative research is more suitable for the study of dynamic processes where it is aimed to develop or discover new concepts instead of imposing preconceived ideas. As opposed to the controlled environment of the quantitative approach, the researcher here conducts the study in a 'natural setting' (Creswell, 1998). Robson (2011), referred to this approach as flexible design because, the research questions and ideas evolve as the research progresses. The main strengths and weaknesses of the qualitative research are shown in Table 3.4.

**Table 3.4 Qualitative Research: Strengths and Weaknesses**

| | **Strengths** | **Weaknesses** |
|---|---|---|
| **Qualitative Approach** | • Direct encounter with world<br>• Allows unique experiences to be taken into account<br>• Economical<br>• Direct contact with participants | • Imprecise measurements<br>• Dependent on author's skills<br>• Time consuming<br>• Problems with validity and reliability<br>• Possible bias |

The qualitative and quantitative research based on classification of assumptions, purpose, method and role of the author are compared in Table 3.5.

**Table 3.5 Comparison of Qualitative and Quantitative Research (Burns, 1997)**

| | **Quantitative Research** | **Qualitative Research** |
|---|---|---|
| **Assumptions** | • Facts and data have an objective reality<br>• Variables can be measured and identified<br>• Events viewed from outsiders' perspective<br>• Static reality to life | • Reality socially constructed<br>• Variables complex and interwoven, difficult to measure<br>• Events viewed from informants' perspective<br>• Dynamic quality to life |
| **Purpose** | • Prediction | • Interpretation |

| | Quantitative Research | Qualitative Research |
|---|---|---|
| | • Generalisation<br>• Causal explanation | • Contextualisation<br>• Understanding the perspectives of others |
| **Method** | • Testing and measuring<br>• Commences with hypothesis and theory<br>• Manipulation and control<br>• Deductive and experimental<br>• Statistical analysis<br>• Statistical reporting<br>• Abstract impersonal write-up | • Data collection using participant observation, unstructured interviews<br>• Conducted with hypothesis and ground theory<br>• Emergence and portrayal<br>• Inductive and naturalistic<br>• Data analysis by themes from informants' descriptions<br>• Data reported in language of informant<br>• Descriptive write-up |
| **Role of researcher** | • Researcher applies formal instruments<br>• Detachment<br>• Objective | • Researcher as instrument<br>• Personal involvement<br>• Emphatic understanding |

It is not likely to undertake qualitative and quantitative research at the same time; however, it is possible for a study to be divided into various phases, where either qualitative or quantitative approaches can be applied. Many authors agree that a mixed methods research, resulting from combining the use of qualitative and quantitative approaches, can enhance the understanding of a topic (Greene and Caracelli, 1997; Tashakkori and Teddlie, 2010).

### 3.1.5 Types of Research Strategy in Qualitative Research

Awasthy et al., (2012) defined research strategy as "a structured set of guidelines or activities to assist in generating valid and reliable research results". According to Creswell (1998), there are five strategies that can be applied for qualitative research: biography, phenomenology, grounded theory, ethnography, and case study. Likewise, Robson (2011) categorised the acceptable for qualitative inquiries strategies into case study, ethnographic study, and grounded theory study. Table 3.6 illustrates the three strategies introduced by Robson (2011).

**Table 3.6 Robson's Three Qualitative Research Strategies**

| | Definition | Typical Features |
|---|---|---|
| **Case study** | Detailed, intensive knowledge development about a single case, or a small number of related cases | • Single case selection<br>• Study of the case within its context<br>• Use of various data collection techniques, such as observation and interviews |
| **Ethnographic study** | Aims to capture, analyse, and explain how a group, organisation or community live and experience the world | • Selection of a group, organisation and community<br>• Researcher involvement in the setting<br>• Use of observation |
| **Grounded theory study** | Aims to generate theory based on the data collected from the study | • Applicable to a broad range of phenomena<br>• Mainly interview based<br>• Provides comprehensive recommendations for data analysis and theory generation |

The following sub-section describes the case study as the chosen research strategy used to carry out this research.

#### 3.1.5.1 The Case study as a research strategy

Yin (2009) described the case study as "an empirical enquiry that investigates a contemporary phenomenon within its real life context, especially when the boundaries between phenomenon and context are not clearly evident". The case study is a research strategy that aims to understand the dynamics present in single or multiple settings in an in-depth manner (Eisenhardt, 1989).

Gerring and McDermott (2007) stated that case study is a form of analysis where one or a few units are studied rigorously in order to clarify a broader class of units. Units may consist of any phenomena provided that each unit is relatively well confined and that these units are positioned at the same level of analysis as the principal assumption.

Benbasat et al., (1987) summarised a list of eleven characteristics of case studies as follows:

| **Key Characteristics of case studies** |
|---|
| 1. Phenomenon is examined in a natural setting<br>2. Data are collected by multiple means<br>3. One or few entities (person, group, or organisation) are examined<br>4. The complexity of the unit is studied intensively<br>5. Case studies are more suitable for the exploration, classification and hypothesis development stages of the knowledge building process<br>6. No experimental controls or manipulation are involved<br>7. The investigator may not specify the set of independent and dependent variables in advance<br>8. The results derived depend heavily on the integrative powers of the investigator<br>9. Changes in the site selection and data collection methods could take place as the investigator develops new hypotheses<br>10. Case research is useful in the study of “why” and “how” questions because these deal with operational links to be traced over time rather than with frequency<br>11. The focus is on contemporary events |

This approach has been widely adopted across political sciences, sociology, urban studies, and other social sciences. The data collection procedure includes a range of techniques, such as: documents, archival records, interviews, observations, and physical artefacts. The selection of the case studies depends on the relevance of the participants to the investigated research domain. The advantages and disadvantages of the case study are presented in Table 3.7

**Table 3.7 Advantages and Disadvantages of Case Study (Zainal, 2007)**

| Advantages | Disadvantages |
|---|---|
| • The examination of the data is most often conducted within the context of its use, that is, within the situation in which the activity takes place | • Case studies are often accused of lack of rigour |
| • variations in terms of intrinsic, instrumental and collective approaches to case studies allow for both quantitative and qualitative analyses of the data | • Case studies provide very little basis for scientific generalisation since they use a small number of subjects, |

| Advantages | Disadvantages |
|---|---|
| | some conducted with only one subject |
| • The detailed qualitative accounts often produced in case studies not only help to explore or describe the data in a real life environment, but also help to explain the complexities of real lie situations which may not be captured through experimental or survey research | • Case studies are often labelled as being too long, difficult to conduct and producing a massive amount of documentation |

The case study research can be adopted for single and multiple-case designs and the details of both designs are represented in Table 3.8. A single case used for exploration may be followed by a multiple-case study (Benbasat et al., 1987).

**Table 3.8 Description of Single and Multiple-case Designs (Darke et al., 1998)**

| Single-Case Study | Multiple-Case Studies |
|---|---|
| • Appropriate where it represents a critical case<br>• Extreme and unique case<br>• Revelatory case<br>• Allows to investigate phenomena in depth to provide rich description and understanding | • Allows cross-case analysis and comparison<br>• Investigates a particular phenomenon in divers settings<br>• To predict similar results or to produce contrasting results for predictable reasons. |

### 3.1.6 Data Collection Techniques

Multiple data collection techniques are typically employed in case research studies. Ideally, evidence from two or more sources will converge to support the research findings (Benbasat et al., 1987). The selection of the data collection technique or techniques depends on the kind of information that is required, from whom and under what circumstances (Robson, 2011). No single technique has a complete advantage over all the others. In fact, the techniques are highly complementary, and a good case study will therefore depend on as many techniques as possible. The following data collection techniques have been utilised driven by the nature of the presented study.

#### 3.1.6.1 Literature review

“The literature is what is already known and written down relevant to your research project” (Robson, 2011). The literature review is a critical and analytical summary of the findings, from the author’s perspective, of the literature search, gathered from books, articles, reports, conference literature, official and legal publication, and reviews. According to Hart (2001) and Robson (2011), there are many reasons for conducting literature review including:

1. Identifying completed work
2. Developing the researchers knowledge and understanding of the research topic
3. Identifying general patterns to research and research findings by analysing multiple examples of research in the same area
4. Defining terminology and identifying variations in the definitions used by researchers or practitioners
5. Preventing duplication of work
6. Avoiding pitfalls and errors of previous research
7. Identifying appropriate research methodologies and instruments for data collection
8. Finding gaps in existing research

#### 3.1.6.2 Interviews

Interviewing usually refers to personal interaction. This interaction may be face to face, by telephone, or through computers (WebEx), whereby the researcher asks questions and receives answers. Interview is a survey approach which allows the researcher to explore a topic of study from a sampled population. According to Brod et al., (2009), the purpose of interviews is “to generate new information and confirm or deny known information”. There are mainly three types of interview, based on their level of standardisation and structure. The three types are fully-structured, semi-structured, and unstructured (Robson, 2011). Table 3.9 compares the three types of interviews.

**Table 3.9 Types of Interviews**
**(Robson, 2011)**

| Interview Type | Overview | Advantages | Disadvantages |
|---|---|---|---|
| **Fully structured** | • Predetermined questions, usually in a pre-set order, using fixed wording | • Quick and cost effective<br>• Allows for easy data analysis | • Interviewer does not have the flexibility to explore issues that arise during the interview<br>• Cannot be used to explore people's reasons for their views or feelings about the issues |
| **Semi-structured** | • Predetermined questions, but the interviewer has the freedom to choose the wording of the questions, their sequence and how long is spent with each one | • Gives interviewer the freedom to explore general views or opinions in more detail | • Difficult and time-consuming to compare and analyse data provided by various respondents |
| **Unstructured** | • Open-ended questions that enable the interviewer to go in-depth, clear up any misunderstanding, establish good rapport between interviewer and interviewee and usually lead to unexpected answers | • The interaction between the participant and the interviewer allows for richer, more valid data. This is because the interviewer can ask follow up questions<br>• The interviewer can change the questions | • There is a significant chance for the interviewer to lose control of the interview and also the analysis of the responses is difficult<br>• Time consuming and costly |

| Interview Type | Overview | Advantages | Disadvantages |
|---|---|---|---|
| | | if, over the course of the study they think the hypothesis should change or they want to take the study in a new direction | |

### 3.1.6.3 Focus group

A focus group can be regarded as a particular case of interview, in which a group participates rather than one-to-one (Robson, 2011). The focus group arises from the generic term ‘group interview’ which is designed with specific characteristics, and is a very popular data collection method in many fields of applied social research (Robson, 2011). The focus group is the brainstorming activity, thus the expert judgements could be captured and documented from the collaborating company. The involvement of key experts in this manner can be seen to provide a considerable level of validation to research and to reduce the level of bias. Table 3.10 shows the advantages and disadvantages of the focus group.

**Table 3.10 Advantages and Disadvantages of Focus Group (Brod et al., 2009)**

| Advantages | Disadvantages |
|---|---|
| • Highly efficient method for qualitative data collection<br>• Group dynamics help in focusing on the most important topics<br>• Participants tend to enjoy the experience<br>• Inexpensive and flexible<br>• Participants can express their opinions freely | • The number of questions covered is limited<br>• Facilitating the group process requires considerable expertise<br>• The interview process needs to be well-managed<br>• Conflicts may arise between personalities<br>• Creates a consensus of opinion, rather than idea generation |

#### 3.1.6.4 Documents

Documentation review is one of the selected data collection methods that refer to written documents such as notices and letters, or non-written documents including diagrams and pictures (Robson, 2011). During the research the author was provided with a number of documents that explain the current processes. Table 3.11 shows the advantages and disadvantages of documentation review.

**Table 3.11 Advantages and Disadvantages of Documentation Review (Yin, 2009)**

| Advantages | Disadvantages |
|---|---|
| • Stable: can be reviewed repeatedly<br>• Unobtrusive: not created as a result of the case study<br>• Exact: contains exact names, references, and details of an event<br>• Broad coverage: long span of time, many events, and many settings | • Access: may be deliberately blocked<br>• Retrievability can be low<br>• Biased selectivity, if collection is incomplete |

#### 3.1.6.5 Observation

Direct observation is widely used in qualitative research as a data collection method, having the advantage of directness (Robson, 2011). Direct observation in this research has been applied in several situations: during industrial meetings and interviews, as well as, industrial visits. Direct observation allows the author to learn and capture the actual things that happen in the service offering process in the collaborative company. Table 3.12 shows the advantages and disadvantages of direct observation.

**Table 3.12 Advantages and Disadvantages of Direct Observation**

| Advantages | Disadvantages |
|---|---|
| • Reality: covers events in real time<br>• Contextual: covers context of event | • Selectivity unless broad coverage<br>• Time consuming<br>• Reflexivity: event may proceed differently because it is being observed |

### 3.1.7 Research Evaluation

Two key areas should be addressed in order to establish the trustworthiness of the study. These two areas are validity and generalisability, both are considered to be central concepts to fixed research designs.

Validity is related to identifying whether a piece of qualitative (flexible) research is true, accurate, or corrects (Robson, 2011). Simply, validity is the degree to which the research provides a true picture of the situation being studied.

Robson (2011) proposed three areas that present possible threats to validity. These threats are reactivity, respondent bias, and researcher bias. These threats can be minimised or eliminated, if addressed well in advance by the researcher. Reactivity refers to the way in which the researcher's presence may interfere with the case setting, and affect the behaviour of the people involved. Respondent bias may result from either respondent trial to hide information from the researcher or respondent trial to give the answer which would please the researcher. Finally, researcher bias refers to the assumptions and preconceptions that the researcher may bring to the situation, which may affect the way in which they behave in the research setting.

Robson (2011) proposed a number of strategies to mitigate the influence of these threats to research validity, these strategies are:

- *Prolonged involvement* - (interaction over a period of time) the researcher spends time within the research setting, developing relationships with the participants and understanding the culture of the setting studied.
- *Triangulation* involves - the use of multiple sources and methods to enhance the rigour of the research.
- *Peer debriefing and support* - involves debriefing sessions with other researchers after data collection to reduce researcher bias
- *Member checking* involves presenting results and analysis to participants in order to get feedback

- *Negative case analysis (Deviant case analysis*) - involves searching for cases, settings, events and so on, that are out of line with the researcher's main findings or even that directly contradict what his explanations would predict.
- *Audit trail* involves keeping a full track and record of all the activities carried out during the study.
- *Research dissemination* - involves activities through which research was publicised resulted in the refinement of research due to criticism and feedback
- *Purposive sampling -* offers researchers a degree of control rather than being at the mercy of any selection bias inherent in pre-existing groups.

It is also important to differentiate between validity and reliability. The objective of reliability is to be sure that the research is repeatable. If theoretically a later investigator conducts the same research all over again using the same procedures, they should arrive at the same conclusions. The goal of reliability is to minimise the errors and biases in a study (Yin, 2009).

The second key area that should be addressed in order to establish the trustworthiness of the study is generalisability. Simply, generalisability refers to the degree to which research findings are applicable to other populations or samples. Generalisability refers to the extent to which the findings of the enquiry are more generally applicable to different situations, persons, context, and times (Robson, 2011). There are two types of generalisability: internal and external. The internal generalisability is related to whether the findings can be extended within the setting studied to those who were not directly involved in the initial study. The external generalisability is related to whether the conclusions can be extended to other research groups or institutions. It is perceived that external generalisability is hard to achieve within a qualitative research context, because the findings make sense for specific individuals or settings studied.

## 3.2 Research Methods Selection and Justification

### 3.2.1 The rationale of exploratory approaches as the research purpose

Taking into account the aim, objectives, and the context of this research; its overall purpose can be best characterised as exploratory. Since the implementation of lean practices in Product-Service System (PSS) has not been researched enough and there is no much information about how lean can be implemented in PSS; exploratory is selected as a research purpose for this study.

### 3.2.2 The rationale of the qualitative approach

A number of factors led to the adoption of a qualitative approach in this study. Firstly, the overall topic calls for further exploration, in order to meet the research objectives. Secondly, the topic needs to be studied in-depth by using individuals in their natural setting and not in a controlled environment; so that the study reaches what the phenomenon “real life” is like. Thirdly, since the study tries to gain a full understanding of the implementation of lean practices in PSS, the ability of qualitative data to provide broader and richer descriptions is a reason to choose the qualitative approach. Finally, although the concept of lean has been exercised for more than three decades, this concept is new in the PSS context. A qualitative approach can be used to further understand any phenomenon about which little is yet known.

Although some of the data collection is analysed in a statistical form, such as by using Microsoft Excel, it is not possible for the research to declare this as a mixed method, as the purpose is only to interpret in depth thereby providing rich descriptions. It is not likely to undertake qualitative and quantitative research at the same time; however, it is possible for a study to be divided in various phases, where either qualitative or quantitative approaches can be applied (Easterby-Smith et al., 2012). A major difference between qualitative and quantitative research is that researchers adopting the first approach rely on few variables and many cases, whereas researchers adopting the second approach work with many variables and a few cases (Creswell, 1998). For this reason, it is hard to follow a quantitative patterned approach in the study of a social or natural setting, since there are many variables that are out of the researcher's control.

### 3.2.3 The rationale of the case study method

Comparing the different research methods, the case study method seems to be the most suitable one. A number of factors were considered for the selection: the context of the research, data collection methods, and the involvement of the collaborating organisations. In addition, Robson (2011) stated that case studies are linked to exploratory work, which is the characteristic of this study. A number of reasons contribute to this belief.

The first rationale behind the selection of the case study is that the implementation of lean practices in PSS is a relatively new phenomenon; and there is no strong theoretical base for the research. Case research is particularly appropriate for this type of problem in which research and theory are at their early stages of formulation. According to Yin (2009), case study is appropriate to research an area in which few previous studies have been carried out to understand the nature and complexity of the processes taking place. Second, this study identify the insight of the current lean practices used in the service offering process; explaining the steps used to implement them; highlighting the main challenges encountered; specifying the most suitable lean tools and techniques used; and identifying the main enabler for the successful implementation. Therefore, the case study approach is suitable to capture the knowledge of experts and developing the theories from it.

Third, since the dominant purpose of this research is exploratory, case studies are suitable. The case method allows the researcher to understand the nature and complexity of the processes taking place. Fourth, the use of a case study is also suitable for the purposes of this study, because the study addresses the contemporary phenomenon of lean implementation in PSS, over which the researcher has no control. As the research is examining existing experience without any trial of influencing factors or behaviours, the case study is preferred as it is suitable in examining contemporary sets of events and when the relevant behaviours cannot be manipulated (Yin, 2009). Finally, the use of a case study claims to offer a richness and depth of information not usually offered by other methods. This is required if the research objectives are to be met.

Besides all the previous reasons for selecting case study, multiple-case study is selected due to its inherent advantages for the perspectives of qualitative research. In addition, the multiple-case study yields more general research findings than a single-case study and allow for cross-case analysis and the extension of theory as they can be used to compare the similarities and differences between cases.

### 3.2.4 The rational of the interview technique

This study uses semi-structured and structured interviews as the primary data collection technique. The reason for this choice is that interviews are the most fundamental of all qualitative methods help to generate insights into how respondents see the studied phenomenon. In addition, interviews are considered to be one of the most important sources of case study data collection.

Through the one-to-one meeting between the researcher and the interviewee, a semi-structured interview technique gives the researcher the opportunity to probe deeply to reveal new clues and open up new dimensions of the studied phenomenon. This helps greatly in securing accurate accounts that are based on the interviewees' personal experiences. Easterby-Smith et al., (2012) mentioned that the semi-structured interview is an appropriate method when it is necessary to understand the constructs that the interviewee uses as a basis for his opinions and beliefs about a particular situation. Additionally, the close-ended question format was selected since the data would be in a quantifiable form ensuring that statistical analysis can be used. Moreover, it is fast and easy to complete, enables automated data entry, and facilitates data analysis and summary of data (Lewis et al., 2007).

The rating scales (Likert scale) and ranking is used within this format to obtain the answers from the respondents. The Likert scale used will provide a more precise measure than yes/no or true/false items and it is fast and easy to complete (Neuman and Robson, 2004). The rating scale used for few questions allows the respondents to indicate the relative importance of choices that facilitates the researchers in identifying the relative importance of the critical issues, factors and challenges.

In the closed ended questionnaire respondents were asked to rank the main enablers and factors, challenges, and tools on a scale of 1 to 5 (1 = last important, 2 = less important, 3 = important, 4 = very important and 5 = crucial).

Five-point Likert scale was selected because, odd numbers of response categories have generally been preferred to even numbers; since odd numbers allow the middle category to be interpreted as a neutral point. Also, five-point Likert scale is the most commonly used, as well as, five-point Likert scale is used to save the time of experts participated in the interview. According to Miller (1956), the human mind has a span of absolute judgment that can distinguish about seven distinct categories, a span of immediate memory for about seven items, and a span of attention that can encompass about six objects at a time, which suggested that any increase in number of response categories beyond six or seven might be useless. Using Likert scale helped respondents to indicate the relative importance of the main enablers and factors, and tools that are critical for implementing lean practices in PSS, as well as, the challenges that obstacle lean implementation in PSS.

## 3.3 An Overview of the Research Methodology

After identifying and justifying the adopted research purpose, research design, and research approach, this section presents an overview the research methodology adopted to achieve the aim of the research. A detailed research methodology used to achieve each objective will be discussed in more details in each of the following chapters (Chapter 4 – 6).

Due to the type of information expected to be gathered along the research process, an inductive approach has been applied. This approach will enable the author to explore new phenomena and to look at previously researched phenomena from different perspective. The proposed research methodology as presented in Figure 3.3 is divided into three main phases:

- Understanding context
- Data collection and framework development
- Validation

### 3.3.1 Phase 1: Understanding the Context

The first phase is related to gaining a contextual understanding. Understanding the context included literature review and attending PSS spring school and other relevant training. The literature review was augmented by the use of online computerised data base like Emerald, Elsevier, Springer Link, Science-Direct, IOS Press, EBSCO Host Academic Search Premier, World Scientific, Taylor and Francis, etc. The literature review covered a number of areas including Product-Service System, lean manufacturing, lean services, lean implementation, and leanness assessment. The link between lean and PSS was the centre of attention. This phase also aimed to establish the available research approaches and to decide a suitable research strategy. Driven by the research objectives, the research followed an exploratory procedure, whereby qualitative approach was considered.

### 3.3.2 Data Collection and Framework Development

The main goal of this phase is centred on data collection and ideas generation. Industrial interaction was achieved with the collaborative companies in the UK. The first step in this phase was conducting a pilot study to understand the current industrial practices. This involved conducting semi-structured interviews with the concerned companies. The main benefit of this approach relates to the flexibility in capturing the required information. The process of piloting consists of an informal pre-test phase where the questions were discussed with supervisor, academic experts in the field of lean and PSS, as well as, fellow colleagues at Cranfield University. After responding to the valuable comments, a formal pilot test procedure was conducted. The selection of the companies tended to be purposive rather than random. Purposive sampling is common in qualitative research. The reason is that the definition of the research cases is limited (the research is only interested in companies that implement lean practices in their service offering). Interviews were carried out with experts from the concerned companies who were familiar with lean implementation. These interviews were semi-structured interviews.

According to Yin (2009), these interviews are used to ask key respondents about facts concerning the case, and to ask for opinions and insights from the respondent, which thereby becomes an informant. Also, documents provided by the collaborative companies are a second major source of data used in this research. Document analysis was conducted by reviewing key reports produced by the concerned companies, as well as, companies' websites. Moreover, statistics reports generated from participants were reviewed. Some of the documents reviewed include business plans, process mapping, value stream mapping, and questionnaires conducted by companies regarding their customers and employees.

The outcomes of the pilot study resulted in exploring the current industrial practices of lean implementation, as well as, comparing the current practices with those that were realised from literature as will be presented in chapter 4. Additional interest was to understand how lean is implemented in the service offerings process and what are the main critical success factors and challenges that existed. This enabled the researcher to get an understanding of both the theoretical and the practical perspectives of lean implementation. The semi-structured interviews were followed by structured interviews using Likert scale questions. Using Likert scale helped respondents to indicate the relative importance of the main enablers and factors, and tools that are critical for implementing lean practices in PSS, as well as, the challenges that obstacle lean implementation in PSS, as will be discussed in chapter 5.

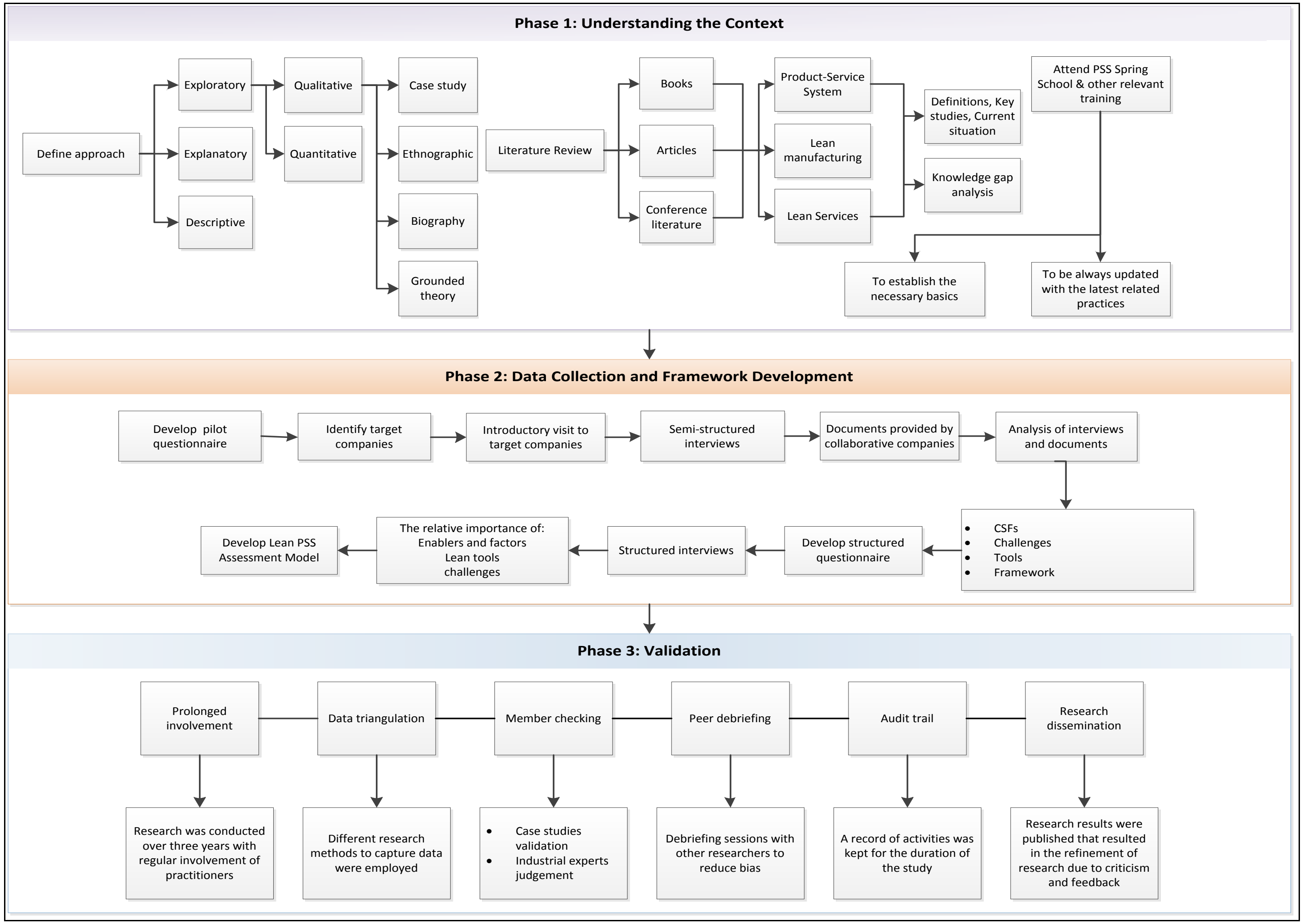



**Figure 3.3 Research Methodology Adopted**

The data collected from both the semi-structured and structured interviews used to develop the lean PSS assessment model. The development of the model was carried out through an iterative process. Starting from literature review as presented before; going through semi-structured interviews with academic researchers involved in lean projects; and ended with semi-structured interviews with a number of experts in the field of lean from three UK manufacturing companies. The research methodology used to develop the assessment model will be explained in details in chapter 6. The model used to evaluate the leanness level of the service offering process in three UK manufacturing companies.

### 3.3.3 Validation

The third phase is concerned with the validation of the results. This was done by means of qualitative and quantitative assessment as will be discussed further in detail at the end of chapters 5 and 6.

Additionally, all the findings were validated using some strategies to ensure the quality of this research's findings as a qualitative research. In order to ensure the trustworthiness of the research, the following tactics were applied:

1. Prolonged involvement - The researcher engaged in a long period of interaction with the case companies spanning close on to three years, from initial access meetings to final meetings.
2. Data triangulation - by employing different research methods to capture data from different sources. These are documentation, archival records, interviews, focus group and direct observations
3. Member checking - involved presenting results and analysis to participants in order to get feedback. Within this research, the findings were continuously reflected back to the interviewees in order to obtain clarification and assure relevance.
4. Peer debriefing and support - debriefing sessions with other researchers after data collection helped to reduce bias.
5. Audit trail - a record of activities was kept for the duration of study. The majority of the data collection lasted for two years starting in 2012 and ending in late

2013. During this period, 40 interviews were conducted. Most these interviews were tape recorded and transcribed verbatim. During all the interviews, notes were taken in order to capture the interpretations during the interview process.

6. Research dissemination - activities through which research was publicised resulted in the refinement of research due to criticism and feedback. The work carried out in this thesis resulted in a number of outputs. Amongst these, the most notable one is the two articles which were peer-reviewed and accepted for publication in the Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture and the International Journal of Agile Systems and Management. In addition, six conference papers were reviewed and accepted into different conferences.

## 3.4 Chapter Summary

In this chapter the different research methods were reviewed and the rationale for selecting the most suitable one for this research was provided. The different data collection methods were presented, together with the research design issues and techniques to minimise threats to the validity and generalisability of the study.

# CHAPTER 4

# 4 A FRAMEWORK FOR LEAN IMPLEMENTATION IN PRODUCT- SERVICE SYSTEM

The aim of this chapter is to present a framework that can be used to implement lean principles in the service offering process. In order to successfully achieve this aim, this chapter is organised as presented in Figure 4.1. Section 4.1, provides a brief introduction about the importance of developing framework or roadmap that guides lean implementation. Section 4.2, describes the methodology used in this chapter to reach the desired aim. A combination of research methodology approaches have been used in this chapter such as reviewing previous studies and case studies. A review of relevant frameworks and models will be presented in Section 4.3. There are various lean implementation frameworks and models proposed in previous research studies. The majority of these frameworks will be discussed in this section. In Section 4.4, the concerned case companies will be describes along with their history in lean initiatives. The proposed framework for lean PSS implementation will be described in details in Section 4.5. Finally, the chapter summary will be presented in Section 4.6.

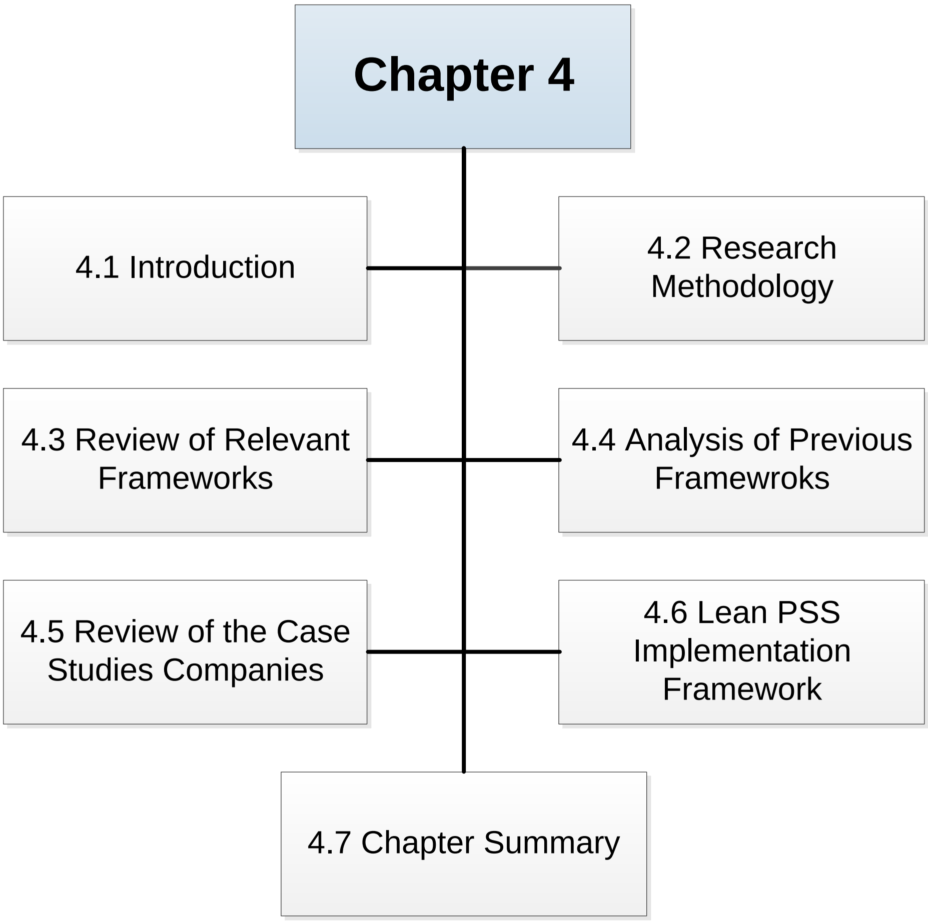



**Figure 4.1 Structure of Chapter 4**

## 4.1 Introduction

In today's global competition, manufacturing companies face a lot of challenges such as rapid technological changes, advances in manufacturing and information technology, massive changes in customers' needs and requirements, and increasing transparency and comparability of products and services. To counter these challenges, manufacturing companies realised the need to continuously improve their operations and processes to compete successfully. Manufacturing companies should consider the efficient use of their resources, as well as, the effectiveness of their operations and process in terms of customers' requirements. One of the improvement initiatives that is now common among manufacturing companies is lean manufacturing.

Many companies have moved toward the implementation of lean because of the benefits that can be gained from the implementation of lean; such as increasing quality, reducing costs, on-time delivery to customers and many other benefits. The concept of lean is designed to eliminate waste in every area extending from production to customer relations, product design, supplier networks and factory management. As mentioned in chapter 2, the concept of lean was developed from the Toyota Production System (TPS) and involves determining the value of any process by distinguishing value-added activities or steps from non-value-added activities or steps, and eliminating waste so that every step or activity adds value to the process to reduce costs, speed up cycle times and improve quality and reliability (Womak and Jones, 1996). Although the concept of lean has been applied in both the manufacturing and the non-manufacturing sectors, few companies have achieved the desired outcomes (Baker, 2002; Bhasin and Burcher, 2006; Tracey and Flinchbaugh, 2006).

The inability to reach the desired outcomes of lean implementation can be traced back to a number of factors. One of these factors is the lack of understanding of the lean concept, its purpose, and its benefits by managers and employees. The lack of understanding may lead to the waste of organisational resources and reduction in employees’ confidence in practising lean (Marvel and Standridge, 2009). Moreover, the unattainability of the desired benefits can be traced back to the misapplication of the lean tools in terms of using the wrong tool to solve a problem, or using of single tool to solve all of the problems, or using the same set of tools on each problem (Pavnaskar et al., 2003). Behrouzi and Wong (2011) and Smeds (1994) stated that the lack of an effective lean implementation methodology and its measurement are significant reasons behind the failure of the lean practices.

Under these circumstances, the implementation of lean can be considered difficult and challenging. Thus, few companies succeed in their lean journey. To avoid these common mistakes in lean implementation, there is a need to define a well-planned framework for the successful lean implementation.

While many attempts have been made to create a useful framework for lean implementation in the manufacturing sector and the non-manufacturing sector, none of the existing frameworks have tried to develop a framework for implementing lean in Product-Service System (PSS). Consequently, the aim of this chapter is to develop a framework that transfer lean approach used in the manufacturing and the non-manufacturing sectors into the service offering process.

## 4.2 Research Methodology

A combination of research methodology approaches have been used in this chapter as presented in Figure 4.2. First the relevant literature is reviewed. The literature review was augmented by the use of online computerised data base like Emerald, Elsevier, Springer Link, Science-Direct, IOS Press, EBSCO Host Academic Search Premier, World Scientific, Taylor and Francis, etc. A literature review of relevant researches pertaining to lean manufacturing implementation, lean transformation, transition to lean, lean framework, lean roadmap, and applying lean was conducted. Based on this search, articles that met the criteria of practices in lean implementation and presented a model or framework were selected.

According to Cooper (1988), it is suggested that the literature review can be elaborated based on the purposive selection approach in which only related articles pivotal to the research topic were chosen to be reviewed. So, the selected literature review specifically focused on the presentation of lean initiatives and process description. It was concluded that there were several existing frameworks for lean implementation especially in the manufacturing sector.  Additionally, the literature review reveals the insufficient research carried out to develop a framework for lean implementation in PSS.

After conducting the literature review, a pilot study was carried out as an initial stage in three UK manufacturing companies, to gather initial insights about the current industrial practices of lean implantation. The process of piloting consists of an informal pre-test phase where the questions had been discussed with supervisor, academic experts in the field of lean and PSS, as well as, fellow colleagues at Cranfield University.

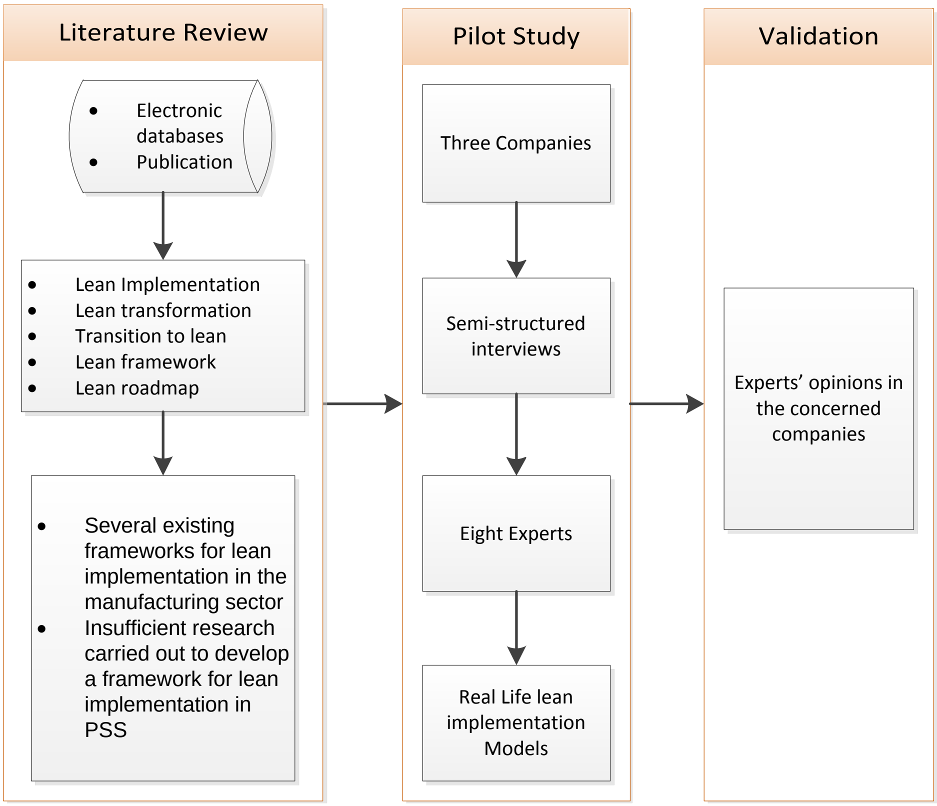



**Figure 4.2 Chapter 4 Research Methodology**

After responding to the valuable comments, a formal pilot test procedure was conducted. The selection of the companies for this tended to be purposive rather than random. Purposive sampling is common in qualitative research. The reason is that the definition of the research cases is limited (the research is interested in companies that are keen to implement lean practices in their service offering process). Interviews were carried out with eight executives from the three companies who were familiar with lean implementation progress. Later in the research the number of interviews has increased to 35 interviews. But, for the purpose of developing the framework, only eight interviews have been conducted. The list of interviewees, along with their positions, and their total number of years of experience is presented in Table 4.1.

**Table 4.1 List of Experts Participated**

| Expert Number | Company | Role | Years of Experience |
|---|---|---|---|
| E1 | A | Lean Six Sigma Strategy and Deployment Manager | 25 |
| E2 | A | GM Strategy and Marketing | 20 |
| E3 | B | Continuous Improvement Manager | 25 |
| E4 | B | Continuous Improvement Manager | 22 |
| E5 | C | CEO | 40 |
| E6 | C | Head of Aftersales Business Development | 40 |
| E7 | C | CRM Manager | 23 |
| E8 | C | Retail Sales Manager | 23 |

These interviews were in-depth interview, using semi-structured questions. According to Yin (2009), in-depth interviews are used to ask key respondents about facts concerning the case, and to ask for opinions and insights from the respondent, which thereby becomes an informant. It was certified before the beginning of the interview that the research would treat the data collected from the interviewee confidentially and that the anonymity of all participants would be assured at all times. Then, the researcher requested permission to tape-record the interview and all the interviewees agreed. All interviews began with a short description of the research, including aim, objectives, estimated time for conducting the interview, and emphasis on the key role of the interviewee's views. The interviews were conducted for approximately one hour and half for each respondent. At the beginning of each meeting, the interviewees were asked to fill out an individual information sheet that includes the date of the meeting and the interviewee's positions. Also, archival documentation was a second major source of data used in this research. Document analysis was conducted by reviewing key reports produced by the targeted companies. Additionally, statistics reports generated from participants were reviewed. Some of the documents reviewed include business plans, process mapping, value stream mapping, and questionnaires conducted by companies regarding their customers and employees. The outcomes of the pilot study resulted in exploring the current industrial practices of lean implementation, as well as, identifying the different phases and steps used by companies to implement lean.

Finally, all the results obtained were validated via experts' opinions and judgements from the companies concerned.

## 4.3 Review of Relevant Frameworks and Models

There have been various lean implementation frameworks and models proposed in previous research studies. Some researchers have chosen the descriptive way to present their lean initiatives, while others portray a framework through diagrams or graphical representations.

Yusof and Aspinwall (2000) described a framework as "a prescriptive set of things to do". Anand and Kodali (2010) defined framework as "a guiding torch that helps a manager in providing necessary direction during the change management programmes that are implemented in an organisation". According to Hakes (1991), a framework should link concept with practical application through some systematic means. Also, Aalbregtse et al., (1991) stated that a framework should: illustrate an overview of a philosophy or change process to be adopted; so as to communicate a new vision of the organisation, force the management to address a substantial list of key issues which otherwise might not be addressed, and give an insight into the organisation's strengths and weaknesses. Therefore, it is believed that a framework can act as a guide in implementing lean practices in the service offering process. In order to comprehensively review the existing frameworks for lean implementation provided in the literature, each framework is reviewed one by one in chronological order. A brief review regarding each framework of lean implementation is presented in this section.

### 4.3.1 Plan for Introducing the Toyota Production System

One of the two inventors of TPS, Shigeo Shingo, introduced the first structured plan for implementing lean in 1989. Shingo (1989) recommended a model in a 'Gantt chart' format in which key elements of lean can be implemented during one year as presented in Figure 4.3

He emphasised that there are two crucial elements for the success of lean implementation, namely: top management commitment and the clear understanding of the system’s tools, techniques, and principles. Top management must be dedicated and committed to shutting down machines and if needed entire production lines in the quest for solving the root cause of problems. Also, he mentioned that the system should be extended to the suppliers. He suggested 15 tools and techniques, for example: initial survey, single minute exchange of dies (SMED), creating suitable space, poke yoke, levelling, Kanban, etc. for lean implementation in a year. By applying these tools and techniques, the inventory will be reduced and problems will be surfaced and can be dealt with in a non-overwhelming manner. Additionally, he emphasised that workers should work on several machines or processes at once in order to reach a state of pre-automation.

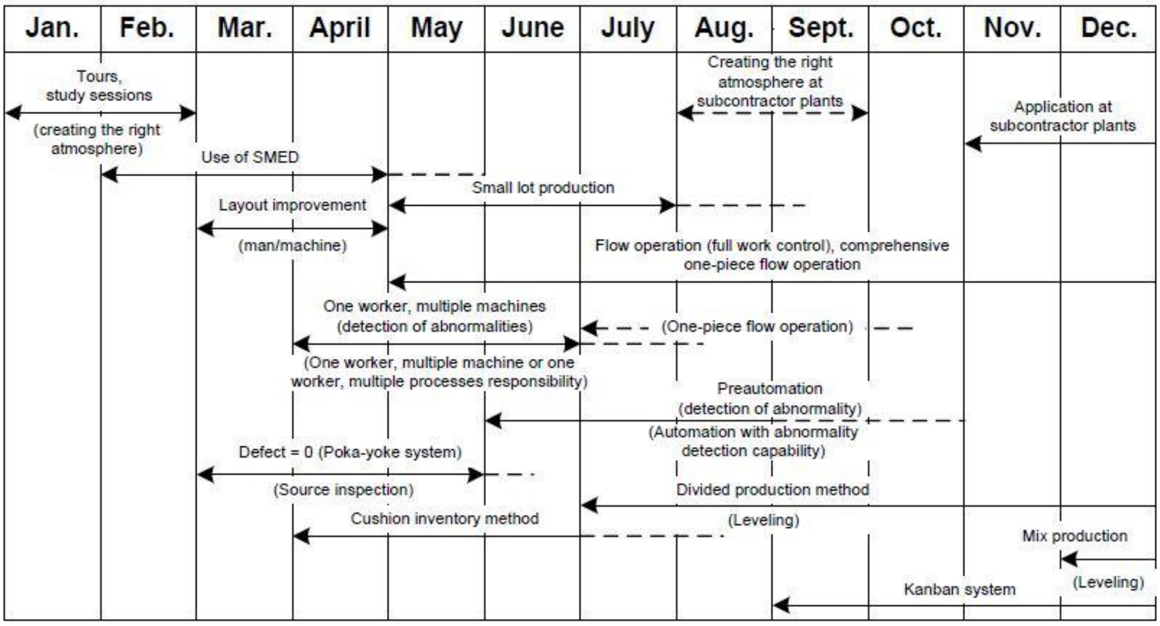



**Figure 4.3 Plan for Introducing TPS**
**(Shingo, 1989)**

### 4.3.2 Managing Change towards a Lean Enterprise

Smeds (1994) proposed a generic framework for the management of changes towards lean enterprise as presented in Figure 4.4. This framework consists of five phases. These phases are: analysis and model of the present state; identification of problems and opportunities; experimentation and selection of future state; implementing the change; and finally; stabilising the new mode of operations.

In the first phase managers should analyse the present state of the company's business strategies and processes with respect to lean characteristics. She mentioned that during this phase some methods can be used, such as value chain analysis and controllability engineering. The current state of the company can be compared with best lean practices already known from the theory and research of production and business management. This can be done using benchmarking. Benchmarking will reveal business activities and processes that need to be improved and restructured. In the second phase a visualisation of the present state should be conducted to identify problems and potential opportunities. The visualisation of the present sate will build a shared understanding of the current business process and the guidelines for change among all managers and employees. The shared understanding will encourage all the employees and managers to participate in lean initiatives and provides new ideas for improvement. These new ideas will be the input of the third phase which is selecting the future state. In the fourth phase, the implementation of the new mode will take place and this implementation should be controlled by management, as well as, by the employees themselves. In this phase the role of communication is vital. Managers should communicate the progress achieved to all the employees, as well as, providing them with feedback to preserve their motivation and learning during the implementation phase. Additionally, the communication and feedback will help in stabilising the new process design. In the final phase of the framework, the new model will be stabilised and the company begins its normal operations according to the new lean organisational and technological design. Smeds (1994) emphasised that this phase is critical in the change process. This phase can be considered as the test of the change project's success. Also, she confirmed that stabilisation does not prevent incremental innovations in the redesigned process. On the contrary, the process is likely to require continuous improvements, which are developed during day-to-day work.

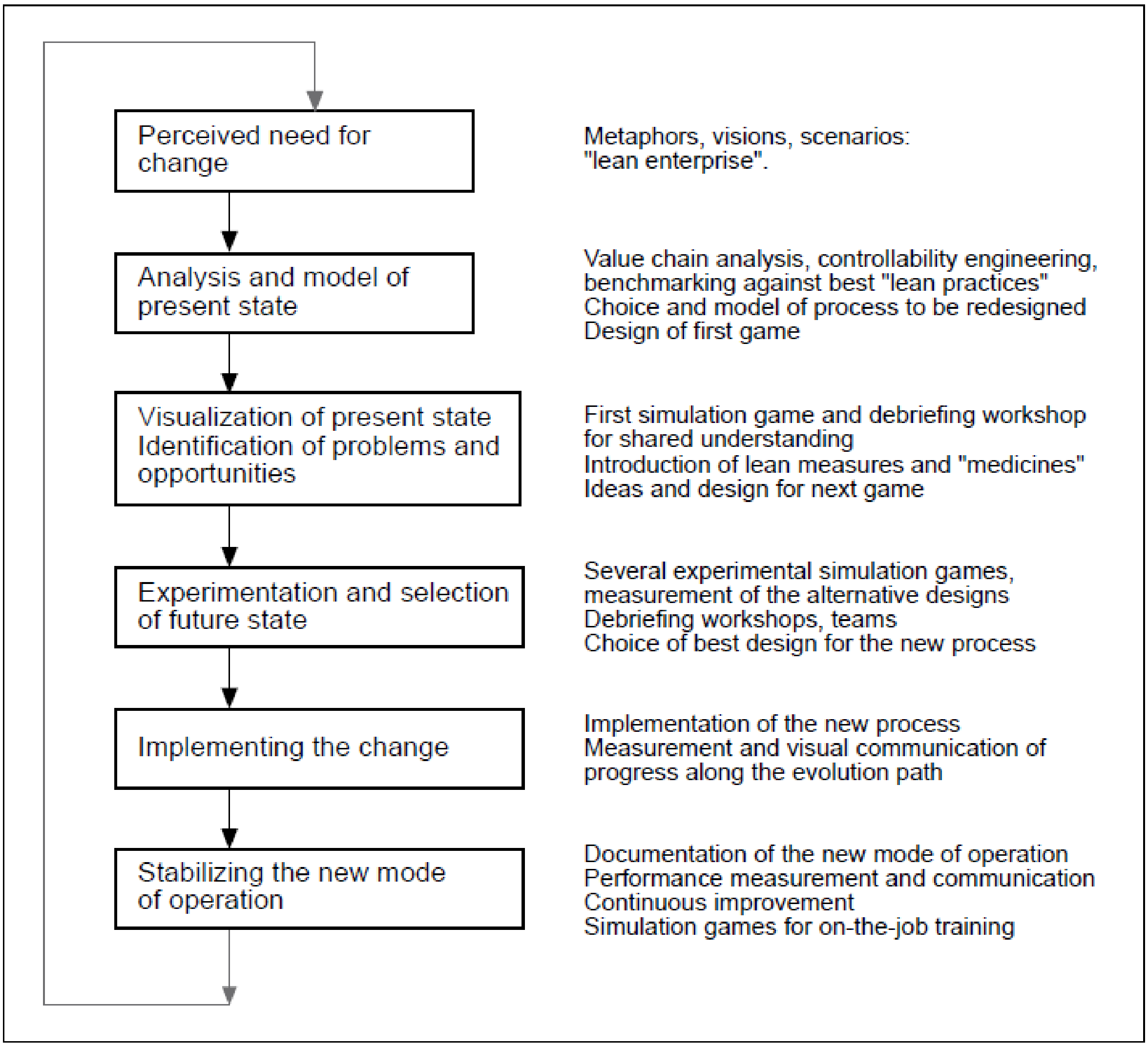



**Figure 4.4 Managing Change towards a Lean Enterprise (Smeds, 1994)**

### 4.3.3 Time Frame for a Lean Leap

Womak and Jones (1996) described a time frame for a lean leap as shown in Table 4.2. This time frame includes four phases: get start, create a new organisation, install business systems, and complete the transformation.  In each phase, they identified a number of specific steps to be conducted for the successful implementation of the phase. Furthermore, they determined a time frame for each phase from six months to five years.

**Table 4.2 Time Frame for Lean Leap**
**(Womak and Jones, 1996)**

| Phase | Specific Steps | Time Frame |
|---|---|---|
| **Get Started** | • Find a change agent<br>• Get lean knowledge<br>• Find a lever<br>• Map value steams<br>• Begin kaikaku<br>• Expand your scope | First six months |
| **Crate a new organisation** | • Reorganise by product family<br>• Create a lean function<br>• Devise a policy for excess people<br>• Devise a growth strategy<br>• Remove anchor-draggers<br>• Instil a "perfection" mind-set | Six months through year two |
| **Install business systems** | • Introduce lean accounting<br>• Relate pay to firm performance<br>• Implement transparency<br>• Initiate policy deployment<br>• Introduce lean learning<br>• Find right-sized tools | Years three and four |
| **Complete the transformation** | • Apply these steps to your suppliers/customers<br>• Develop global strategy<br>• Transition from top-down to bottom-up improvement | By end of year five |

### 4.3.4 Business Process Change Framework for Lean Implementation

Motwani (2003) applied Kettinger and Grover (1995) model of business process change to develop a theoretical framework for lean implementation as given in Figure 4.5. This framework explains the critical factors involved in the implementation of lean manufacturing. According to Motwani (2003), lean manufacturing implementation requires:

- A strategic initiative where top managers act as leaders in defining and communicating a vision of change. For the successful implementation of lean manufacturing, a commitment by the entire company is necessary and without this commitment all the company's efforts towards lean will be worthless.
- An organisational environment willingness to learn. Organisations should have the ability to respond quickly to any environmental changes. Organisations can increase their learning capacity through their internal employees who constantly review the environment for new developments and opportunities. Also, organisations can depend on external consultants or their customers to increase their learning capacity.
- Culture readiness. Organisations have to assess their culture readiness prior to lean implementation. Organisational culture is a vital element in implementing lean, since culture either facilitates or inhabits lean initiatives implementation. Some of the important aspects that organisations have to consider are: leadership, management commitment and support, communications, and training.
- Balanced network relationships. Organisations have to create a balanced relationship with external partners, such as suppliers and customer. Suppliers' relationships play a crucial role and have an important influence on the organisations ability to implement lean. Organisations lean initiatives should be compatible with their suppliers in order to be able to satisfy their customers' needs and demands on time and in the right quality.
- Technology leveragability and knowledge sharing. The role of IT in lean implementation can be dominant and enabler. One of the elements of lean is the utilisation of tools and techniques. All the employees should be familiar with all the tools and techniques used and this can be done through training.
- Prescribed process management and change management practices. Lean transformation requires a general dissatisfaction with the current situation. This may be incorporated with resistance to change from some employees. In order to

overcome this resistance the role of leaders, communication and employee involvement is important. Additionally, all the process should be managed in way that remove non-value added activities or waste and this requires the use of the lean tools and techniques.

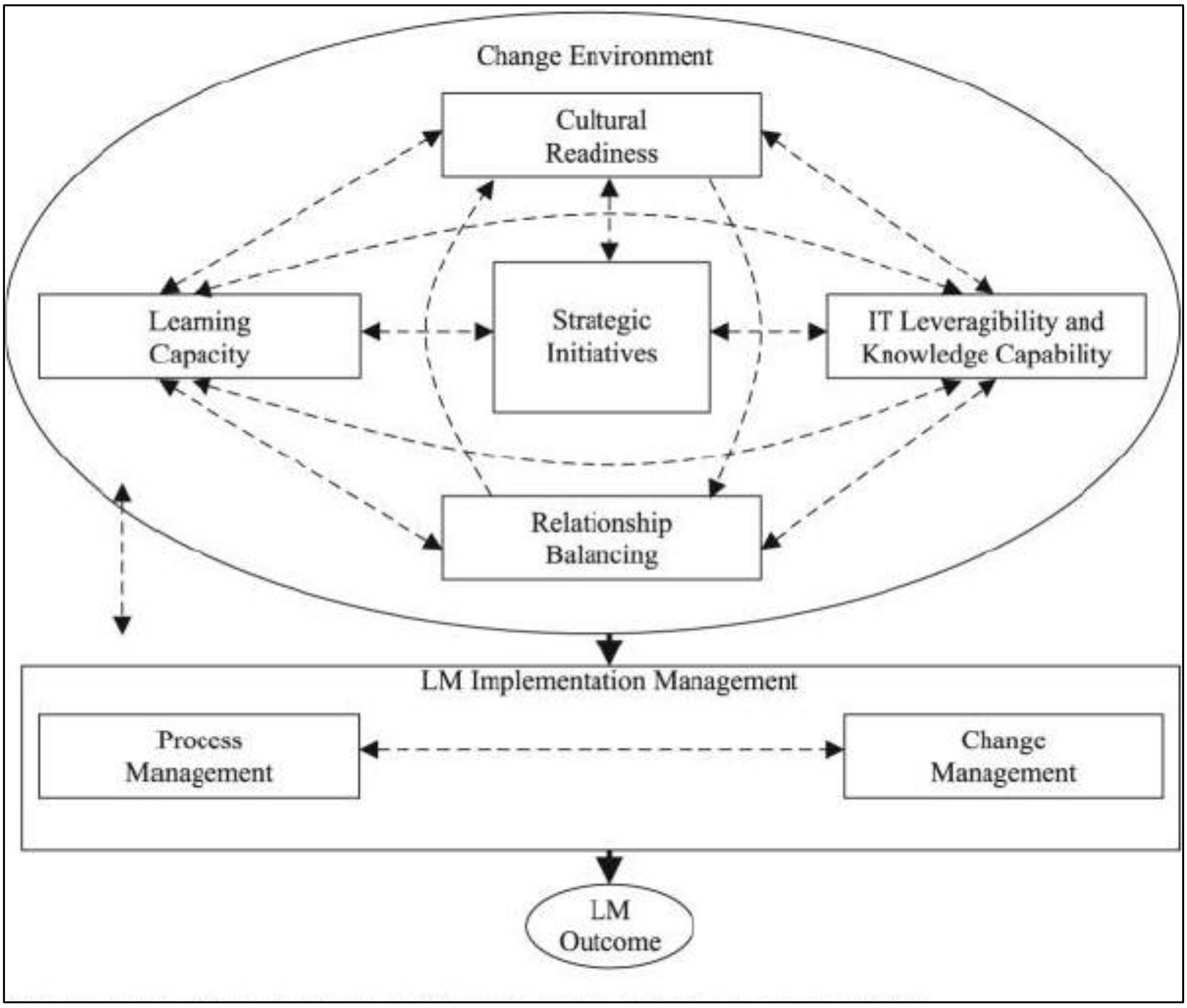



**Figure 4.5 Business Process Change Framework for Lean Implementation (Motwani, 2003)**

### 4.3.5 Simulation-Enhanced Approach to Lean Manufacturing

Marvel and Standridge (2009) proposed a streamlined roadmap for lean implementation through five phases: lean assessment, current state gap, future state design, future state validation, and implementation as shown in Figure 4.6. In the first phase, the trained lean implementation team assess the product offerings based on the organisation's competitive strategy and market objectives. In the next phase, the lean team document the current state of the operations; manufacturing processes are verified; and the value streams are identified. The next phase is devoted to designing the future state using lean principles and techniques. According to Marvel and Standridge (2009), an overall concept of how the facility should ideally operate is developed and expressed in the future state VSM. The last phase of this model is the implementation of lean practices in the factory floor. A review of the production system performance should be carried out throughout the implementation phase. Additionally during this phase; operational issues are addressed, policies and procedures are adjusted to promote lean operations.

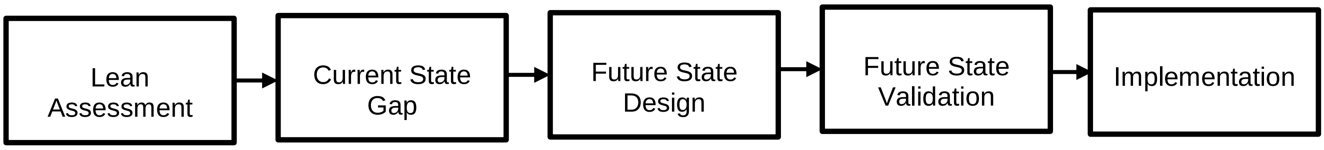



**Figure 4.6 Roadmap for Lean Implementation (Marvel and Standridge, 2009)**

### 4.3.6 Eight Pillars Framework for Lean Implementation

Anand and Kodali (2010) presented a conceptual framework for lean implementation as presented in Figure 4.7. The proposed framework utilises 65 lean manufacturing elements, which are categorised according to the decision levels and the role of internal stakeholders in an organisation. The foundation of the framework represents the prerequisite that any organisation should have before lean implementation as they are common for any change management programmes. This foundation includes good leadership, commitment, culture and human aspects. In the proposed framework, the pillars represent the main principles of lean manufacturing. There are eight main principles according to this framework.

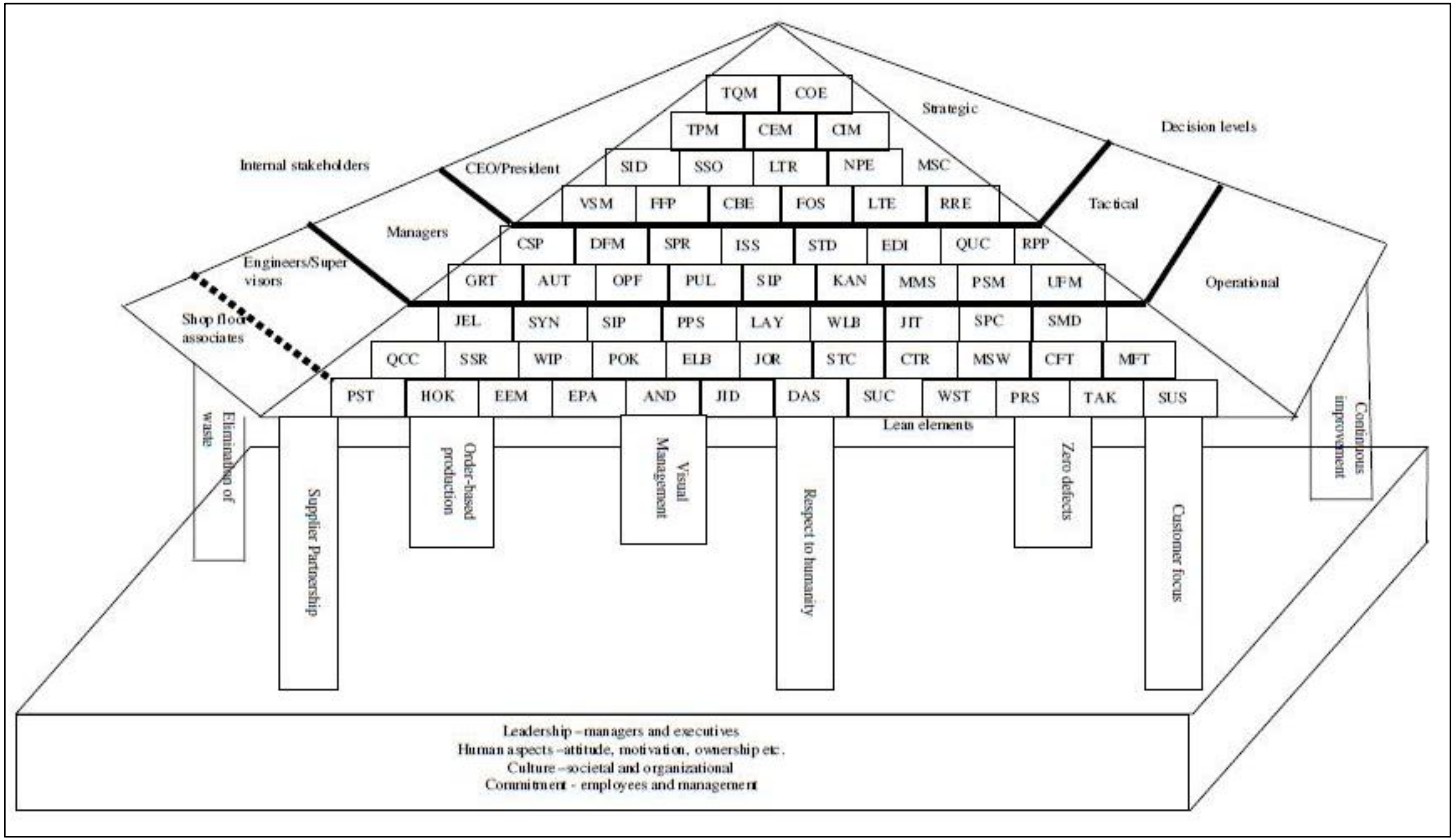



**Figure 4.7 Eight Pillars Framework for Lean Implementation (Anand and Kodali, 2010)**

These principles are: small lot production, zero defects, elimination of waste, continuous improvement, customer focus, supplier partnership, respect for humanity, and visual management. These principles are interrelated. Also, this framework identified a group of lean tools and techniques that can be used to achieve the previously mentioned eight principles. Furthermore, in this framework, the identified elements were classified with respect to the decision levels in an organisation - strategic, tactical, or operational. Finally, the proposed framework identified the role of various internal stakeholders in lean implementation. According to the framework there are four internal stakeholders who are shop floor associates, engineers, managers, and executives.

### 4.3.7 Dynamic Model to Leanness

Anvari et al., (2011) developed a dynamic roadmap for lean implementation determining the tools needed to be implemented in a firm based on its current state and type of industry. The model is organised in four major phases plus one initial phase for assessment of lean implementation as presented in Figure 4.8. According to Anvari et al., (2011) model, in phase 0 (initial investigation) an assessment should be carried out, to determine if the company has the prerequisites to implement lean or not. In this phase three questions should be answered, namely:

- Is there a level of commitment of management, change agent?
- Is there lean knowledge to apply tools and techniques in terms of the capability and resources among managers and employees?

If the answers of the previous questions were yes, so the company can go to the next phase. The next phase is the preparation phase. In this phase the lean practices should be linked to the company strategic planning; and lean experts should be identified. Additionally, in this phase an analysis of the organisation structure, resources, and limitation should be carried out. After finishing the preparation phase, the company can move to the next phase, namely, focus on specified pilot. In this phase the company will select a family product as a pilot project and try to implement some of the lean tools in the selected family product.

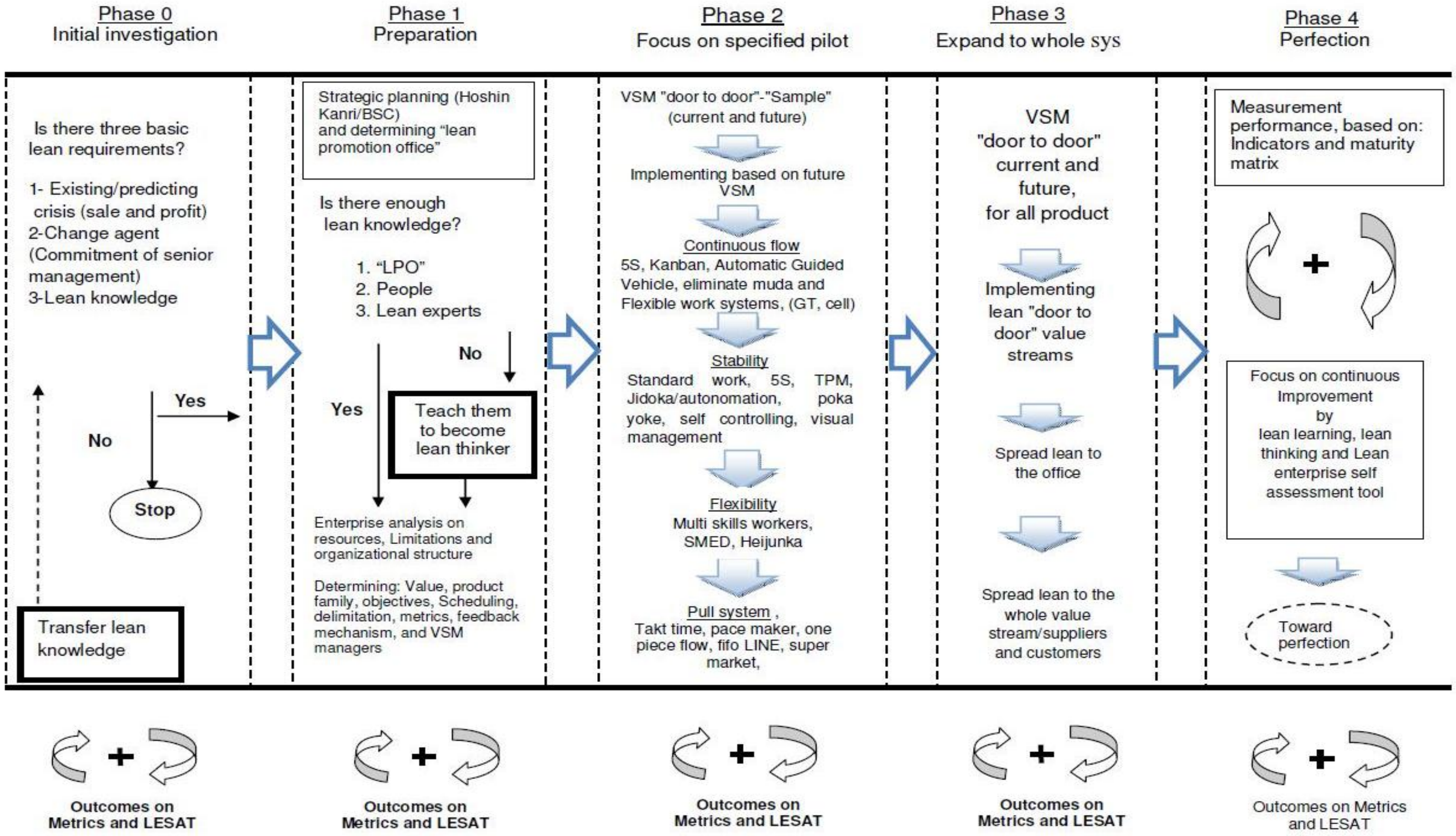



**Figure 4.8 Dynamic Model to Leanness (Anvari et al., 2011)**

Anvari et al., (2011) stated that during this phase the company can use a variety of lean tools and techniques such as: 5s, Kanban and cellular manufacturing to create continuous flow. Also, in order to achieve stability in the processes they suggested the use of standard work, TPM, Poka Yoke, and visual management. After implementing lean tools in the selected pilot project, the company can move to the following phase through expanding lean practices to the whole system. Finally, the last phase in this model is perfection. The emphasis of this phase is the continuous improvement by the regular performance measurement and feedback.

Anvari et al., (2011) mentioned that the company can use maturity matrix and lean enterprise self- assessment tool (LESAT) for the regular performance measurement.

### 4.3.8 Circles Model for Lean Implementation

Wong and Wong (2011) presented a framework that serves as a guideline to implement lean manufacturing as given in Figure 4.9. The framework consists of three parts: the first part is the foundation, where it serves as a basic condition for the improvement to be carried out. The second part is the improvement practices that start with the current state to the defined ideal state. The third part is the outer circle which indicates continuous improvement in the 13 key areas of lean manufacturing. Wong and Wong (2011) emphasised that the initial step before lean implementation is to understand the five lean principles. After the full understanding of the five lean principles, they determined three main prerequisites for lean implementation, namely: stability, standardisation, and discipline. Wong and Wong (2011) argued that before improvement process is commenced, the organisation should identify the sates quo then develop a vision of the future state. Three main elements are necessary in order to identify the present situation and develop the future state; these three elements are: people, think lean, and act lean.

They mentioned that in order to enhance the human factor; organisations need to train their employees, stress team working, empower employees, encourage suggestions, and develop a reward and recognition system. The next element in the framework is ‘think lean’. ‘Think lean’ is to have the mind-set based on lean principles.

In order to have this mind-set the organisation needs to apply systematic problem solving methods. Some problem solving tools can be used include: 5 whys, A3 thinking, FMEA, and cause and effect diagram. The third element is ‘act lean’. Act lean implies that organisation needs to put the plan into action by identifying all the types of wastes in the process, distinguish value-added activities from non-value-added activities, remove all types of waste, create continuous flow. Based on this framework, some tools can be used to ‘act lean’ such as: VSM, Poka-yoke, SMED, JIT and Kanban. Additionally, in this framework Wong and Wong (2011) identified key areas for potential improvements. These key areas are: management and culture, inventory, scheduling, material handling, equipment, work processes, quality, layout, employees, suppliers, customers, product design, and safety and ergonomics. Finally, the circle indicates that lean is a never ending process that keeps going on to achieve continuous improvement.

### 4.3.9 Stepwise Implementation of Lean Production System

Dombrowski et al., (2012) presented a lean implementation framework, this framework include four main phases as given in Figure 4.10. The four phases are basic planning, setting up, rollout, and finally daily operations. Each phase includes a number of steps. The total number of the steps in this framework is nine steps. The first phase is the basic planning and includes four steps:

- The awareness of lean benefits
- Assessing whether the organisation strategy matches with the lean principles or not
- Developing a conceptual design for lean implementation by identifying the main lean tools and techniques that will be used.
- At the last step of the first phase, the master plan for lean implementation is developed.

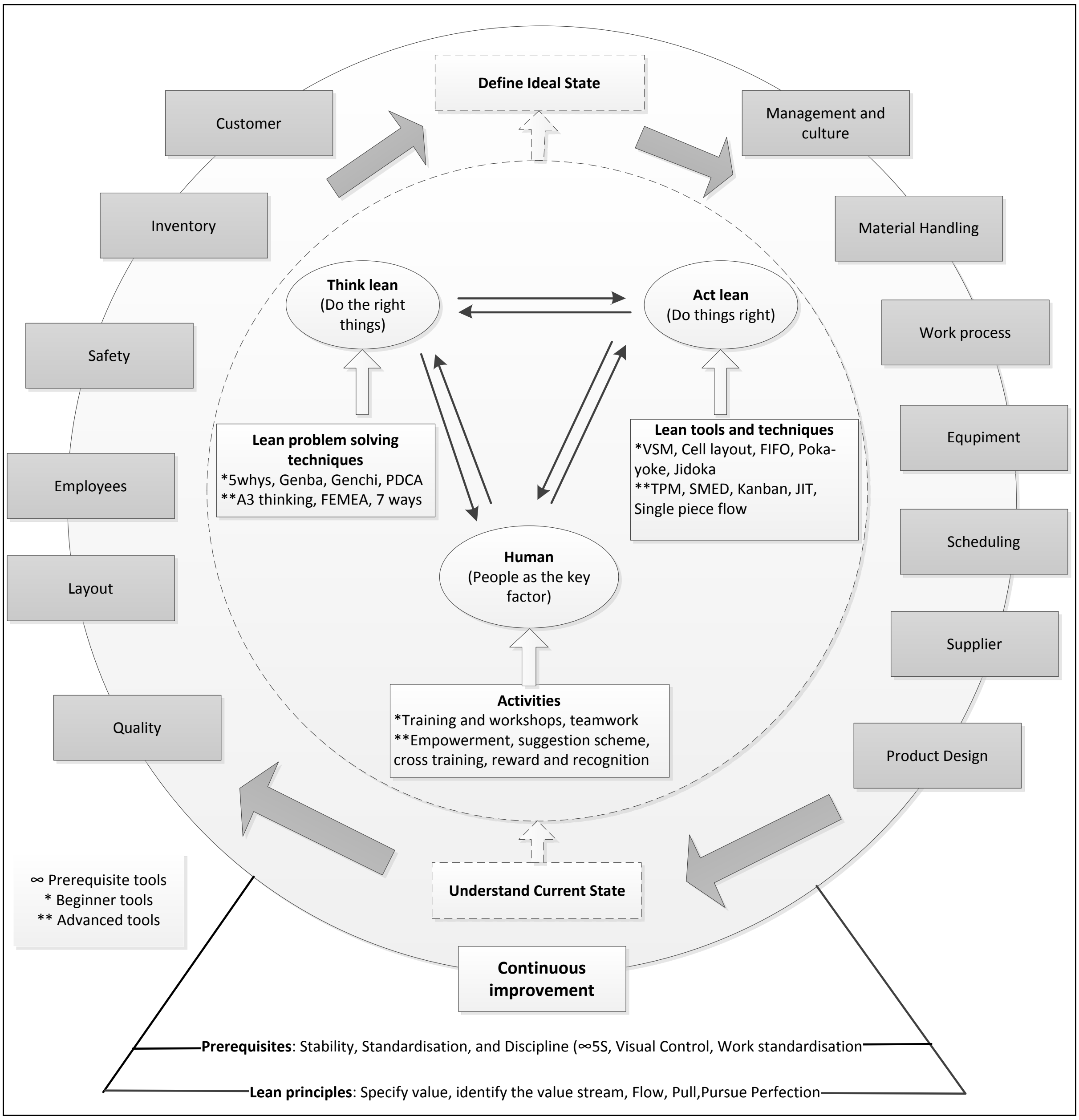



**Figure 4.9 Circles Model for Lean Implementation**
**(Wong and Wong, 2011)**

The second phase is setting up and describing the preparation for the actual implementation of lean. This phase includes two steps:

- Carrying out all the necessary changes for lean implementation
- Providing a detailed planning, that considers local conditions either internal or external customers.

The third phase is the rollout. This phase includes two steps:

- Conducting one or more pilot projects in order to avoid unfavourable implementation strategies.
- Carrying out the actual rollout and implement lean in all departments of the organisation

The last phase and step of the implementation is the daily operations and continuous improvement.

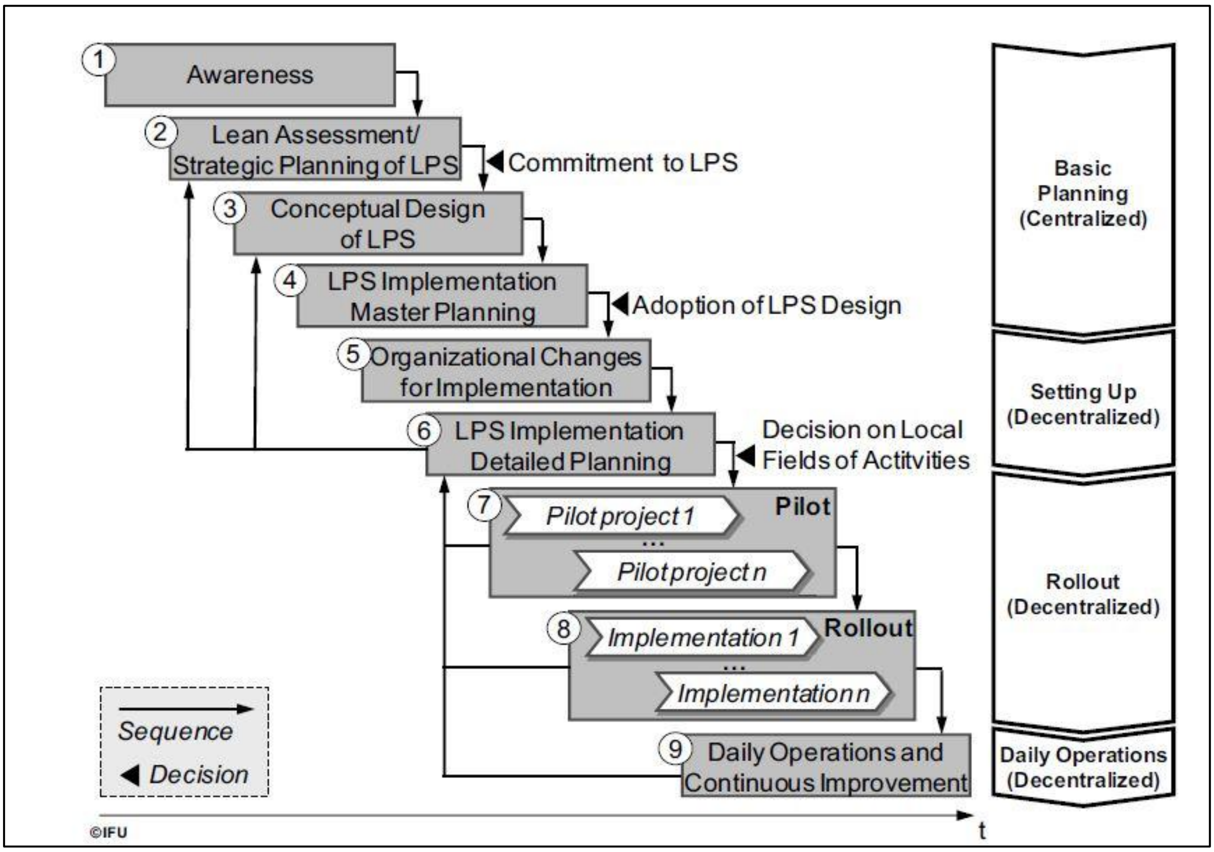



**Figure 4.10 Stepwise Implementation of Lean Production (Dombrowski et al., 2012)**

### 4.3.10 Organisational Change Framework for Lean Implementation

Nordin et al., (2012) proposed an organisational change framework for lean implementation. This framework has two interacting cycles: readiness for change, and implementing change as presented in Figure 4.11. Nordin et al., (2012) explained that every change effort starts with some sort of driver for the change and these drivers need to be identified at the first place. After identifying the pressure to change, organisations should determine its readiness for the change. For organisations to be able to change and implement lean, they should have a clear and consistent leadership and direction, as well as, a strong change agent team who will be responsible for the implementation process. Nordin et al., (2012) emphasised that it is important that those who will lead the change projects need to have the right skills, competencies and aptitude to implementing lean. After ensuring that the organisation is ready for the change, the organisation can start the implementation of lean tools and techniques in business processes and activities. Nordin et al., (2012) mentioned that the implementation of the lean tools and techniques will be useless without an effective communication and empowered employees. The transition from traditional management philosophy to lean principles will be easier by: information transparency, knowledge sharing, continuous learning and continual evaluation of lean effort. The ability to quantify the effort and progress towards lean should enable more successful and longer lasting change. Nordin et al., (2012) stated that the change process must be seen as a dynamic process, since lean is considered as an intended direction rather than a static state.

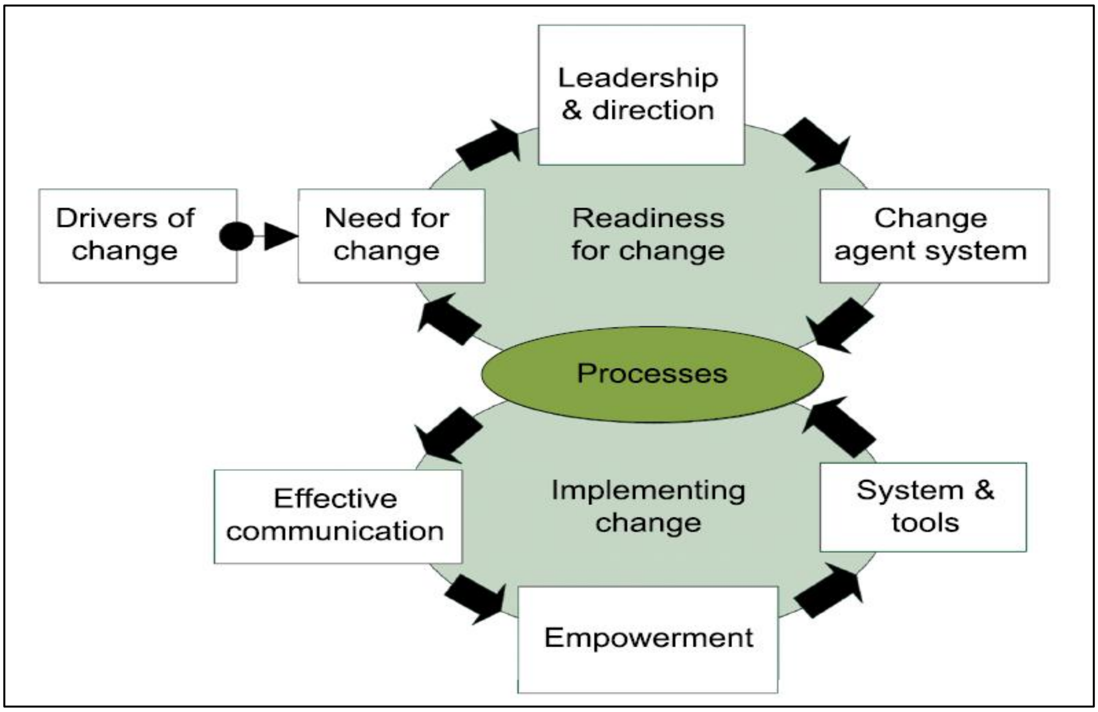



**Figure 4.11 Organisational Change Framework for Lean Implementation (Nordin et al., 2012)**

### 4.3.11 Continuous Performance Measurement Framework

Karim and Arif-Uz-Zaman (2013) developed a methodology for lean implementation based on the five lean principles as shown in Figure 4.12. According to Karim and Arif-Uz-Zaman (2013), there are some specific steps that should be followed to successfully implement lean. Karim and Arif-Uz-Zaman (2013) mentioned that, at the beginning, companies need to define their own systems in terms of production type, order volume, and demand quantity. Since these indicators are highly related to lean implementation. After that, companies should be sure that the lean culture exists in terms of management commitment and support, leadership, management practices, employees' empowerment.

Karim and Arif-Uz-Zaman stated that lean culture can be initiated by forming a lean team that will be responsible for implementing lean, communicating the lean benefits to all the employees, and ensuring that employees have the right skills required for lean implementation.  Additionally, the lean team will be able to assess the present situation or the current situation of the company to identify the non-value-added activates or waste in the process, and determines the existing system performance. Some of lean tools can be used during this step such as process mapping, value stream mapping, and visual control. After capturing the current state of the company, the team should design the future state that the company desires to reach. In this step the lean team have to determine the most suitable lean tools and techniques that can be used at the right time within the budget of the company. Finally, the lean team should be sure that that improvement process is continuous since lean is a never ending process.

### 4.3.12 Project-Based Framework for Lean Implementation

Mostafa et al., (2013) proposed 22 elements for the lean implementation framework with a detailed four implementation phases as in Figure 4.13. Appropriate practices and decision tools are proposed and assigned to each phase. The phases include conceptual, implementation design, implementation and evaluation, and complete lean transformation phase.

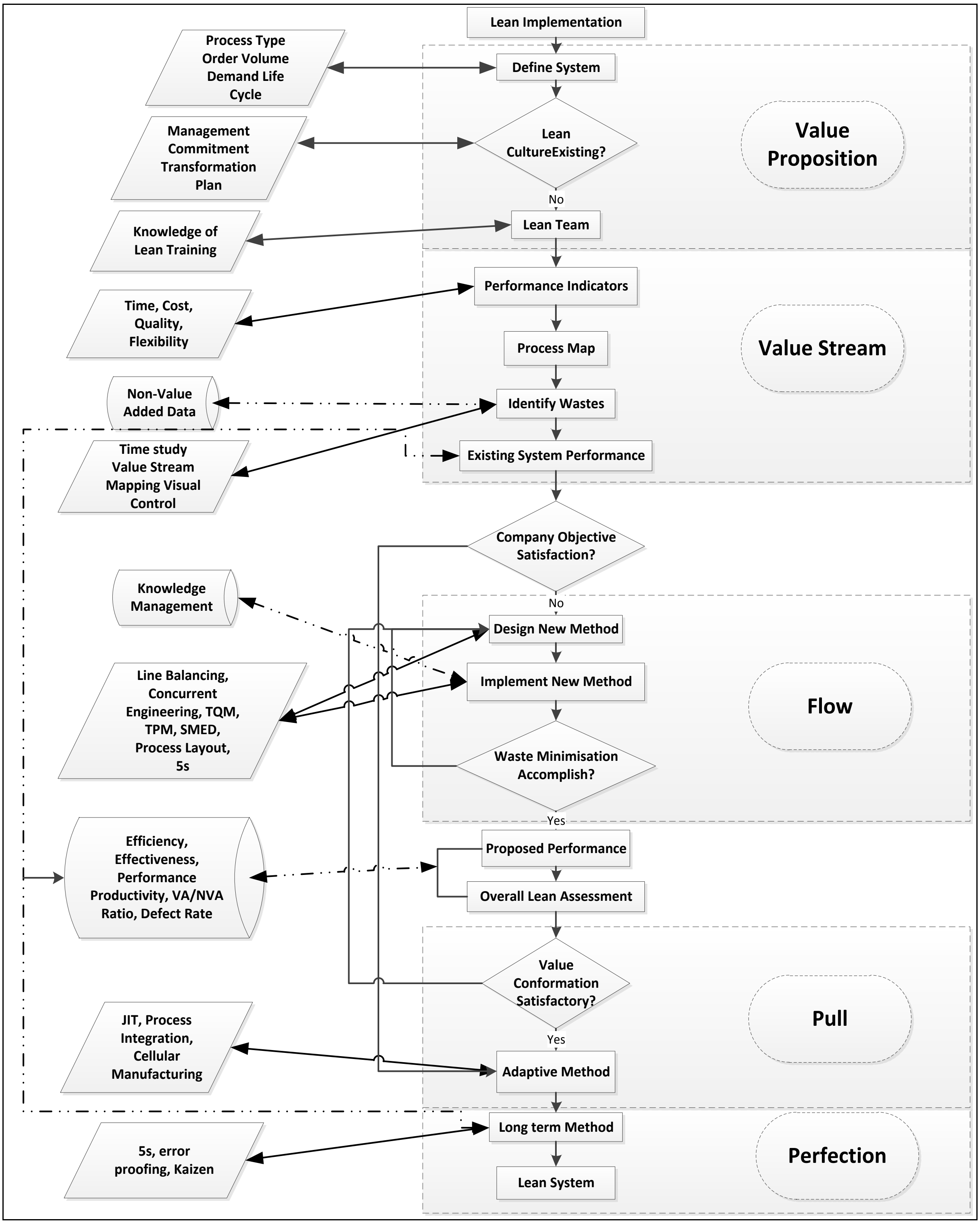



**Figure 4.12 Continuous Performance Measurement Framework for Lean Implementation (Karim and Arif-Uz-Zaman, 2013)**

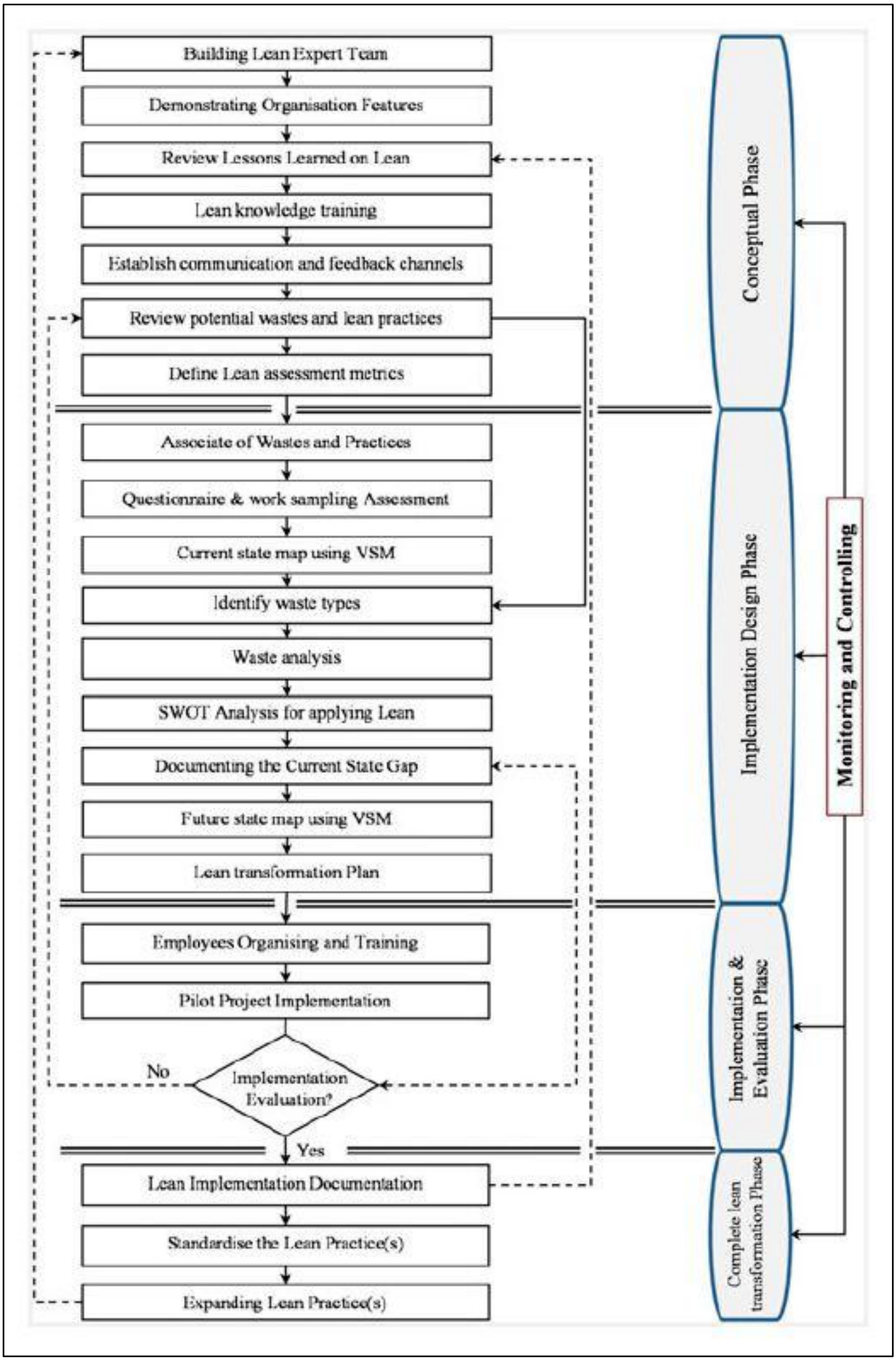



**Figure 4.13 Project-Based Framework for lean Implementation (Mostafa et al., 2013)**

The conceptualisation phase aims to enhancing the understanding of lean concept. During this phase the lean implementation team should be selected and a proper training to all the members of the team should be provided. Benefits of lean to the organisation should be explored to make each member aware of the drivers of implementing lean. In the second phase the current state of the organisation should be identified.

Mostafa et al., (2013) stated that during this phase some tools can be used to identify the current state such as: analytic hierarchy process, work sampling, predesigned questionnaire, cause and effect diagram, and the quality function deployment. The third phase is the execution phase where the lean implementation process starts. Mostafa et al., (2013) recommended conducting a pilot project during this phase in order to create a prototype or a trial implementation. The aim of this pilot project is to ensure that any expansion of lean implementation is based on the accuracy, effectiveness, and efficiency. Finally the aim of the last phase is to optimise the results of lean practice prior to the process of standardisation or future utilisation of the practice.

## 4.4 Review of the Case Study Companies

In this section an overview about the case companies along with the current industrial practices will be presented. There are three main collaborating case companies in this research. The companies are large UK manufacturing companies across various sectors. Due to confidentiality agreement with these companies, the companies names will not be disclosed and will be referred as Company (A), Company (B); and Company (C).

This section will provide a brief description about each case company, as well as, lean initiatives conducted in each case company.

### 4.4.1 Case Study 1 – Company (A)

Company (A) is a document management company that produces and sells portfolio of offerings such as: colour and black-and-white printing, publishing systems, multifunction devices, photocopiers, fax machines, and related consulting services.

The company is considered to be one of the world's leading enterprises for business process and document management. It provides its customers with a wide variety of services such as: document outsourcing, information technology outsourcing, and business process outsourcing. The company offers service expertise such as helping businesses develop online document archives, analysing the best option for customers to share document and knowledge in the office, operating in house print shops and mailrooms, building Web-based for processes for personalising direct mail, invoices and brochures and etc. The company's operations are guided by customer focused and employee centred core values such as social responsibility, diversity and quality. Additionally, all the company's operations are supported by a strong motivation for innovation, speed, and adaptability.

Company (A) started its quality journey in the early 1980. At that time, TQM program was started in the company by providing employees basic quality improvement training programmes. These training programmes include for examples identifying customers' requirements and problem solving techniques. In 1998, the company started to implement lean and six sigma in some of its manufacturing operations. But, in 2003 six sigma and lean were integrated and driven as a company strategy and implemented in all business areas. Improvement processes, tools and techniques were deployed across the company and centred on improving business processes to create a higher level of customer satisfaction, quality and productivity. There were some factors that drive the company towards the implementation of lean and six sigma such as: the strong desire to be a leading company in the business in applying improvement initiatives, strong customers' pressure to receive high quality products and services, and the strong competition.

At the early stage of the implementation process the company relied on consultants. The consultants played a key role in the deployment and the implementation of lean and six sigma. Some of the activities carried out by the consultants include:

- Formulating the overall approach that the company should take
- Provide training to senior managers to understand the new approach, the benefit of the new approach, and how managers should select the right employees to carry out the task

- Provide Master Black Belt expertise
- Developed a detailed deployment guideline booklet. This guideline contains information explaining: company structure, project selection methodology, deployment manager and black belt selection criteria, financial guidelines for valuing projects, cultural barriers, training paths, certification standards and additional resources.

The company also, created a new position as the Vice President, with a title of Corporate Lean Six Sigma (LSS) Deployment. This person reports directly to the CEO of the company. Furthermore, the company assigned a deployment manager of each business operation. Those deployment managers were responsible for selecting black belt candidates and prioritising the business issues that need to be improved. The company set a time schedule for training programmes, including: Black Belt training, green belt training, master black belt training, and design for lean six sigma (DFLSS). The implantation plan of company (A) is presented in Figure 4.14 and can be summarised in the following points:

- Assessment of the present situation in terms of risk management, capabilities, and customers and suppliers relationships.
- Seeding the new culture into the company by deciding the implementation of Lean Six Sigma (LSS), conducting leadership training, and identifying deployment managers.
- Starting Black Belt and deployment manager training.
- Design and execute the implementation roadmap.
- Starting Master Black Belt and Green Belt training.
- Initiating design for lean six sigma (DFLSS) training and implementation.

The selection of lean six sigma projects in company (A) goes through different steps as shown in Figure 4.15. The management team identifies projects based on customer experience improvement opportunities, alignment of strategic plans, ability to close business gaps and key areas for process improvement. The company views lean six sigma processes as two distinctly different stages. The first phase of the process focuses on project selection and prioritisation. Potential projects are assessed based on their potential business impact and estimated effort. The business unit deployment manager works with the leadership team to identify the next best opportunity based on various business factors. To assure alignment to the company's goals, it is ultimately the leader of the operation that is accountable for the projects being selected.

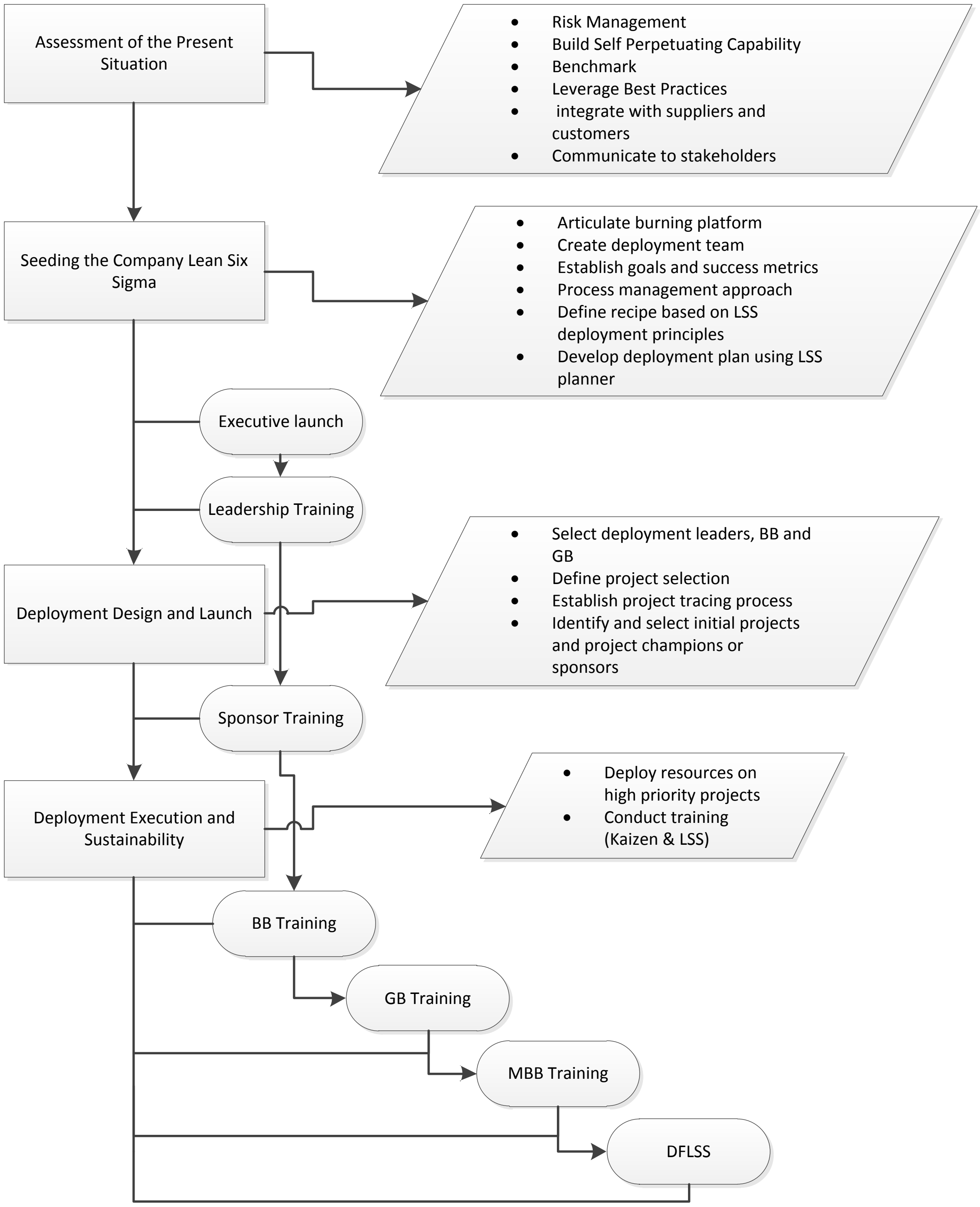



**Figure 4.14 Company (A) Lean Initiatives Plan**

BB: Black Belt; GB: Green Belt; MBB: Master Black Belt; DFLSS: Design for lean six sigma

Once the project is selected and the appropriate sponsor is confirmed, the project is queued up for assignment to the next available Black Belt. The Black Belt is responsible for the project execution. The company employs a wide variety of lean and six sigma methodologies to identify and deploy the best solution for the defined business problem such as:

- DMAIC (Define, Measure, Analyse, Improve, Control): A standard approach for re- engineering existing processes.
- DMEDI (Define, Measure, Explore, Develop, Implement): Ideal for optimising new processes.
- DFLSS (Design for Lean Six Sigma): Used, with specialised tools, for customer-driven design of new technologies and services.

A description of the DMAIC methodology by company (A) can be summarised and presented as given in Table 4.3. The Table presents an explanation of each phase and the desired aim from each phase, as well as, the tools and techniques that can be used in each phase.

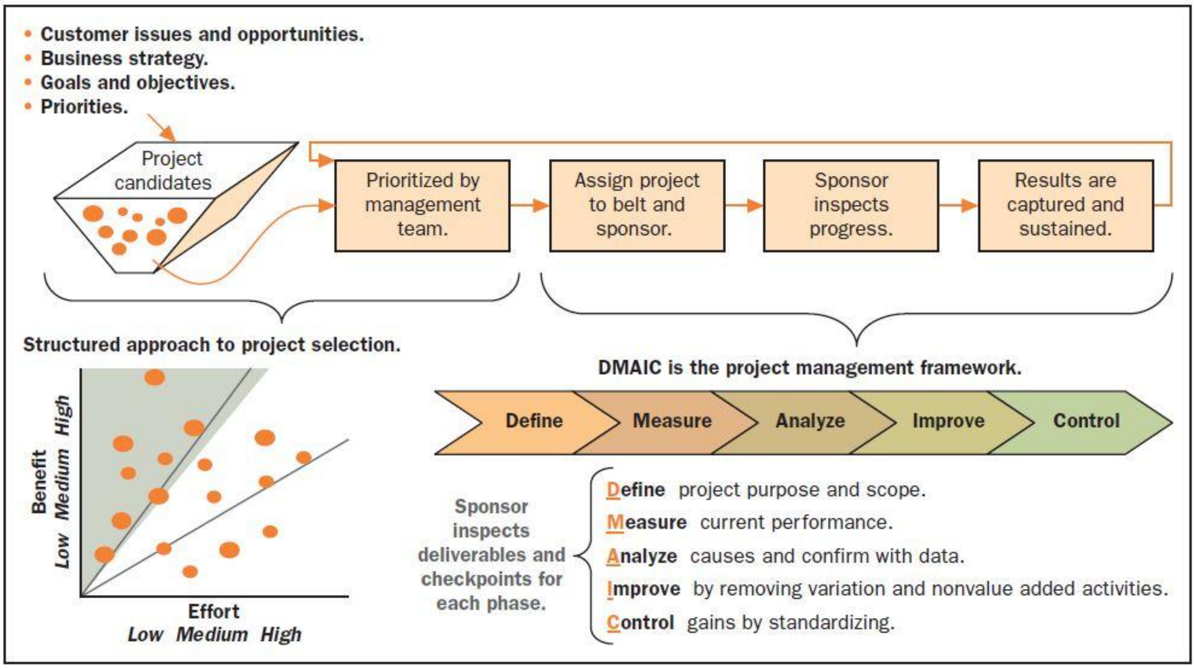



**Figure 4.15 Lean and Six Sigma Processes at Company (A)**

**Table 4.3 DMAIC Methodology Used By Company (A)**

| | Define | Measure | Analyse | Improve | Control |
|---|---|---|---|---|---|
| **Description** | Establish problem statement<br>Establish success criteria | Establish current state, identify where a process can be streamlined | Identify root causes<br>Identify time-intensive activities of a process<br>Identify how to eliminate non-value-added steps | Develop, plan solutions<br>Run pilot<br>Failure analysis | Implement solution<br>Monitor success of solutions<br>Develop process controls and mistake proofing |
| **Tools and methods** | **SIPOC**<br>Capture voice of customer, business, and process<br>Document success criteria | **VSM**<br>Non-value-added steps<br>Business value-added steps<br>Customer value-added steps | **Pareto/Regression/Bar Charts** | **Solution selection**<br>People, process and technologies | **Dashboards**<br>Solution replication<br>Visual process controls |
| **Value** | Provides single-minded focus for the entire process improvement engagement | Allows all stakeholders to agree on objective process metrics | Provides an opportunity to formulate key insights that will drive implementation of the solution | Gives participants a clear roadmap for executing the appropriate process changes | Allows for process control and continuous improvement based on metrics defined earlier in the process |

### 4.4.2 Case Study 2 – Company (B)

Company (B) is a specialist train manufacturers that provides a comprehensive range of design, manufacturing, operating and maintenance service for the rail transport. Company (B) is a worldwide leader in the rail transportation market for equipment and services. The company develops and markets the most complete range of systems, equipment and services in the railway sector, including rolling stock, infrastructure and signalling equipment, as well as, maintenance operations. The company has a full service provision and technical support contracts with a number of train and metro operating companies. The main goals for the company are to deliver fully functional, clean and reliable trains to the customer and meet their demands in terms of punctuality and safety of the trains. To achieve these objectives in the most efficient way, the company has created and developed its own production system. The system is inspired by the concept of lean production. The company production system is defined by its standardisation of operations, problem-solving, operator involvement and management of methods and tools for continual improvement. The purpose with the system is to attain success in safety, quality, costs and delivery while working with continuous improvement. Additionally, the system enables the company to ensure flexibility in its manufacturing processes, reduce cycle time, and achieve productivity gains.

In 2004, the company faced maintenance issues, causing the company to miss availability targets. The availability rate of specific model was just 72%. Additionally, the company faced other service issues, such as faulty air-conditioning units (76 faulty out of 583 (13%)) and out of service toilets (40 to 60 locked out of use, out of 371 (13%)), and catering equipment failure. Moreover, crews took six weeks to repair trains involved in minor collisions.

In 2006, the company has brought the knowledge of lean gained in the manufacturing process directly into its maintenance routine with the support of a consulting company. The goal was to optimise the layout and the maintenance process by improving the work methods and reduce waste. In the initial stage of implementing lean the company developed a business improvement team including two business improvement managers and four representatives in Wembley, Midlands, Manchester, and Glasgow. The improvement team took a training sessions arranged by a specialised consultant company to understated the concept of lean, the tools and techniques that can be used, the challenges that may be faced during the implementation and how to overcome them, as well as, the benefits of lean implementation. The improvement team defined four objectives during these training sessions:

- Meet availability and double reliability.
- Grow the business by 20%.
- Maintain the current cost base.
- Provide greater value to the customer.

To turn things around, the company used some lean tools and techniques to transform its maintenance practices. In particular, the company used policy deployment, daily management process, 5S, and Kaizen.

Through the policy deployment process, the company developed a clear strategy for that everyone has bought into across the management team. Through this process the company become aligned as to what is important to improve. At the same time, lean processes were implemented in the business. Policy deployment also called (Hoshin Kanri). Hoshin Kanri is “a form of corporate-wide management that combines strategic management and operational management by linking the achievement of top management goals with daily management at an operation level” (Witcher and Butterworth, 2001). Hoshin Kanri is a method for ensuring that the strategic goals of a company drive progress and action at every level within that company. According to Witcher and Butterworth (1999), Hoshin Kanri is an organising framework for strategic management, which is concerned with the following four primary tasks:

- To provide a focus on corporate direction by setting, annually, a few strategic priorities;
- To align the strategic priorities with local plans and programmes;
- To integrate the strategic priorities with daily management;
- To provide a structured review of the progress of the strategic priorities.

The initial focus was to implement a pit stop maintenance approach to treat the trains like Formula One cars in a pit stop and shorten repair times. Ongoing use of the policy deployment process allowed the improvement team to focus on other improvements needed to significantly grow the business. One of the tools used during policy deployment was the "catch-ball" process. By using "catch-ball" process the improvement team throws goals, objectives and strategies back and forth throughout the entire management chain. Starting from, the corporate level and cascades down through senior management, operations leader, depots and production management, respectively. The application of Hoshin Kanri relies on a process called "catch-ball" to gain consensus on the deployment of Hoshin targets and measures in a team environment. The catch-ball process is necessary for successful implementation of Hoshin Kanri. It is a critical element that requires continuous communication to ensure the development of appropriate targets and means, and their deployment at all levels in the organisation (Tennant and Roberts, 2001) .

Also, Kaizen was one of the tools used to provide a common way of working across the business to deliver its Safety, Quality, Delivery, and Cost (SQDC) commitments. The SQDC is reviewed everyday morning to determine what the company can do today to improve the last night performance. Furthermore, the company implemented a daily management process as shown in Figure 4.16 where all the levels of the business, from the boardroom to depot management and specific train repairs, have standard visible measures covering all aspects of what they do. On visual boards they review their performance each shift and agree as a team what they need to do to improve their measures. By 9am each day they do a complete review of their business and all employees are involved in that review in their particular part of the business.

Through this management system, which involves managers walking around these boards discussing with the teams their performance; management becomes directly involved and aware of the issues that the business face. When they discuss problems in a management review the team has first-hand awareness of the real issues behind the changing numbers they are looking at.

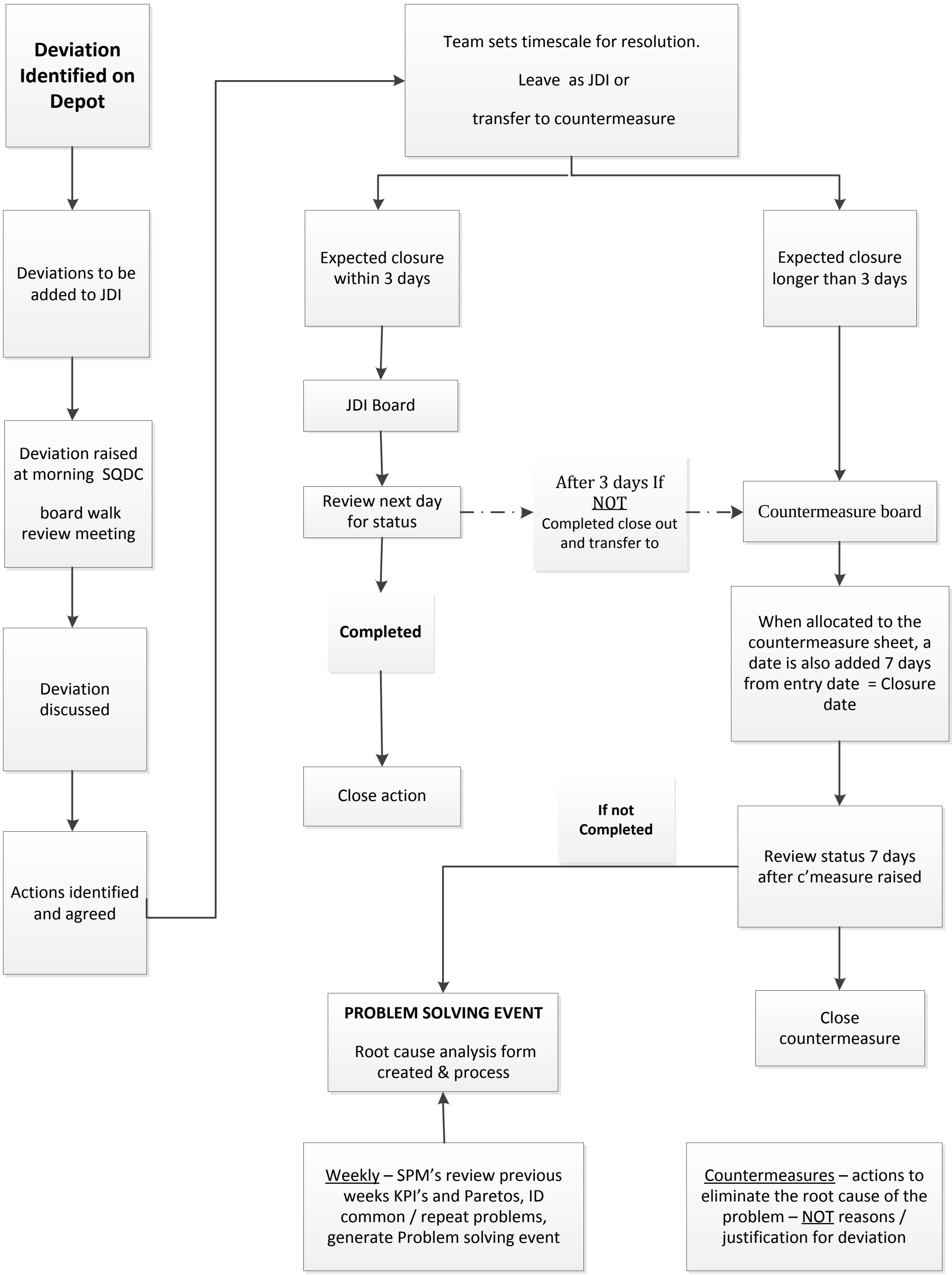



**Figure 4.16 Company (B) Daily Management Process**

As a result of these improvement activities, the company increased availability rate of trains from 72% to approximately 90%, met its five year goal to grow the business by 100%, and increased customer satisfaction that lead to extending maintenance contract of the company customers. The company has seen remarkable success in its lean transformation and has continued to strengthen its commitment to the journey.

As discussed before company (B) lean journey started in 2005 and in each year the company has achieved a great progress towards the implementation of lean practices in its operations and processes as presented in Table 4.4

**Table 4.4 Company (B) Lean Journey**

| 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|
| Set up repair centers (First Kaizen event)<br>Bogie overhaul facility set up using lean principles<br>Set up visual planning and control<br>5S initiative launched | June- lean training for management team<br>July- management team attend policy deployment event<br>Oct- first Kaizen workshop<br>Nov- business growth plan reviewed | Jan - First Kaizen Promotion Office set up<br>April – First Production Preparation Kaizen Event held<br>May – 20 Kaizen projects completed (2 – 3 projects per month)<br>June – Public event held in the Manchester and Oxley Train care Centre<br>June – First Business Process Kaizen to be held<br>July – Kaizen Promotion Offices at 3 /5 West Coast depots<br>July – 3rd Policy Deployment session<br>Aug / Sept Business Improvement Cascades<br>Oct – Kaizen Instructor training<br>Nov – Energy Kaizen<br>Dec – 4th Policy Deployment Session held | Jan – Train-care Centers develop their own Improvement Plans and kaizen calendars<br>Feb – 3 Lean projects launched<br>Model line<br>Standard Operations<br>Managing for Daily Improvement<br>July – Held our 5th Policy deployment session<br>August – over 18 months, 50 Kaizen projects completed with over 250 people attending. |

The lean journey of company (B) can be summarised in the following phases and steps:

- **Phase One: Introduction of Lean Tools and Techniques** (2004-2006)
  - Demonstrating the power of lead-time reduction.
  - Implementation of visual planning process.
  - Point Kaizen on critical business issues only.
  - Implementation of 5S.
- **Phase Two: Structured Approach to Lean** (2006-2009)
  - Introduction of policy deployment.
  - Senior management team aligned to strategy.
  - Pit stop approach to train maintenance.
  - Structured Kaizen program linked to strategy.
- **Phase Three: Operational Excellence** (2009-2013)
  - Leveraging lean for significant growth.
  - Policy deployment using software.
  - Implementation of a daily management system.

### 4.4.3 Case Study 3 – Company (C)

Company (C) is specialised in manufacturing commercial heavy vehicles. The company offers customers comprehensive services in one stop shopping such as, service and repair contracts, fleet management, tailor made financing, leasing and insurance, flexible rental options and many other tailored services. Company (C) still in the early stage of lean implementation and is keen to implement it. The company started its lean project in the service offering process only few years ago. The aim of the project was to identify any further improvements that can be done in the current process; in order to increase efficiency, customer satisfaction both internally and externally, reduce the WIP (Work in Progress), and ultimately reduce the invoices in query. The first phase of the project was to develop an implementation team. The team started the project by documenting and reviewing the current processes. During this phase the team used process mapping to analyse the current process flow. This analysis enabled the team to identify how work is actually done and how it should be done. After analysing the current process, the team designed a proposed process based on certain criteria they considered to be important to improve the current process. The next phase was the pilot phase. In this phase two branches were selected to conduct trials to ensure that the theory can be transfer into real practice. The pilot phase lasted for almost two months. After that, the company started to conduct some training sessions for their employees to clearly understand the concept of lean, its tools and techniques, and the benefit of implementing it. One of the main tools used by this company is the key performance Indicators (KPIs). The company designed some metrics to track and encourage progress towards predetermined goals. These KPIs used to track and monitor the performance of the process. These KPIs were audited and reviewed on a regular basis.

## 4.5 **Framework Development Process**

The development process of the framework is based on reviewing previous lean implementation frameworks and models, as well as, investigating the current industrial practices as mentioned in Figure 4.17.

First the relevant literature was reviewed.  As mentioned in section 4.2 a literature review of relevant researches pertaining to lean manufacturing implementation, lean transformation, transition to lean, lean framework, lean roadmap, and applying lean was conducted. As a result of this review, 12 lean implementation frameworks and models were analysed as mentioned in section 4.3. Some researchers have chosen the descriptive way to present their lean initiatives, while others portray a framework through diagrams or graphical presentations.

In addition to reviewing relevant frameworks and models, the current lean industrial practices of three large UK manufacturing companies were identified as mentioned in section 4.5. Three main data collection techniques were used to identify the current industrial practices, namely: semi-structured interviews with eight experts from the three companies, documents provided by the three companies, and observation.

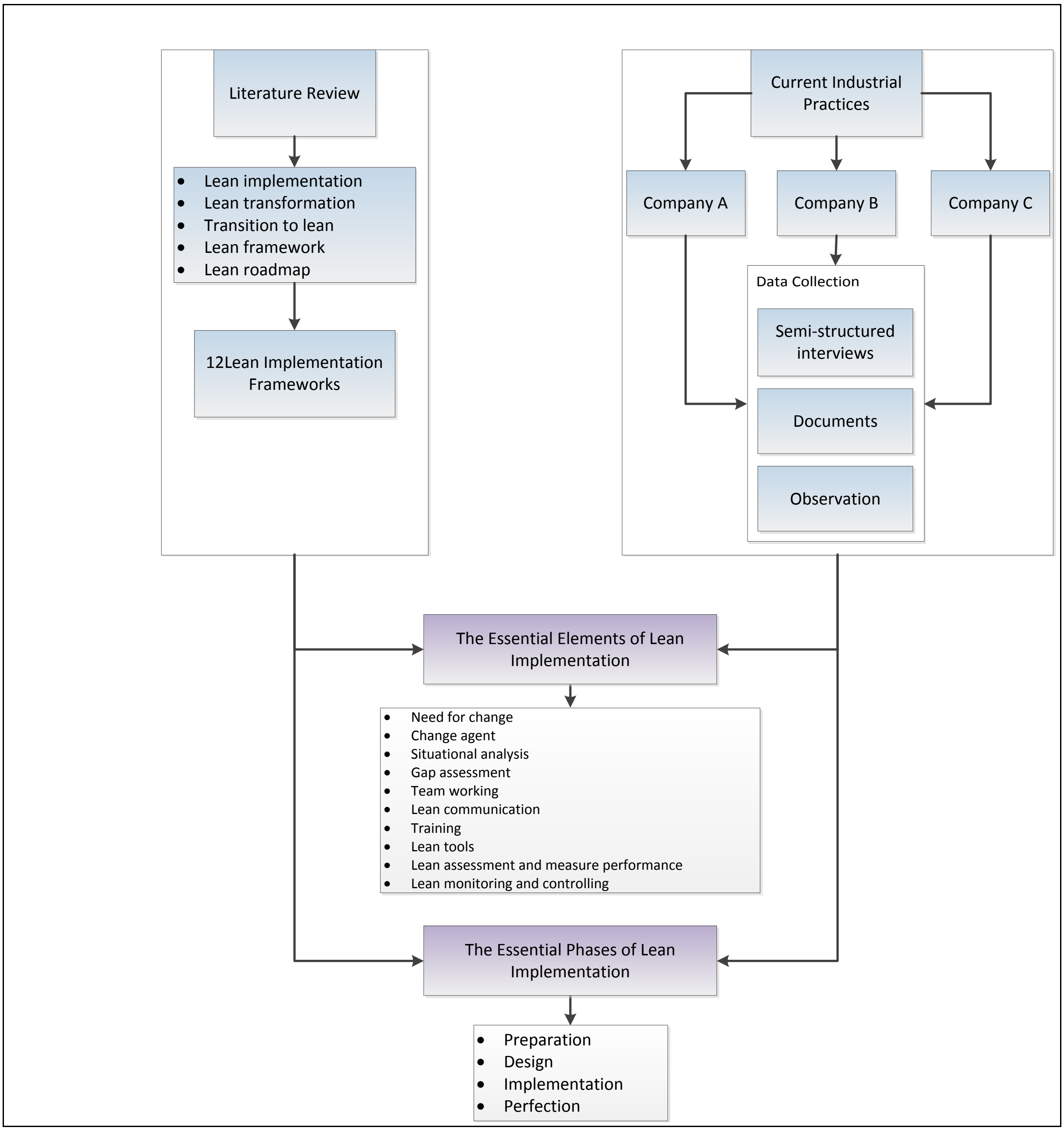



**Figure 4.17 Framework Development Process**

The outcomes of reviewing relevant frameworks and investigating the current industrial practices were to identify:

- The essential elements required for implementing lean principles in PSS.
- The essential phases necessary for the implementation process of lean principles in PSS.

From all the previous frameworks and industrial practices, there are some essential factors that are crucial for developing the implementation framework. These factors can be summarised in the following points:

- Changing from any production system to lean could be one big change which would affect entire value stream and everyone working in an organisation. Following Kotter's eight steps for change could help successful implementation of lean. But as lean involves continuous improvement, it is expected for an organisation to have to deal with changes continuously (Mishra, 2013). Kotter's eight step model for change (Kotter, 1995) comes from the eight common errors that managers make when they need to implement change. Kotter's eight steps for successful organisational change are:

Step 1: Establishing a sense of urgency
  - Top management support change when they understand why
  - They are more likely to be involved and committed when there is urgency

Step 2: Forming a powerful guiding coalition
  - Group acting a team is more likely to bring about change than a single person
  - They facilitate better communication, knowledge sharing, stronger support and decision making

Step 3: Creating a vision
  - Creating a common vision helps channelize the change efforts
  - A common strategy has to be developed on how to achieve the vision

Step 4: Communicating the vision
  - This will help gain the necessary resources and also commitment from the workforce. It also helps to create the motivation and assistance to the members.

Step 5: Empowering others to act on the vision
  - Empowering employees to act on the vision will help maintain the credibility of change

Step 6: Planning for and creating short-term wins

    - This will help boost motivation, morale and commitment of people at all levels
    - This will also prevent people giving up when they are close to the achievement

Step 7: Consolidating improvements and producing still more change

    - Further improvements will be created by short term wins

Step 8: Institutionalising new approaches

    - The change that has already been brought should be practiced and enforced every day

- Situational analysis to define the internal strengths and weaknesses, as well as, external opportunities and threats to implement lean. Internal analysis includes identifying the internal attributes of the company with regard to resources, employees, products, services, etc. While external analysis includes analysing factors such as competitors, customers, economic, technology, etc.
- Lean assessment to evaluate lean practices in different areas, to provide a baseline for future improvement. Lean assessment will provide the company with an overall index of the lean status and how lean the process or a system is; this can be done using set of lean metrics. Furthermore, lean assessment will reflect the real lean performance and direct managers to set an action plan.
- The development of lean implementation team that have the required skills, knowledge, and experience to manage the implementation process. To implement lean successfully, there should be a good implementation team that guides the company during the lean journey. The lean implementation team will provide the required training to employees. Moreover, the team will be responsible for creating the implementation plan, assigning responsibilities for various activities, and determining due dates. Also, the team will make sure that all necessary resources will be available as needed. If the managers have not the required knowledge and skills of lean implementation, companies can rely on consultants.
- Providing lean training programmes for managers and employees is vital in all of the previous frameworks. Successful transition to lean will require a deep

understanding of its principles and practices, with extensive training at all levels. The focus should be on changing beliefs, behaviour and attitudes throughout all the employees. Lean training programmes will enable the company to overcome employees resistance to lean improvements by providing them with the required skills and knowledge

- Committed and supportive top management is crucial. Committed management is necessary to provide the required resources, to take fast and effective decisions, to promote acceptance of the lean concept among employees.
- Developing an effective communication plan. A successful lean implementation depends upon how effectively management communicates with those affected by the implementation. This communication must address, what is happening, why it is happening and how it is happening. Miscommunication may lead to misunderstanding and misapplication of lean concept and tools. Furthermore, it generates an ambiguity in employees' roles and responsibilities.
- Selecting the best combinations of lean tools and techniques is important factors in the implementation process. The lean tools should be implemented in a structured manner and at an appropriate time whilst taking into account their interactions. The misapplication of the lean tools in terms of using the wrong tool to solve a problem, or using a single tool to solve all of the problems, or using the same set of tools on each problem is one of the significant reasons behind the failure of the lean implementation. The selection of the lean tools depends on the needs of the company. No single set of tools can be suitable for all the companies.
- Monitoring and reviewing the lean implementation performance and progress on a regular basis is necessary. Monitoring and reviewing mechanisms ensures the sustainability of lean performance over long term, as well as, encouraging the desired behaviours by all employees. The process of monitoring includes measuring the actual lean accomplishment and comparing it with the desired gaols. This auditing process ensures that the implementation process follows the plan and provides corrective actions in case of deviation.

- Additionally, from reviewing the previous frameworks and current industrial practices, it can be found that there are some basic phases that are required to be followed for implementing lean these phases can be summarised as presented Table 4.5

**Table 4.5 Phases and Steps of Lean Implementation**

| Phase | Steps |
|---|---|
| Preparation | • Recognise the need for change<br>• Training<br>• Developing implementation team<br>• Finding a change agent<br>• Understanding waste<br>• Assessment of the current situation<br>• Supplier and customers involvement |
| Design | • Mapping the value stream<br>• Identifying weak areas for further improvement<br>• Planning the change<br>• Identifying metrics to measure the implementation progress and performance |
| Implementation | • Pilot project<br>• Evaluating the progress towards the required change<br>• Communicating the benefits of lean implementation to all the employees<br>• Expand the implementation scope to include all the system |
| Perfection | • Standardise lean practices<br>• Regular assessment and evaluation of the implementation progress<br>• Continuous improvement |

## 4.6 Lean PSS Implementation Framework

In this section, a conceptual framework has been proposed to identify the main phases that should be followed for the successful implementation of lean in the service offering process. The framework was built on two main sources, namely: literature review and data collected from the case companies. The framework is structured on three phases. In each phase different kind of tools and methods will be used. Each phase should be completed before going to the next phase. The three phases are:

- Assessment of the current lean implementation (As-Is)
- Developing the future state (To-Be)
- Stabilising the new way of operations

If these phases applied effectively and properly, the framework should enable the PSS provider to identify the challenges of lean implementation in PSS, as well as, identifying the strength areas and areas for further improvement. Moreover, the framework is useful in enabling managers to develop an improvement proposal that focuses on weak areas. Additionally, by using this framework mangers will be able to achieve continuous improvements, through measuring the current performance and compare it with the target performance. The following section will discuss the framework and its phases. The full framework and its phases and steps are presented in Figure 4.18.

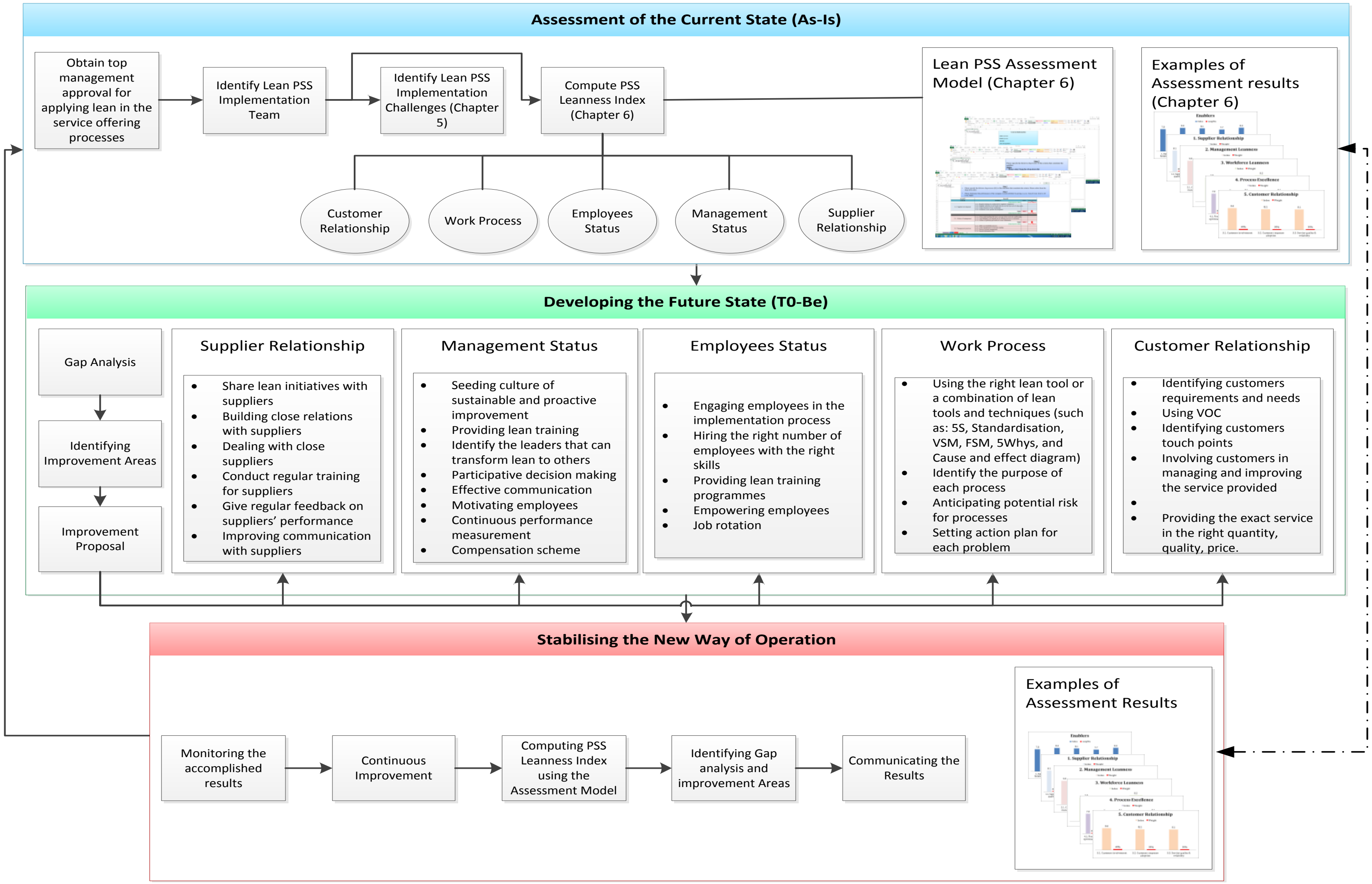



**Figure 4.18 Lean PSS Implementation Framework**

### 4.6.1 Phase One: Assessment of the Current Lean Implementation (As-Is)

This is the kick-off phase, which is essential before the implementation process. The steps in this phase must be addressed before the actual lean implementation can begin. This phase enables the company to define the gap between the expected outcomes and the current situations, as well as, identify improvement areas.

In order to grasp the real situation and define the problem, there is a need to go to the real place and see what is really happening there. The first step in this phase is to obtain top management approval for implementing lean practices in the service offering process. This step creates the right atmosphere before lean initiative is undertaken. Most important of these is top management commitment and support, which must be present from the very beginning for any initiative to succeed. Top management commitment must be present, and they must establish a believable change vision and promote it, so that it gains wide acceptance in the company. Management issues are usually among the main reason for lean failure.

The second step in this phase is to develop lean PSS implementation team. Establishing a team of multi-skilled members, as well as, a team leader is very important in this phase. The lean team is usually consisted of experts and mangers from different department and their main objective is to implement lean initiatives.

Team members should clearly understand the concept of lean and the lean tools and techniques. They have to accept different views and respect other people opinion. They have to communicate lean benefits to all the related members, as well as, motivate employees and give them more ideas for improvement. Furthermore, the team members will provide the required lean training to the employees of the company. But, if lean experts are not available inside the company, the company can depend on external consultants or give the team members intensive lean training programs. The team will be responsible for two major tasks. The first task is to identify the challenges of lean implementation in the service offering process and the second task is to assess the PSS leanness level.

The implementation of lean practices remains popular among manufacturing and non-manufacturing companies, and the requirement for customised steps in its implementation is widely accepted; however the challenges of implementing lean in PSS are not yet consider. There are several challenges that the implementation team should take into their account during the implementation process. Some of these challenges are: the nature of service, resistance to change, and defining waste. These challenges will be discussed in more details in chapter 5.

After identifying the main challenges, the team should assess and evaluate the PSS leanness level using Lean PSS Assessment Model. The model assesses the PSS leanness level in terms of five main enablers. These enablers are supplier relationship, management status, employees' status, work process, and finally customer relationship. A brief description of the model is provided in this section, but the full explanation and description of the model will be presented in chapter 6.

The PSS Leanness Assessment Model is developed on three levels as presented in Figure 4.19. The first level consists of five enablers, the second level contains 21 criteria, and finally the third level involves 73 attributes. The rationale behind the formulation of the model is that it represents five major perspectives of lean in PSS, namely: supplier relationship, management leanness, workforce leanness, process excellence and customer relationship. The computation of PSS leanness index goes through successive steps. The assessment of each level depends on the assessment of the preceding level. For instance, the PSS leanness index is the sum of the indices calculated for each enabler. Also, the index of each enabler is the sum of the indices computed for the criteria pertaining to each enabler. Finally, the index computed for each criterion will be determined by the assessment scores for each attribute pertaining to each criterion. Computing PSS leanness index can contribute to successful lean implementation as it provides authentic results for lean performance and directs decision makers to corrective actions. Additionally, the index will provide the base that can be used as a start point for implementing lean in PSS.

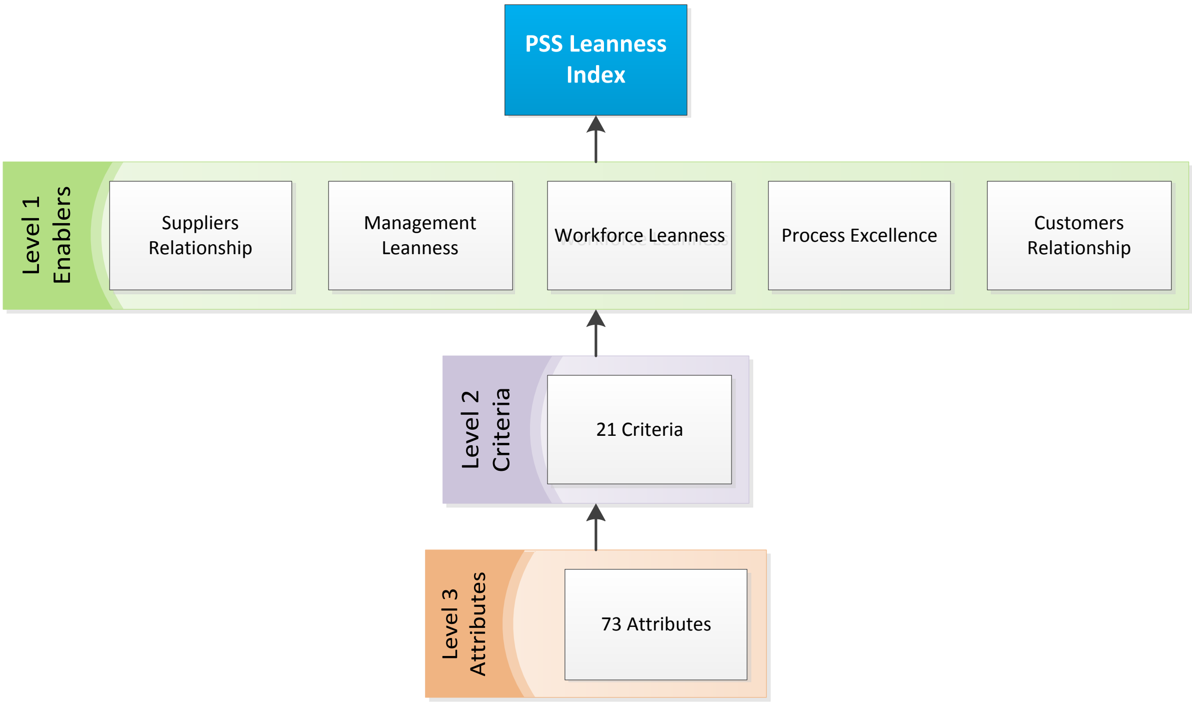



**Figure 4.19 Components of Lean PSS Assessment Model**

### 4.6.2 Phase Two: Developing the Target State (To-Be)

Although the assessment process highlights what is the real situation, it does not indicate the desired future state. The aim of this phase is to determine the best way that the company can use to improve the performance of each enabler pertaining to the implementation of lean in PSS. This first step in this phase is gap analysis.

After computing the PSS leanness level, the implementation team will have a quantifiable measure of how lean PSS is. Additionally, the team will be able to identify the gap between the current state and the desired future state. The PSS leanness index will enable the team to determine weak areas that need more improvement, as well as, develop improvement proposal with respect to the five main enablers (chapter 5). Now the lean implementation team have all the information about how lean the service offering process is. The implementation team is ready to improve the five main lean PSS enablers and apply the suitable tools to enhance each enabler.

Supplier relationship can be improved by: sharing lean initiatives with suppliers; building close relations with suppliers; dealing with close suppliers; conduct regular training for suppliers; give regular feedback on suppliers' performance; and improving communication with suppliers. The status of management can be enhanced by seeding culture of continuous improvement, waste elimination and problem solving. Additionally, managers should clearly understand that lean is not just about tools and techniques, but a philosophy and they have to feel enthusiastic about it. Also, a committed management is necessary. All managers at all levels should be convinced that lean is the right path for the service offering process development. Managers should take the required lean training and facilitate training programs to their employees. Additionally, managers should allow employees to participate in making decisions, communicate the benefits of lean among employees, motivate employees, measuring the performance towards lean in a regular basis, and provide compensation for employees on their performance.

At the same time, employees' status need be improved in order for the company to be able to implement lean successfully. Employees need to be motivated empowered, and willing to accept lean initiatives. The company should have the exact number of employees with the right skills. These employees should be empowered to be able to respond quickly to customers' demands and requirements. To have the suitable employees that are able to implement lean, the company need to engage employees in the implementation process; hire the right number of employees with the right skills; provide lean training programmes; empower employees; and implement job rotation system.

With regard to the work process enabler, the lean principle of developing flow production does not work well without paying attention to work processes. Work processes across the value stream should also be emphasised in the implementation process. Work process refers to all the tasks or activities required for producing a product or a service for customers. The service offering process should be managed in an effective and efficient way to achieve a world class performance. Processes used to provide services to customers should be performed with a minimum of non-value added activities in order to reduce waiting time, queuing time, moving time, and other delays. Improving work process is important to create value; find more wastes to eliminate from the value stream; flow process and parts faster; and respond to customers quickly by pulling products and services rather than pushing them on the marketplace. There are many lean tools and techniques that can be used to improve the work process such as 5S, standardisation, VSM, benchmarking, 5Whys, cause-and-effect diagram, and KPIs. A detailed explanation of these tools will be presented in chapter 5. The company need to identify the purpose of each process, anticipate potential risk for processes, and set an action plan for each problem. The final and one of the most important enablers that should be improved is customer relationship. The critical starting point for lean implementation is value. External customer is the only one who can clearly define value from his perspective. The full identification of customer demand allows managers to leverage the knowledge of their customer preferences and hence improve the accuracy of forecast plans and service quality level. The main objective of any lean initiatives is to satisfy customers need to the maximum level by delivering high quality goods and services and responding quickly to their changing demands. Customer relationship is one of the crucial requirements in implementing lean in PSS. The company need to be sensitive to their customers' requirements and this can be done through listening to the Voice of the Customer (VOC); identifying customers touch points; providing the exact product or service in the right quantity, quality, and price from the first time. Also, the company need to involve their customers in managing and improving services provided.

### 4.6.3 Phase Three: Stabilising the New Way of Operation

The new way of operation should be institutionalised, along with continuous improvement practices to take advantage of the initial momentum and push toward the established goals. In this phase, there is an emphasis on measurement and continuous improvement. Lean is a never ending journey that keeps going on.

The first step in this phase is monitoring the implementation to ensure that the implementation on lean PSS is going on the right track. Monitoring will ensure the sustainability of lean performance in the long run. In this step the actual performance is measured and compared against the desired goals. This auditing process ensures that the implementation process follows the plan and provides corrective actions in case of deviation. Again, the implementation team will use the Lean PSS Assessment Model to measure the actual performance achieved and compare the results with the initial results obtained in the first phase. The feedback obtained in this phase enables the company to monitor any deviation and take corrective actions. Moreover, through monitoring the actual accomplishment, the company will be able to take preventive actions for any unanticipated situations and identify any influencing factors that may affect the implementation process. Absence of monitoring on lean implementation may result in the failure of the implementation process.

## 4.7 Chapter Summary

This chapter focuses on the development of the lean PSS implementation framework. In Section 4.1, a brief introduction about the importance of developing and creating lean implementation framework was highlighted. In Section 4.2, the research methodology followed to develop lean PSS implementation framework was explained. The development of the framework is based on previous studies carried out in implementing lean initiatives and data collected from the case companies. Section 4.3, discussed the existing frameworks for lean implementation provided in the literature. Section 4.4, revealed some of the common factors used in previous lean implementation frameworks such as:

- Assessment of the present situation
- Evaluating lean practices using some metrics to identify the level of lean implementation
- The development of lean implementation team that have the required knowledge and experience to manage the implementation process
- If the managers have not the required knowledge and skills of lean implementation, companies can rely on consultants
- Providing lean training programmes for managers and employees is vital in all of the frameworks

- Committed and supportive top management is crucial
- Developing an effective communication plan
- Selecting the best combinations of lean tools and techniques is important factors in the implementation process
- Monitoring and reviewing the lean implementation performance and progress on a regular basis is necessary

An overview about the case companies along with their lean initiatives were presented in Section 4.5. There are three main case companies used in this research. All the three companies are large UK manufacturing companies across various sectors. Company (A) is a document management company, company (B) is a specialist train manufacturers, and finally, company (C) is specialised in manufacturing commercial heavy vehicles.

Section 4.6, presented lean PSS implementation framework,  The framework is structured in three phases each requiring different kind of tools and methods, each phase should be completed in a proper way before going to the next phase. The three phases are:

- Assessment of the current lean implementation (As-Is)
- Developing the future  state (To-Be)
- Stabilising the new way of operations

# CHAPTER 5

# 5 LEAN PRODUCT- SERVICE SYSTEM: CHALLENGES, ENABLERS, AND TOOLS

The aim of this chapter is to present the main enablers and factors, as well as, the lean tools that are considered to be important for the successful implementation of lean in PSS. Additionally, this chapter specifics some of the challenges companies approached when they implement lean practices in Product-Service System (PSS). In order to successfully achieve the aim of this chapter, the chapter is organised as presented in Figure 5.1

Section 5.1 provides a brief introduction about lean and PSS. Section 5.2, describes the methodology used in this chapter to reach the desired goal. A combination of research methodology approaches have been used in this chapter. Starting from literature review to identify the Critical Success Factors (CSFs) and tools for lean implementation in the manufacturing and the non-manufacturing sectors, as well as, the challenges that hinder lean implementation. This was followed by interviewing the relevant key managers working in three UK manufacturing companies that successfully implement lean practices in the service offering process. Finally, results obtained were validated via experts in the target companies. In section 5.3 the challenges of implementing lean PSS are demonstrated. There are eight challenges that will be discussed in detail in this section. Section 5.4 presents the five main enablers and 33 factors emerging from the main enablers that are considered to be vital for the successful application of lean in PSS. The main enablers are management status; work process; customer relationship; employees' status and finally, supplier relationship. Section 5.5, provides insights into the appropriate lean tools used to implement lean in PSS. The validation of the results reached will be described in section 5.6. Summary of the chapter are presented in section 5.7.

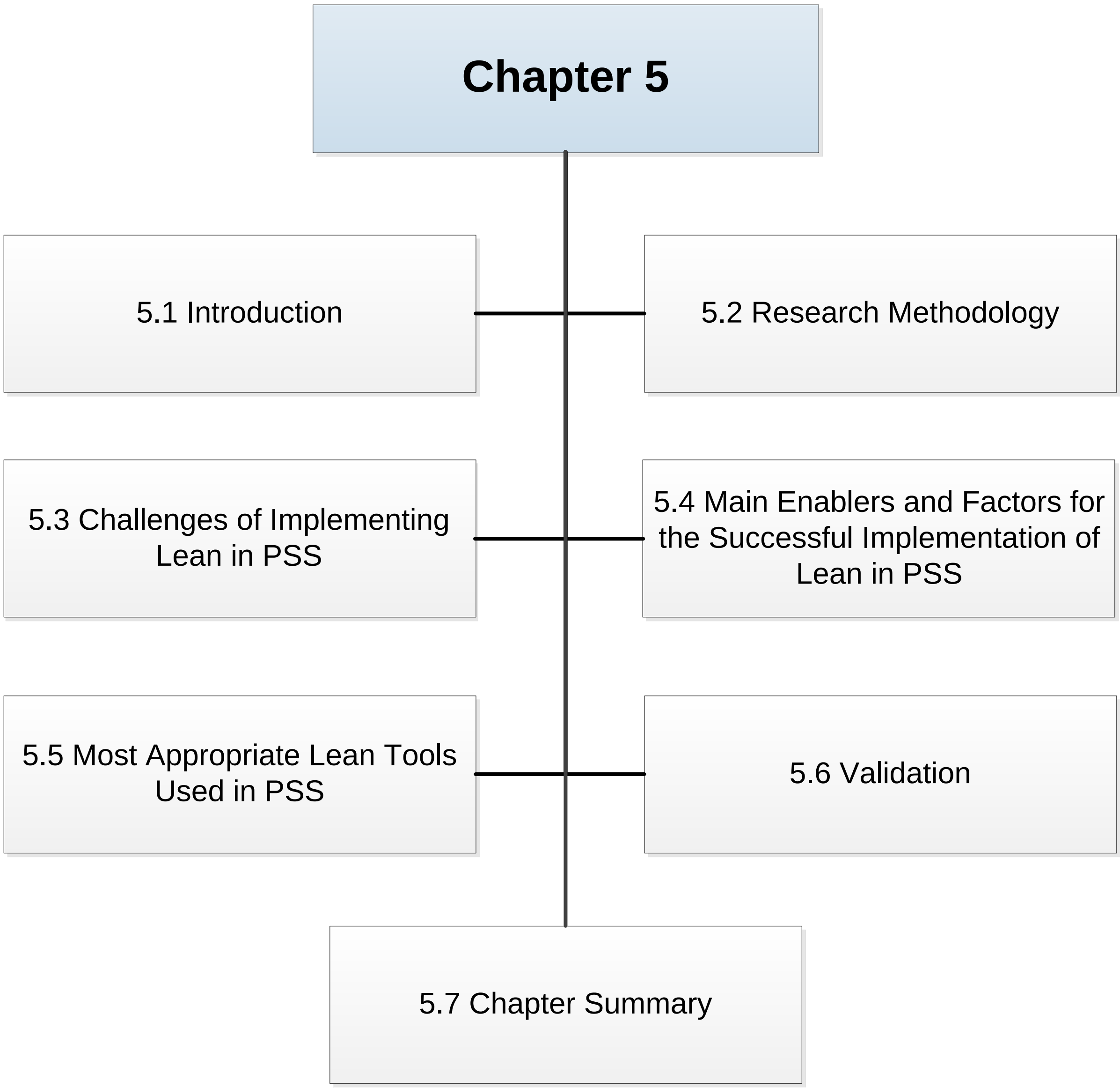



**Figure 5.1 Structure of Chapter 5**

## 5.1 Introduction

As mentioned in chapter 2, lean has been widely applied in manufacturing sectors especially in the automotive industry where it started. But recently because of the possible benefits gained by applying lean, the popularity of lean in the non-manufacturing sector is growing.

The successful lean implementation is a complex process that requires a proper plan prior to its implementation. Successful lean implementation is governed and facilitated by certain crucial factors. A thorough understanding of these crucial factors will benefit the organisations who would like to implement lean principles. In addition, a series of inhibitors that could hinder the implementation of lean should be removed. The misapplication of lean tools in terms of using the wrong tool to solve a problem, or using a single tool to solve all of the problems, or using the same set of tools on each problem is one of the significant reasons behind the failure of the lean implementation process.

To date, factors, challenges, and tools for implementing lean principles in the service offering process have not been examined and investigated as mentioned in chapter 2. Most of the existing studies have derived their set of factors, challenges, and tools from manufacturing and non-manufacturing perspectives. Thus, the aim of this chapter is to present the main enablers and lean tools that are considered to be important for the successful implementation of lean in PSS, as well as, identifying the main barriers and challenges of implementing lean in PSS. This chapter also, aims to presents the rankings of the enablers and factors by identifying the relative importance of each enabler and factor, as well as, the challenges and tools used in implementing lean in PSS.

## 5.2 Research Methodology

A combination of research methodology approaches have been used in this chapter as presented in Figure 5.2. Starting from existing literature on critical success factors (CSFs) and lean tools that are necessary for the successful implementation of lean practices and lean Six Sigma, as well as, challenges of lean implementation in both manufacturing and non-manufacturing sectors. The extensive literature review conducted resulted in three main outcomes. The first outcome was identifying the main factors and lean tools that are crucial for implementing lean in manufacturing and non-manufacturing sectors. The second outcome reveals the insufficient research carried out to determine factors and barriers that affect the application of lean in PSS. Finally, developing questions used in the interviews.

After conducting the literature review, a pilot study was carried out to investigate the factors deemed to be crucial for the successful lean implementation in PSS, as well as, the main challenges that hinder lean implementation in PSS. The purpose of this pilot study was to gather initial insights about what the factors that influence lean implementation in PSS could be. The surveys also aim to gain more knowledge about lean PSS implementation from real life beside the knowledge the researcher obtained from literature.

The targeted respondents were those who are working closely in services and lean projects in their companies. Although the context was general, the benefit attained from the results of this pilot study is the comprehension of the factors that influence the process of implementing lean in the service offering process from a point of industrial experts.

The process of piloting consists of an informal pre-test phase where the questions had been discussed with supervisor, academic experts in the field of lean and PSS, as well as, fellow colleagues at Cranfield University. After responding to the valuable comments, a formal pilot test procedure was conducted. The survey used in the pilot study and the results are included in Appendix A.

The choice of whom to interview for this specific research purpose is crucial, although not an easy decision to make. The selection of cases and interviewees for this research tended to be purposive rather than random.

Purposive sampling is common in qualitative research. The reason is that the definition of the research cases is limited (the research is only interested in companies that implement lean practices in their service offering process).

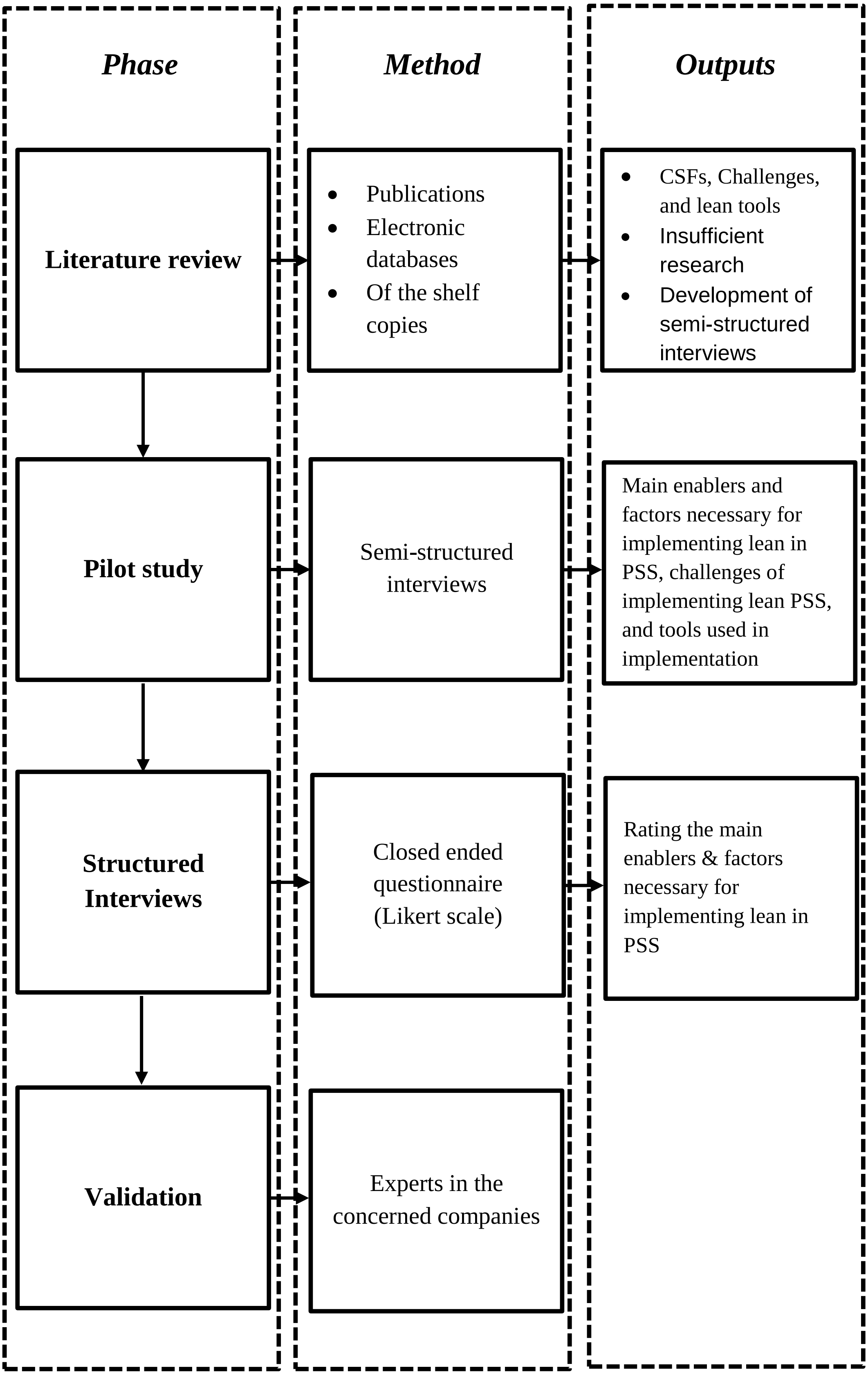



**Figure 5.2 Chapter 5 Research Methodology**

Furthermore, it allows the researcher to choose the cases. When identifying the interviewees, the author began with initial choices of key interviewees. They were chosen based on their interest, experience, and involvement in lean projects in their companies. Those initial interviewees were asked to recommend others whom they thought were eligible for this research interview (snowballing technique).The total number of interviews conducted is 35. The entire list of interviewees, along with their positions, and their total number of years of experience is presented in Table 5.1

After being guaranteed permission to proceed in conducting the interviews, the researcher started to correspond with the interviewees and arranged meetings with them one after the other. It was certified before the beginning of the interview that the research would treat the data collected from the interviewee confidentially and that the anonymity of all participants would be assured at all times. Then the researcher requested permission to tape-record the interview and all the interviewees agreed. All interviews began with a short description of the research, including aim, objectives, estimated time for conducting the interview, and emphasis on the key role of the interviewee’s views. The interviews’ duration ranged from 60 to 90 minutes each and they were all tape-recorded. In addition to these recordings, notes were taken to record observations about the meetings. These notes helped later when writing a full report for each interview, along with the recording’s transcription.

At the beginning of each meeting, the interviewees were prompted to fill out an individual information sheet that includes the date of the meeting and the interviewee’s positions. At the end of the meetings they were also asked to recommend other persons whom they thought would be eligible for interview.

As described in Miles and Huberman (1994), the information obtained from each interview was analysed separately where each interview was broken down into themes. These themes had been already specified at the beginning of the semi-structured interview document before conducting the interviews.

**Table 5.1 Experts Participated**

| Expert Number | Company | Role | Years of Experience |
|---|---|---|---|
| E1 | A | Service Supply Chain Manager | 15 |
| E2 | A | Service Manager | 25 |
| E3 | A | Lean Six Sigma Strategy and Deployment Manager | 25 |
| E4 | A | Business Improvement Manager | 30 |
| E5 | A | Project Manager | 22 |
| E6 | A | Operations Manager | 27 |
| E7 | A | Business Development Manager | 26 |
| E8 | A | GM Strategy and Marketing | 30 |
| E9 | A | Director and General Manager | 30 |
| E10 | A | Service Supply Chain Manager | 20 |
| E11 | B | Continuous Improvement Manager | 25 |
| E12 | B | Industrial Manager | 35 |
| E13 | B | Continuous Improvement Leader | 20 |
| E14 | B | Continuous Improvement Manager | 22 |
| E15 | B | Change Manager | 15 |
| E16 | B | Project Manager | 14 |
| E17 | B | Chief Engineer | 25 |
| E18 | B | Service Manager | 30 |
| E19 | B | Service Manager | 28 |
| E20 | B | Continuous Improvement Manager | 25 |
| E21 | B | Quality Manager | 15 |
| E22 | C | CEO | 40 |
| E23 | C | Head of UK Service | 30 |
| E24 | C | Operating Manager | 26 |
| E25 | C | CRM Manager | 23 |
| E26 | C | Director UK Aftersales | 40 |
| E27 | C | Chief Financial Officer | 22 |
| E28 | C | HR Director | 26 |
| E29 | C | Financial Controller Operations | 15 |
| E30 | C | Head of UK Parts | 28 |
| E31 | C | UK Sales Director | 36 |
| E32 | C | Retail Sales Manager | 23 |
| E33 | C | Business Improvement Manager | 15 |
| E34 | C | Service Manager | 14 |
| E35 | C | Commercial Manager | 35 |

The reason for this thematic analysis was to identify the issues that are important in order to understand the implementation of lean in PSS. Those major themes are:

- Type of services provided by the company
- The history of the company in implementing lean
- Managers' background and understanding of lean and its tools
- Areas in the company in which lean is implemented
- Motivations of applying lean in the service offering process
- Challenges and barriers of implementing lean in PSS
- Lean tools and techniques used in PSS
- Factors contributing to the success of lean implementation in PSS
- Outcomes of implementing lean in PSS

The outcomes of the pilot study resulted in exploring the As-Is of implementing lean practices in PSS ,as well as, identifying the key enablers, factors, and tools considered necessary for the successful implementation of lean in PSS. Additionally, this pilot study was helpful in identifying the major barriers and challenges encountered either before or during the implementation of lean in PSS.

All the elements derived from the pilot study were grouped into:

- Five main enablers and 33 factors emerging from the main enablers. These factors are considered crucial for the successful implementation of lean in PSS.
- Eight challenges. These challenges are considered to hinder the implantation of lean in PSS.
- Finally, nine lean tools and techniques. These tools and techniques are the most commonly used in lean implementation in PSS.

All these enablers and factors, challenges, and tools were used in constructing a closed end questionnaire. The close-ended question format was selected since the data would be in a quantifiable form ensuring that statistical analysis can be used. Moreover, it is fast and easy to complete, and facilitates data analysis and summary of data (Fowler, 2002; Lewis et al., 2007).

The rating scales (Likert scale) and ranking is used within this format to obtain the answers from the respondents. The Likert scale used will provide a more precise measure than yes/no or true/false items and it is fast and easy to complete (Neuman, 2004). The rating scale used allows the respondents to indicate the relative importance of choices that facilitates the researchers in identifying the relative importance of the critical issues, factors and challenges.

In the closed ended questionnaire (Appendix B) respondents were prompted to rank the main enablers and factors, challenges, and tools on a scale of 1 to 5 (1 = last important, 2 = less important, 3 = important, 4 = very important and 5 = crucial).

Using Likert scale helped respondents to indicate the relative importance of the main enablers and factors, and tools that are critical for implementing lean practices in PSS, as well as, the challenges that obstacle lean implementation in PSS. Finally, all the results obtained were validated via the companies concerned.

## 5.3 Challenges of Implementing Lean in PSS

The implementation of lean practices remains popular among manufacturing and non-manufacturing companies; however, research has not yet considered the different challenges of implementing lean in PSS. This section derives a list of specific challenges companies approached when they implement lean practices in PSS. The interviews with the experts revealed several challenges companies faced during the implementation of lean in PSS. Eight key challenges were identified from the data analysis. These were:

- Nature of service
- Defining waste
- Resistance to change
- Understanding lean
- Multi-site of the company
- Overloaded people in the workplace
- Lack of management commitment and support
- What is the customer and what do they value

All these challenges will be discussed in more details in this section along with identifying the relative importance of each challenge. Figure 5.3 provides the results of the relative importance of the main challenges that affect the successful implementation of lean in PSS.

It is obvious from the Figure that the most important challenge that companies have to pay more attention when they implement lean PSS is the nature of service with a mean score of 5. All experts agreed that the nature of the service adds a lot of difficulties when they implement lean in the service offering process. After the nature of service, there are three other obstacles that are considered to be crucial in lean implementation in PSS. These obstacles are: the ability to define waste, resistance to change, and lack of management commitment and support with a relative importance of 4.8, 4.8, and 4.6 respectively. These were followed by understanding lean with a mean score of 4 and multi-site of the company with a mean score of 3. Finally, the least important challenges that influence the implementation of lean in PSS are identifying customers and their value, and overloaded people in the workplace with a mean score of 2.5 and 2 respectively.

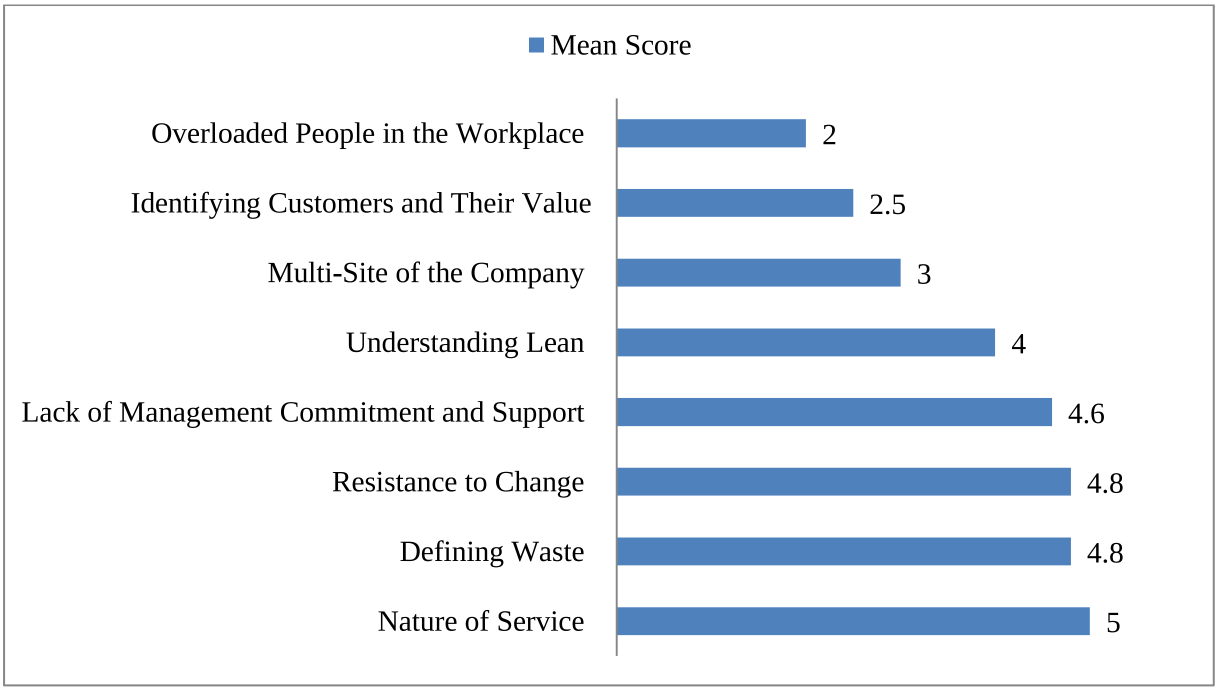



**Figure 5.3 Challenges of Implementing Lean in PSS**

### 5.3.1 Nature of Service

The nature of the service process differs from the nature of the manufacturing process. Manufacturing operations use a router to schedule the flow of materials through processes, so even the process has not been mapped there is still awareness of the process flow. According to (Grönroos, 1990; Moeller, 2010; Damrath, 2012) services have some distinctive characteristics that make it unique. Services are intangible; services cannot be displayed for customers to see or touch before deciding to buy it or not. Products are goods that are tangible, but services are series of activities rather than things. The intangibility and invisibility of the services make the identification of wastes and non-value added activities very difficult task. This invisibility may result in invisible wastes that are more difficult to extract.

Also, in service processes customers participate in the production process to some extent. Customers are required to give inputs and participate for executing the process and their mood can affect their opinion about how they perceive the quality of the services provided. It is difficult to establish flow when the customer is part of the process, because his input must be timely planned.

Another important characteristic of services is that services produced and consumed simultaneously; service provision and provider are inseparable from the service consumption and consumer. The service must be consumed at the point of provision. So, the production of the service and the consumption of the service occur simultaneously, consequently, the idea of smoothing the demand will be difficult.

Moreover, services are heterogeneous. This heterogeneity makes it difficult to ensure the consistency of the service quality. Additionally, services cannot be stored and carried forward to a future time period, thus services are time dependent and should be consumed immediately.

Due to these distinctive features of services, service processes are very complex compared to manufacturing processes. The complexity of the service processes makes it harder to be standardised because the process of providing services includes many activities or steps that may be ambiguous or involving more than one employee. Furthermore, the complexity of the service processes makes it difficult to define an adequate performance measure. Also, some services are not compatible with lean ideas. For example, the idea of smoothing the demand is difficult because of the simultaneity of service production and consumption.

### 5.3.2 Defining Waste

Lean aims to identify waste to provide better services to customers. Waste is anything that does not deliver value to the customer or contribute to the efficient running of the services. For customers, waste is a cost that they are not willing to pay. It is important for companies to be aware of sources of waste and how to identify and remove them.

One of the crucial challenges in implementing lean in PSS is the inability to recognise wastes in the service offering processes. As mentioned in chapter 2, there are mainly seven types of waste that manufacturing companies face. These wastes are overproduction, over processing, waiting, unnecessary transport, defects, excess movement and inventory. (George, 2003) stated that these wastes can be translated to a service context as:

- Overproduction – The excess production of service outputs beyond what is needed for customers' immediate use.
- Over processing – adding more value to service than what customers are willing to pay for. This adds extra costs for the company. Over processing waste may include for example: double-checking and re-entering customer data.
- Waiting – Waiting involves any delay in one activity which causes a delay in the following activity. Examples of waiting include time wasted in queuing, delayed information, or waiting for approval.
- Transportation – The movement of materials and information, which should be reduced for activities that do not add value, or related to occurrence of waiting time and queues that, dissatisfy customers. Example for transportation includes: customers collecting materials and information by asking different people until they reach the right person.

- Defect – Any aspect of a service that does not satisfy customers’ needs. It happens when services are not performed within the specifications of the customer. Examples of defect include: data entry errors and lack of information or inaccurate process of documentation.
- Motion – Unnecessary movement of people. This motion dose not adds value to services, because it only takes additional time and cost due to poor layout of the service area.  Unnecessary motion includes for example: searching for people and equipment which are placed within long distance.
- Inventory – Any work-in-process that is in excess of what is actually required to provide service to customers. Inventory waste includes for example: pending requests and queues.

### 5.3.3 Resistance to Change

Virtually every failure of lean implementation can be traced to people's resistance to change. Any new process is expected to face some degree of resistance. Overcoming resistance is critical to the successful implementation of lean in PSS. Resistance can cause unnecessary delays, waste and process performance that falls short. As a result, implementation efforts should include strategies to overcome resistance. Resistance can be defined as any conduct that strives to maintain the status quo in the face of pressure to change. It is a responsive behaviour which is intended to protect an individual from the effects of real or imagined change (Luthans, 2010).

Most people do not like change, see change as evil and unnecessary, prefer to stay in their comfort zone, and like the way things are currently being done. Resistance typically arises from loss of control of the new process, wondering if change is good, not enough information and knowledge, and loss of employment (Hon et al., 2014). Resistance can appear in several forms such as: Ignoring the new process, failing to comprehend the process, challenging the validity of the process' benefits, criticising the process tools, allowing exceptions, and delaying process implementation (Erwin and Garman, 2010).

Companies have to provide employees with adequate training to identify: why implementing lean is happening, how the company and its employees will benefit from it. Without a lot of effort to overcome this resistance, lean implementation in PSS will be resisted by the people directly involved.

### 5.3.4 Understanding Lean

The transition to lean in the service offerings process requires a significant investment of time. The current Toyota Production System has been in existence since 1945; it has had many years of development to where it is now. But, due to the competitive nature of the current manufacturing market, most manufacturers usually apply lean practices in rush.

The focus on efficiency gains have led to a number of partial implementations of lean as companies have attempted to replicate the success of other without understanding the underlying principles of lean. The misapplication and misunderstanding of lean practices by manufacturers resulted in many failures, where most of them look for immediate results and impacts. Thus, Poor understanding of lean principles by companies' managers is considered to be one of the barriers that hinder the implementation process of lean in the service offering process.

### 5.3.5 Multi-site of the Company

The widespread of the company makes it difficult to deploy lean practices and principles in PSS throughout all the branches, as well as, makes it difficult to monitor and control the progress achieved in each branch. Wide spread companies additionally, face difficulties in developing a unified culture and perspective. Culture diversity can be considered as one of the critical factors that companies may face when implementing lean, because different culture means different attitudes, behaviours, approaches and perceptions.

### 5.3.6 Overloaded People in the Workplace

Employees today certainly have more stress due to the increased responsibilities and tasks required added to them. Employees usually face the negative impacts of work overload to their mental and physical wellbeing.

Bliese and Castro (2000) defined work overload as an interaction between actual work demands and psychological strain that comes from the meeting that demands. These psychological strains come when the actual demands are perceived to exceed the capacity of the employees. Work overload represents the weight of the hours, the sacrifice of time, and the sense of frustration with the inability to complete tasks in the time given. Employees must fulfil their work demands with the required quality and quantity within the predetermined deadlines.  These conditions results in employee burnout, stress and dissatisfaction. Work overload hinder employees ability to learn, and accept new ways of doing the work, as well as, affect training programs.

### 5.3.7 Lack of Management Commitment and Support

Lean is not just a tool kit which is used to reduce the costs and inventories, or about removing wastes and enhancing productivity. Nevertheless; lean is about human resources, leadership, management, and culture. To succeed in lean PSS implementation, a committed management is crucial.

One of the key reasons of the failure of any change efforts is the lack of management commitment.  All managers at all levels should be convinced that lean is the right path for organisational development. Senior management need to show full commitment and belief in providing the required support, resources, budget and investment to their employees.

### 5.3.8 Identifying Customers and their Value

The lean philosophy is founded on the concept of value to the customer. Defining value may be simpler to achieve in manufacturing industries, where the customer is easily identifiable as the next person in the process. However, the complexity and the nature of the service process make it difficult to easily determine what customers need.

## 5.4 Main Enablers for the Successful Implementation of Lean in PSS

The idea of identifying the critical success factors (CSFs) as a basis for determining the information needs of managers was popularised by Rockart (1979). Critical success factors (CSFs) in this context represent the essential ingredients without which any continuous improvement initiative stands little chance of success. Each one must receive constant and careful attention from management, as these are the areas that must “go right” for the company to flourish. If results in these areas are not adequate, then the efforts of the company will be less than desired.

The literature reviews reveals that many researchers have examined and investigated the factors that are necessary for the successful implementation of lean in both the manufacturing sector and the non-manufacturing sector. In addition to the literature reviews, the interviews conducted with the industrial experts resulted in adding some factors that are important for the implementation of lean practices in PSS. The factors revealed from both the literature reviewed and the interviews can be grouped into five main enablers. By merging some factors and introducing some new ones, a comprehensive set of enablers and factors were developed for the successful implementation of lean practices in Product-Service System (PSS). These enablers include:

- Supplier relationship
- Management quality
- Employees quality
- Work process
- Customer relationship

Figure 5.4 presents the relative importance of the five main enablers necessary for the successful implementation of lean in PSS. As evident from the analysed data, the most critical enablers are work process and management status with a mean score of 4.6 and 4.4 respectively. This is followed by customer relationship and employees' status with a mean score of 4 and 3.5 respectively. Finally, the least important enabler is suppliers' relationship with a mean score of 2.5.

This section presents a detailed discussion of these enablers and the factors under each enabler. Furthermore, this section shows the relative importance of all the enablers and factors.

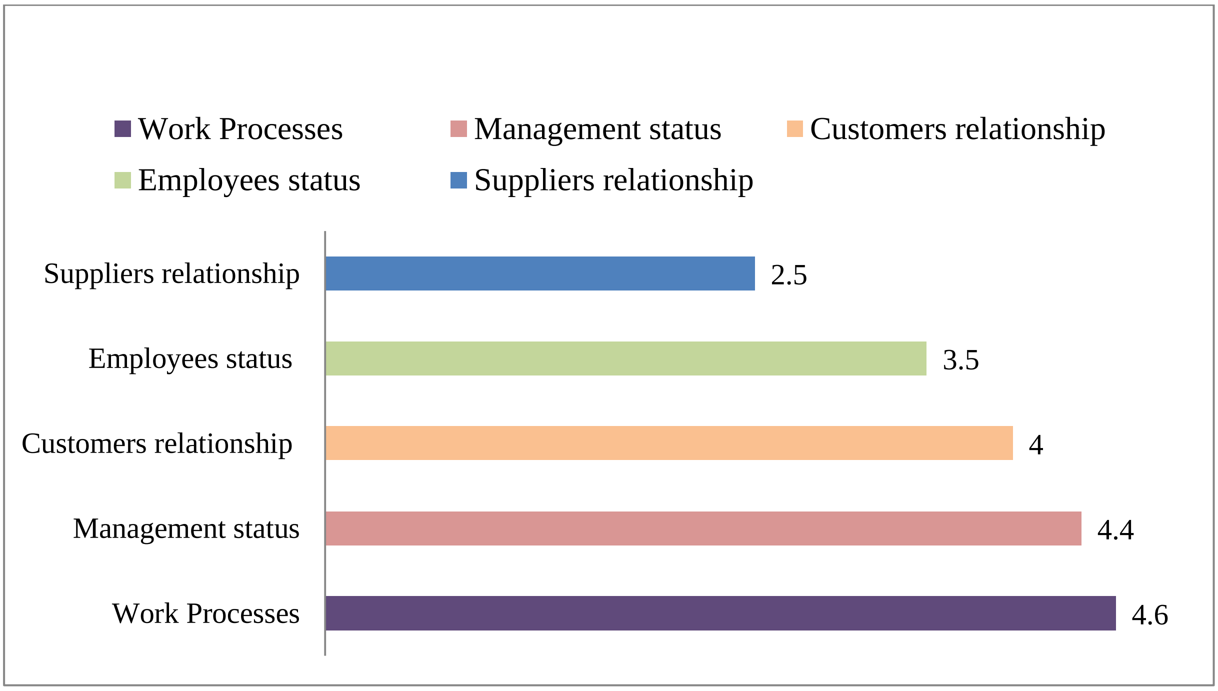



**Figure 5.4 Main Enablers for the Successful Lean PSS Implementation**

### 5.4.1 Work Processes

The lean principle of developing flow production does not work well without paying attention to organisations' work processes.  Work processes across the value stream should also be emphasised in lean PSS implementation.

Work process refers to all the tasks or activities required for producing a product or a service for customers. The service offering process should be managed in an effective and efficient way to achieve a world class performance. Processes used to provide services to customers should be performed with a minimum of non-value added activities in order to reduce waiting time, queuing time, moving time, and other delays. Improving work process is important to create value, find more wastes to eliminate from the value stream, flow process and parts faster, and respond to customers quickly by pulling products and services rather than pushing them on the marketplace.

Because variations in the performance of processes have a negative impact on the flow of the product or the service provided to customers, several practices and tools are used to stabilise the performance of processes such as: standardised work, value stream mapping, 5S and Kaizen. By applying these practices, the current service offering processes will be optimised while eliminating wastes and maintaining quality.

Standardised work ensures that each job is organised and is carried out in the most effective manner. It attempts to eliminate waste by consistently applying best practices, and form a baseline for future improvement activities. If companies did not first set a standard, they can never improve upon that standard. Standardisation of the service offering processes is needed to facilitate efficient, safe work methods and eliminate wastes, while maintaining quality. Standardisation ensures a consistent performance and creates a foundation for continuous improvement. In addition to work standardisation, it is necessary for employees to have a neat, tidy and safe work environment.

The 5S can be used to maintain an organised, clean, safe, and high performance work place. Therefore, eliminates waste that results from a poorly organised work area. Once 5S has been initially implemented, employees are encouraged to maintain a neat, tidy and safe workplace that will help them to operate in an efficient, organised and safe manner. Kaizen also is an important tool to improve the service offerings processes.

As mentioned in chapter 2, Kaizen is a Japanese term that means continuous improvement taken from words 'Kai', which means continuous and 'zen' which means improvement. Kaizen is based on making little changes on a regular basis to improve productivity, safety and effectiveness while reducing waste. Through Kaizen the job of improvement is never ended and the current process can always be improved. Kaizen is a process emphasis to make changes anywhere where improvements can be made.

Furthermore, using value stream mapping provides a mechanism to identify where waste exists and to define the shape of the desired lean value stream, thus facilitating the deployment of resources and effort into improvements that will have a significant beneficial impact on the value stream (Rother and Shook, 2003). Value stream mapping creates a common basis for the process of providing services to customers, thus facilitating more thoughtful decisions to improve the value stream. Without value stream mapping, lean activities and improvements often fail to focus on the critical issues.

The work process enabler contains seven factors. These factors are considered critical for improving the service offerings process to create value, find more wastes to eliminate from the value stream, flow process and parts faster, and respond to customers quickly by pulling services rather than pushing them to customers. As mentioned in section 5.2 experts were prompted to identify the relative importance of the enablers, as well as, the factors needed to successfully accomplish the enablers. As mentioned in Table 5.2 there are seven factors emerging from the work process enabler. These factors are:

- Identifying the purpose of each process
- Identifying standards for the process
- Quantifying the seven wastes
- Using Kaizen and 5S
- Anticipating potential risks for the process
- Adopting value stream mapping
- Setting action plan for each problem

Figure 5.5 provides the results of the relative importance of the main factors pertaining to the business process enabler. It is obvious from the figure that the most important factors are using Kaizen and 5s, identifying standards for each process and identifying a purpose for each process with a mean score of 4.6, 4.5, and 4.5 respectively.

**Table 5.2 Factors Pertaining to Work Process Enabler**

| Work process factors | Description |
|---|---|
| 1. Identifying the purpose of each process | Each process should have a clear objective that should be achieved at the end of the process. |
| 2. Identifying standards for the process | Each process should have standards regarding how it should be done, how long it should take, and how problems are to be handled. |
| 3. Quantifying the seven wastes | All the wastes that may accrue in any process should be determined and removed. |
| 4. Using Kaizen & 5s | Kaizen and 5s are among the most important lean tools that can be used in improving processes. |
| 5. Anticipating potential risks for processes | Risks that may affect the performance of process should be anticipated in advance. |
| 6. Adopting value stream mapping | VSM will capture the flow of all the activities in the process and will create an “As-Is” version to visualise the improvement opportunities in any process. |
| 7. Setting an action plan for each problem | Identifying an action plan for each problem will facilitate solving the problem quickly. |

Kaizen enables manufacturing companies to achieve better operations and improve productivity. Kaizen is centred on making little changes on regular basis, and this provides immediate results without having to go through radical changes that require capital intensive. Every employee from upper level to lower level is involved in Kaizen, thus the resistance to change is minimised. The continual small improvements gained by Kaizen result in improved productivity and quality, faster delivery, lower cost, and greater customer satisfaction. With respect to 5s, its application is simple and it can improve the business processes. By using 5s value is added to the product or the service before passing them to the next process. Implementing 5s can increase productivity, quality, and reduce costs, through: (a) reduce the amount of time wasted searching for tools; (b) reduce the amount of errors; (c) reduce the amount of scrap thereby reducing production cost; (d) improve safety; and (e) reduce lead time. Having standards for each process leads to the stability of the work processes; the consistency among employees performing the work; reducing errors of mistake in the process; and improved productivity.

The previous three factors are followed by quantifying the seven wastes, anticipating potential risks for each process and adopting value stream mapping with a mean score of 4.3, 4, and 4. Finally, setting an action plan for each problem is the last factor with a mean score of 3.7

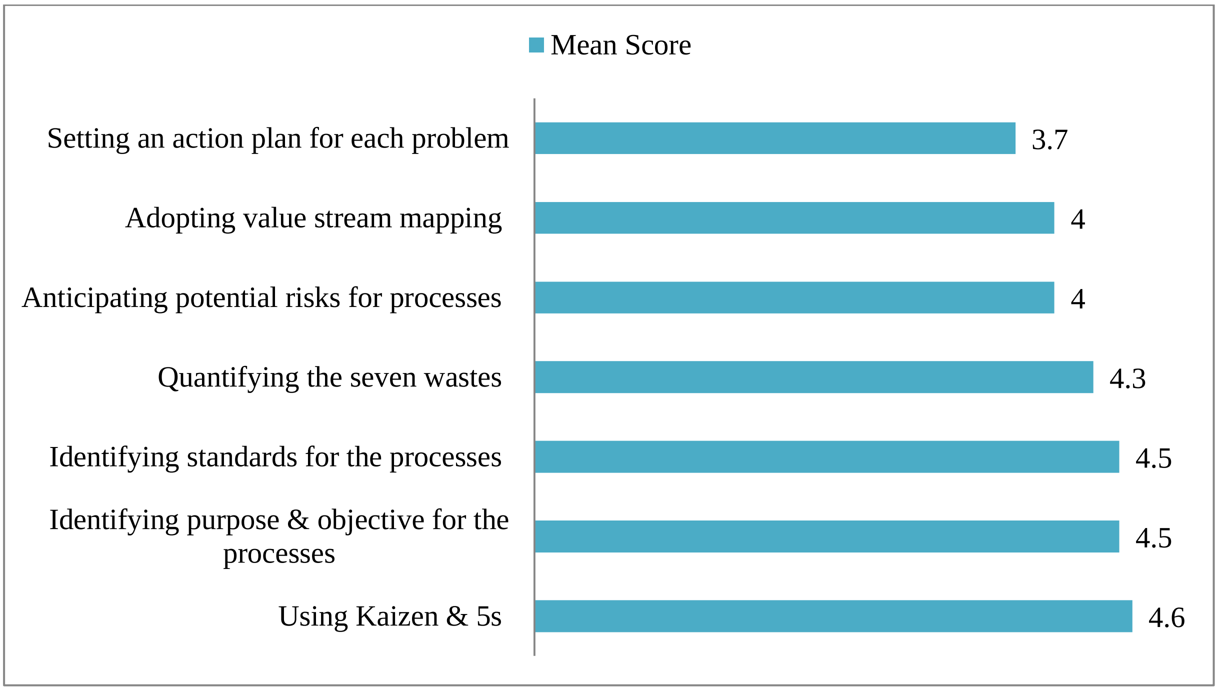



**Figure 5.5 Relative Importance of the Work Process Factors**

## 5.4.2 Management Status

From the collected data, management status is one of the imperative enablers for the successful implementation of lean in PSS. It includes factors such as culture of management, leadership, management commitment, and other management practices. The culture of management, leadership, and management commitment are considered from the top factors for implementing lean. Culture and management issues are usually the main reason for lean failure (Mann, 2010; Bhasin, 2010). The culture of management is one of the main pillars when implementing lean practices in PSS. High performing companies are those with a culture of sustainable and proactive improvement (Achanga et al., 2006). 80% of becoming lean is culture related (Bhasin, 2010).

Management should have a culture of continuous improvement, waste elimination and problem solving. Additionally, managers should fully understand the concept of lean. They have to recognise that lean is not just about tools and techniques, but a philosophy and they have to feel enthusiastic about it. Lean is more than just tools, it is important to establish an understanding of the concept. A lean culture focuses sustaining change to eliminate all types of waste and apply lean thinking in all business processes through leadership, empowerment and communication.

Moreover, managers should act as leaders. The role of leader is vital when implementing lean initiatives in PSS. Womack and Jones (1996) mentioned that to transform to lean, a company needs three types of leaders:

- Someone that deeply understands lean techniques (lean specialist).
- Someone who can be the champion and solve all the challenges arose as a result of implementing lean.
- Someone who is committed to lean.

Managers should act as leaders to establish the necessary conditions for the effective implementation of lean, communicate the importance and benefits of implementing lean practices in the process of providing services to customers, and create a sustainable motivation among employees. Leaders have the total responsibility for the creation of lean culture among all the members of the company. Leaders stimulate the inspiration and passion of employees, which leads to new solutions, a faster adoption of new ideas which subsequently satisfies the customers.

To succeed in lean PSS implementation, a committed management is crucial. One of the key reasons of the failure of any change efforts is the lack of management commitment.  All managers at all levels should be convinced that lean is the right path for the development of the service offerings processes. Senior management need to show full commitment and belief in providing the required support, resources, budget and investment to their employees. Highly committed managers tend to have positive attitudes to change, are more willing to accept different ways of working and learn more effectively. A lack of management commitment may bear the risk that employees are less motivated to implement lean initiatives.

In addition to, the culture of management, leadership and commitment, there are some management practices that affect the successful implementation of lean such as: involving employees in decision making and effective communications. Bhasin (2010) stated that 18% of the variation in productivity and 19% in profitability are accounted for by management practices. Managers should encourage employees to participate in decision making. Employees should have all the required information and data concerning the running processes and have insights concerning how these processes are running. Also, allowing employees to participate in decision making will give them a sense of ownership which will increase their willingness to apply and accept lean. Employees participative in decision making can result in improved the service offerings processes and performance. Furthermore, communication between managers and employees is critical to ensure that the vision of lean is attainable. Managers also should measure the performance of employees regularly, rewarding and compensating employees for any achievements toward continuous improvement and lean. The management status enabler contains eight factors, these factors are crucial for improving and enhancing the management status in order to be able to successfully implement lean in PSS as presented in Table 5.3. Factors necessary to enhance the status of management are:

- Management commitment
- Culture of problem prevention and waste elimination
- Leadership
- Ongoing measurement of performance
- Clear understanding that lean is not just about tools and techniques but a philosophy
- Daily accountability process
- Participative decision making

- Communication and smooth information flow

**Table 5.3 Factors Pertaining to Management Status**

| Management Status factors | Description |
|---|---|
| 1. Management commitment | Management commitment implies the direct participation by the highest level management in the lean journey. |
| 2. Culture of problem prevention & waste elimination | Implementing lean initiatives require the right attitude of managers working within the company at all levels. |
| 3. Leadership | Managers should inspire motivate their employees as well as communicating the importance of implementing lean. |
| 4. On-going measurement of performance | Managers should collect, analyse, and report information regarding employees' performance on a regular basis. |
| 5. Clear understanding that lean is not just about tools but a philosophy | Managers should understand that lean is not just using some tools and techniques and anticipating quick results. |
| 6. Daily accountability process | Managers should communicate status, identify problems, and communicate problem resolutions on a daily basis. |
| 7. Participative decision making | Managers should allow employees to participate in making decisions. Team decision making will provide employees with the feeling of belongings, make them work more closely together, and motivate them. |
| 8. Communication and smooth information flow | Information should be transferred easily either vertically or horizontally. |

The relative importance of each factor related to the management status enabler is shown in Figure 5.6. It is obvious from the figure that management commitment, culture of problem prevention and waste elimination, leadership, and on-going measurement of performance are the most important elements pertaining to the management status with a mean score of 4.8, 4.6, 4.6, and 4.5 respectively. Commitment to lean implementation starts at the top and flows from there throughout the company. Management commitment is the backbone for the successful implementation of lean in PSS. Senior management commitment is essential to help get started with a lean implementation; to provide the required resources; to take fast and effective decisions; and to promote acceptance of the lean concept among employees. One of the key reasons of the failure of any change efforts is the lack of management commitment.

An organization's culture dictates how people work, their attitudes toward work and change, their relationships with each other and management, and the way change is introduced, embraced and tackled. Having a waste elimination culture means several things; among them is that the company encourages employees to actively seek solutions to problems, to do their work in the perfect way, to minimise waste as possible (Crute et al., 2003; Rich and Bateman, 2003; Suárez-Barraza and Ramis-Pujol, 2010; Pedersen and Huniche, 2011; Kundu and Manohar, 2012; Achanga et al., 2006; Scherrer-Rathje et al., 2009)..

Leaders have the total responsibility for the creation of lean culture among all the members of the company. Managers should act as leaders to establish the necessary conditions for the effective implementation of lean, communicate the importance and benefits of implementing lean practices in the process of providing services to customers, and create a sustainable motivation among employees. Leaders have the total responsibility for the creation of lean culture among all the members of the company.

On-going measurement of performance on a regular basis is necessary. Monitoring and reviewing mechanisms ensures the sustainability of lean performance over long term, as well as, encouraging the desired behaviours by all employees. The process of monitoring includes measuring the actual lean accomplishment and comparing it with the desired gaols. This auditing process ensures that the implementation process follows the plan and provides corrective actions in case of deviation.

These factors are followed by clear understanding that lean is not just about tolls but a philosophy and daily accountability process with a mean score of 4 and 3.9 respectively. Factors such as team management for decision making and smooth information flow were not ranked very high.

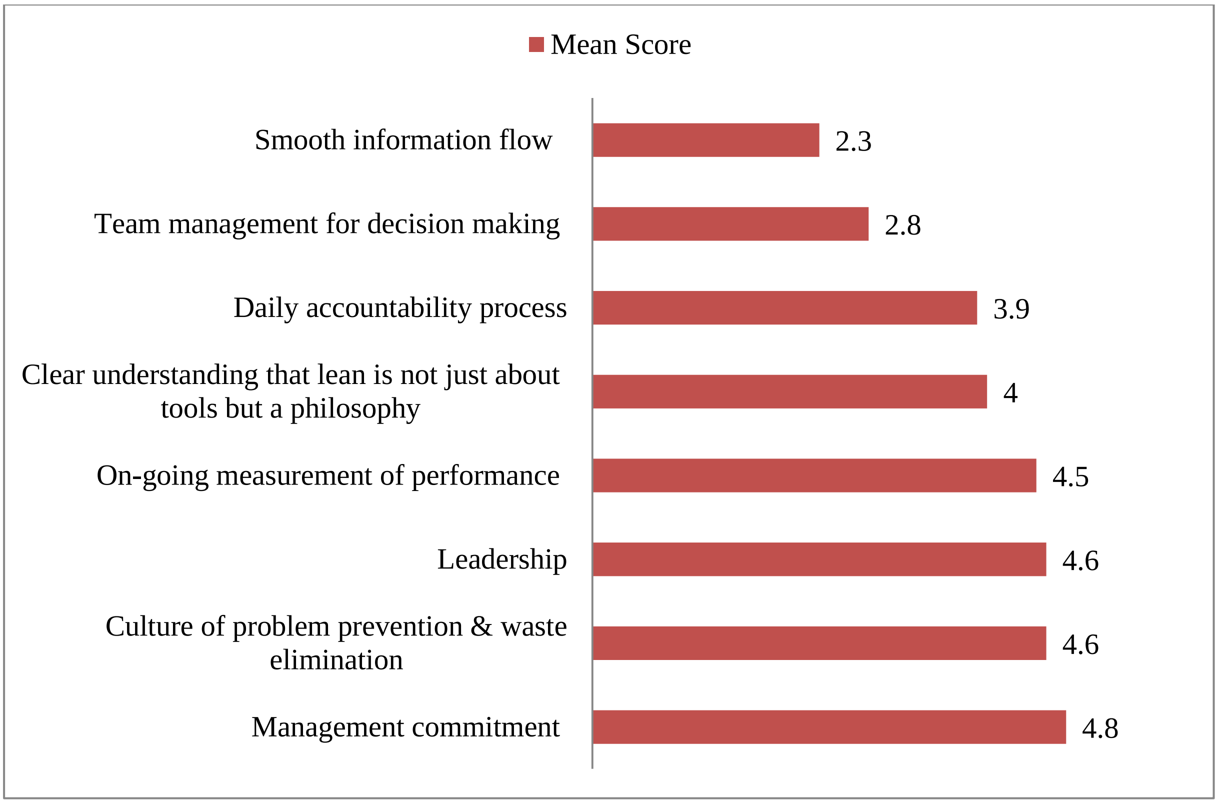



**Figure 5.6 Relative Importance of the Management Status Factors**

### 5.4.3 Customer Relationship

The first lean principle is that companies must clearly define the value of their products and services as perceived by their customers. The goal is to deliver products and services that precisely match the customer's need without waste. Lean should begin and end with the customer. The first step in lean implementation should be the determination of customer requirements. Customers decide what to buy, and when and how they are going to purchase a product or service. Since value is determined by the customers, it is essential to develop a good relationship with them. Setting up good relationships with customers will enable an organisation to understand and meet their needs and predict their demands accurately, as it is important to attain a perfect match between market demands and production flows (Panizzolo, 1998).

The main objective of any lean initiatives is to satisfy customers need to the maximum level by delivering high quality goods and services and responding quickly to their changing demands. Customer relationship is one of the crucial requirements in applying lean (Suárez-Barraza and Ramis-Pujol, 2010; Chakrabarty and Tan, 2007; Coronado and Antony, 2002; Antony and Desai, 2009). Also, customer relationship perceived to be one of the most important enablers for the successful implementation of lean in PSS as indicated from the analysis of the collected data.

Companies should be sensitive to their customers' requirements. Lean initiatives should start with customer, by identifying customers' value. Value from an external customer perspective is getting the exact product or service required, in the right quantity, at the right time, with perfect quality, and at the right price (Bicheno, 2008). The full identification of customer demand allows managers to leverage the knowledge of their customer preferences and hence improve the accuracy of forecast plans and service quality level.

Building customer relationship can be done using variety of tools and practices such as voice of the customer (VOC), identifying customers touch points, involving customer in managing and improving the products and services provided and receiving feedback from customers on the performance of products and services.

Voice of the customer (VOC) is the process of identifying and prioritising customer needs and wants to improve product development and service quality (Found and Harrison, 2012). This process is all about being proactive and constantly innovative to capture the changing requirements of the customers with time. Customers' voice should guide companies' lean practices in PSS. An effective VOC will help company to identify new products or services, refine existing products and services, improve product and service quality, and create a springboard for innovation. The voice of the customer can be captured in a variety of ways, such as: direct discussion or interviews, surveys, focus groups, customer specifications, observation, warranty data, field reports, complaint logs, etc.

In addition to using VOC, companies need to identify customers touch points. Customers touch points refers to a point of contact or communication (human and physical interactions) between an organisation and an individual consumer (Meyer and Schwager, 2007). Identifying touch points include some activities such as:

- Mapping an existing situation by picking out the touch-points that are relevant at each stage of a customer journey or service.
- Identifying pain points that do not perform particularly well from a customer point of view
- Determining who is responsible for each touchpoint
- Improving weak points

Five main factors constitute customers relationship enabler. These factors are presented in Table 5.4.

**Table 5.4 Factors Pertaining to Customers Relationship**

| Customers relationship factors | Description |
|---|---|
| 1. Customers involvement | Customers should share in managing and improving the services provided by the company. |
| 2. Customers feedback on quality, cost and delivery performance | Customers' feedback is important for companies in order to solve any customers' problems. |
| 3. On time delivery to customers | Companies should fulfil customers demand on time without any delay. |
| 4. Identifying customer touch points | Companies need to identify all the communications both human and physical with customers during customer relationship with the company. |
| 5. Usage of a well-defined VOC | Companies have to capture all the requirements and preferences of their customers. |

As evident from Figure 5.7 all the factors are highly important especially the usage of a well-defined VOC with a mean score of 4.6, followed by customer involvement and customers give feedback on quality, cost, and delivery performance with a mean score of 4.5, and 4.5 respectively.

VOC is critical since, customer is the central focus of lean implementation. The final customer is the most important person that can determine whether the product or the service provided is considered quality or not. For companies, in order to improve the service offerings process, they have to identify exactly what their customer value otherwise; their lean efforts will be useless. By listening to the VOC companies will be able to better understand the lost, current, and future requirements and demands of their customers, set priorities and goals consistent with customers' needs, and determine what customers' need that the company can profitably meet and satisfy.

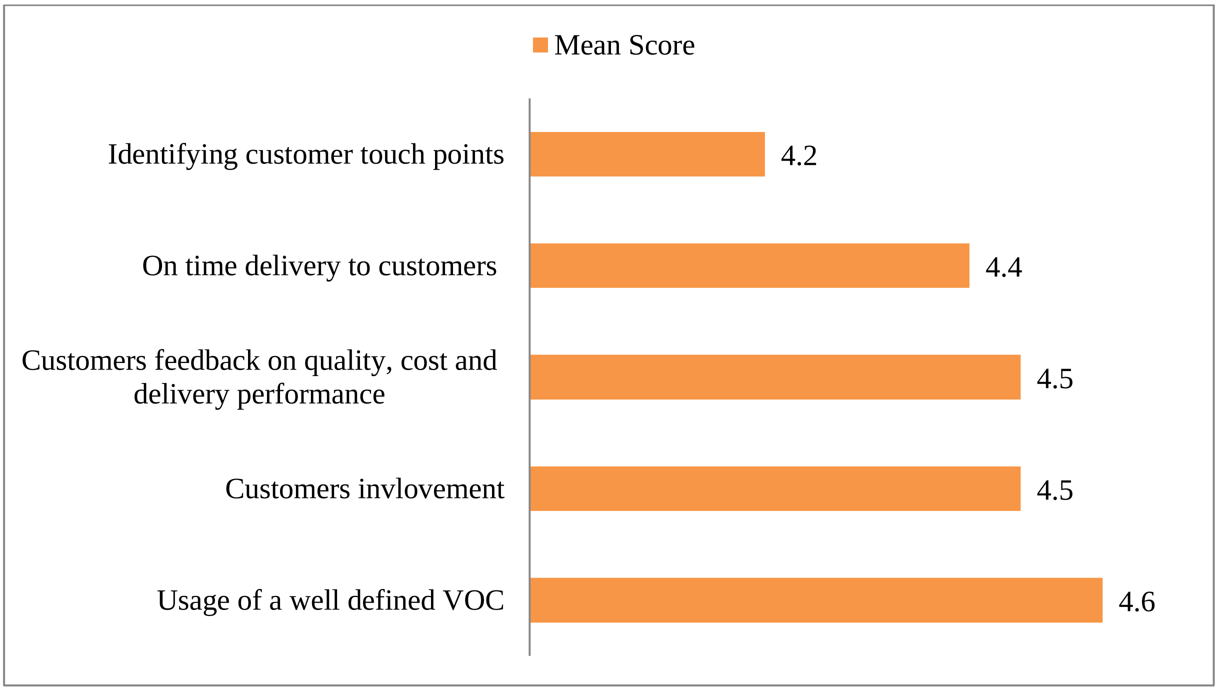



**Figure 5.7 Relative Importance of Customers Relationship Factors**

### 5.4.4 Employees Status

Employees are considered one of the important factors in implementing any new business changes; they can either accelerate these changes or hinder them. Without the support and participation of employees all the lean efforts in PSS will be useless. Radnor et al., (2006) reported that workforce that are willing to accept lean initiatives, is one of the key factors for the successful lean implementation. The lean management views all employees as an asset, because they are the ones who are going to solve problems and improve the service offerings processes.

There is a relationship between satisfying internal customers (employees) and meeting external customers' needs. When companies cannot treat their employees correctly, they will not be able to treat external customers.

Employees should be engaged in the improvement process from very early stages to become more committed and motivated. Implementing lean requires hiring the right number of employees, with the right skills, that work safely and productively without errors. Employees who are motivated and empowered are essential in lean PSS implementation. The saying of "No one knows the job better than those who do it" indicates that the person who is experienced in his job is most likely to have a better understanding on it, thus employees play a crucial role in lean PSS implementation.

To successfully compete in now global market and to satisfy customers changing demand, organisations need flexible employees who are empowered, skilled, confident, well trained and able to apply their knowledge and experience in the workplace. Improving employees' status requires the development of best practices, and training on how to use lean tools and techniques.

Employees empowerment, job rotation, training and multi-skilled employees enable companies to successfully implement lean practices in PSS and respond faster to changes in products and processes.

According to Womack et al., (1990), tasks and responsibilities should be transferred to the workers who actually adding value. Employees' willingness to adopt a more empowering role is important aspect of lean, and is essential for flow of services.

Employee empowerment is defined as "enlarging employee jobs so that the added responsibility and authority is moved to the lowest level possible in the organisation" (Heizer et al., 2004). Lean initiatives in Product-Service System will be useless, if an organisation has not been actively initiating employee empowerment. Empowered employees are committed, loyal and conscientious. Empowered employees increase organisational responsiveness to customers, since employees can serve their customers much better and faster. Also, employees' empowerment crates a healthy work environment which increases productivity and motivation.

Furthermore, training is a crucial factor in the successful implementation of lean PSS. No company can create high quality work process, products, and services without making sure that each employee is well trained. Lean implementation most likely requires different training than what is currently offered. Training answers the questions of why lean is needed, how it is supposed to be implemented, and what will be the benefits of applying it. Training is necessary to provide the opportunity to employees to improve their comfort level with lean, as well as, prepare them for the change and enhance their readiness. Well trained employees will spread the lean philosophy throughout the company and help others to understand it.

Beside empowerment and training, job rotation is crucial for lean implementation in PSS. Womack et al., (1996) mentioned that by rotating jobs, employees can solve quality problems in an efficient and effective way. In lean companies, workers are multi-skilled and job rotation is implemented.

Job rotation can be defined as “lateral transfers of employees between jobs in an organisation” (Campion et al., 1994). Job rotation enables employees to be exposed to various work tasks that will overcome the stress of repetitive and monotonous tasks undertaken in a non-lean environment. Also, this cross-training will increase the flexibility, adaptability and skills portfolio of employees through gaining knowledge and skills learned from different jobs. Additionally, job rotation will enhance the motivation and the enthusiasm of employees.

From the collected data, in order to improve employees’ status to be ready for implementing lean in PSS, some factors should be recognised as presented in Table 5.5. These factors include:

- Employees training
- Employees empowerment
- Strong employees spirit and cooperation
- Flexible workforce
- Multi-skilled employees

**Table 5.5 Factors Pertaining to Employees Status**

| Employees status factors | Description |
|---|---|
| 1. Employees Training | Training will help employees to better understand the main tools and techniques of lean and how to implement them effectively. |
| 2. Employees empowerment | Managers should share information and power with their employees, to be able to make decisions and solve problems quickly. |
| 3. Strong employee spirit and cooperation | Enhancing employees' spirit and cooperation will facilitate the implementation of lean initiatives. |
| 4. Flexible workforce | The workforce should accept changes and new ways of doing the business. |
| 5. Multi-skilled personnel | Employees should understand how to perform a variety of different jobs and functions within a company |

Three main factors are considered highly important namely: training of employees, empowerment of employees, and strong employees' spirit and cooperation with a mean score of 4.5, 4.4, and 4.4 respectively. After these three factors and in the fourth place is flexible workforce with a mean score of 3.5, followed by multi-skilled personnel as shown in Figure 5.8

Lean implementation requires different training than what is currently offered. Training answers the questions of why lean is needed, how it is supposed to be implemented, and what will be the benefits of applying it. Training is necessary to provide the opportunity to employees to improve their comfort level with lean, as well as, prepare them for the change and enhance their readiness. Well trained employees will spread the lean philosophy throughout the company and help others to understand it.

Empowered employees increase organisational responsiveness to customers, since employees can serve their customers much better and faster. Also, employees' empowerment crates a healthy work environment which increases productivity and motivation.

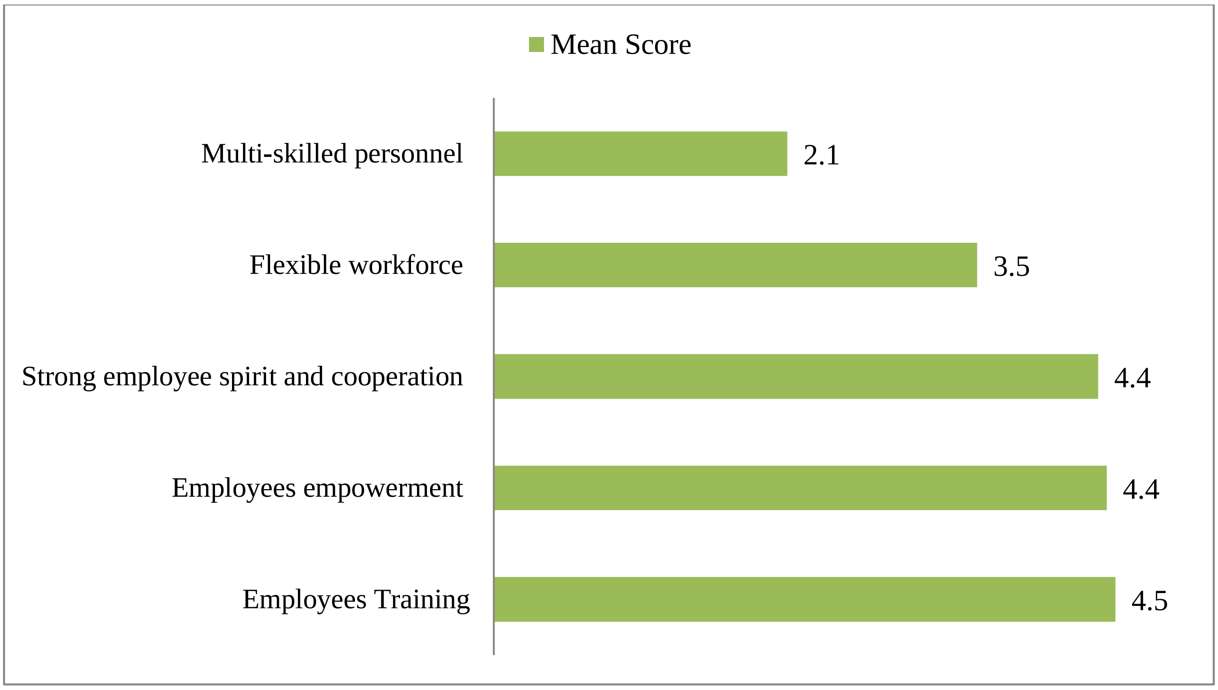



**Figure 5.8 Relative Importance of Employees Status Factors**

### 5.4.5 Supplier Relationship

To follow the third lean principle of creating a constant material flow, building close relations with suppliers is essential. The late delivery or delivered parts in an inappropriate quality and quantity will have a negative impact on the process of offering services to customers. Lean initiatives are not limited to the entire company. Other external factors such as, suppliers have an impact on the successful implementation of lean in PSS. Lean companies try to expand their lean initiatives beyond the companies' walls. One way is to share their lean initiatives with suppliers who have a direct participation in companies' deliveries.

Suppliers have been considered as an important factor for the successful implementation of lean practices (Keller et al., 1991; MacDuffie and Helper, 1997; Lewis, 2000; Sánchez and Pérez, 2004; Wu, 2003).

One of the objectives of lean initiatives is to satisfy customers need to the maximum level by delivering high quality goods and services and responding quickly to their changing demands. Accordingly, an effective material procurement system becomes necessary, as well as, improving the internal manufacturing methods and techniques. Lean companies try to apply just-in-time (JIT) concept, minimise inventories and deliver high quality products and services by building up close relations with suppliers who are able to deliver top quality parts at the right time. Building a mutual goal between manufacturers and suppliers to reduce waste and cut down cost is crucial to drive lean PSS initiatives to success.

Close suppliers enable manufacture to develop a reliable distribution system which does not need buffers. The closer the distance to the manufacture, the lower the risk of unexpected incidents and long delivery times, the more efficient scheduling and the more efficient inventory planning (Bollbach, 2012).

Some companies conduct regular training for their suppliers, for example: (a) Honda America applied a successful supplier development project in its supplier's sites which resulted in a large improvement in the quality of its supplying and delivery processes (MacDuffie and Helper, 1997). (b) The Ford Motor Company also implemented JIT distribution approach to create more efficient and cost-effective supplier relationship by consolidating suppliers' products and takes full loads to production plants instead of each supplier delivering its own part (Christensen, 1996).

Bases on the collected data, to successfully implement lean in PSS, manufacturing companies should: involve their suppliers in their internal manufacturing process, deal with close suppliers, build long-term relations and commitments with their suppliers, give regular feedback on suppliers' performance, improve communication with their suppliers, and finally, conduct regular training to suppliers' employees.

On the other side, Wu (2003) identified various features of lean suppliers, these features include:

- Lean Suppliers understand that they have to employ frequent and quick changeovers to meet their customers demand for an ever increasing variety of products.
- Lean suppliers are expected to be responsive to shop floor quality problems so defects can be prevented.

- Lean suppliers need effective telecommunications networks with their customers to get information on orders and production schedules and to track and manage material flows and inventories.

Obviously, suppliers that apply lean will be more compatible with a manufacture that implements lean. So, lean manufacturers are likely to find it more productive to work with lean suppliers. The supplier relationship enabler contains eight factors as presented in Table 5.6.

**Table 5.6 Factors Pertaining to Suppliers Relationship**

| Suppliers relationship factors | Description |
|---|---|
| 1. Supplier lead time | Lead time reduction is a critical factor in lean implementation. It should be reduced as possible |
| 2. Deliveries arrive on time and in the right quality | Suppliers should deliver frequently, as required at the point of use on time, with the total quality guaranteed to eliminate the need for incoming inspection |
| 3. Supplier after sales service & support | Supplier after sales service & support are important elements that help the company to successfully apply lean initiatives |
| 4. Supplier Involvement | Companies should align their lean initiatives with their suppliers, where suppliers should be part from these initiatives |
| 5. Supplier sensitivity to complaints | Suppliers should respond quickly to their customers demand and problems |
| 6. Regular feedback to suppliers on their performance | Companies should monitor the performance of their suppliers to mitigate risk and to drive lean initiatives |
| 7. Culture of waste elimination compatibility | Suppliers that implement lean practices will be more compatible with a manufacture that implements lean initiatives |
| 8. Location of key suppliers | Some companies free close supplier, where this reduce the delivery time and lead time |
| 9. Regular training are conducted for suppliers employees | Some companies train suppliers' employees on lean tools to:<br>Improve quality<br>Reduce lead time<br>Reduce cost of inventory<br>Improve the delivery time |

Figure 5.9 provides results of the relative importance of the main factors pertaining to the supplier relationship enabler. As evident from the figure, supplier lead time,

deliveries arrive on time and in the right quality, supplier after sales service and support, and supplier involvement are the most important elements with a mean score of 4.8, 4.8, 4.7, and 4.5 respectively. This is followed by supplier sensitivity to complaints and regular feedback to suppliers on their performance with a mean score of 4.1 and 4.0 respectively. Elements such as conducting regular training for suppliers' employees were not ranked very high.

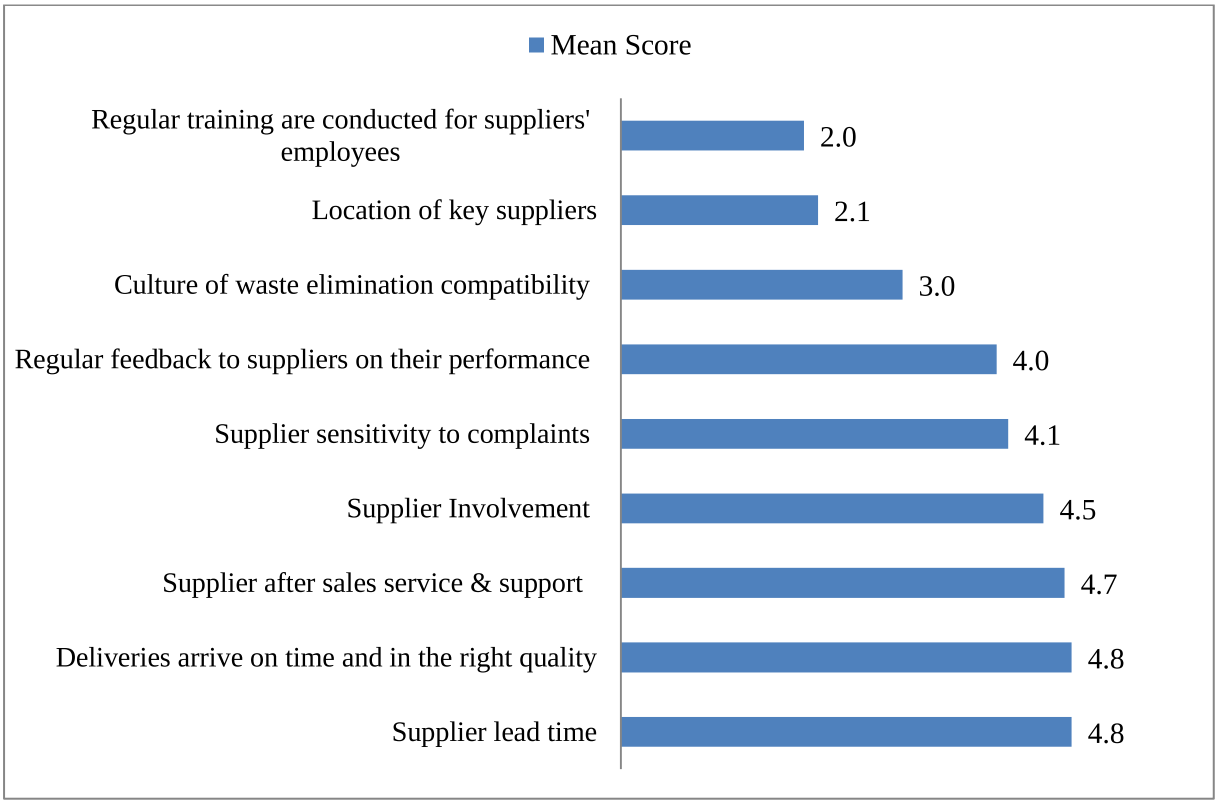



**Figure 5.9 Relative Importance of the Suppliers Relationship Factors**

## 5.5 The Most Common Lean Tools Used in PSS

The application of lean principles is mostly associated with using lean tools. Fundamentally the tools should be implemented in a structured manner and at an appropriate time whilst taking into account their interactions. The misapplication of lean tools in terms of using the wrong tool to solve a problem; or using a single tool to solve all the problems; or using the same set of tools on each problem is one of the significant reasons behind the failure of the process of lean implementation in PSS.

Many organisations use some kind of systematic approach when deciding which tool to apply under certain situations, when to apply tools and how to apply them. This yields significant benefits in the long run. The selection of the lean tools depends on the needs of the company, no single set of tools can be appropriate for all the companies. This section presents the most relevant lean tools used in PSS and their relative importance as mentioned in Figure 5.10

It is obvious from Figure 5.10 that all the mentioned tools are highly important for implementing lean in PSS with very little differences in the mean score. On the top of all the enabler is Kaizen with a mean score of 4.8, followed by, 5S, just-in-time (JIT), voice of the customer (VOC), standardisation, and 5 Whys with a relative importance of 4.7, 4.7, 4.6, 4.5, and 4.4 respectively. Then in the third place and with the same mean score of 4, value stream mapping (VSM) and key performance indicators (KPIs). Finally, the least important tool that is not important like the previous tools is benchmarking with a mean score of 2.5.

### 5.5.1 5S

As mentioned in chapter 2, the five components of 5S are defined as sort, set in order, shine, standardise, and sustain. The 5S is one of the most fundamental and widely applied components of lean. Its application is simple, involving basic common sense; however, its advantages cannot be ignored due to its simplicity. By using 5S value is added to the products or services before passing them to next process where they are formed. 5S is a cornerstone in lean PSS implementation. Companies agreed that by applying 5S they increased productivity by reducing lead times, improving delivery time and reducing the time wasted searching for tools and equipment. Additionally, the 5S enabled companies to increase the quality of their product or service by reducing the amount of errors and defects and increasing the consistency of the services provided. Moreover, there was a cost reduction by cutting the amount of inventories, worker injuries and the amount of scrapped produced. 5S is a simple, but is an effective lean tool that helps companies to simplify, clean, and sustain a productive work environment.

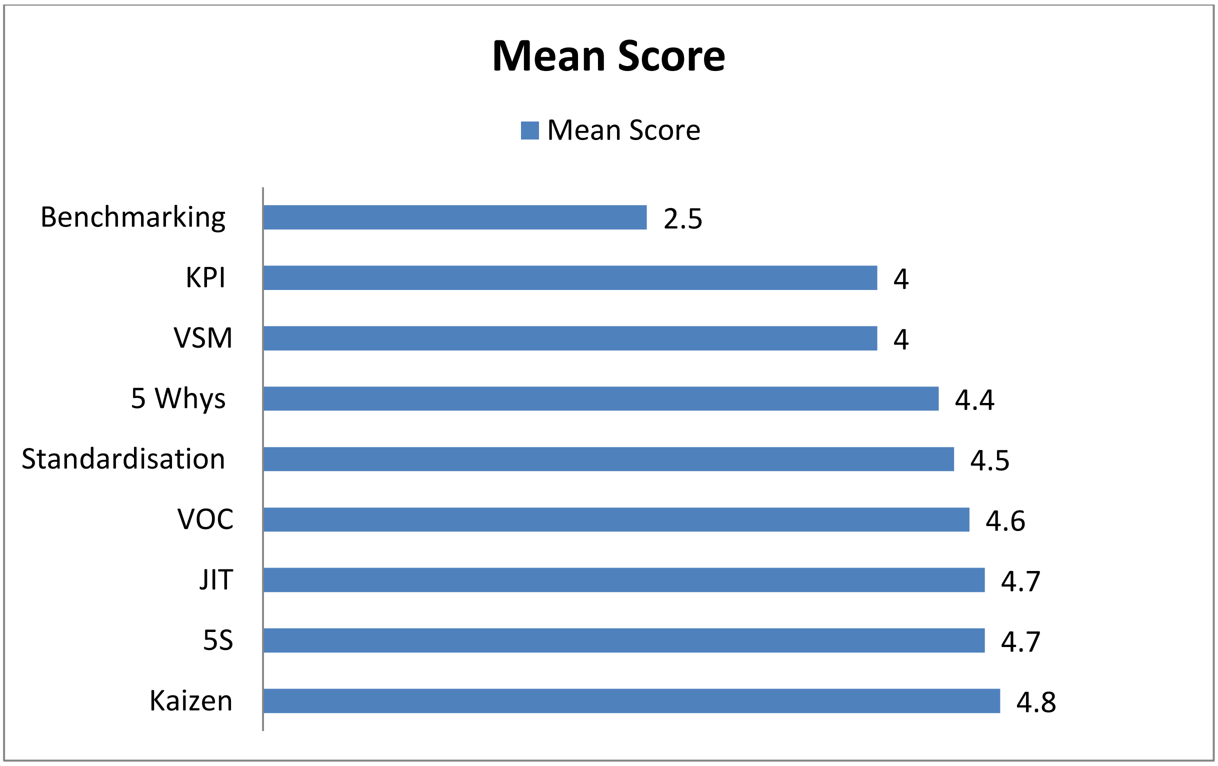



**Figure 5.10 Relative Importance of Lean Tools**

### 5.5.2 Kaizen

As mentioned in chapter 2, Kaizen is Japanese term and stands for 'a change for better' which results is continuous improvement that involves everyone in the company. It focuses on the continuous and incremental improvements, where improvement is a never ending process and the status quo is always challenged. Most of the companies agreed that it is one of the most important tools that can be used in implementing lean in PSS. It provides immediate results via incremental steps without having to go through any radical changes that require capital intensive and may be resisted by employees. Additionally, Kaizen can be used to overcome resistance to change, where it is a people oriented tool that every employee in the company is involved in the process. Implementing Kaizen can result in improved productivity and quality; lower costs; faster delivery of services; and greater customer satisfaction, as well as, job satisfaction.

### 5.5.3 Voice of the Customer (VOC)

The primary purpose of listening to the VOC is to define the customers' expectations and requirements with respect to the service delivery process. The customer is the central focus of lean implementation, because the final customer is the most important person that can determine whether the product or the service provided is considered quality or not. Companies struggle to gain a clear understanding of the customers' wants and needs to translate these requirements into their service processes.

Many service processes provide outputs that the customer does not value, or provide outputs in a costly or time consuming manner. For companies, in order to improve the service offerings process, they have to identify exactly what their customer value otherwise; their lean efforts will be useless. By listening to the VOC companies will be able to better understand the lost, current, and future requirements and demands of their customers, set priorities and goals consistent with customers' needs, and determine what customers' need that the company can profitably meet and satisfy.

### 5.5.4 Value Stream Mapping

Value stream refers to all activities both value-added activities and non-value added activities, required to carry out a service and fulfil a customer request from order to delivery. Value Stream Mapping is a visual tool used to identify wastes in the process of providing services to customers. This tool can help in capturing all the stages from receiving the customer request till the delivery of the order (As-Is), as well as, identifying potential opportunities for waste and cost reduction. Also, it is helpful tool for creating the "should-Be" map version. But, due to the nature of the service processes some companies find this tool difficult to be used. Moreover, some companies find VSM time and resources consuming.

### 5.5.5 Standardisation

Standardised work provides the baseline for comparison required for continuous improvement. Standardised work presents the current best practices for employees to follow in the completion of their jobs. By applying work standards, process variations are minimised, consistent quality improved, errors and mistakes reduced, employees safety increased, and productivity increased.

### 5.5.6 Benchmarking

Benchmarking is a tool that provides a review of the best practices to be potentially applied to improve processes. It enables companies to identify the key processes that need improvement, and to search for applicable solutions from the best in class. It provides a way for companies to outperform competitors, opening minds to new ideas, and placing the company in a continuous improvement mode.

The company should document the process that they will benchmark, and then select who they will benchmark. It is not necessary to benchmark a company in the same industry, but to focus on the process to be benchmarked, and select a company that is known for having world class or best practice processes. However, the advantages of this tool some companies find some difficulties to use it because sometimes it is not easy to find who will be benchmarked, and if the company found it, it is not easy to collect the required information. Also, some companies find this tool time consuming and costly.

### 5.5.7 5 Whys and Cause-and-effect Diagram

5 whys and cause-and-effect diagram are powerful tools to generate the root causes of the problem. They are used for discovering all the possible causes for a particular effect. The major purpose of the case-and-effect diagram is to act as a first step in problem solving by generating a comprehensive list of possible causes. The 5 whys and cause-and-effect analysis can lead to immediate identification of major causes and point to the potential remedial actions or, failing this, it may indicate the best potential areas for further exploration and analysis.

### 5.5.8 Just-in-Time (JIT)

JIT is closely associated with lean implementation in PSS. As mentioned in chapter 2 JIT refers to the production of goods and services to meet customer demand exactly, in time, quality and quantity. The customer is the final purchaser of the product or another process further along the production line. JIT is closely related to pull systems. JIT attempts to minimise inventories, work-in-progress, and poor scheduling of parts delivered. By applying JIT companies will be able to reduce costs and improve their customers' satisfaction.

### 5.5.9 Key Performance Indicators

Some companies use the dashboard to assess the performance of processes and to control the improvement achieved on a daily basis through predetermined Key Performance Indicators (KPIs). This tool is used to display critical information, so that anyone entering a workplace, even those who are not familiar with the details of the process can easily and rapidly see what is going on, understand it, and see what is under control and what is out of control.

## 5.6 Validation

Validity is a very important criterion of research; it essentially is about the question whether the measuring really reflects what is measured (Yin, 2009). Measuring validity is important in qualitative research and in social science (Bryman, 2008). According to Yin (2009), validity can be improved by use of multiple sources. When researching an organisation the use of multiple sources can mean interviewing as many people as possible with regard to their relevance for the research goal.

The identified enablers and factors, challenges, and tools of lean PSS implementation were validated by 15 experts from three companies. The plan was to capture their views after presenting the final results. Details of the experts involved in the validation study are provided in Table 5.7

First of all, face-to-face PowerPoint presentation of about 30 minutes was developed and presented to each company's experts. The purpose of this presentation was to demonstrate all the reached results (the enablers and factors, the challenges, and the tools). Any question that the experts had regarding the results was clarified during the session. After that two types of validation were conducted. The first one is qualitative and the second one was quantitative.

**Table 5.7Experts Participated in the Validation Process**

| Expert Number | Company | Role | Years of Experience |
|---|---|---|---|
| E1 | A | Lean Six Sigma Strategy and Deployment Manager | 25 |
| E2 | B | Continuous Improvement Manager | 25 |
| E3 | B | Industrial Manager | 35 |
| E4 | B | Continuous Improvement Leader | 20 |
| E5 | C | CEO | 40 |
| E6 | C | Head of UK Service | 30 |
| E7 | C | Operating Manager | 26 |
| E8 | C | CRM Manager | 23 |
| E9 | C | Director UK Aftersales | 40 |
| E10 | C | Chief Financial Officer | 22 |
| E11 | C | HR Director | 26 |
| E12 | C | Financial Controller Operations | 15 |
| E13 | C | Head of UK Parts | 28 |
| E14 | C | UK Sales Director | 36 |
| E15 | C | Retail Sales Manager | 23 |

### 5.6.1 Qualitative Validation

The PowerPoint presentation was followed by a group discussion in each company. In this group discussion experts were asked about their opinion on the reached results. The following issues were discussed:

- Are the enablers considered to be vital for implementing lean in the service offering process?
- Are the suggested lean tools appropriate and can be used to implement lean in the service offering process?
- Did the company face any of the suggested challenges?

They stated that the enablers and factors pertaining to these enablers, as well as, the challenges and tools captured by the researcher, represent a comprehensive and well-organised set, which will be valuable to companies when they first attempt to plan for lean PSS implementation.

Additionally, the 15 experts claimed that the results represent the current practices in their companies. Finally, they mentioned that all the enablers and factors, the challenges, and the tools are comprehensive and covers most of the elements.

### 5.6.2 Quantitative Validation

After the group discussion, the 15 experts were asked to complete a validation questionnaire independently. The validation questionnaire consists of four questions, in each question experts were asked to choose from a Likert scale ranging from 0 to 10. The responses of the experts are presented in Table 5.8. The analysis of the responses of the experts indicated that all of them agreed on the results achieved with an average mean above 8.

## 5.7 Chapter Summary

In this chapter, the enablers and factors, challenges, and tools of lean PSS were identified. These elements represent a comprehensive and well-organised set, which will be valuable to companies when they first attempt to plan for lean PSS implementation. In Section 5.1, a brief introduction about PSS and lean was highlighted. In Section 5.2, the research methodology followed to identify the CSFs, tools, and challenges of lean PSS implementation was explained. Section 5.3, explained the challenges countered by companies when they implement lean in PSS, along with the relative importance of each challenge. Eight main challenges were highlighted, these challenges are:

- Nature of service
- Defining waste
- Resistance to change
- Understanding lean
- Multi-site of the company
- Overloaded people in the work place
- Lack of management commitment and support
- Identifying customers and their value

**Table 5.8 Responses of Experts ($E_1$ – $E_{15}$) in the Validation Process**

| Question | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $E_6$ | $E_7$ | $E_8$ | $E_9$ | $E_{10}$ | $E_{11}$ | $E_{12}$ | $E_{13}$ | $E_{14}$ | $E_{15}$ | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| To what extent do you believe that the enablers considered critical for the successful implementation of lean in PSS? | 8 | 7 | 8 | 8 | 9 | 9 | 9 | 7 | 8 | 9 | 9 | 7 | 10 | 7 | 9 | 8.2 |
| To what extent do you believe that the factors pertaining to the enablers are important in lean PSS implementation? | 8 | 8 | 7 | 9 | 9 | 8 | 9 | 8 | 7 | 9 | 9 | 7 | 10 | 7 | 7 | 8.1 |
| To what extent do you believe that the stated challenges reflect the real life situation faced during lean PSS implementation? | 8 | 8 | 8 | 9 | 8 | 9 | 9 | 9 | 8 | 9 | 9 | 9 | 10 | 9 | 9 | 8.7 |
| To what extent do you believe that the tools represent the real tools used in lean PSS implementation? | 8 | 8 | 7 | 10 | 9 | 9 | 8 | 8 | 9 | 10 | 9 | 10 | 10 | 9 | 9 | 8.9 |

In Section 5.4, all the required enablers to successfully implement lean in PSS, as well as, the factors pertaining to these factors were discussed. There are five main enablers required for implementing lean PSS, these enablers are:

- Suppliers relationship
- Management status
- Work process
- Employees status , and finally
- Customers relationship

Additionally, in this section the relative importance of each enabler was identified, besides the relative importance of the 33 factors emerging from the main enablers.

The most common lean tools used by companies to implement lean in PSS were discussed in Section 5.5. Finally, in the last section of this Chapter the validation process that has been followed was discussed. Two types of validations were carried out. The first one was a qualitative validation and the second one was a quantitative validation.

# CHAPTER 6

# 6 PRODUCT- SERVICE SYSTEM LEANNESS ASSESSMENT MODEL

The aim of this chapter is to present an innovative model to assess PSS leanness incorporated with validating the model via three real life case studies across various industries thus improving the practical validity and relevance of the model.

In order to successfully achieve the above aim, this chapter is organised as follows. Section 6.1 briefly introduces both the concepts of lean and Product-Service System (PSS). Section 6.2 describes the methodology used in this chapter to reach the desired goal. The development of the model was carried out through an iterative process. Starting from literature review going through semi-structured interviews with academic researchers involved in lean projects and ended with semi-structured interviews with a number of experts in the field of lean from five UK manufacturing companies. Section 6.3 provides insights into the Product-Service System leanness assessment model. The model comprises of three levels, namely: enablers, criteria and attributes. The first level contains five enablers, in the second level there are 21 criteria, and finally the third level consists of 73 attributes. In Section 6.4 the case studies validation will be presented. The model was validated by applying the model to compute the PSS leanness level for three UK manufacturing companies and identifying areas for further improvement for these companies. The results indicate that the model is able to assess PSS leanness level effectively and has a practical relevance. Section 6.5 presents results and discussions. Finally, Section 6.6 presents summary of the chapter. The structure of this chapter is illustrated in Figure 6.1

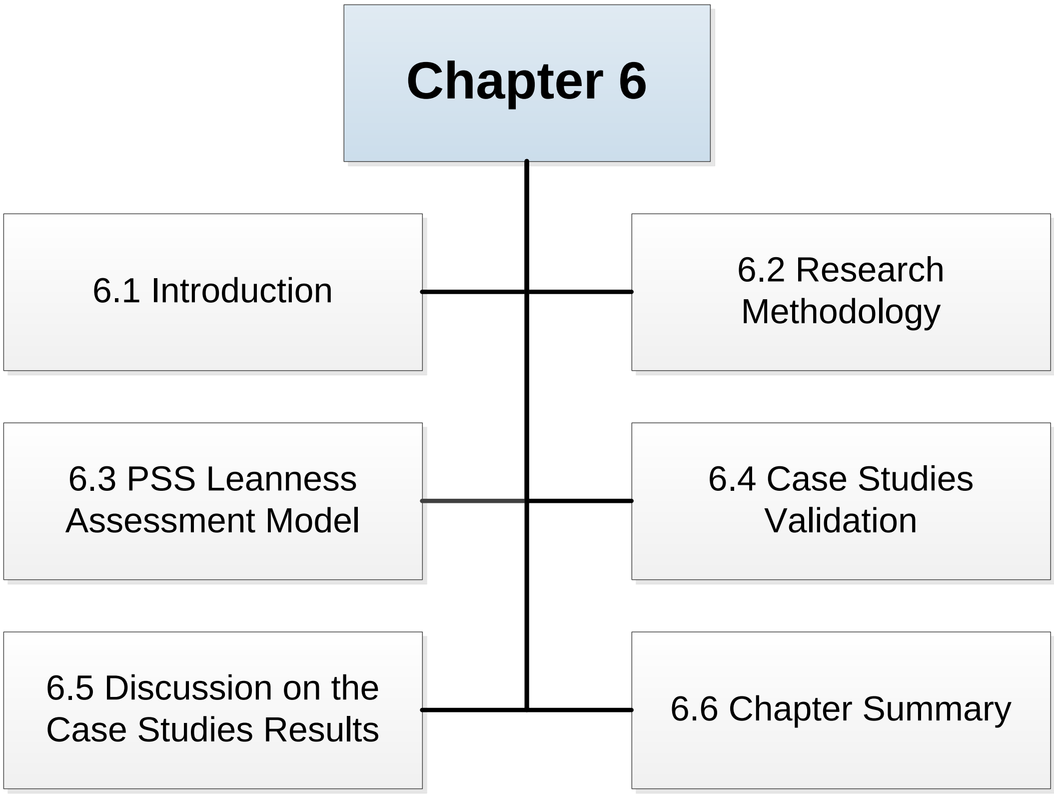



**Figure 6.1 Structure of Chapter 6**

## 6.1 Introduction

In today's competitive market, manufacturing companies are more focused on the improvement of core competitiveness. Manufacturing companies try to improve and develop their ability for competition through modern manufacturing initiatives and from these initiatives are lean manufacturing and Product-Service System (PSS). Lean and PSS can lead to dematerialisation through reducing the creation of wastes and the consumption of raw materials; improving customers' satisfaction by meeting customers' needs better and improving competitiveness through increasing customers' value.

Despite the vast research carried out either on lean manufacturing or lean service, the definition of leanness was not stated explicitly as mentioned in chapter 2. Few attempts were made to precisely define leanness in the context of assessing lean status. Bayou and De Korvin (2008) described leanness as a strategy to incur less input to better achieve the organisation's goals through producing better output. Vinodh and Chintha (2011) defined leanness as the performance measure of lean practices. The leanness measurement gains importance as it indicates the leanness performance of the organisation. Throughout this chapter, Product-Service System (PSS) leanness is defined as the degree of the adoption and implementation of the lean principles in the process of providing services to customers. PSS leanness can be considered as an assessment parameter to measure the lean status of the process of providing services to customers (Elnadi and Shehab, 2014a, b).

## 6.2 Research Methodology

The research methodology comprises two main parts, namely, the development of the model and the validation of the model as presented in Figure 6.2.

Starting from existing literature on lean manufacturing assessment and lean service assessment, the terms "lean" and "leanness" have been used interchangeably together with four keywords related to measurement: "assess", "measure", "evaluate" and "audit". A key intention of the literature review was to develop an understanding of different choices in designing an instrument for assessing lean in both the manufacturing and non-manufacturing sectors. The literature reviewed resulted in developing an initial model for assessing PSS leanness. After conducting literature review, semi-structured interviews with five academic researchers involved in lean projects were conducted. Each interview was held independently and ranged from 45 to 60 minutes. In each interview an explanation of the model, its items, and how it will be used in calculating the leanness of PSS were presented. Every researcher was asked about his opinion in the model in order to validate the model and assess its feasibility. These interviews ended up with the second version of the model.

The second version of the model was refined using semi-structured interviews with a number of experts working in different UK manufacturing industries (trucks and buses, transportations, document management and aerospace), involved in lean and continuous improvement projects, and with working experience ranged from 15 years to 30 years.

Each interview took about 60 minutes discussing the model and examining its items, its structure, and its ability to measure PSS leanness. These interviews resulted in refining the second version of the model by adding and removing some items as well as changing the names of other items.

The second part of the research methodology started with identifying suitable companies for applying the model. The validation of the model has been carried out in three UK manufacturing companies across various sectors. All of these companies have applied PSS successfully and are keen to implement lean practices. Due to confidentiality agreements, the companies name will not be disclosed and will be referred as company (A), company (B) and company (C) as mentioned in chapter 4. Then, the collection of data was started from the case companies to calculate the PSS leanness index for each company.

Fifteen experts ($E_1$ – $E_{15}$) participated in the assessment process, five experts from each company as shown in Table 6.1. Every expert has completed an Excel tool - as will be presented in section 6.3 - independently by identifying the relative importance (weight) of each enabler; criterion and attributes. Then each expert evaluates the performance of his company on each attribute by giving a score for every attribute which ranges from 0 to 10 this will be discussed in more details later in this chapter in section 6.4.

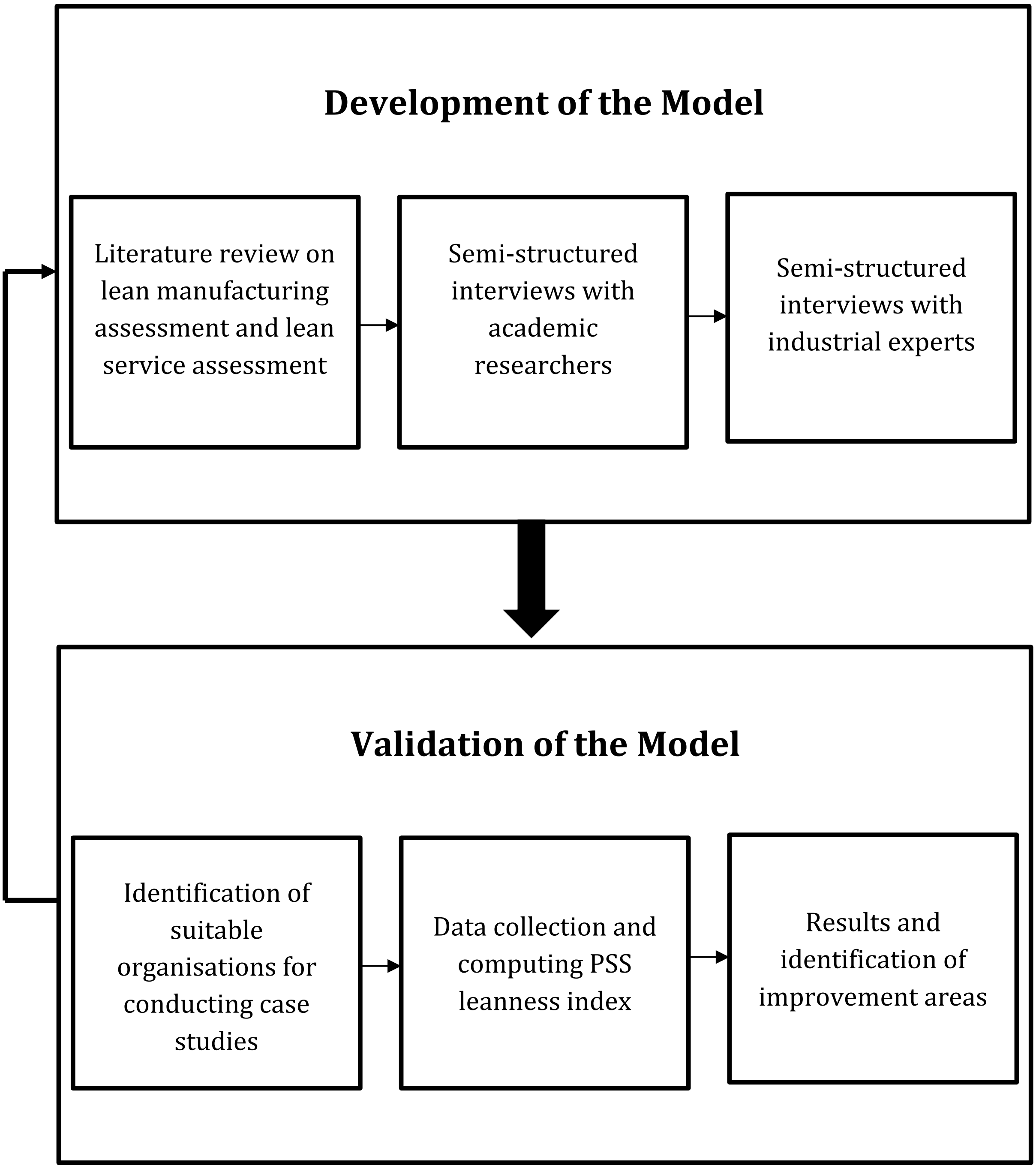



**Figure 6.2 Chapter 6 Research Methodology**

After the calculation of the PSS leanness indices, a comparison between the case companies was conducted and areas for further improvement for each company were identified.

**Table 6.1 Experts Involved in the Assessment**

| Expert Number | Company | Role | Years of Experience |
|---|---|---|---|
| E1 | A | Service Supply Chain Manager | 15 |
| E2 | A | Service Manager | 25 |
| E3 | A | Lean Six Sigma Strategy and Deployment Manager | 25 |
| E4 | A | Business Improvement Manager | 30 |
| E5 | A | Project Manager | 22 |
| E6 | B | Continuous Improvement Manager | 14 |
| E7 | B | Industrial Manager | 35 |
| E8 | B | Continuous Improvement Leader | 20 |
| E9 | B | Continuous Improvement Manager | 22 |
| E10 | B | Change Manager | 15 |
| E11 | C | CEO | 40 |
| E12 | C | Head of UK Service | 30 |
| E13 | C | Operating Manager | 26 |
| E14 | C | CRM Manager | 23 |
| E15 | C | Director UK Aftersales | 40 |

## 6.3 Product- Service System Leanness Assessment Model

### 6.3.1 Overview of the Model

The PSS leanness assessment model comprises three levels as presented in Figure 6.3. The first level consists of five enablers as presented in chapter 5, the second level contains 21 criteria, and finally the third level involves 73 attributes. The rationale behind the formulation of the model is that it presents the five major enablers required for implementing lean practices in PSS. As explained before in chapter 5, these enablers are supplier relationship, management leanness, workforce leanness, process excellence and customer relationship. The enablers, criteria and attributes used in computing the leanness level of PSS are presented in

Figure 6.4 (a) and (b), and Table 6.2. This section provides a brief discussion of these five enablers.

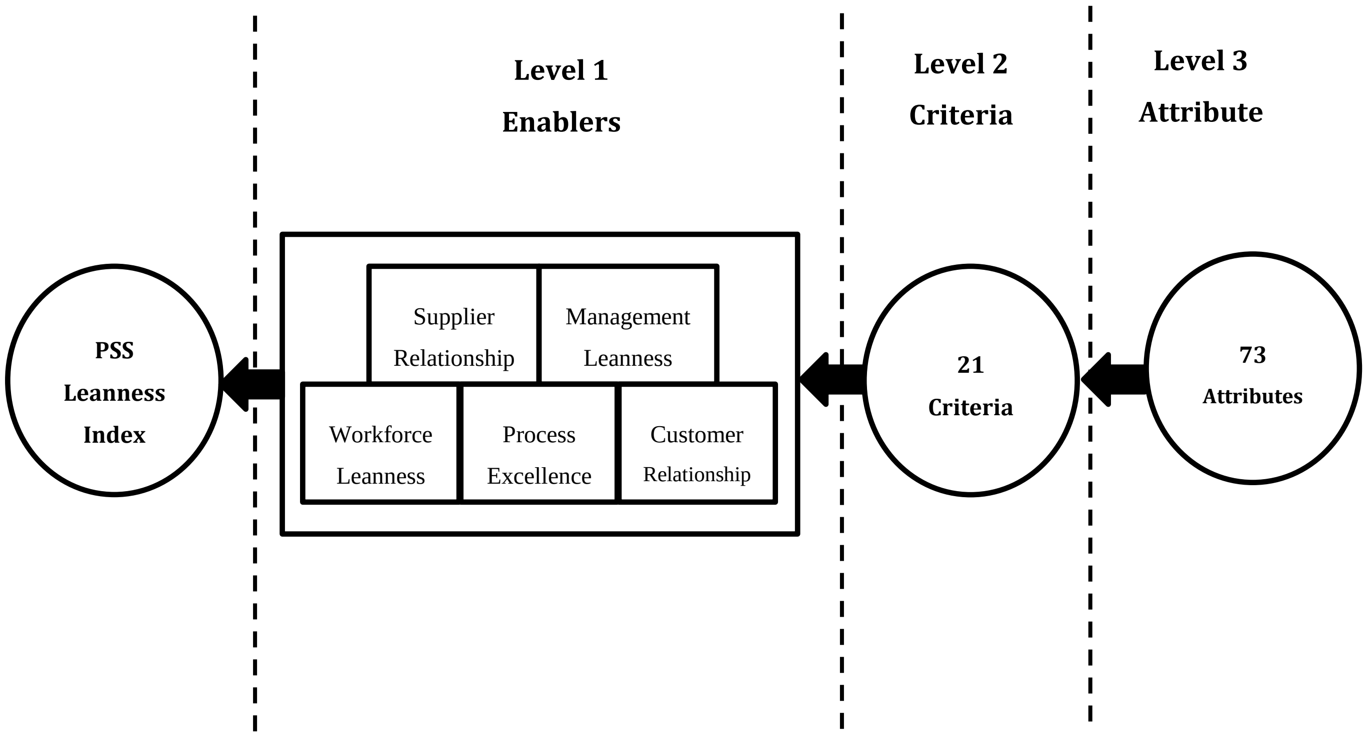



**Figure 6.3 PSS Summary of the PSS Leanness Assessment Model**

#### 6.3.1.1 Supplier Relationship

Supplier support is a critical factor for the successful implementation of lean practices (MacDuffie and Helpe, 1997). The adoption of lean practices is associated with higher levels of integration of both information flows and physical flows with suppliers (Cagliano, 2006). The main objective of any lean initiatives is to satisfy customers' needs to the maximum level by delivering high quality goods and services and responding quickly to their changing demands. Accordingly, an effective material procurement system becomes necessary as well as improving the internal manufacturing methods and techniques (Barla, 2003). Suppliers that implement lean practices will be more compatible with a manufacturer that implements lean initiatives. In other words, lean manufacturers are likely to find it more productive to work with lean suppliers.

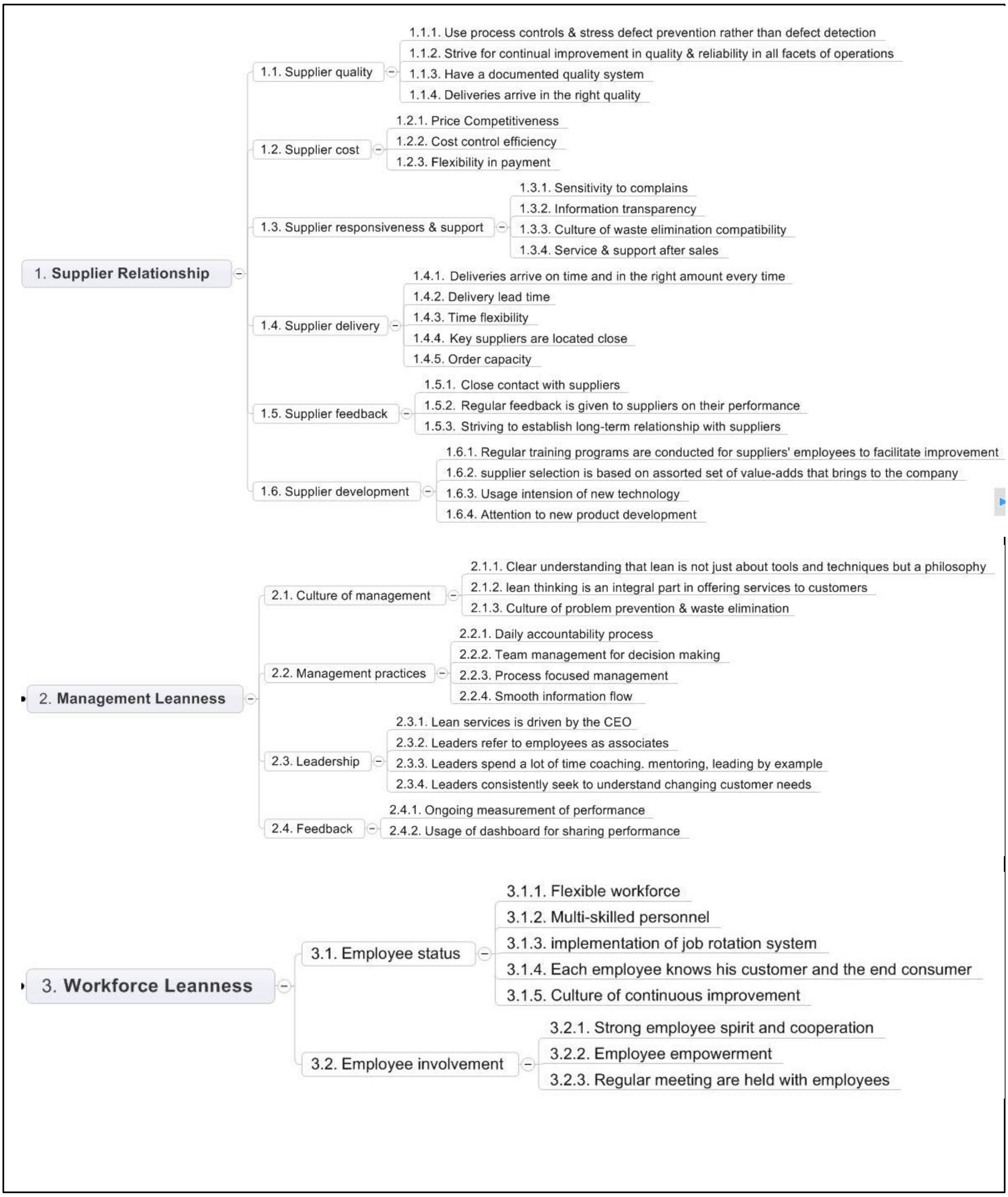



**Figure 6.4 (a) PSS Leanness Assessment Model**

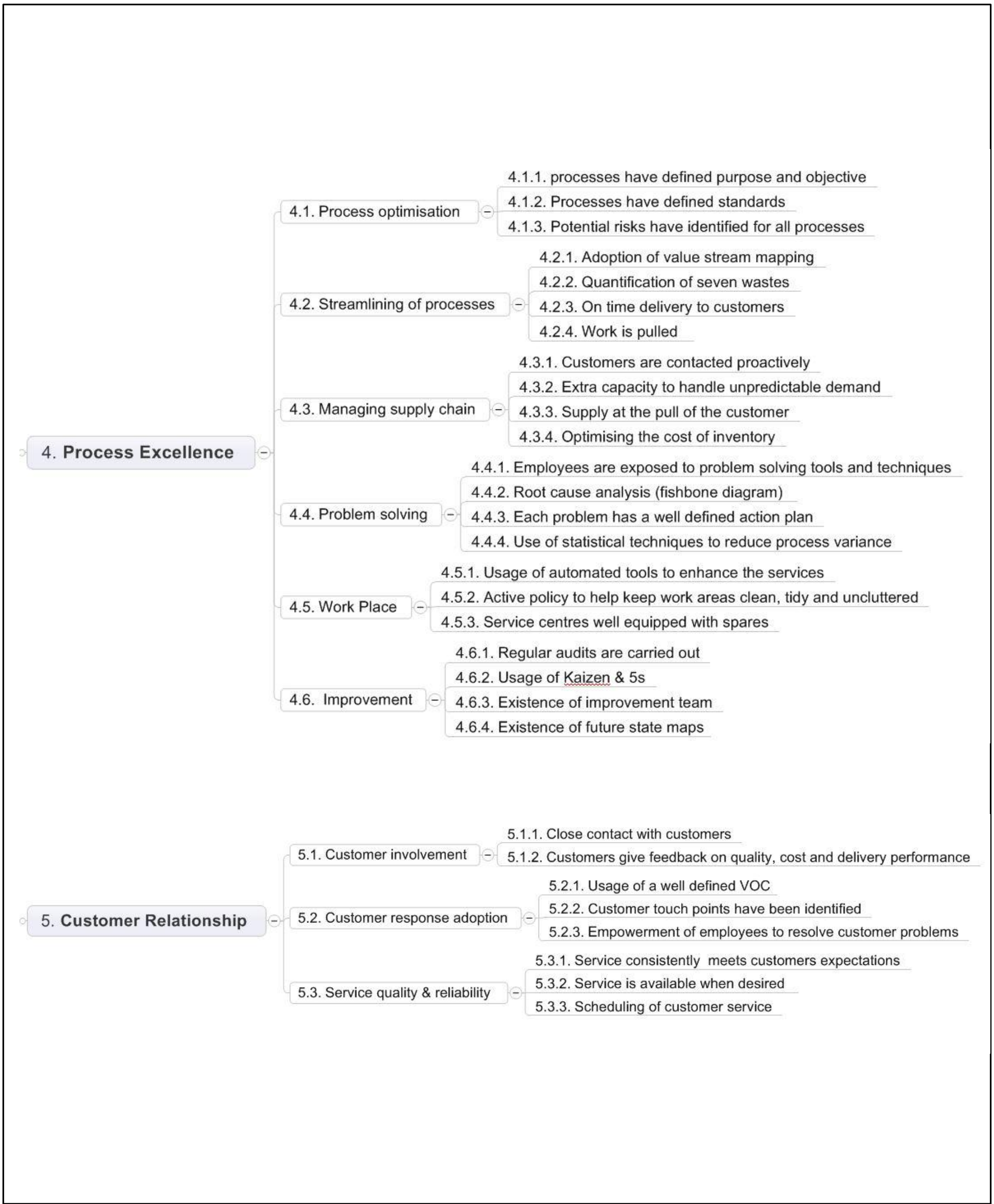



**Figure 6.4 (b) PSS Leanness Assessment Model**

For manufacturing companies it is important to involve their suppliers in their internal manufacturing process, build long-term relations and commitments with suppliers, give regular feedback on suppliers' performance, improve communication with suppliers, and conduct regular training to suppliers' employees. Furthermore, suppliers should deliver frequently, in small quantities, as required at the point of use with the total quality guaranteed to eliminate the need for incoming inspection and respond quickly to their customers demand and problems (Handfield, 1993).

#### 6.3.1.2 Management Leanness

Management leanness includes the culture of management, leadership, and management commitment.

The culture of management is one of the main pillars when implementing lean practices. High performing companies are those with a culture of sustainable and proactive improvement (Achanga et al., 2006). Management should have a culture of continuous improvement, waste elimination and problem solving. Additionally, managers should clearly understand that lean is not just about tools and techniques, but a philosophy and they have to feel enthusiastic about it.

Moreover, the role of leader is vital when implementing lean practices, managers should act as leaders in order to:

- Communicate the importance of implementing lean practices.
- Prepare employees for the required changes and the consequences that may occur.
- Create a sustainable motivation for implementing lean practices among employees.
- Empower their team members, so they can take decisions easily to solve customers' problems.
- Spend a lot of time coaching, mentoring and leading by example.
- Give regular feedback on employees' performance.

Besides the culture of management and leadership, a committed management is necessary. All managers at all levels should be convinced that lean practices are the right path for organisational development. Senior management need to show full commitment and belief in providing the required support, resources, budget and investment to their employees.

#### 6.3.1.3 Workforce Leanness

Workforce that is motivated, empowered, and willing to accept lean initiatives is one of the key important factors for the successful lean implementation. A lean workforce should have the exact number of workers with the right skills and should be empowered to be able to respond quickly to customers' demands and requirements. Moreover, a lean workforce should work safely and productively without errors.

Workforce leanness requires: the development of best practices and training on how to perform each job, the implementation of the job rotation system, and a strong employees' spirit and cooperation.

#### 6.3.1.4 Process Excellence

Process excellence is the systematic management of all the processes to achieve world class performance (Lee and Dale, 1998).  Process excellence can be realised by the efficient utilisation of tools, the optimisation of resources, and the elimination of process waste and inefficiencies. Process excellence is important to create value, find more wastes to eliminate from the value stream, flow the process and parts faster, and respond to customers by pulling products and services rather than pushing them on the marketplace.

#### 6.3.1.5 Customer Relationship

The critical starting point for lean implementation is value. External customer is the only one who can clearly define value from his perspective. Value from an external customer perspective is getting the exact product or service required, in the right quantity, at the right time, with perfect quality, and at the right price (Bicheno, 2008). The full identification of customer demand allows managers to leverage the knowledge of their customer preferences and hence improve the accuracy of forecast plans and service quality level.

**Table 6.2 PSS Leanness Assessment Model**

| ***Enabler*** $(I_i)$ | ***Criteria*** $(I_{ij})$ | ***Attributes*** $(I_{ijk})$ |
|---|---|---|
| **1. Supplier Relationship** | 1.1. Supplier quality | 1.1.1 Use process controls & stress defect prevention<br>1.1.2. Strive for continual improvement in quality in all facets of operations<br>1.1.3. Have a documented quality system<br>1.1.4. Deliveries arrive in the right quality |
| | 1.2. Supplier cost | 1.2.1. Price Competitiveness<br>1.2.2. Cost control efficiency<br>1.2.3. Flexibility in payment |
| | 1.3. Supplier responsiveness & support | 1.3.1. Sensitivity to complains<br>1.3.2. Information transparency<br>1.3.3. Culture of waste elimination compatibility<br>1.3.4. Service & support after sales |
| | 1.4. Supplier delivery | 1.4.1. Deliveries arrive on time and in the right amount every time<br>1.4.2. Delivery lead time<br>1.4.3. Time flexibility<br>1.4.4. Key suppliers are located close |
| | 1.5. Supplier feedback | 1.5.1. Close contact with suppliers<br>1.5.2. Regular feedback is given to suppliers on their performance<br>1.5.3. Striving to establish long-term relationship with suppliers |
| | 1.6. Supplier development | 1.6.1. Regular training is conducted for suppliers' employees<br>1.6.2. Supplier selection is not based only on cost, but on a set of value-adds<br>1.6.3. Usage intension of new technology<br>1.6.4. Attention to new product development |
| **2. Management Leanness** | 2.1. Culture of management | 2.1.1. The clear understanding that lean is not just about tools, but a philosophy<br>2.1.2. Lean thinking is an integral part in offering services to customers<br>2.1.3. Culture of problem prevention & waste elimination |
| | 2.2. Management practices | 2.2.1. Daily accountability process<br>2.2.2. Team management for decision making<br>2.2.3. Process focused management<br>2.2.4. Smooth information flow |
| | 2.3. Leadership | 2.3.1. Lean services is driven by the CEO<br>2.3.2. Leaders refer to employees as associates<br>2.3.3. Leaders spend a lot of time coaching, mentoring, leading by example<br>2.3.4. Leaders consistently seek to understand changing customer needs |
| | 2.4. Feedback | 2.4.1. Ongoing measurement of performance<br>2.4.2. Usage of dashboard for sharing performance |

| *Enabler* $(I_i)$ | *Criteria* $(I_{ij})$ | *Attributes* $(I_{ijk})$ |
|---|---|---|
| **3. Workforce Leanness** | 3.1. Employee status | 3.1.1. Flexible workforce<br>3.1.2. Multi-skilled personnel<br>3.1.3. Implementation of job rotation system<br>3.1.4. Each employee knows his internal and external customer<br>3.1.5. Culture of continuous improvement |
| | 3.2. Employee involvement | 3.2.1. Strong employee spirit and cooperation<br>3.2.2. Employee empowerment<br>3.2.3. Regular meetings are held with employees |
| **4. Process Excellence** | 4.1. Process optimisation | 4.1.1. Processes have defined purpose and objective<br>4.1.2. Processes have defined standards<br>4.1.3. Potential risks have identified for all processes |
| | 4.2. Streamline of processes | 4.2.1. Adoption of value stream mapping<br>4.2.2. Quantification of seven wastes<br>4.2.3. On time delivery to customers<br>4.2.4. Work is pulled |
| | 4.3. Managing demand (Supply chain) | 4.3.1. Customers are contacted proactively<br>4.3.2. Extra capacity to handle unpredictable demand<br>4.3.3. Supply at the pull of the customer<br>4.3.4. Optimising the cost of inventory |
| | 4.4. Problem solving | 4.4.1. Employees are exposed to problem solving tools and techniques<br>4.4.2. Root cause analysis (Fishbone diagram)<br>4.4.3. Each problem has a well-defined action plan<br>4.4.4. Use of statistical techniques to reduce process variance |
| | 4.5. Workplace | 4.5.1. Usage of automated tools to enhance the services<br>4.5.2. Active policy to help keep work areas clean and tidy<br>4.5.3. Service centres well equipped with spares |
| | 4.6. Improvement | 4.6.1. Regular audits are carried out<br>4.6.2. Usage of Kaizen & 5s<br>4.6.3. Existence of improvement team<br>4.6.4. Existence of future state maps |
| **5. Customer Relationship** | 5.1. Customer involvement | 5.1.1. Close contact with customers<br>5.1.2. Customers give feedback on quality, cost and delivery performance |
| | 5.2. Customer response adoption | 5.2.1. Usage of a well-defined VOC<br>5.2.2. Customer touch points have been identified<br>5.2.3. Empowerment of employees to resolve customer problems |
| | 5.3. Service quality & reliability | 5.3.1. Service consistently meets customers' expectations<br>5.3.2. Service is available when desired<br>5.3.3. Scheduling of customer service |

### 6.3.2 Design of the Assessment Process

The assessment tool has integrated into a comprehensive problem solving methodology. Problem solving processes entail a variety of tasks, such as problem formulation, diagnosing the root causes and development of solutions (De Mast, 2011). The design assessment process in Figure 6.5 integrates the assessment tool into solving problems associated with lean PSS implementation.

The lean PSS assessment tool provides the manufacturing company with the PSS leanness index. This PSS leanness index enables the manufacturing company to identify the current state of how lean the service offering process is. By identifying the current state, the company can determine the gap between the current situation and the desired future situation, in other words, the gap between how lean the service offering process is and how lean the service offering process should be. The identification of this gap results in determining areas for further improvements, as well as, root causes of the lower performance areas. Thus, the suitable solutions will be available and improvement plan can be developed. After implementing the proposed improvement plan, the company should reassess PSS leanness level again using lean PSS assessment tool to control the process and identify any deviation.

### 6.3.3 Multi-grade Fuzzy Approach

Multi-grade fuzzy approach has been used by some researchers for the purpose of developing an index that can assess specific concept. For instance, Yang and Li (2002) developed an index to evaluate mass customisation product agility manufacturing based on three aspects, including enterprise organisation management, products design and processing and manufacturing. They used the multi-grade fuzzy assessment method to evaluate the mass customisation products manufacture agility of a manufacturing company.

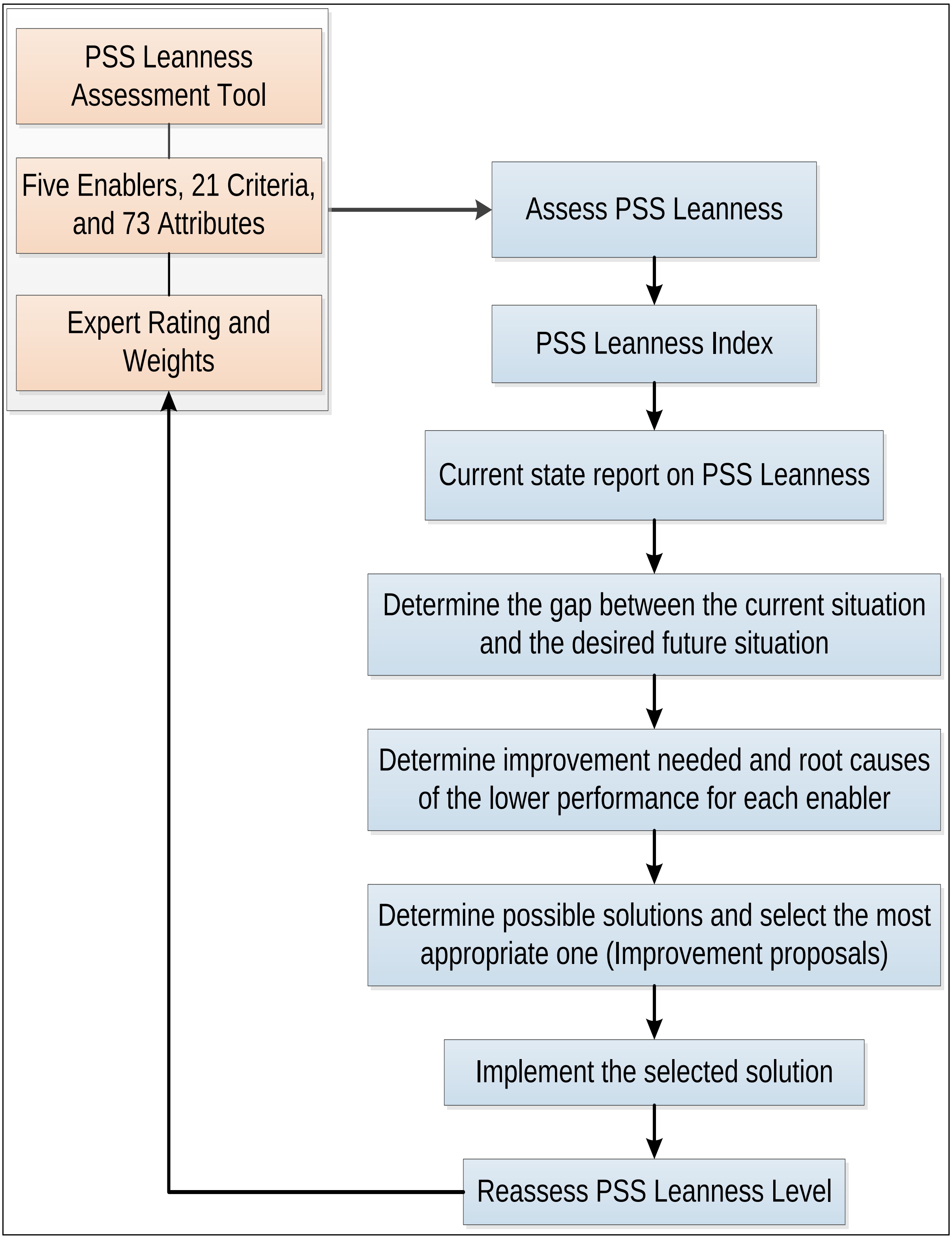



**Figure 6.5 Lean PSS Assessment Process**

Also, Vinodh and Chintha (2011) developed an index using multi-grade fuzzy approach for measuring the leanness of an Indian electronics manufacturer. They developed a model consisting of three levels. The first level consists of five leanness enablers; the second level consists of 20 lean criteria, and the third level consists of several lean attributes. By using this model they have specified the degree of leanness and the areas for leanness improvements. Vinodh and Prasanna, (2011) have used multi-grade fuzzy approach to develop an index that can be used in to evaluate the agility in supply chain. Furthermore, an index for assessing the sustainability of an organization using multi-grade fuzzy approach was developed by (Vinodh, 2011). Also, an index for evaluating the degree of Product-Service System leanness using multi-grade fuzzy approach was developed by (Elnadi and Shehab, 2014b).

Fuzzy logic has it origin based on the human logic that takes advantage of conceptual knowledge without boundaries. Some of the concept of fuzzy logic includes fuzzy set, linguistic variables, probability distribution, and fuzzy if then rules (Vinodh and Chintha, 2011). One of the challenges in qualitative research is the vagueness in which case data may not be expressed as exact number (Yang and Li, 2002). The expression of the experts needs to be determined using fuzzy numbers and membership functions.

Multi-grade decision making is a branch of operations research models that deal with decision problems under the presence of a number of decision criteria (Kahraman, 2008). It refers to screening, prioritising, ranking, or selecting a set of alternatives under usually independent, incommensurate or conflicting criteria (Belton and Stewart, 2002; Fenton and Wang, 2006). A multi-grade decision problem is characterized by: (a) the ratings of each alternative with respect to each criterion and (b) the weights given to each criterion (Fenton and Wang, 2006). The multi-grade decision making approach requires that the choice be made among decision alternatives described by their attributes. This approach is used to solve a case which has several alternatives and priority for various attributes. It is a popular technique and has widely been used in several fields, including: engineering, economics, management, etc.

Multi-grade fuzzy approach is a method used to find the optimal alternative from a number of alternatives to certain criteria. Multi-grade fuzzy approach is the core of determining the value of the weights for each attribute, followed by a ranking process that will select the alternative that has been given (Deni et al., 2013). Fuzzy logic provides a useful way to approach a multi-grade decision making problem. Very often in multi-grade decision problems, data are imprecise and fuzzy. For example, the value of alternative A may be “very good” or “moderate”, and the value of the criteria C pertaining to alternative A may be “very high importance” or “low importance” and so on. If the preference is given linguistically, then fuzzy logic can be used to help solving the problem. Fuzzy logic is very effective to solve the multi-grade decision problem where the given data is ambiguous or presented linguistically (Klir and Yuan, 1995). According to (Uyun and Riadi, 2013), the fuzzy multi-grade approach procedure follows these steps:

1. Set a number of alternatives and some attributes or criteria.

Decision-makers determine some alternatives that will be selected following several attributes or criteria. For example $S = \{S_1, S_2, \ldots\ldots, S_m\}$ is the set of alternatives; $K = \{K_1, K_2, \ldots\ldots, K_m\}$ is the set of attributes or criteria, and $A = \{a_{ij} \mid i=1,2,...,m; j=1,2,...,n\}$ is the matrix decision where $a_{ij}$ is the numerical value of alternative i for attribute j

2. Evaluation of Fuzzy set, there are two activities at this step:
    a. Choosing a set of rating for the weight of criteria and the degree of suitability for each alternative with the criteria.
    b. Evaluating the weight of criteria and degree of suitability for each alternative with the criteria.

### 6.3.4 Development of the Assessment Tool

The computation of PSS leanness index goes through successive steps. The assessment of each level depends on the assessment of the preceding level. For instance, the PSS leanness index is the sum of the indices calculated for each enabler. Also, the index of each enabler is the sum of the indices computed for the criteria pertaining to each enabler. Finally, the index computed for each criterion will be determined by the assessment scores for each attribute pertaining to each criterion.

For example, the management leanness enabler has been explained. The major perspectives of management leanness are culture of management, management practices, leadership and feedback which forms the criteria. The culture of management criteria includes attributes such as a clear understanding that lean is not just about tools and techniques, but a philosophy, lean thinking is an integral part in offering services to customers and culture of problem prevention and waste elimination.

By following the same approach of calculating the leanness index presented by Vinodh and Chintha (2011), the PSS leanness index of a company is presented by ***(I)***. Where, ***(I)*** is the product of the overall assessment factor ***(R )*** and the overall weight ***( W)***. The equation for PSS leanness index is given by:

$$\mathbf{I = W \times R}$$

The assessment has been divided into five grades as follows:

| **(Less than 2)** | **(2-4)** | **(4-6)** | **(6-8)** | **(8-10)** |
|---|---|---|---|---|
| **Extremely not lean** | **Not lean** | **Generally lean** | **Lean** | **Extremely lean** |

The assessment has been divided into five grades since every leanness factor involves fuzzy determination. $I = \{10, 8, 6, 4, 2\}$ (8 – 10 represents 'extremely lean', 6 – 8 represents 'lean', 4 – 6 represents 'generally lean', 2 – 4 represents 'not lean', and less than 2 represents 'extremely not lean' as mentioned before.

After an introductory session that took about one hour with five experts in each company, every expert was prompted to complete the Excel tool independently. The first window in the assessment tool have been designed to provide the expert with a brief explanation about the aim of the assessment; the steps to be followed in the assessment; rules to be considered during the assessment; and who should be involved in the assessment process as presented in Figure 6.6

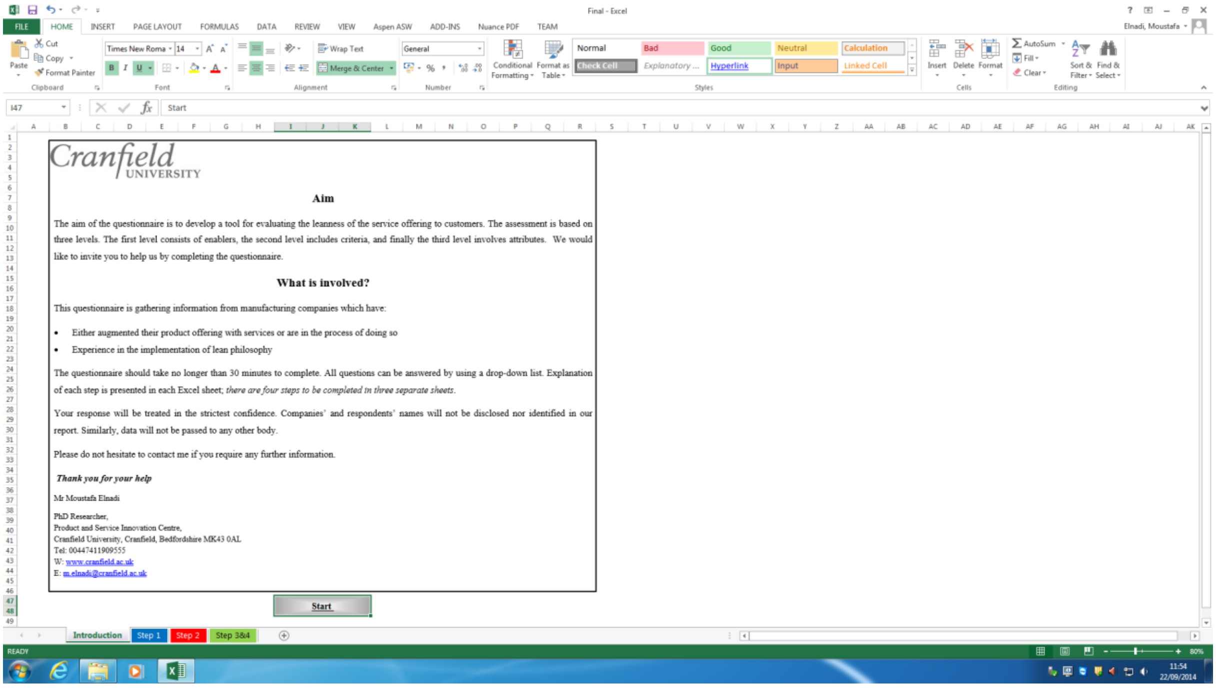



**Figure 6.6 The Introduction Window of the Assessment tool**

After the expert finishes the introductory window, he/she can move to the next step by just clicking on start button. This will move the expert to the second window as shown in Figure 6.7. In this window the expert has to provide general information about his/her name, job title, and number of years of experience.

Considerable care has been taken into account to make the tool user friendly, where each action involving the expert with the tool will be validated in such a way that no error occurs. After the expert finishes the general information section, he/she can move to the next step.

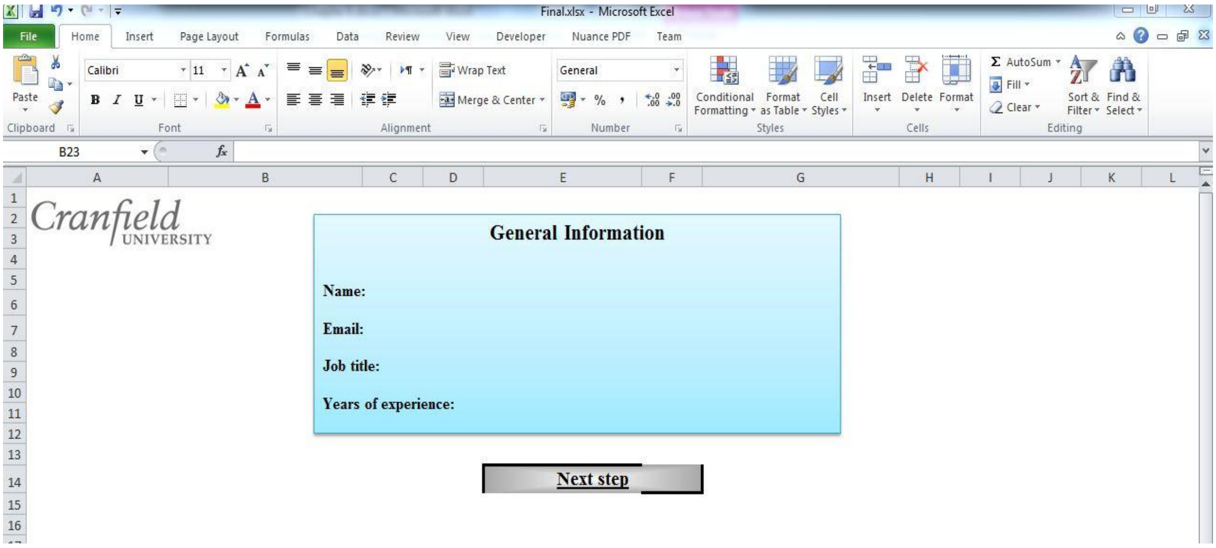



**Figure 6.7 General Information Window**

In the next step the expert provides the weights or the relative importance of each of the five main enablers by just selecting from the drop-down list, as presented in Figure 6.8. The expert should follow the rule that the sum of weights pertaining to the enablers should be equal to one. The tool also alerts the expert when he/she commit any mistake in entering the weights. After that, the expert clicks on the next button to move to the next step as in Figure 6.9.

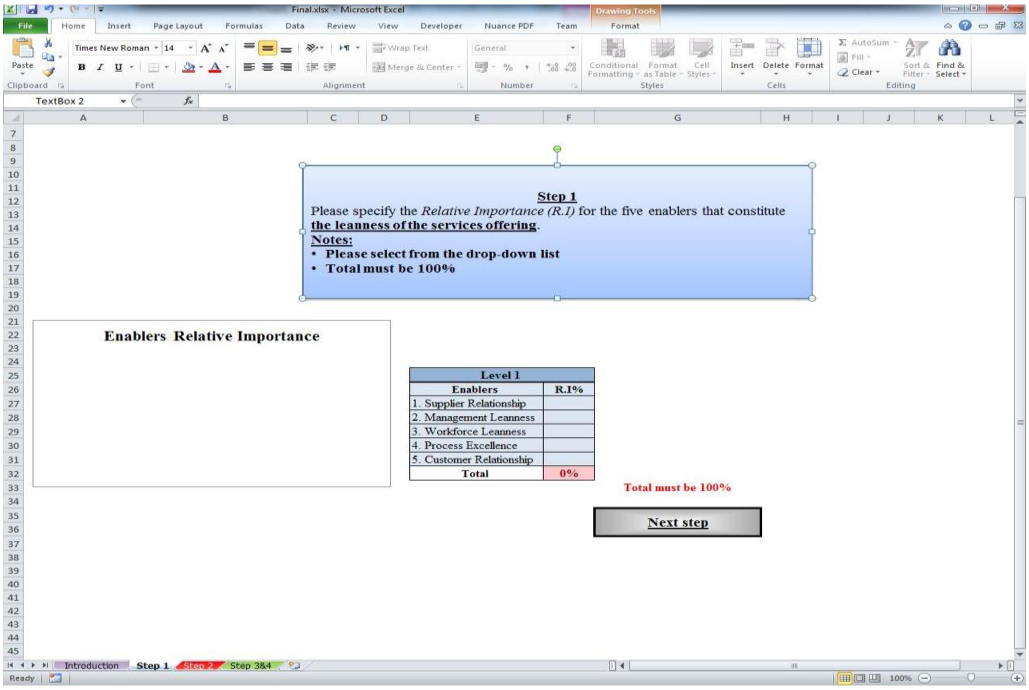



**Figure 6.8 The First Step in the Assessment Tool**

In this step the expert provides the weights of each criteria pertaining to the enabler by just selecting from the drop-down list. As mentioned in the previous step, the sum of the weights should not be less than one or more than one.

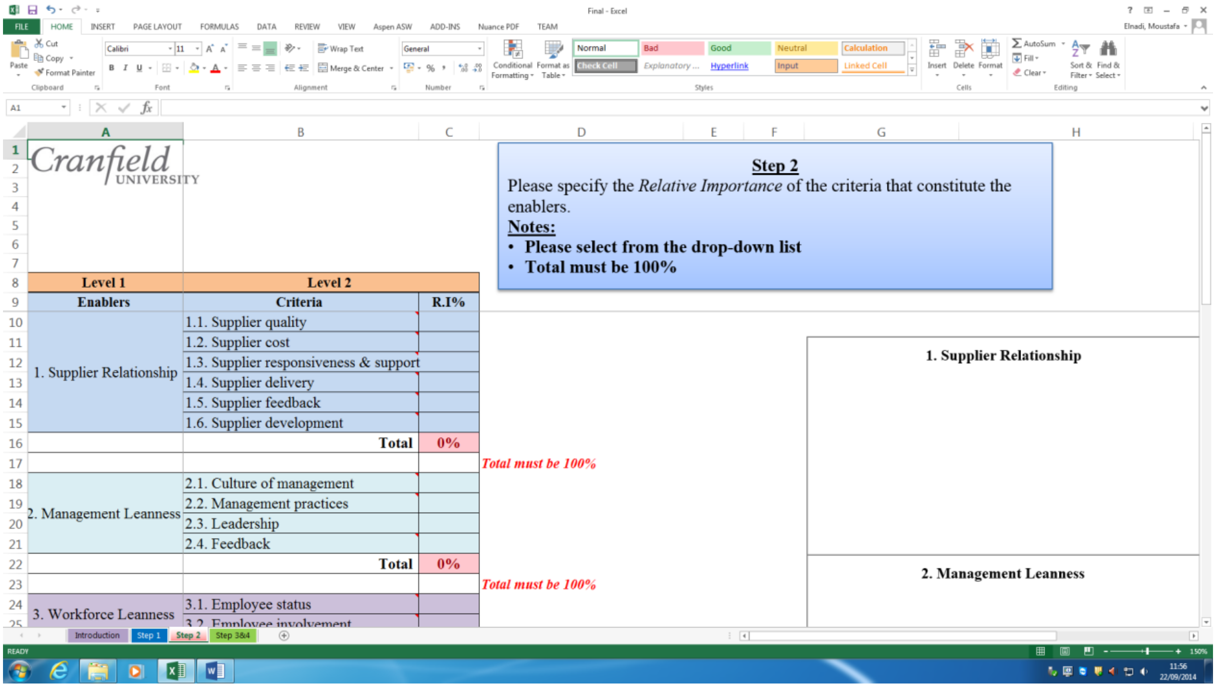


**Figure 6.9 The Second Step in the Assessment Tool**

After that, the expert move to steps 4 and 5 as presented in Figure 6.10; to enter the weights and assessment scores of each attributes. The total sum of weights should be equal to one, and the assessment scores must be a number ranging from one to ten. As mentioned before, the tool alerts the expert when he/she commit any mistake in entering the assessment values.

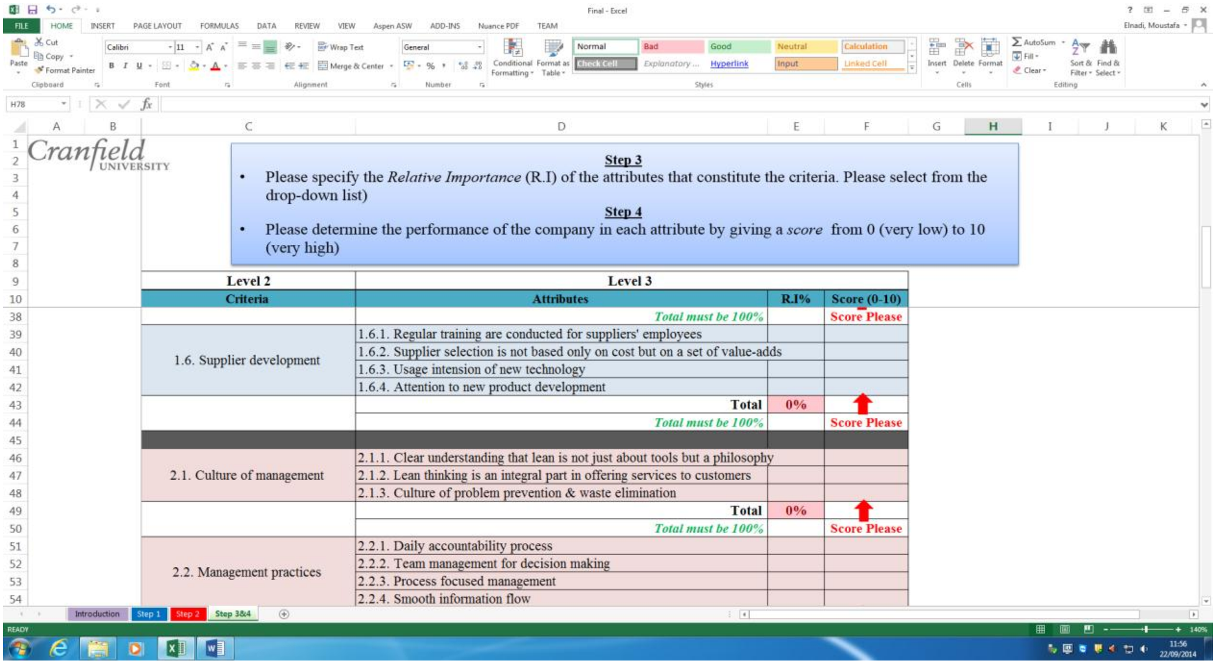



**Figure 6.10 The Fourth and Fifth Step in the Assessment Tool**

## 6.4 Case Studies Validation

### 6.4.1 The Case Study Companies

The validation of the model has been carried out in three large UK manufacturing companies across various sectors as mentioned before. All of these companies have applied PSS successfully. Due to confidentiality agreements, the companies' name will not be disclosed and will be referred as company (A), company (B) and company (C).  The following presents a brief summary about each company.

***Company (A)*** is a document management company that produces and sells portfolio of offerings such as: colour and black-and-white printing, publishing systems, multifunction devices, photocopiers, fax machines, and related consulting services. Company (A) started its quality journey in the early 90s and in 2003 six sigma and lean were integrated and driven as a company strategy. Improvement processes, tools and techniques were deployed across the company and cantered on improving business processes to create a higher level of customer satisfaction, quality and productivity.

***Company (B)*** is a specialist train manufacturers that provides a comprehensive range of design, manufacturing, operating and maintenance service for the rail transport. Company (B) develops and markets the most complete range of systems, equipment and services in the railway sector, including rolling stock, infrastructure and signalling equipment, as well as maintenance operations. The company started its lean journey in 2006. The company deployed the lean concept throughout the whole company via a policy deployment process. The company uses a wide variety of lean tools and techniques including Kaizen, 5s, daily management process, standard work, visual control, KPIs and daily accountability process.

***Company (C)*** is specialised in manufacturing commercial heavy vehicles. The company offers customers comprehensive services in one stop shopping such as, service and repair contracts, fleet management, tailor made financing, leasing and insurance, flexible rental options and many other tailored services. Company (C) still in the early stage of lean implementation.

### 6.4.2 Assessment of the Three Companies PSS Leanness

After collecting all the required information from the experts of the three companies as shown in Table 6.3, the assessment process for each company started.

## Table 6.3 Weights and Assessment Scores for the Three Companies (Refer to Table 6.2 for Enablers, Criteria and Attributes)

**Legend:** $I_i$= Enabler index; $I_{ij}$ = Criterion index; $I_{ijk}$ = Attribute index; $E_i$ = Experts participated in the assessment; $W_{ij}$ = Attribute weight; $W_i$ = Criterion weight; $W$ = Enabler weight

***Company (A)***

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_1$ | $I_{11}$ | $I_{111}$ | 6 | 6 | 6 | 7 | 7 | 0.2 | 0.2 | 0.1 |
| | | $I_{112}$ | 10 | 8 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{113}$ | 7 | 7 | 8 | 8 | 8 | 0.2 | | |
| | | $I_{114}$ | 10 | 8 | 8 | 9 | 10 | 0.3 | | |
| | $I_{12}$ | $I_{121}$ | 7 | 7 | 7 | 7 | 7 | 0.5 | 0.1 | |
| | | $I_{122}$ | 8 | 7 | 9 | 8 | 7 | 0.3 | | |
| | | $I_{123}$ | 6 | 6 | 7 | 7 | 7 | 0.2 | | |
| | $I_{13}$ | $I_{131}$ | 10 | 8 | 9 | 9 | 8 | 0.3 | 0.2 | |
| | | $I_{132}$ | 7 | 7 | 8 | 7 | 7 | 0.1 | | |
| | | $I_{133}$ | 10 | 7 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{134}$ | 8 | 7 | 8 | 8 | 7 | 0.3 | | |
| | $I_{14}$ | $I_{141}$ | 8 | 7 | 8 | 8 | 7 | 0.3 | 0.3 | |
| | | $I_{142}$ | 9 | 7 | 8 | 9 | 8 | 0.3 | | |
| | | $I_{143}$ | 7 | 6 | 7 | 8 | 8 | 0.2 | | |
| | | $I_{144}$ | 8 | 7 | 8 | 8 | 9 | 0.2 | | |
| | $I_{15}$ | $I_{151}$ | 8 | 7 | 7 | 8 | 8 | 0.2 | 0.1 | |
| | | $I_{152}$ | 8 | 7 | 7 | 9 | 8 | 0.4 | | |
| | | $I_{153}$ | 8 | 8 | 9 | 7 | 8 | 0.4 | | |
| | $I_{16}$ | $I_{161}$ | 7 | 6 | 7 | 8 | 6 | 0.1 | 0.1 | |
| | | $I_{162}$ | 7 | 7 | 7 | 7 | 7 | 0.4 | | |
| | | $I_{163}$ | 8 | 7 | 8 | 9 | 8 | 0.2 | | |
| | | $I_{164}$ | 8 | 6 | 8 | 8 | 7 | 0.3 | | |
| $I_2$ | $I_{21}$ | $I_{211}$ | 10 | 9 | 10 | 10 | 10 | 0.3 | 0.3 | 0.2 |
| | | $I_{212}$ | 10 | 8 | 10 | 9 | 9 | 0.4 | | |
| | | $I_{213}$ | 10 | 9 | 10 | 9 | 10 | 0.3 | | |
| | $I_{22}$ | $I_{221}$ | 8 | 7 | 9 | 8 | 8 | 0.4 | 0.3 | |
| | | $I_{222}$ | 8 | 7 | 8 | 7 | 8 | 0.2 | | |
| | | $I_{223}$ | 7 | 6 | 8 | 7 | 7 | 0.3 | | |
| | | $I_{224}$ | 6 | 5 | 7 | 7 | 6 | 0.1 | | |
| | $I_{23}$ | $I_{231}$ | 10 | 9 | 9 | 10 | 8 | 0.3 | 0.2 | |
| | | $I_{232}$ | 8 | 8 | 7 | 7 | 8 | 0.1 | | |
| | | $I_{233}$ | 8 | 6 | 8 | 6 | 7 | 0.2 | | |
| | | $I_{234}$ | 8 | 7 | 8 | 7 | 8 | 0.4 | | |
| | $I_{24}$ | $I_{241}$ | 8 | 8 | 9 | 8 | 9 | 0.7 | 0.2 | |

***Company (B)***

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_1$ | $I_{11}$ | $I_{111}$ | 5 | 0 | 6 | 10 | 7 | 0.2 | 0.2 | 0.1 |
| | | $I_{112}$ | 4 | 2 | 9 | 8 | 6 | 0.3 | | |
| | | $I_{113}$ | 8 | 5 | 6 | 10 | 8 | 0.2 | | |
| | | $I_{114}$ | 9 | 10 | 7 | 6 | 5 | 0.3 | | |
| | $I_{12}$ | $I_{121}$ | 4 | 10 | 2 | 8 | 4 | 0.5 | 0.2 | |
| | | $I_{122}$ | 8 | 5 | 5 | 10 | 7 | 0.3 | | |
| | | $I_{123}$ | 5 | 2 | 5 | 8 | 6 | 0.2 | | |
| | $I_{13}$ | $I_{131}$ | 5 | 3 | 4 | 8 | 7 | 0.3 | 0.2 | |
| | | $I_{132}$ | 7 | 4 | 7 | 8 | 6 | 0.3 | | |
| | | $I_{133}$ | 5 | 3 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{134}$ | 5 | 7 | 9 | 9 | 8 | 0.1 | | |
| | $I_{14}$ | $I_{141}$ | 8 | 8 | 2 | 6 | 7 | 0.3 | 0.2 | |
| | | $I_{142}$ | 5 | 4 | 2 | 6 | 3 | 0.4 | | |
| | | $I_{143}$ | 6 | 2 | 4 | 8 | 5 | 0.1 | | |
| | | $I_{144}$ | 3 | 2 | 7 | 5 | 4 | 0.2 | | |
| | $I_{15}$ | $I_{151}$ | 7 | 3 | 8 | 7 | 6 | 0.2 | 0.1 | |
| | | $I_{152}$ | 5 | 3 | 7 | 7 | 5 | 0.4 | | |
| | | $I_{153}$ | 6 | 6 | 3 | 8 | 5 | 0.4 | | |
| | $I_{16}$ | $I_{161}$ | 3 | 1 | 1 | 0 | 2 | 0.1 | 0.1 | |
| | | $I_{162}$ | 6 | 3 | 6 | 10 | 8 | 0.3 | | |
| | | $I_{163}$ | 5 | 3 | 2 | 8 | 6 | 0.3 | | |
| | | $I_{164}$ | 5 | 3 | 6 | 8 | 5 | 0.3 | | |
| $I_2$ | $I_{21}$ | $I_{211}$ | 8 | 5 | 5 | 8 | 5 | 0.4 | 0.2 | 0.3 |
| | | $I_{212}$ | 8 | 7 | 6 | 8 | 7 | 0.3 | | |
| | | $I_{213}$ | 8 | 5 | 1 | 10 | 9 | 0.3 | | |
| | $I_{22}$ | $I_{221}$ | 9 | 10 | 7 | 10 | 8 | 0.5 | 0.3 | |
| | | $I_{222}$ | 7 | 4 | 6 | 10 | 7 | 0.2 | | |
| | | $I_{223}$ | 7 | 7 | 6 | 8 | 6 | 0.2 | | |
| | | $I_{224}$ | 7 | 5 | 3 | 6 | 5 | 0.1 | | |
| | $I_{23}$ | $I_{231}$ | 6 | 2 | 4 | 7 | 6 | 0.2 | 0.4 | |
| | | $I_{232}$ | 3 | 2 | 1 | 0 | 1 | 0.1 | | |
| | | $I_{233}$ | 5 | 2 | 6 | 8 | 4 | 0.3 | | |
| | | $I_{234}$ | 9 | 2 | 6 | 10 | 4 | 0.4 | | |
| | $I_{24}$ | $I_{241}$ | 7 | 10 | 5 | 10 | 8 | 0.5 | 0.1 | |

***Company (C)***

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_1$ | $I_{11}$ | $I_{111}$ | 8 | 3 | 6 | 6 | 4 | 0.2 | 0.3 | 0.2 |
| | | $I_{112}$ | 4 | 4 | 5 | 4 | 3 | 0.2 | | |
| | | $I_{113}$ | 7 | 7 | 5 | 5 | 4 | 0.2 | | |
| | | $I_{114}$ | 5 | 5 | 5 | 8 | 4 | 0.4 | | |
| | $I_{12}$ | $I_{121}$ | 3 | 5 | 5 | 4 | 4 | 0.5 | 0.1 | |
| | | $I_{122}$ | 3 | 8 | 2 | 6 | 2 | 0.3 | | |
| | | $I_{123}$ | 5 | 8 | 3 | 0 | 3 | 0.2 | | |
| | $I_{13}$ | $I_{131}$ | 5 | 2 | 5 | 0 | 3 | 0.3 | 0.2 | |
| | | $I_{132}$ | 3 | 3 | 3 | 2 | 4 | 0.2 | | |
| | | $I_{133}$ | 4 | 7 | 5 | 1 | 2 | 0.1 | | |
| | | $I_{134}$ | 6 | 3 | 5 | 3 | 4 | 0.4 | | |
| | $I_{14}$ | $I_{141}$ | 8 | 6 | 6 | 7 | 5 | 0.4 | 0.2 | |
| | | $I_{142}$ | 7 | 5 | 7 | 6 | 4 | 0.3 | | |
| | | $I_{143}$ | 6 | 3 | 6 | 2 | 3 | 0.2 | | |
| | | $I_{144}$ | 3 | 5 | 2 | 1 | 2 | 0.1 | | |
| | $I_{15}$ | $I_{151}$ | 8 | 3 | 4 | 3 | 5 | 0.3 | 0.1 | |
| | | $I_{152}$ | 7 | 3 | 2 | 5 | 2 | 0.3 | | |
| | | $I_{153}$ | 9 | 3 | 2 | 4 | 6 | 0.4 | | |
| | $I_{16}$ | $I_{161}$ | 6 | 3 | 1 | 0 | 2 | 0.1 | 0.1 | |
| | | $I_{162}$ | 3 | 3 | 3 | 4 | 4 | 0.3 | | |
| | | $I_{163}$ | 3 | 5 | 4 | 7 | 5 | 0.3 | | |
| | | $I_{164}$ | 5 | 7 | 4 | 8 | 5 | 0.3 | | |
| $I_2$ | $I_{21}$ | $I_{211}$ | 2 | 2 | 2 | 1 | 4 | 0.2 | 0.2 | 0.2 |
| | | $I_{212}$ | 1 | 3 | 2 | 2 | 4 | 0.3 | | |
| | | $I_{213}$ | 4 | 4 | 4 | 2 | 5 | 0.5 | | |
| | $I_{22}$ | $I_{221}$ | 1 | 5 | 4 | 7 | 3 | 0.2 | 0.3 | |
| | | $I_{222}$ | 6 | 3 | 6 | 5 | 4 | 0.2 | | |
| | | $I_{223}$ | 1 | 3 | 6 | 2 | 5 | 0.4 | | |
| | | $I_{224}$ | 2 | 5 | 5 | 3 | 4 | 0.2 | | |
| | $I_{23}$ | $I_{231}$ | 3 | 5 | 4 | 2 | 6 | 0.1 | 0.3 | |
| | | $I_{232}$ | 0 | 6 | 4 | 6 | 4 | 0.1 | | |
| | | $I_{233}$ | 4 | 4 | 6 | 3 | 4 | 0.4 | | |
| | | $I_{234}$ | 7 | 5 | 6 | 4 | 6 | 0.4 | | |
| | $I_{24}$ | $I_{241}$ | 5 | 4 | 6 | 4 | 6 | 0.5 | 0.2 | |

| Company (A) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
| | | $I_{242}$ | 7 | 8 | 8 | 8 | 7 | 0.3 | | |
| $I_3$ | $I_{31}$ | $I_{311}$ | 8 | 6 | 8 | 8 | 7 | 0.1 | 0.2 | 0.1 |
| | | $I_{312}$ | 6 | 5 | 7 | 6 | 7 | 0.1 | | |
| | | $I_{313}$ | 6 | 6 | 5 | 7 | 6 | 0.1 | | |
| | | $I_{314}$ | 6 | 7 | 7 | 7 | 7 | 0.3 | | |
| | | $I_{315}$ | 10 | 8 | 9 | 9 | 8 | 0.4 | | |
| | $I_{32}$ | $I_{321}$ | 8 | 7 | 8 | 9 | 8 | 0.3 | 0.8 | |
| | | $I_{322}$ | 8 | 8 | 9 | 8 | 9 | 0.5 | | |
| | | $I_{323}$ | 9 | 7 | 8 | 8 | 9 | 0.2 | | |
| $I_4$ | $I_{41}$ | $I_{411}$ | 8 | 6 | 7 | 8 | 9 | 0.3 | 0.2 | 0.4 |
| | | $I_{412}$ | 8 | 7 | 8 | 8 | 8 | 0.3 | | |
| | | $I_{413}$ | 8 | 6 | 8 | 7 | 8 | 0.4 | | |
| | $I_{42}$ | $I_{421}$ | 8 | 7 | 8 | 7 | 8 | 0.3 | 0.2 | |
| | | $I_{422}$ | 7 | 6 | 7 | 8 | 6 | 0.2 | | |
| | | $I_{423}$ | 10 | 8 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{424}$ | 9 | 8 | 8 | 8 | 9 | 0.2 | | |
| | $I_{43}$ | $I_{431}$ | 8 | 7 | 9 | 8 | 9 | 0.3 | 0.1 | |
| | | $I_{432}$ | 8 | 7 | 8 | 8 | 7 | 0.2 | | |
| | | $I_{433}$ | 8 | 7 | 9 | 9 | 7 | 0.3 | | |
| | | $I_{434}$ | 10 | 8 | 8 | 8 | 9 | 0.2 | | |
| | $I_{44}$ | $I_{441}$ | 8 | 8 | 8 | 7 | 8 | 0.2 | 0.2 | |
| | | $I_{442}$ | 8 | 7 | 9 | 8 | 8 | 0.3 | | |
| | | $I_{443}$ | 7 | 6 | 7 | 7 | 7 | 0.3 | | |
| | | $I_{444}$ | 7 | 6 | 8 | 7 | 6 | 0.2 | | |
| | $I_{45}$ | $I_{451}$ | 9 | 8 | 8 | 8 | 8 | 0.4 | 0.1 | |
| | | $I_{452}$ | 9 | 8 | 7 | 7 | 9 | 0.3 | | |
| | | $I_{453}$ | 8 | 7 | 8 | 9 | 8 | 0.3 | | |
| | $I_{46}$ | $I_{461}$ | 8 | 7 | 8 | 8 | 7 | 0.2 | 0.2 | |
| | | $I_{462}$ | 9 | 8 | 8 | 9 | 9 | 0.3 | | |
| | | $I_{463}$ | 7 | 7 | 7 | 8 | 6 | 0.3 | | |
| | | $I_{464}$ | 8 | 6 | 8 | 7 | 7 | 0.2 | | |
| $I_5$ | $I_{51}$ | $I_{511}$ | 10 | 8 | 9 | 8 | 10 | 0.5 | 0.4 | 0.2 |
| | | $I_{512}$ | 8 | 7 | 8 | 9 | 9 | 0.5 | | |
| | $I_{52}$ | $I_{521}$ | 9 | 8 | 8 | 9 | 8 | 0.4 | 0.3 | |
| | | $I_{522}$ | 9 | 8 | 8 | 9 | 8 | 0.4 | | |
| | | $I_{523}$ | 7 | 7 | 7 | 8 | 7 | 0.2 | | |
| | $I_{53}$ | $I_{531}$ | 9 | 8 | 8 | 9 | 8 | 0.4 | 0.3 | |
| | | $I_{532}$ | 9 | 8 | 7 | 8 | 8 | 0.4 | | |
| | | $I_{533}$ | 8 | 7 | 8 | 9 | 7 | 0.2 | | |

| Company (B) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
| | | $I_{242}$ | 9 | 10 | 7 | 10 | 9 | 0.5 | | |
| $I_3$ | $I_{31}$ | $I_{311}$ | 5 | 2 | 8 | 8 | 6 | 0.3 | 0.5 | 0.2 |
| | | $I_{312}$ | 7 | 7 | 9 | 10 | 7 | 0.2 | | |
| | | $I_{313}$ | 3 | 2 | 2 | 7 | 2 | 0.1 | | |
| | | $I_{314}$ | 4 | 0 | 4 | 10 | 3 | 0.1 | | |
| | | $I_{315}$ | 7 | 2 | 2 | 8 | 8 | 0.3 | | |
| | $I_{32}$ | $I_{321}$ | 5 | 2 | 3 | 8 | 5 | 0.3 | 0.5 | |
| | | $I_{322}$ | 4 | 2 | 2 | 9 | 5 | 0.2 | | |
| | | $I_{323}$ | 8 | 7 | 9 | 10 | 9 | 0.5 | | |
| $I_4$ | $I_{41}$ | $I_{411}$ | 7 | 5 | 7 | 10 | 8 | 0.3 | 0.2 | 0.2 |
| | | $I_{412}$ | 7 | 5 | 8 | 10 | 6 | 0.4 | | |
| | | $I_{413}$ | 6 | 8 | 8 | 10 | 7 | 0.3 | | |
| | $I_{42}$ | $I_{421}$ | 2 | 2 | 7 | 0 | 1 | 0.2 | 0.2 | |
| | | $I_{422}$ | 8 | 3 | 6 | 6 | 4 | 0.3 | | |
| | | $I_{423}$ | 9 | 10 | 9 | 10 | 9 | 0.3 | | |
| | | $I_{424}$ | 9 | 5 | 6 | 8 | 7 | 0.2 | | |
| | $I_{43}$ | $I_{431}$ | 9 | 10 | 7 | 10 | 9 | 0.3 | 0.1 | |
| | | $I_{432}$ | 7 | 3 | 8 | 10 | 8 | 0.2 | | |
| | | $I_{433}$ | 7 | 7 | 3 | 8 | 7 | 0.3 | | |
| | | $I_{434}$ | 6 | 5 | 2 | 6 | 4 | 0.2 | | |
| | $I_{44}$ | $I_{441}$ | 5 | 6 | 8 | 8 | 6 | 0.3 | 0.1 | |
| | | $I_{442}$ | 7 | 4 | 3 | 8 | 8 | 0.2 | | |
| | | $I_{443}$ | 8 | 7 | 9 | 9 | 9 | 0.3 | | |
| | | $I_{444}$ | 5 | 7 | 7 | 10 | 7 | 0.2 | | |
| | $I_{45}$ | $I_{451}$ | 5 | 3 | 1 | 6 | 4 | 0.1 | 0.2 | |
| | | $I_{452}$ | 9 | 3 | 9 | 10 | 10 | 0.6 | | |
| | | $I_{453}$ | 9 | 10 | 8 | 8 | 9 | 0.3 | | |
| | $I_{46}$ | $I_{461}$ | 8 | 8 | 8 | 10 | 9 | 0.2 | 0.2 | |
| | | $I_{462}$ | 9 | 8 | 9 | 10 | 9 | 0.4 | | |
| | | $I_{463}$ | 9 | 10 | 9 | 10 | 10 | 0.3 | | |
| | | $I_{464}$ | 4 | 2 | 6 | 10 | 2 | 0.1 | | |
| $I_5$ | $I_{51}$ | $I_{511}$ | 9 | 10 | 7 | 10 | 9 | 0.6 | 0.4 | 0.2 |
| | | $I_{512}$ | 9 | 9 | 9 | 10 | 10 | 0.4 | | |
| | $I_{52}$ | $I_{521}$ | 5 | 9 | 8 | 10 | 6 | 0.4 | 0.1 | |
| | | $I_{522}$ | 7 | 5 | 7 | 10 | 5 | 0.4 | | |
| | | $I_{523}$ | 7 | 1 | 2 | 8 | 6 | 0.2 | | |
| | $I_{53}$ | $I_{531}$ | 9 | 10 | 9 | 9 | 9 | 0.5 | 0.5 | |
| | | $I_{532}$ | 9 | 0 | 4 | 10 | 5 | 0.2 | | |
| | | $I_{533}$ | 9 | 0 | 8 | 10 | 7 | 0.3 | | |

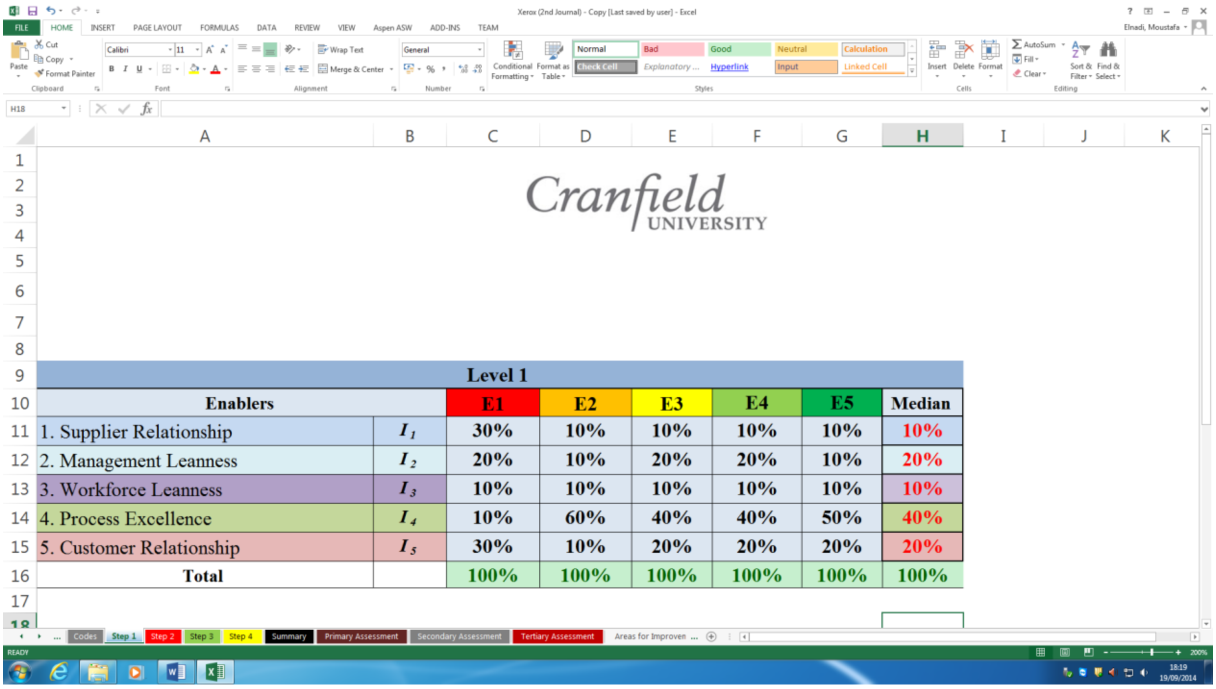
| Company (C) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
| | | $I_{242}$ | 5 | 5 | 5 | 3 | 6 | 0.5 | | |
| $I_3$ | $I_{31}$ | $I_{311}$ | 4 | 7 | 6 | 3 | 6 | 0.2 | 0.5 | 0.2 |
| | | $I_{312}$ | 4 | 6 | 6 | 5 | 5 | 0.2 | | |
| | | $I_{313}$ | 1 | 2 | 2 | 0 | 3 | 0.1 | | |
| | | $I_{314}$ | 3 | 5 | 6 | 4 | 2 | 0.3 | | |
| | | $I_{315}$ | 2 | 3 | 6 | 2 | 3 | 0.2 | | |
| | $I_{32}$ | $I_{321}$ | 4 | 6 | 6 | 5 | 6 | 0.3 | 0.5 | |
| | | $I_{322}$ | 4 | 5 | 2 | 4 | 2 | 0.5 | | |
| | | $I_{323}$ | 7 | 7 | 5 | 7 | 4 | 0.2 | | |
| $I_4$ | $I_{41}$ | $I_{411}$ | 6 | 3 | 6 | 5 | 3 | 0.4 | 0.2 | 0.2 |
| | | $I_{412}$ | 7 | 4 | 4 | 4 | 5 | 0.4 | | |
| | | $I_{413}$ | 3 | 3 | 4 | 7 | 4 | 0.2 | | |
| | $I_{42}$ | $I_{421}$ | 1 | 1 | 2 | 3 | 1 | 0.2 | 0.2 | |
| | | $I_{422}$ | 2 | 2 | 4 | 2 | 1 | 0.3 | | |
| | | $I_{423}$ | 5 | 5 | 5 | 4 | 4 | 0.3 | | |
| | | $I_{424}$ | 5 | 5 | 4 | 6 | 3 | 0.2 | | |
| | $I_{43}$ | $I_{431}$ | 2 | 4 | 5 | 5 | 6 | 0.3 | 0.1 | |
| | | $I_{432}$ | 2 | 2 | 6 | 7 | 3 | 0.2 | | |
| | | $I_{433}$ | 3 | 2 | 2 | 7 | 5 | 0.2 | | |
| | | $I_{434}$ | 2 | 7 | 4 | 3 | 2 | 0.3 | | |
| | $I_{44}$ | $I_{441}$ | 5 | 3 | 2 | 1 | 3 | 0.3 | 0.2 | |
| | | $I_{442}$ | 3 | 3 | 2 | 3 | 2 | 0.2 | | |
| | | $I_{443}$ | 5 | 3 | 4 | 4 | 3 | 0.3 | | |
| | | $I_{444}$ | 4 | 2 | 4 | 2 | 4 | 0.2 | | |
| | $I_{45}$ | $I_{451}$ | 7 | 2 | 5 | 6 | 4 | 0.4 | 0.1 | |
| | | $I_{452}$ | 6 | 6 | 5 | 4 | 6 | 0.2 | | |
| | | $I_{453}$ | 5 | 6 | 6 | 7 | 3 | 0.4 | | |
| | $I_{46}$ | $I_{461}$ | 7 | 7 | 3 | 8 | 7 | 0.3 | 0.2 | |
| | | $I_{462}$ | 3 | 2 | 4 | 1 | 3 | 0.3 | | |
| | | $I_{463}$ | 4 | 1 | 2 | 1 | 2 | 0.2 | | |
| | | $I_{464}$ | 2 | 1 | 2 | 2 | 1 | 0.2 | | |
| $I_5$ | $I_{51}$ | $I_{511}$ | 4 | 6 | 5 | 4 | 5 | 0.6 | 0.2 | 0.2 |
| | | $I_{512}$ | 7 | 4 | 5 | 6 | 3 | 0.4 | | |
| | $I_{52}$ | $I_{521}$ | 5 | 2 | 5 | 5 | 2 | 0.3 | 0.3 | |
| | | $I_{522}$ | 5 | 6 | 4 | 3 | 3 | 0.2 | | |
| | | $I_{523}$ | 3 | 5 | 4 | 6 | 3 | 0.5 | | |
| | $I_{53}$ | $I_{531}$ | 7 | 5 | 6 | 4 | 4 | 0.6 | 0.5 | |
| | | $I_{532}$ | 6 | 8 | 5 | 4 | 4 | 0.2 | | |
| | | $I_{533}$ | 8 | 7 | 5 | 6 | 3 | 0.2 | | |

### 6.4.2.1 Assessment of Company (A) PSS Leanness

***Step (1) Computing the relative importance (weight) for each enabler, criterion, and attribute***

Because of the small sample size, median has been used instead of the mean in calculating the relative importance in order to avoid the effect of the outliers and sensitivity to extreme values pertaining to mean.

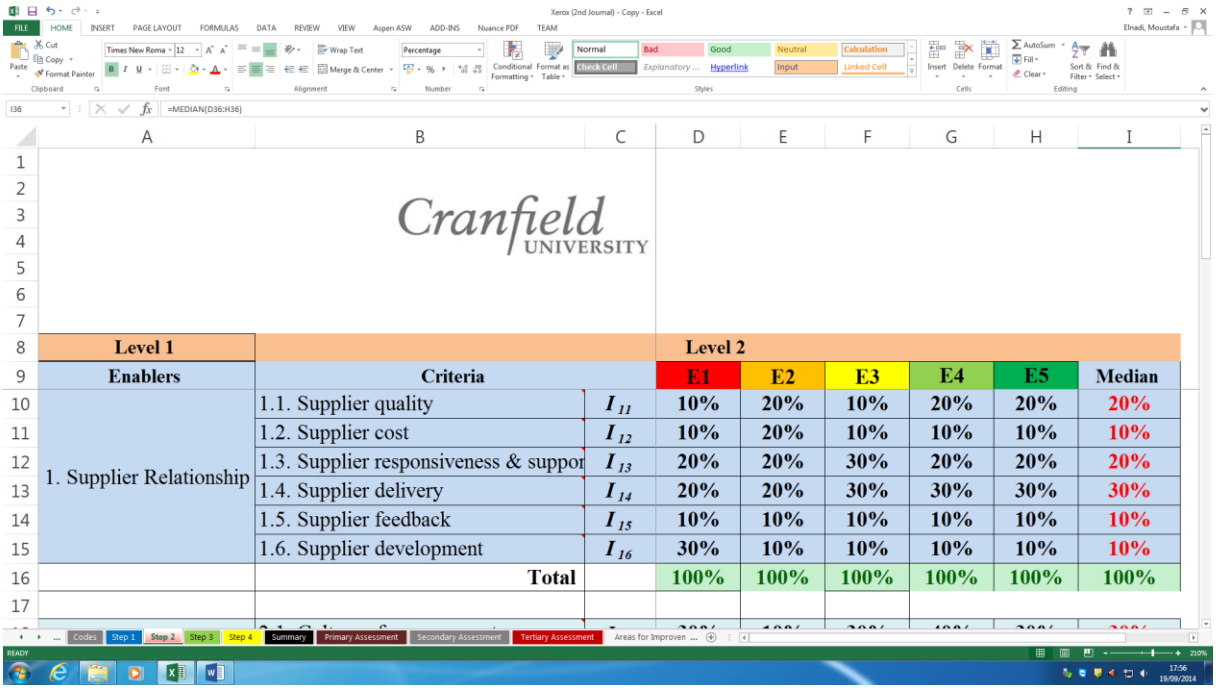
By calculating the median for each enabler, the relative importance of each enabler was computed. For example, the relative importance given by the experts for the supplier relationship enabler was: 30%, 10%, 10%, 10% and 10%. By using the median, the relative importance (weight) for supplier relationship was 10% as presented in Figure 6.11. Using the same procedures, the relative importance for the remaining enablers was computed.



| Level 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Enablers | | E1 | E2 | E3 | E4 | E5 | Median |
| 1. Supplier Relationship | $I_1$ | 30% | 10% | 10% | 10% | 10% | 10% |
| 2. Management Leanness | $I_2$ | 20% | 10% | 20% | 20% | 10% | 20% |
| 3. Workforce Leanness | $I_3$ | 10% | 10% | 10% | 10% | 10% | 10% |
| 4. Process Excellence | $I_4$ | 10% | 60% | 40% | 40% | 50% | 40% |
| 5. Customer Relationship | $I_5$ | 30% | 10% | 20% | 20% | 20% | 20% |
| Total | | 100% | 100% | 100% | 100% | 100% | 100% |

**Figure 6.11 Weights of Company (A) Enablers**

Moving to the second level in the assessment, the relative importance for each criterion was computed using the median also. For example, the weights given by company (A) experts for the supplier quality criterion were: 10%, 20%, 10%, 20% and 20% as shown in Figure 6.12. Thus, the relative importance of the supplier quality criterion was calculated to be 20% using median.

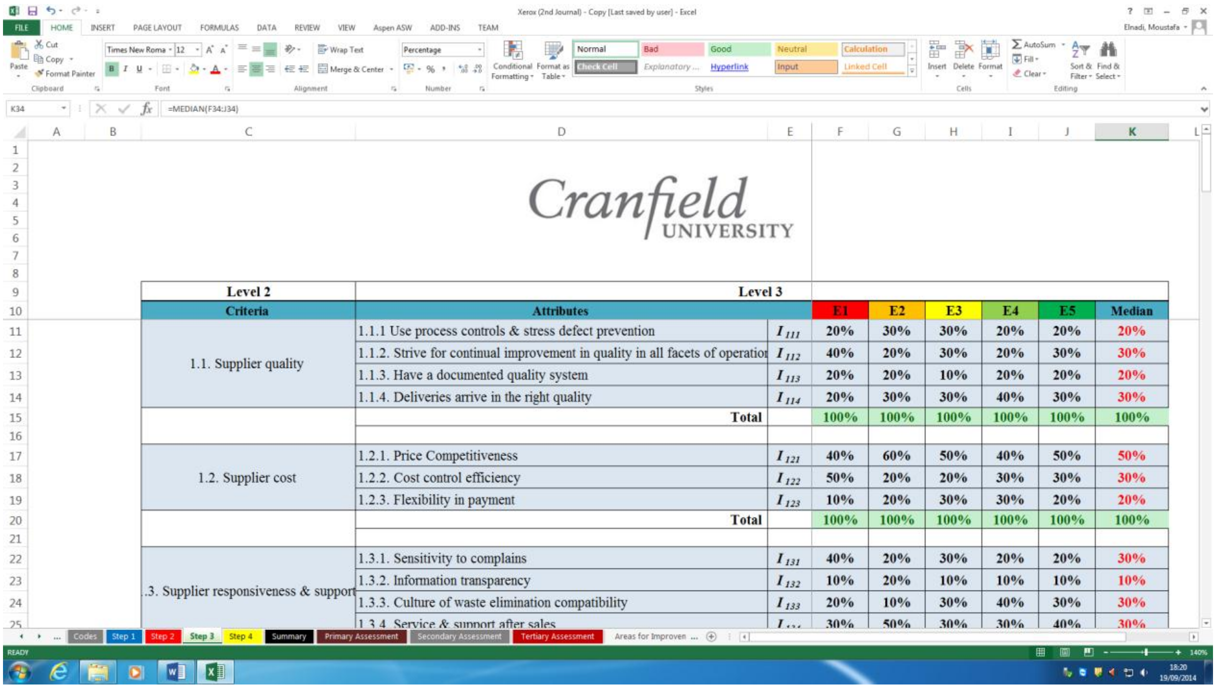


| Level 1 | | | Level 2 | | | | | |
|---|---|---|---|---|---|---|---|---|
| Enablers | Criteria | | E1 | E2 | E3 | E4 | E5 | Median |
| 1. Supplier Relationship | 1.1. Supplier quality | $I_{11}$ | 10% | 20% | 10% | 20% | 20% | 20% |
| | 1.2. Supplier cost | $I_{12}$ | 10% | 20% | 10% | 10% | 10% | 10% |
| | 1.3. Supplier responsiveness & suppor | $I_{13}$ | 20% | 20% | 30% | 20% | 20% | 20% |
| | 1.4. Supplier delivery | $I_{14}$ | 20% | 20% | 30% | 30% | 30% | 30% |
| | 1.5. Supplier feedback | $I_{15}$ | 10% | 10% | 10% | 10% | 10% | 10% |
| | 1.6. Supplier development | $I_{16}$ | 30% | 10% | 10% | 10% | 10% | 10% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |

**Figure 6.12 Weights of Company (A) Criteria**

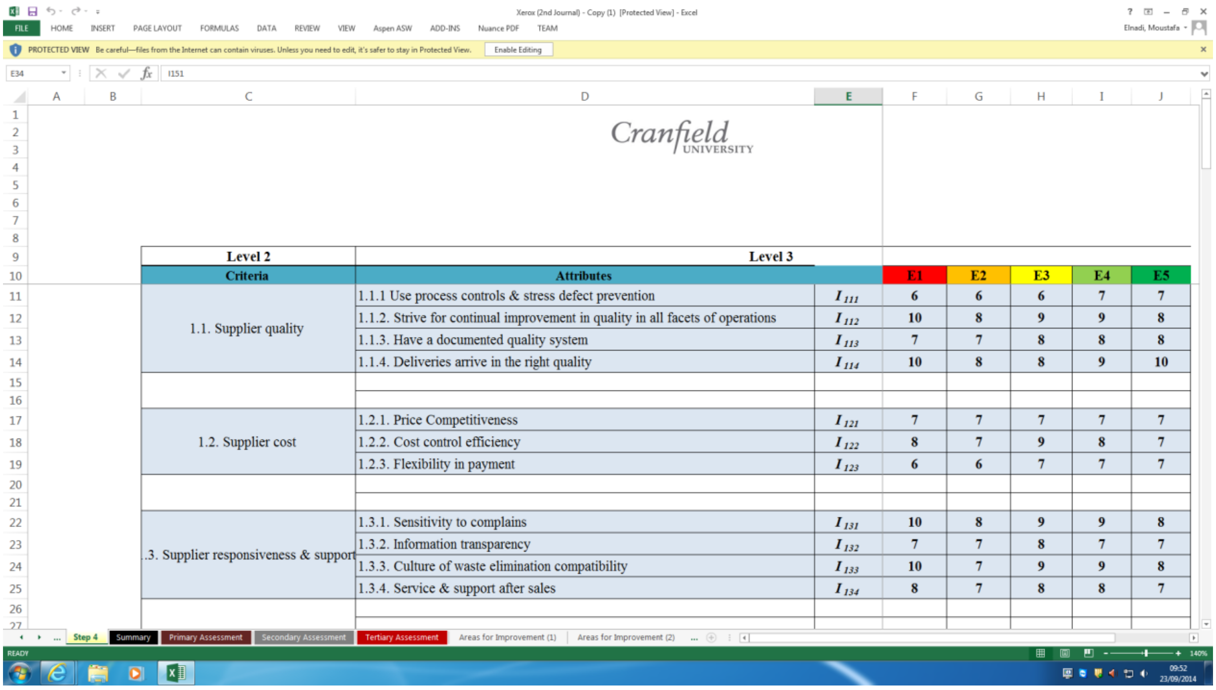
Using the same procedures, the relative importance (weight) for each attributes was calculated as shown in Figure 6.13. Finally, all the assessment scores provided by each expert were collected as presented in Figure 6.14**.**

All the relative importance (weights) computed for the enablers, criteria and attributes, as well as, all the assessment scores of each attribute collected from company (A) experts are presented in Table 6.4.



| Level 2 Criteria | Level 3 Attributes | | E1 | E2 | E3 | E4 | E5 | Median |
|---|---|---|---|---|---|---|---|---|
| 1.1. Supplier quality | 1.1.1 Use process controls & stress defect prevention | $I_{111}$ | 20% | 30% | 30% | 20% | 20% | 20% |
| | 1.1.2. Strive for continual improvement in quality in all facets of operatio | $I_{112}$ | 40% | 20% | 30% | 20% | 30% | 30% |
| | 1.1.3. Have a documented quality system | $I_{113}$ | 20% | 20% | 10% | 20% | 20% | 20% |
| | 1.1.4. Deliveries arrive in the right quality | $I_{114}$ | 20% | 30% | 30% | 40% | 30% | 30% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |
| 1.2. Supplier cost | 1.2.1. Price Competitiveness | $I_{121}$ | 40% | 60% | 50% | 40% | 50% | 50% |
| | 1.2.2. Cost control efficiency | $I_{122}$ | 50% | 20% | 20% | 30% | 30% | 30% |
| | 1.2.3. Flexibility in payment | $I_{123}$ | 10% | 20% | 30% | 30% | 20% | 20% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |
| .3. Supplier responsiveness & support | 1.3.1. Sensitivity to complains | $I_{131}$ | 40% | 20% | 30% | 20% | 20% | 30% |
| | 1.3.2. Information transparency | $I_{132}$ | 10% | 20% | 10% | 10% | 10% | 10% |
| | 1.3.3. Culture of waste elimination compatibility | $I_{133}$ | 20% | 10% | 30% | 40% | 30% | 30% |
| | 1.3.4. Service & support after sales | | 30% | 50% | 30% | 30% | 40% | 30% |

**Figure 6.13 Weights of Company (A) Attributes**



| Level 2 Criteria | Level 3 Attributes | | E1 | E2 | E3 | E4 | E5 |
|---|---|---|---|---|---|---|---|
| 1.1. Supplier quality | 1.1.1 Use process controls & stress defect prevention | $I_{111}$ | 6 | 6 | 6 | 7 | 7 |
| | 1.1.2. Strive for continual improvement in quality in all facets of operations | $I_{112}$ | 10 | 8 | 9 | 9 | 8 |
| | 1.1.3. Have a documented quality system | $I_{113}$ | 7 | 7 | 8 | 8 | 8 |
| | 1.1.4. Deliveries arrive in the right quality | $I_{114}$ | 10 | 8 | 8 | 9 | 10 |
| 1.2. Supplier cost | 1.2.1. Price Competitiveness | $I_{121}$ | 7 | 7 | 7 | 7 | 7 |
| | 1.2.2. Cost control efficiency | $I_{122}$ | 8 | 7 | 9 | 8 | 7 |
| | 1.2.3. Flexibility in payment | $I_{123}$ | 6 | 6 | 7 | 7 | 7 |
| .3. Supplier responsiveness & support | 1.3.1. Sensitivity to complains | $I_{131}$ | 10 | 8 | 9 | 9 | 8 |
| | 1.3.2. Information transparency | $I_{132}$ | 7 | 7 | 8 | 7 | 7 |
| | 1.3.3. Culture of waste elimination compatibility | $I_{133}$ | 10 | 7 | 9 | 9 | 8 |
| | 1.3.4. Service & support after sales | $I_{134}$ | 8 | 7 | 8 | 8 | 7 |

**Figure 6.14 Assessment Scores for Company (A)**

**Table 6.4 Weights and Assessment Scores for Company (A)**
**Refer to Table 6.2 for Enablers, Criteria and attributes**

**Legend:** $\boldsymbol{I_i}$= Enabler index; $\boldsymbol{I_{ij}}$ = Criterion index; $\boldsymbol{I_{ijk}}$ = Attribute index; $\boldsymbol{E_i}$ = Experts participated in the assessment; $\boldsymbol{W_{ij}}$ = Attribute weight; $\boldsymbol{W_i}$ = Criterion weight; $\boldsymbol{W}$ = Enabler weight

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_1$ | $I_{11}$ | $I_{111}$ | 6 | 6 | 6 | 7 | 7 | 0.2 | 0.2 | 0.1 |
| | | $I_{112}$ | 10 | 8 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{113}$ | 7 | 7 | 8 | 8 | 8 | 0.2 | | |
| | | $I_{114}$ | 10 | 8 | 8 | 9 | 10 | 0.3 | | |
| | $I_{12}$ | $I_{121}$ | 7 | 7 | 7 | 7 | 7 | 0.5 | 0.1 | |
| | | $I_{122}$ | 8 | 7 | 9 | 8 | 7 | 0.3 | | |
| | | $I_{123}$ | 6 | 6 | 7 | 7 | 7 | 0.2 | | |
| | $I_{13}$ | $I_{131}$ | 10 | 8 | 9 | 9 | 8 | 0.3 | 0.2 | |
| | | $I_{132}$ | 7 | 7 | 8 | 7 | 7 | 0.1 | | |
| | | $I_{133}$ | 10 | 7 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{134}$ | 8 | 7 | 8 | 8 | 7 | 0.3 | | |
| | $I_{14}$ | $I_{141}$ | 8 | 7 | 8 | 8 | 7 | 0.3 | 0.3 | |
| | | $I_{142}$ | 9 | 7 | 8 | 9 | 8 | 0.3 | | |
| | | $I_{143}$ | 7 | 6 | 7 | 8 | 8 | 0.2 | | |
| | | $I_{144}$ | 8 | 7 | 8 | 8 | 9 | 0.2 | | |
| | $I_{15}$ | $I_{151}$ | 8 | 7 | 7 | 8 | 8 | 0.2 | 0.1 | |
| | | $I_{152}$ | 8 | 7 | 7 | 9 | 8 | 0.4 | | |
| | | $I_{153}$ | 8 | 8 | 9 | 7 | 8 | 0.4 | | |
| | $I_{16}$ | $I_{161}$ | 7 | 6 | 7 | 8 | 6 | 0.1 | 0.1 | |
| | | $I_{162}$ | 7 | 7 | 7 | 7 | 7 | 0.4 | | |
| | | $I_{163}$ | 8 | 7 | 8 | 9 | 8 | 0.2 | | |
| | | $I_{164}$ | 8 | 6 | 8 | 8 | 7 | 0.3 | | |
| $I_2$ | $I_{21}$ | $I_{211}$ | 10 | 9 | 10 | 10 | 10 | 0.3 | 0.3 | 0.2 |
| | | $I_{212}$ | 10 | 8 | 10 | 9 | 9 | 0.4 | | |
| | | $I_{213}$ | 10 | 9 | 10 | 9 | 10 | 0.3 | | |
| | $I_{22}$ | $I_{221}$ | 8 | 7 | 9 | 8 | 8 | 0.4 | 0.3 | |
| | | $I_{222}$ | 8 | 7 | 8 | 7 | 8 | 0.2 | | |
| | | $I_{223}$ | 7 | 6 | 8 | 7 | 7 | 0.3 | | |
| | | $I_{224}$ | 6 | 5 | 7 | 7 | 6 | 0.1 | | |
| | $I_{23}$ | $I_{231}$ | 10 | 9 | 9 | 10 | 8 | 0.3 | 0.2 | |
| | | $I_{232}$ | 8 | 8 | 7 | 7 | 8 | 0.1 | | |
| | | $I_{233}$ | 8 | 6 | 8 | 6 | 7 | 0.2 | | |
| | | $I_{234}$ | 8 | 7 | 8 | 7 | 8 | 0.4 | | |
| | $I_{24}$ | $I_{241}$ | 8 | 8 | 9 | 8 | 9 | 0.7 | 0.2 | |
| | | $I_{242}$ | 7 | 8 | 8 | 8 | 7 | 0.3 | | |

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_3$ | $I_{31}$ | $I_{311}$ | 8 | 6 | 8 | 8 | 7 | 0.1 | 0.2 | 0.1 |
| | | $I_{312}$ | 6 | 5 | 7 | 6 | 7 | 0.1 | | |
| | | $I_{313}$ | 6 | 6 | 5 | 7 | 6 | 0.1 | | |
| | | $I_{314}$ | 6 | 7 | 7 | 7 | 7 | 0.3 | | |
| | | $I_{315}$ | 10 | 8 | 9 | 9 | 8 | 0.4 | | |
| | $I_{32}$ | $I_{321}$ | 8 | 7 | 8 | 9 | 8 | 0.3 | 0.8 | |
| | | $I_{322}$ | 8 | 8 | 9 | 8 | 9 | 0.5 | | |
| | | $I_{323}$ | 9 | 7 | 8 | 8 | 9 | 0.2 | | |
| $I_4$ | $I_{41}$ | $I_{411}$ | 8 | 6 | 7 | 8 | 9 | 0.3 | 0.2 | 0.4 |
| | | $I_{412}$ | 8 | 7 | 8 | 8 | 8 | 0.3 | | |
| | | $I_{413}$ | 8 | 6 | 8 | 7 | 8 | 0.4 | | |
| | $I_{42}$ | $I_{421}$ | 8 | 7 | 8 | 7 | 8 | 0.3 | 0.2 | |
| | | $I_{422}$ | 7 | 6 | 7 | 8 | 6 | 0.2 | | |
| | | $I_{423}$ | 10 | 8 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{424}$ | 9 | 8 | 8 | 8 | 9 | 0.2 | | |
| | $I_{43}$ | $I_{431}$ | 8 | 7 | 9 | 8 | 9 | 0.3 | 0.1 | |
| | | $I_{432}$ | 8 | 7 | 8 | 8 | 7 | 0.2 | | |
| | | $I_{433}$ | 8 | 7 | 9 | 9 | 7 | 0.3 | | |
| | | $I_{434}$ | 10 | 8 | 8 | 8 | 9 | 0.2 | | |
| | $I_{44}$ | $I_{441}$ | 8 | 8 | 8 | 7 | 8 | 0.2 | 0.2 | |
| | | $I_{442}$ | 8 | 7 | 9 | 8 | 8 | 0.3 | | |
| | | $I_{443}$ | 7 | 6 | 7 | 7 | 7 | 0.3 | | |
| | | $I_{444}$ | 7 | 6 | 8 | 7 | 6 | 0.2 | | |
| | $I_{45}$ | $I_{451}$ | 9 | 8 | 8 | 8 | 8 | 0.4 | 0.1 | |
| | | $I_{452}$ | 9 | 8 | 7 | 7 | 9 | 0.3 | | |
| | | $I_{453}$ | 8 | 7 | 8 | 9 | 8 | 0.3 | | |
| | $I_{46}$ | $I_{461}$ | 8 | 7 | 8 | 8 | 7 | 0.2 | 0.2 | |
| | | $I_{462}$ | 9 | 8 | 8 | 9 | 9 | 0.3 | | |
| | | $I_{463}$ | 7 | 7 | 7 | 8 | 6 | 0.3 | | |
| | | $I_{464}$ | 8 | 6 | 8 | 7 | 7 | 0.2 | | |
| $I_5$ | $I_{51}$ | $I_{511}$ | 10 | 8 | 9 | 8 | 10 | 0.5 | 0.4 | 0.2 |
| | | $I_{512}$ | 8 | 7 | 8 | 9 | 9 | 0.5 | | |
| | $I_{52}$ | $I_{521}$ | 9 | 8 | 8 | 9 | 8 | 0.4 | 0.3 | |
| | | $I_{522}$ | 9 | 8 | 8 | 9 | 8 | 0.4 | | |
| | | $I_{523}$ | 7 | 7 | 7 | 8 | 7 | 0.2 | | |
| | $I_{53}$ | $I_{531}$ | 9 | 8 | 8 | 9 | 8 | 0.4 | 0.3 | |
| | | $I_{532}$ | 9 | 8 | 7 | 8 | 8 | 0.4 | | |
| | | $I_{533}$ | 8 | 7 | 8 | 9 | 7 | 0.2 | | |

***Step (2) Computing the index belonging to each criterion***

The index pertaining to each criterion will be calculated using the following equation:

$$\boldsymbol{I_{ij} = W_{ij} \times R_{ij}}$$

For example, the calculation related to supplier quality criterion for company (A) is shown as follows:

Weights pertaining to the supplier quality criterion $\mathrm{W}_{11} = (0.2, 0.3, 0.2, 0.3)$

Assessment scores pertaining to the supplier quality criterion is given by:

$$\mathbf{R_{11}} = \begin{bmatrix} \mathbf{6} & \mathbf{6} & \mathbf{6} & \mathbf{7} & \mathbf{7} \\ \mathbf{10} & \mathbf{8} & \mathbf{9} & \mathbf{9} & \mathbf{8} \\ \mathbf{7} & \mathbf{7} & \mathbf{8} & \mathbf{8} & \mathbf{8} \\ \mathbf{10} & \mathbf{8} & \mathbf{8} & \mathbf{9} & \mathbf{10} \end{bmatrix}$$

Index pertaining to the supplier quality criterion for company (A) is given by

$$\boldsymbol{I_{11} = W_{11} \times R_{11}}$$

$$\mathbf{I_{11}} = (\mathbf{8.6}, \mathbf{7.4}, \mathbf{7.9}, \mathbf{8.4}, \mathbf{8.4})$$

Using the same procedures, the indices pertaining to the remaining lean criteria have been computed as presented in Table 6.5

**Table 6.5 Indices of the Criteria for Company (A)**

**$E_i$ = Experts participated in the assessment**

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ |
|---|---|---|---|---|---|
| $I_{11}$ | 8.6 | 7.4 | 7.9 | 8.4 | 8.4 |
| $I_{12}$ | 7.1 | 6.8 | 7.6 | 7.3 | 7 |
| $I_{13}$ | 9.1 | 7.3 | 8.6 | 8.5 | 7.6 |
| $I_{14}$ | 8.1 | 6.8 | 7.8 | 8.3 | 7.9 |
| $I_{15}$ | 8 | 7.4 | 7.8 | 8 | 8 |
| $I_{16}$ | 7.5 | 6.6 | 7.5 | 7.8 | 7.1 |
| $I_{21}$ | 10 | 8.6 | 10 | 9.3 | 9.6 |
| $I_{22}$ | 7.5 | 6.5 | 8.3 | 7.4 | 7.5 |
| $I_{23}$ | 8.6 | 7.5 | 8.2 | 7.7 | 7.8 |
| $I_{24}$ | 7.7 | 8 | 8.7 | 8 | 8.4 |

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ |
|---|---|---|---|---|---|
| $I_{31}$ | 7.8 | 7 | 7.7 | 7.8 | 7.3 |
| $I_{32}$ | 8.2 | 7.5 | 8.5 | 8.3 | 8.7 |
| $I_{41}$ | 8 | 6.3 | 7.7 | 7.6 | 8.3 |
| $I_{42}$ | 8.6 | 7.3 | 8.1 | 8 | 7.8 |
| $I_{43}$ | 8.4 | 7.2 | 8.6 | 8.3 | 8 |
| $I_{44}$ | 7.5 | 6.7 | 8 | 7.3 | 7.3 |
| $I_{45}$ | 8.7 | 7.7 | 7.7 | 8 | 8.3 |
| $I_{46}$ | 8 | 7.1 | 7.7 | 8.1 | 7.3 |
| $I_{51}$ | 9 | 7.5 | 8.5 | 8.5 | 9.5 |
| $I_{52}$ | 8.6 | 7.8 | 7.8 | 8.8 | 7.8 |
| $I_{53}$ | 8.8 | 7.8 | 7.6 | 8.6 | 7.8 |

***Step (3) Computing the indices belonging to each enabler***

The index pertaining to each enabler will be calculated using the following equation:

$$\boldsymbol{I_i = W_i \times R_i}$$

For example, the calculation related to the supplier relationship enabler for company (A) is given by:

$$\boldsymbol{I_1 = W_1 \times R_1}$$

Weight pertaining to the supplier relationship enabler is given by:

$$\mathbf{W_1} = (\mathbf{0.2, 0.1, 0.2, 0.3, 0.1, 0.1})$$

Assessment scores pertaining to the supplier relationship enabler is given by:

$$\mathbf{R_1} = \begin{bmatrix} \mathbf{8.6} & \mathbf{7.4} & \mathbf{7.9} & \mathbf{8.4} & \mathbf{8.4} \\ \mathbf{7.1} & \mathbf{6.8} & \mathbf{7.6} & \mathbf{7.3} & \mathbf{7} \\ \mathbf{9.1} & \mathbf{7.3} & \mathbf{8.6} & \mathbf{8.5} & \mathbf{7.6} \\ \mathbf{8.1} & \mathbf{6.8} & \mathbf{7.8} & \mathbf{8.3} & \mathbf{7.9} \\ \mathbf{8} & \mathbf{7.4} & \mathbf{7.8} & \mathbf{8} & \mathbf{8} \\ \mathbf{7.5} & \mathbf{6.6} & \mathbf{7.5} & \mathbf{7.8} & \mathbf{7.1} \end{bmatrix}$$

Index pertaining to the supplier relationship for company (A) enabler is given by:

$$\boldsymbol{I_1 = W_1 \times R_1}$$

$\mathbf{I_1} = (\mathbf{8.23, 7.06, 7.93, 8.18, 7.78})$

Using the same principle, the following indices have been calculated for remaining lean enablers for company (A) as in Table 6.6

**Table 6.6 Indices of the Enablers for Company (A)**

**$E_i$ = Experts participated in the assessment**

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ |
|---|---|---|---|---|---|
| $I_1$ | 8.23 | 7.06 | 7.93 | 8.18 | 7.78 |
| $I_2$ | 8.51 | 7.63 | 8.87 | 8.15 | 8.37 |
| $I_3$ | 8.12 | 7.4 | 8.34 | 8.2 | 8.42 |
| $I_4$ | 8.13 | 6.97 | 7.93 | 7.83 | 7.77 |
| $I_5$ | 8.82 | 7.68 | 8.02 | 8.62 | 8.48 |

***Step (4) Computing PSS Leanness Index for Company (A)***

The PSS Leanness Index for company (A) was computed using the following equation:

$$\boldsymbol{I = W \times R}$$

The PSS leanness index for company (A) has been computed as:

Overall weight $\mathbf{W} = (\mathbf{0.1, 0.2, 0.1, 0.4, 0.2})$

Overall assessment vector $\mathbf{R} = \begin{bmatrix} \mathbf{8.23} & \mathbf{7.06} & \mathbf{7.93} & \mathbf{8.18} & \mathbf{7.78} \\ \mathbf{8.51} & \mathbf{7.63} & \mathbf{8.87} & \mathbf{8.15} & \mathbf{8.37} \\ \mathbf{8.12} & \mathbf{7.4} & \mathbf{8.34} & \mathbf{8.2} & \mathbf{8.42} \\ \mathbf{8.13} & \mathbf{6.97} & \mathbf{7.93} & \mathbf{7.83} & \mathbf{7.77} \\ \mathbf{8.82} & \mathbf{7.68} & \mathbf{8.02} & \mathbf{8.62} & \mathbf{8.48} \end{bmatrix}$

Company (A) PSS leanness index has been calculated as:

$\boldsymbol{I = W \times R}$

$\mathbf{I} = (\mathbf{8.353, 7.296, 8.177, 8.124, 8.098})$

$\mathbf{I} = \frac{\mathbf{1}}{\mathbf{5}}(\mathbf{8.353 + 7.296 + 8.177 + 8.124 + 8.098})$

$\mathbf{I = 8.0096}$

The PSS Leanness Index computed for company (A) is approximately 8.

All the indices and weights calculated for company (A) enablers and criteria are presented in Figures 6.15, 16, 17, 18, 19 and 20 respectively.

For company (A), the most important enabler is process excellence with a relative importance of 40% and an index of 7.7. These results matches with the results in chapter 5, where the most important enabler for implementing lean practices in PSS was work processes. However process excellence is considered the most important enabler for company (A), the performance of company (A) with respect to this enabler is the lowest compared to other enablers. The least important enablers for company (A) are supplier relationship and workforce leanness with a relative importance of 10%. The performance of company (A) in management leanness and customer relationship is the highest with an index of 8.3. Full detailed explanation of the performance of company (A) with respect to all the enablers, criteria, and attributes will be discussed later in this chapter.

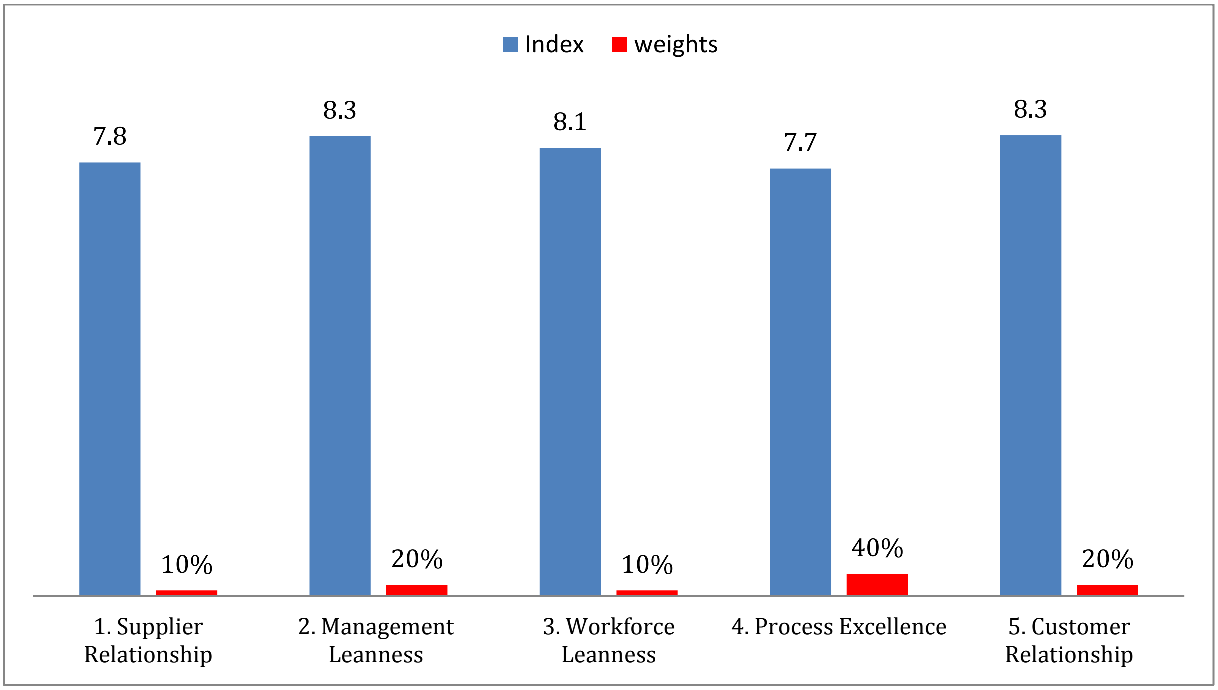



**Figure 6.15 Weights and Indices for Company (A) Enablers**

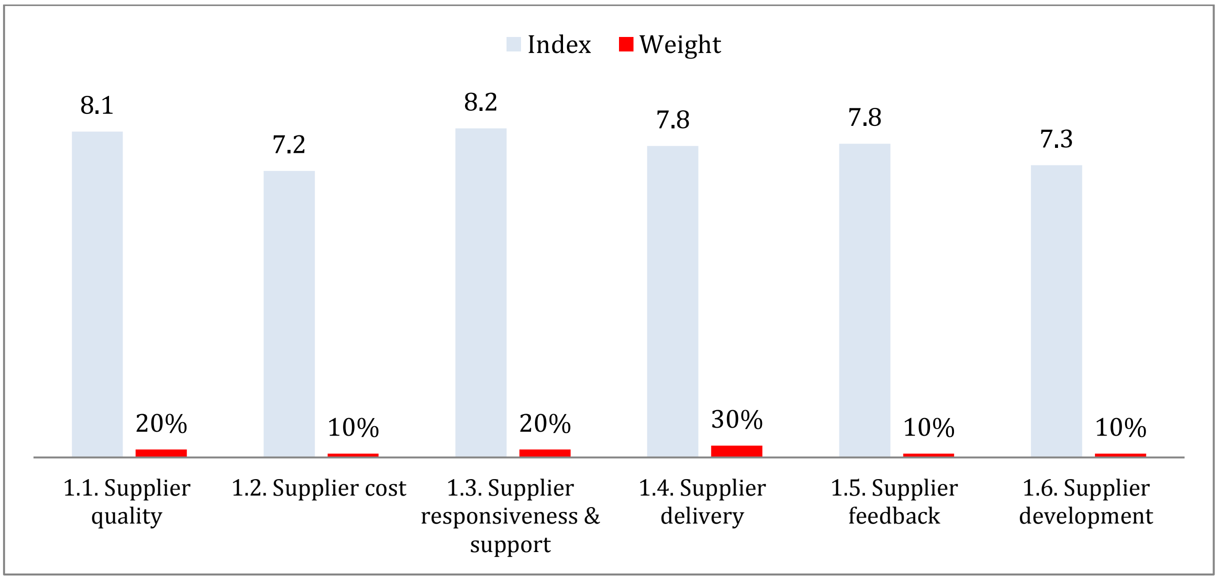



**Figure 6.16 Weights and Indices of Supplier Relationship Criteria (Company A)**

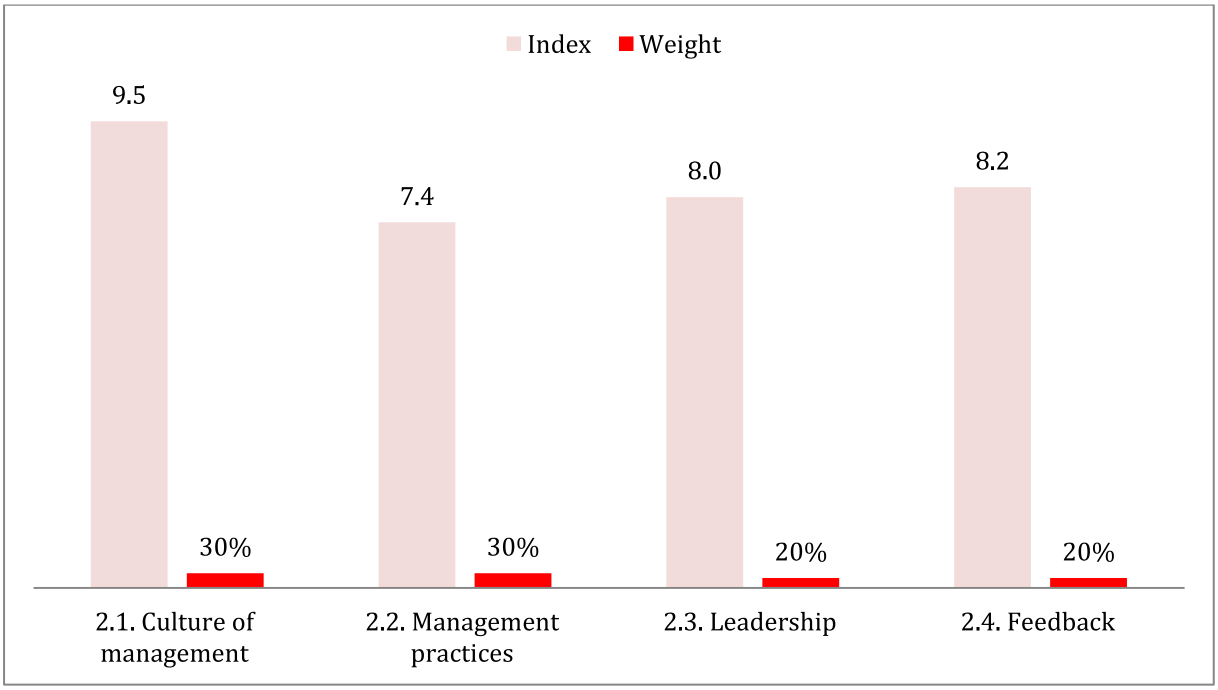



**Figure 6.17 Weights and Indices of Management Leanness Criteria (Company A)**

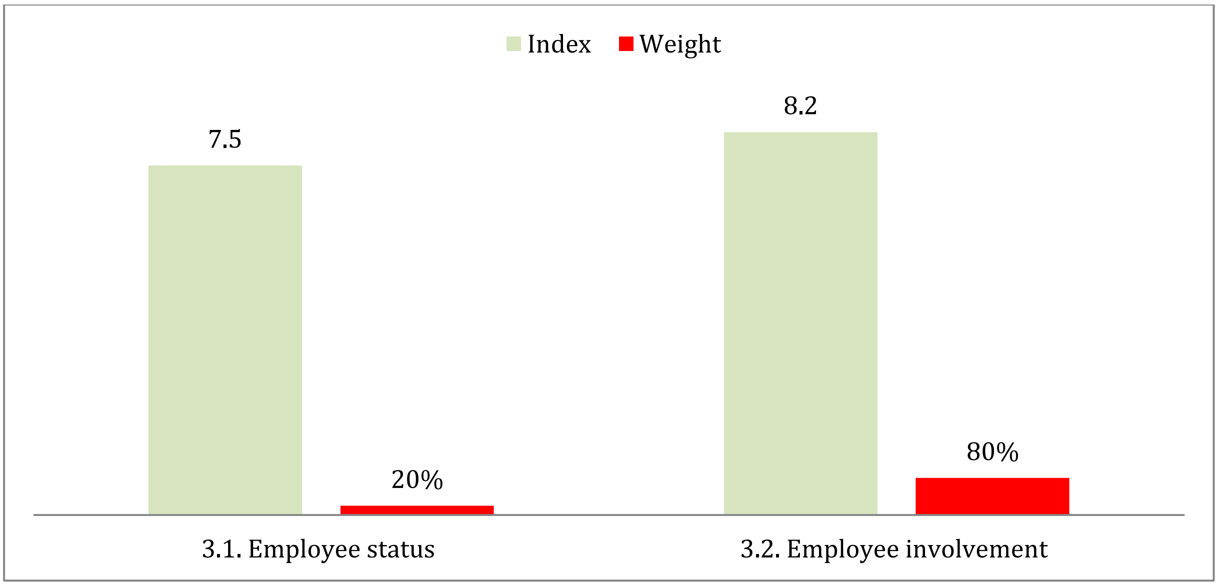



**Figure 6.18 Weights and Indices of Workforce Leanness Criteria (Company A)**

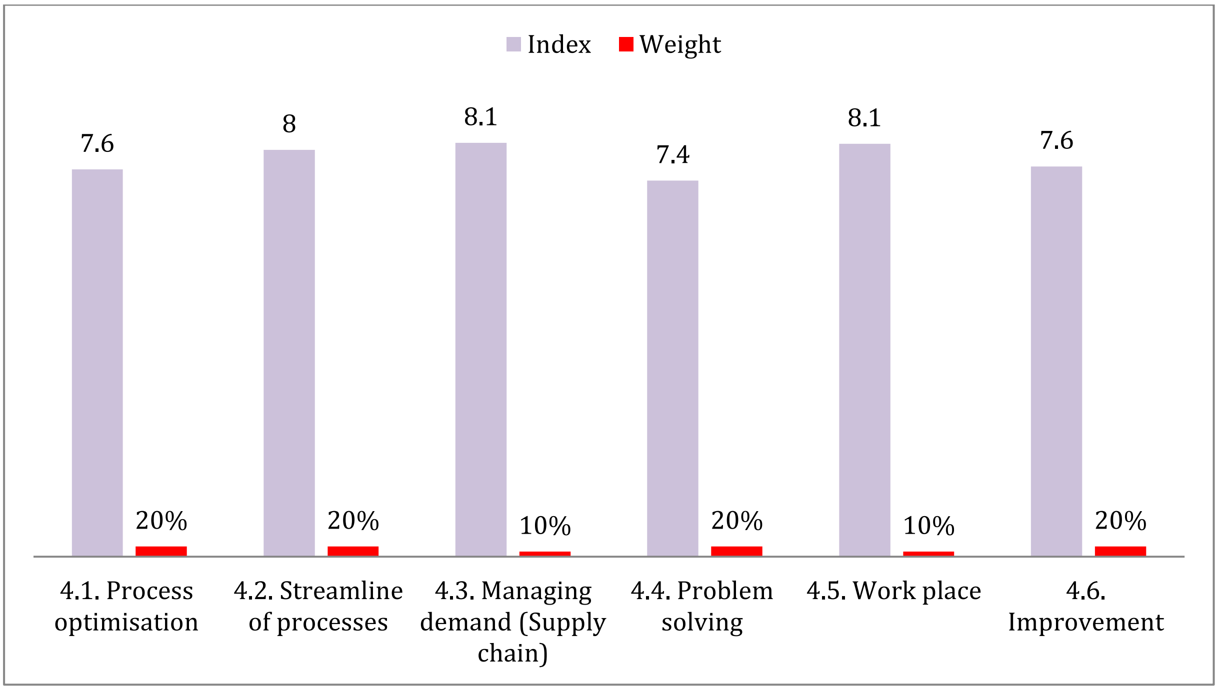



**Figure 6.19 Weights and Indices of Process Excellence Criteria (Company A)**

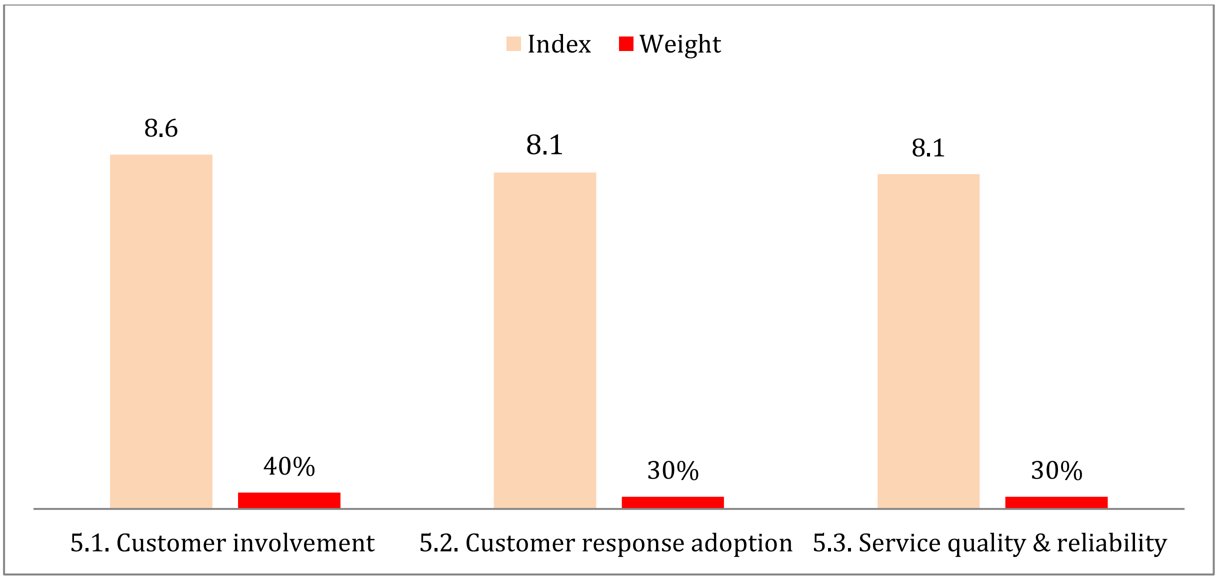


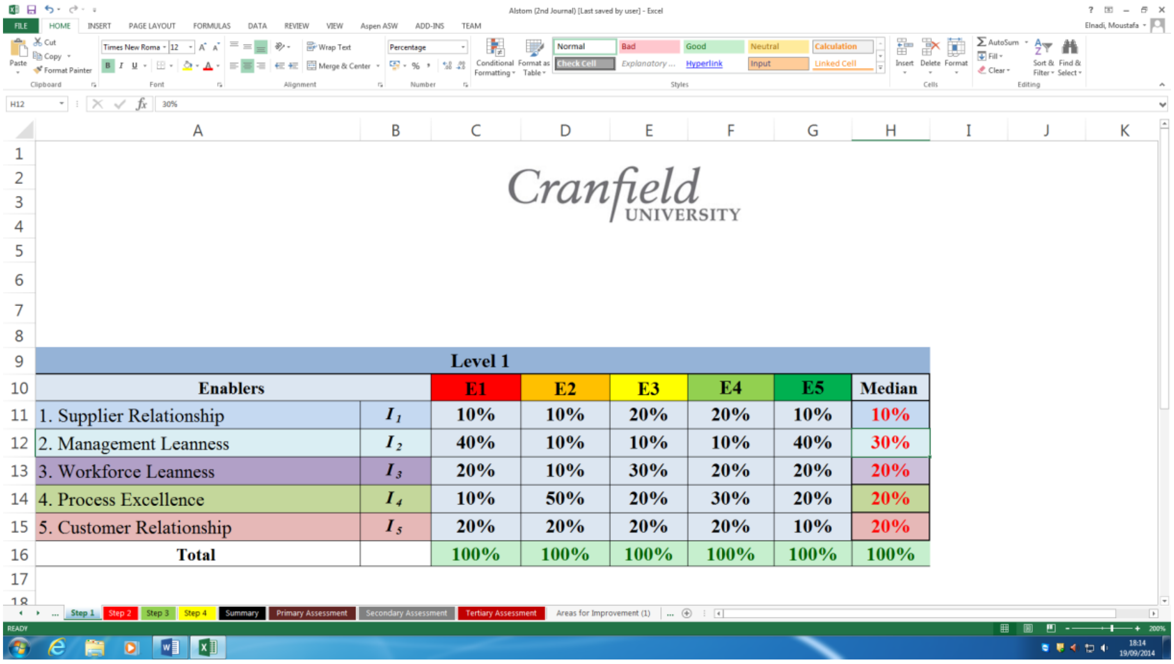

**Figure 6.20 Weights and Indices of Customer Relationship Criteria (Company A)**

### 6.4.2.2 Assessment of Company (B) PSS Leanness

***Step (1) Computing the relative importance (weight) for each enabler, criterion, and attribute***

As mentioned before in calculating PSS leanness index for company (A), median has been used instead of the mean in calculating the relative importance in order to avoid the effect of the outliers and sensitivity to extreme values pertaining to mean.

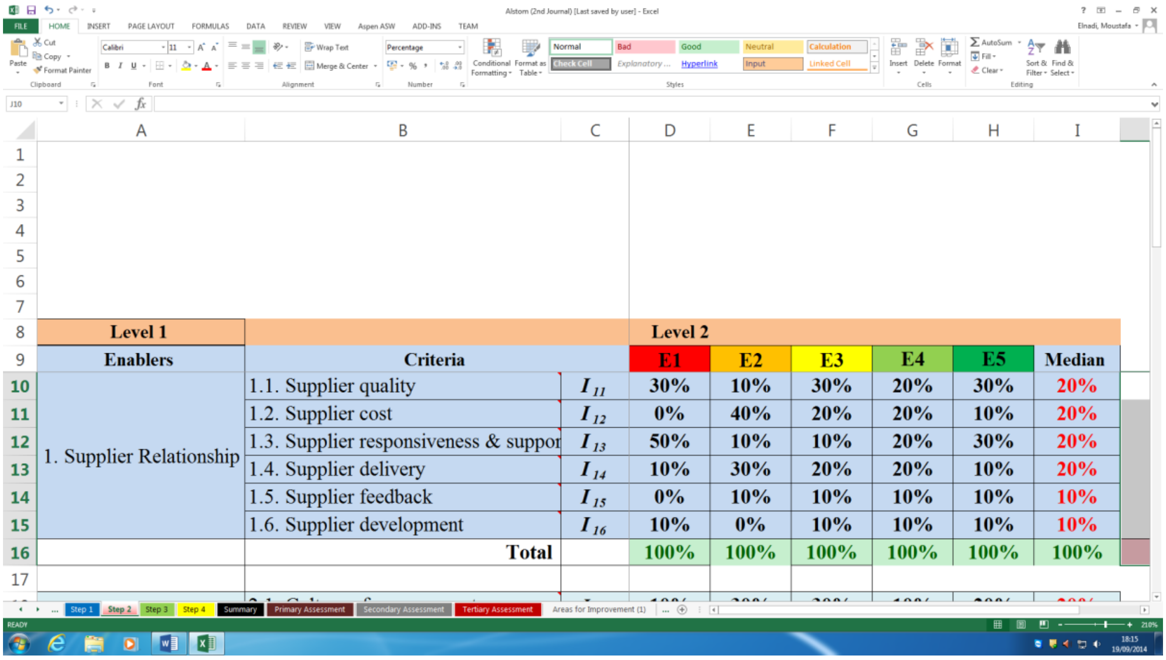
By calculating the median for each enabler, the relative importance of each enabler was computed. For example, the relative importance given by the experts for the supplier relationship enabler was: 10%, 10%, 20%, 20% and 10%. By using median, the relative importance (weight) for supplier relationship was 10% as presented in Figure 6.21. Using the same procedures, the relative importance for the remaining enablers was computed.



| Level 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Enablers | | E1 | E2 | E3 | E4 | E5 | Median |
| 1. Supplier Relationship | $I_1$ | 10% | 10% | 20% | 20% | 10% | 10% |
| 2. Management Leanness | $I_2$ | 40% | 10% | 10% | 10% | 40% | 30% |
| 3. Workforce Leanness | $I_3$ | 20% | 10% | 30% | 20% | 20% | 20% |
| 4. Process Excellence | $I_4$ | 10% | 50% | 20% | 30% | 20% | 20% |
| 5. Customer Relationship | $I_5$ | 20% | 20% | 20% | 20% | 10% | 20% |
| Total | | 100% | 100% | 100% | 100% | 100% | 100% |

**Figure 6.21 Weights of Company (B) Enablers**

Moving to the second level in the assessment, the relative importance for each criterion was computed. For example, the weights given by company (B) experts for the supplier quality criterion were: 30%, 10%, 30%, 20% and 30% as shown in Figure 6.22. Thus, the relative importance of the supplier quality criterion was calculated to be 20% using median.

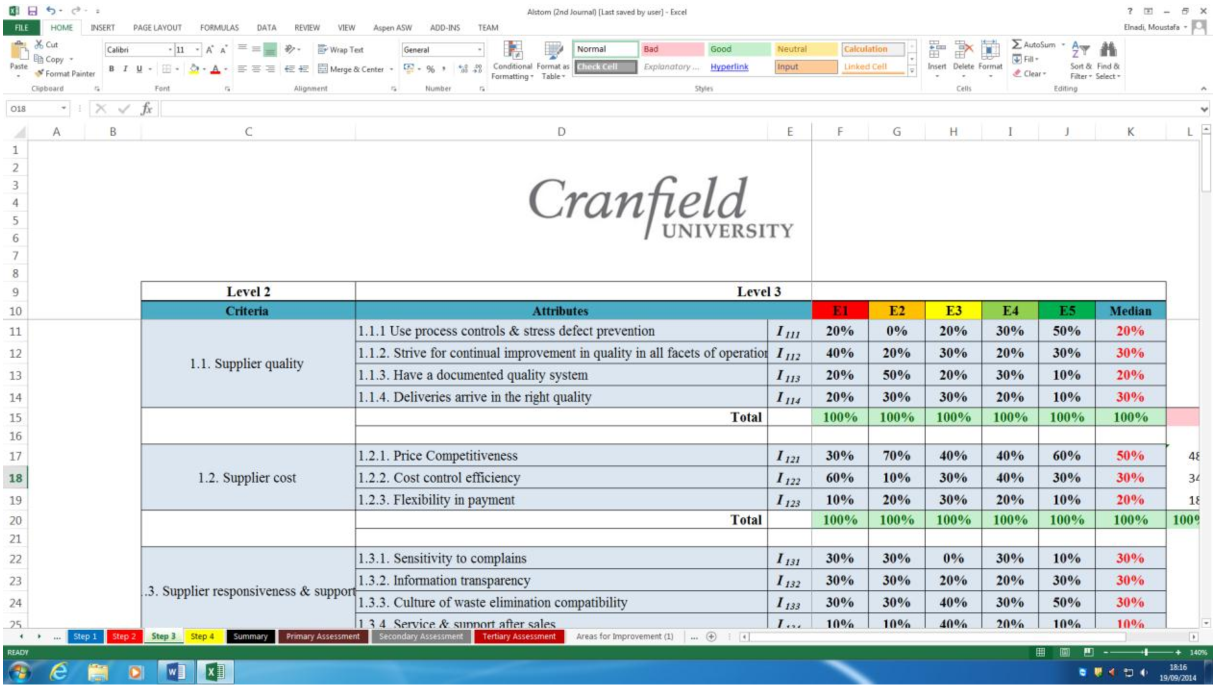


| Level 1 | | | Level 2 | | | | | |
|---|---|---|---|---|---|---|---|---|
| Enablers | Criteria | | E1 | E2 | E3 | E4 | E5 | Median |
| 1. Supplier Relationship | 1.1. Supplier quality | $I_{11}$ | 30% | 10% | 30% | 20% | 30% | 20% |
| | 1.2. Supplier cost | $I_{12}$ | 0% | 40% | 20% | 20% | 10% | 20% |
| | 1.3. Supplier responsiveness & suppor | $I_{13}$ | 50% | 10% | 10% | 20% | 30% | 20% |
| | 1.4. Supplier delivery | $I_{14}$ | 10% | 30% | 20% | 20% | 10% | 20% |
| | 1.5. Supplier feedback | $I_{15}$ | 0% | 10% | 10% | 10% | 10% | 10% |
| | 1.6. Supplier development | $I_{16}$ | 10% | 0% | 10% | 10% | 10% | 10% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |

**Figure 6.22 Weights of Company (B) Criteria**

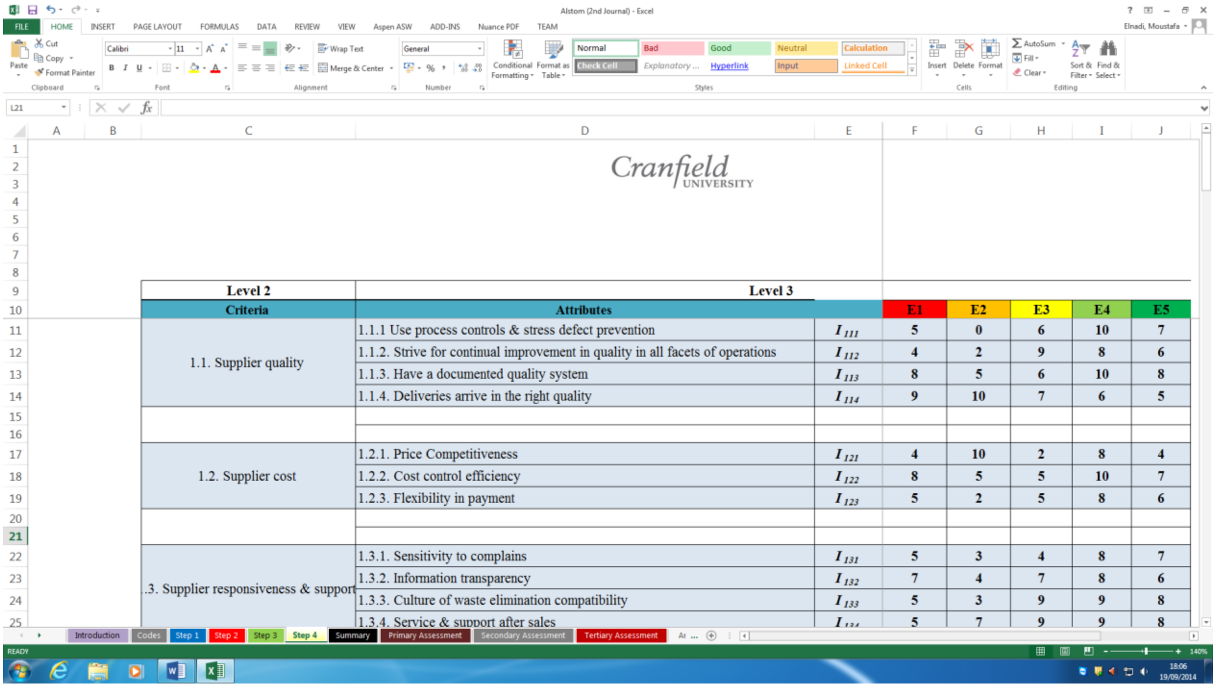
Using the same procedures, the relative importance (weight) for each attributes was calculated as shown in Figure 6.23. Finally, all the assessment scores provided by each expert were collected as presented in Figure 6.24.

Table 6.7 presents a summary of the relative importance (weights) computed for the enablers, criteria and attributes and all the assessment scores of each attribute collected from company (B) experts.



| Level 2 | Level 3 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Criteria | Attributes | | E1 | E2 | E3 | E4 | E5 | Median |
| 1.1. Supplier quality | 1.1.1 Use process controls & stress defect prevention | $I_{111}$ | 20% | 0% | 20% | 30% | 50% | 20% |
| | 1.1.2. Strive for continual improvement in quality in all facets of operatior | $I_{112}$ | 40% | 20% | 30% | 20% | 30% | 30% |
| | 1.1.3. Have a documented quality system | $I_{113}$ | 20% | 50% | 20% | 30% | 10% | 20% |
| | 1.1.4. Deliveries arrive in the right quality | $I_{114}$ | 20% | 30% | 30% | 20% | 10% | 30% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |
| 1.2. Supplier cost | 1.2.1. Price Competitiveness | $I_{121}$ | 30% | 70% | 40% | 40% | 60% | 50% |
| | 1.2.2. Cost control efficiency | $I_{122}$ | 60% | 10% | 30% | 40% | 30% | 30% |
| | 1.2.3. Flexibility in payment | $I_{123}$ | 10% | 20% | 30% | 20% | 10% | 20% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |
| .3. Supplier responsiveness & support | 1.3.1. Sensitivity to complains | $I_{131}$ | 30% | 30% | 0% | 30% | 10% | 30% |
| | 1.3.2. Information transparency | $I_{132}$ | 30% | 30% | 20% | 20% | 30% | 30% |
| | 1.3.3. Culture of waste elimination compatibility | $I_{133}$ | 30% | 30% | 40% | 30% | 50% | 30% |
| | 1.3.4. Service & support after sales | | 10% | 10% | 40% | 20% | 10% | 10% |

Figure 6.23 Weights of Company (B) Attributes



| Level 2 Criteria | Level 3 Attributes | | E1 | E2 | E3 | E4 | E5 |
|---|---|---|---|---|---|---|---|
| 1.1. Supplier quality | 1.1.1 Use process controls & stress defect prevention | $I_{111}$ | 5 | 0 | 6 | 10 | 7 |
| | 1.1.2. Strive for continual improvement in quality in all facets of operations | $I_{112}$ | 4 | 2 | 9 | 8 | 6 |
| | 1.1.3. Have a documented quality system | $I_{113}$ | 8 | 5 | 6 | 10 | 8 |
| | 1.1.4. Deliveries arrive in the right quality | $I_{114}$ | 9 | 10 | 7 | 6 | 5 |
| 1.2. Supplier cost | 1.2.1. Price Competitiveness | $I_{121}$ | 4 | 10 | 2 | 8 | 4 |
| | 1.2.2. Cost control efficiency | $I_{122}$ | 8 | 5 | 5 | 10 | 7 |
| | 1.2.3. Flexibility in payment | $I_{123}$ | 5 | 2 | 5 | 8 | 6 |
| .3. Supplier responsiveness & support | 1.3.1. Sensitivity to complains | $I_{131}$ | 5 | 3 | 4 | 8 | 7 |
| | 1.3.2. Information transparency | $I_{132}$ | 7 | 4 | 7 | 8 | 6 |
| | 1.3.3. Culture of waste elimination compatibility | $I_{133}$ | 5 | 3 | 9 | 9 | 8 |
| | 1.3.4. Service & support after sales | $I_{134}$ | 5 | 7 | 9 | 9 | 8 |

**Figure 6.24 Assessment Scores for Company (B)**

**Table 6.7 Weights and Assessment Scores for Company (B)**
**Refer to Table 6.2 for Enablers, Criteria and attributes**

**Legend:** $\boldsymbol{I_i}$= Enabler index; $\boldsymbol{I_{ij}}$ = Criterion index; $\boldsymbol{I_{ijk}}$ = Attribute index; $\boldsymbol{E_i}$ = Experts participated in the assessment; $\boldsymbol{W_{ij}}$ = Attribute weight; $\boldsymbol{W_i}$ = Criterion weight; $\boldsymbol{W}$ = Enabler weight

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_1$ | $I_{11}$ | $I_{111}$ | 5 | 0 | 6 | 10 | 7 | 0.2 | 0.2 | 0.1 |
| | | $I_{112}$ | 4 | 2 | 9 | 8 | 6 | 0.3 | | |
| | | $I_{113}$ | 8 | 5 | 6 | 10 | 8 | 0.2 | | |
| | | $I_{114}$ | 9 | 10 | 7 | 6 | 5 | 0.3 | | |
| | $I_{12}$ | $I_{121}$ | 4 | 10 | 2 | 8 | 4 | 0.5 | 0.2 | |
| | | $I_{122}$ | 8 | 5 | 5 | 10 | 7 | 0.3 | | |
| | | $I_{123}$ | 5 | 2 | 5 | 8 | 6 | 0.2 | | |
| | $I_{13}$ | $I_{131}$ | 5 | 3 | 4 | 8 | 7 | 0.3 | 0.2 | |
| | | $I_{132}$ | 7 | 4 | 7 | 8 | 6 | 0.3 | | |
| | | $I_{133}$ | 5 | 3 | 9 | 9 | 8 | 0.3 | | |
| | | $I_{134}$ | 5 | 7 | 9 | 9 | 8 | 0.1 | | |
| | $I_{14}$ | $I_{141}$ | 8 | 8 | 2 | 6 | 7 | 0.3 | 0.2 | |
| | | $I_{142}$ | 5 | 4 | 2 | 6 | 3 | 0.4 | | |
| | | $I_{143}$ | 6 | 2 | 4 | 8 | 5 | 0.1 | | |
| | | $I_{144}$ | 3 | 2 | 7 | 5 | 4 | 0.2 | | |
| | $I_{15}$ | $I_{151}$ | 7 | 3 | 8 | 7 | 6 | 0.2 | 0.1 | |

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $I_{152}$ | 5 | 3 | 7 | 7 | 5 | 0.4 | | |
| | | $I_{153}$ | 6 | 6 | 3 | 8 | 5 | 0.4 | | |
| | $I_{16}$ | $I_{161}$ | 3 | 1 | 1 | 0 | 2 | 0.1 | 0.1 | |
| | | $I_{162}$ | 6 | 3 | 6 | 10 | 8 | 0.3 | | |
| | | $I_{163}$ | 5 | 3 | 2 | 8 | 6 | 0.3 | | |
| | | $I_{164}$ | 5 | 3 | 6 | 8 | 5 | 0.3 | | |
| $I_2$ | $I_{21}$ | $I_{211}$ | 8 | 5 | 5 | 8 | 5 | 0.4 | 0.2 | 0.3 |
| | | $I_{212}$ | 8 | 7 | 6 | 8 | 7 | 0.3 | | |
| | | $I_{213}$ | 8 | 5 | 1 | 10 | 9 | 0.3 | | |
| | $I_{22}$ | $I_{221}$ | 9 | 10 | 7 | 10 | 8 | 0.5 | 0.3 | |
| | | $I_{222}$ | 7 | 4 | 6 | 10 | 7 | 0.2 | | |
| | | $I_{223}$ | 7 | 7 | 6 | 8 | 6 | 0.2 | | |
| | | $I_{224}$ | 7 | 5 | 3 | 6 | 5 | 0.1 | | |
| | $I_{23}$ | $I_{231}$ | 6 | 2 | 4 | 7 | 6 | 0.2 | 0.4 | |
| | | $I_{232}$ | 3 | 2 | 1 | 0 | 1 | 0.1 | | |
| | | $I_{233}$ | 5 | 2 | 6 | 8 | 4 | 0.3 | | |
| | | $I_{234}$ | 9 | 2 | 6 | 10 | 4 | 0.4 | | |
| | $I_{24}$ | $I_{241}$ | 7 | 10 | 5 | 10 | 8 | 0.5 | 0.1 | |
| | | $I_{242}$ | 9 | 10 | 7 | 10 | 9 | 0.5 | | |
| $I_3$ | $I_{31}$ | $I_{311}$ | 5 | 2 | 8 | 8 | 6 | 0.3 | 0.5 | 0.2 |
| | | $I_{312}$ | 7 | 7 | 9 | 10 | 7 | 0.2 | | |
| | | $I_{313}$ | 3 | 2 | 2 | 7 | 2 | 0.1 | | |
| | | $I_{314}$ | 4 | 0 | 4 | 10 | 3 | 0.1 | | |
| | | $I_{315}$ | 7 | 2 | 2 | 8 | 8 | 0.3 | | |
| | $I_{32}$ | $I_{321}$ | 5 | 2 | 3 | 8 | 5 | 0.3 | 0.5 | |
| | | $I_{322}$ | 4 | 2 | 2 | 9 | 5 | 0.2 | | |
| | | $I_{323}$ | 8 | 7 | 9 | 10 | 9 | 0.5 | | |
| $I_4$ | $I_{41}$ | $I_{411}$ | 7 | 5 | 7 | 10 | 8 | 0.3 | 0.2 | 0.2 |
| | | $I_{412}$ | 7 | 5 | 8 | 10 | 6 | 0.4 | | |
| | | $I_{413}$ | 6 | 8 | 8 | 10 | 7 | 0.3 | | |
| | $I_{42}$ | $I_{421}$ | 2 | 2 | 7 | 0 | 1 | 0.2 | 0.2 | |
| | | $I_{422}$ | 8 | 3 | 6 | 6 | 4 | 0.3 | | |
| | | $I_{423}$ | 9 | 10 | 9 | 10 | 9 | 0.3 | | |
| | | $I_{424}$ | 9 | 5 | 6 | 8 | 7 | 0.2 | | |
| | $I_{43}$ | $I_{431}$ | 9 | 10 | 7 | 10 | 9 | 0.3 | 0.1 | |
| | | $I_{432}$ | 7 | 3 | 8 | 10 | 8 | 0.2 | | |
| | | $I_{433}$ | 7 | 7 | 3 | 8 | 7 | 0.3 | | |
| | | $I_{434}$ | 6 | 5 | 2 | 6 | 4 | 0.2 | | |
| | $I_{44}$ | $I_{441}$ | 5 | 6 | 8 | 8 | 6 | 0.3 | 0.1 | |
| | | $I_{442}$ | 7 | 4 | 3 | 8 | 8 | 0.2 | | |
| | | $I_{443}$ | 8 | 7 | 9 | 9 | 9 | 0.3 | | |
| | | $I_{444}$ | 5 | 7 | 7 | 10 | 7 | 0.2 | | |
| | $I_{45}$ | $I_{451}$ | 5 | 3 | 1 | 6 | 4 | 0.1 | 0.2 | |

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $I_{452}$ | 9 | 3 | 9 | 10 | 10 | 0.6 | | |
| | | $I_{453}$ | 9 | 10 | 8 | 8 | 9 | 0.3 | | |
| | $I_{46}$ | $I_{461}$ | 8 | 8 | 8 | 10 | 9 | 0.2 | 0.2 | |
| | | $I_{462}$ | 9 | 8 | 9 | 10 | 9 | 0.4 | | |
| | | $I_{463}$ | 9 | 10 | 9 | 10 | 10 | 0.3 | | |
| | | $I_{464}$ | 4 | 2 | 6 | 10 | 2 | 0.1 | | |
| $I_5$ | $I_{51}$ | $I_{511}$ | 9 | 10 | 7 | 10 | 9 | 0.6 | 0.4 | 0.2 |
| | | $I_{512}$ | 9 | 9 | 9 | 10 | 10 | 0.4 | | |
| | $I_{52}$ | $I_{521}$ | 5 | 9 | 8 | 10 | 6 | 0.4 | 0.1 | |
| | | $I_{522}$ | 7 | 5 | 7 | 10 | 5 | 0.4 | | |
| | | $I_{523}$ | 7 | 1 | 2 | 8 | 6 | 0.2 | | |
| | $I_{53}$ | $I_{531}$ | 9 | 10 | 9 | 9 | 9 | 0.5 | 0.5 | |
| | | $I_{532}$ | 9 | 0 | 4 | 10 | 5 | 0.2 | | |
| | | $I_{533}$ | 9 | 0 | 8 | 10 | 7 | 0.3 | | |

***Step (2) Computing the index belonging to each criterion***

The index pertaining to each criterion will be calculated using the following equation:

$$\boldsymbol{I_{ij} = W_{ij} \times R_{ij}}$$

For example, the calculation related to supplier quality criterion for company (B) is shown as follows:

Weights pertaining to the supplier quality criterion $W_{11} = (0.2, 0.3, 0.2, 0.3)$

Assessment scores pertaining to the supplier quality criterion is given by:

$$\mathbf{R_{11}} = \begin{bmatrix} \mathbf{5} & \mathbf{0} & \mathbf{6} & \mathbf{10} & \mathbf{7} \\ \mathbf{4} & \mathbf{2} & \mathbf{9} & \mathbf{8} & \mathbf{6} \\ \mathbf{8} & \mathbf{5} & \mathbf{6} & \mathbf{10} & \mathbf{8} \\ \mathbf{9} & \mathbf{10} & \mathbf{7} & \mathbf{6} & \mathbf{5} \end{bmatrix}$$

Index pertaining to the supplier quality criterion for company (B) is given by

$$\boldsymbol{I_{11} = W_{11} \times R_{11}}$$

$$\mathbf{I_{11}} = (\mathbf{6.5}, \mathbf{4.6}, \mathbf{7.2}, \mathbf{8.2}, \mathbf{6.3})$$

Using the same procedures, the indices pertaining to the remaining lean criteria have been computed as presented in Table 6.8

**Table 6.8 Indices of the Criteria for Company (B)**

**$E_i$ = Experts participated in the assessment**

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ |
|---|---|---|---|---|---|
| $I_{11}$ | 6.5 | 4.6 | 7.2 | 8.2 | 6.3 |
| $I_{12}$ | 5.4 | 6.9 | 3.5 | 8.6 | 5.3 |
| $I_{13}$ | 5.6 | 3.7 | 6.9 | 8.4 | 7.1 |
| $I_{14}$ | 5.6 | 4.6 | 3.2 | 6 | 4.6 |
| $I_{15}$ | 5.8 | 4.2 | 5.6 | 7.4 | 5.2 |
| $I_{16}$ | 5.1 | 2.8 | 4.3 | 7.8 | 5.9 |
| $I_{21}$ | 8 | 5.6 | 4.1 | 8.6 | 6.8 |
| $I_{22}$ | 8 | 7.7 | 6.2 | 9.2 | 7.1 |
| $I_{23}$ | 6.6 | 2 | 5.1 | 7.8 | 4.1 |
| $I_{24}$ | 8 | 10 | 6 | 10 | 8.5 |
| $I_{31}$ | 5.7 | 2.8 | 5.4 | 8.5 | 6.1 |
| $I_{32}$ | 6.3 | 4.5 | 5.8 | 9.2 | 7 |
| $I_{41}$ | 6.7 | 5.9 | 7.7 | 10 | 6.9 |
| $I_{42}$ | 7.3 | 5.3 | 7.1 | 6.4 | 5.5 |
| $I_{43}$ | 7.4 | 6.7 | 5 | 8.6 | 7.2 |
| $I_{44}$ | 6.3 | 6.1 | 7.1 | 8.7 | 7.5 |
| $I_{45}$ | 8.6 | 5.1 | 7.9 | 9 | 9.1 |
| $I_{46}$ | 8.3 | 8 | 8.5 | 10 | 8.6 |
| $I_{51}$ | 9 | 9.6 | 7.8 | 10 | 9.4 |
| $I_{52}$ | 6.2 | 5.8 | 6.4 | 9.6 | 5.6 |
| $I_{53}$ | 9 | 5 | 7.7 | 9.5 | 7.6 |

***Step (3) Computing the indices belonging to each enabler***

The index pertaining to each enabler will be calculated using the following equation:

$$I_i = W_i \times R_i$$

For example, the calculation related to the supplier relationship enabler for company (B) is given by:

$$I_1 = W_1 \times R_1$$

Weight pertaining to the supplier relationship enabler is given by:

$$\mathbf{W_1} = (\mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2}, \mathbf{0.1}, \mathbf{0.1})$$

Assessment scores pertaining to the supplier relationship enabler is given by:

$$\mathbf{R_1} = \begin{bmatrix} \mathbf{6.5} & \mathbf{4.6} & \mathbf{7.2} & \mathbf{8.2} & \mathbf{6.3} \\ \mathbf{5.4} & \mathbf{6.9} & \mathbf{3.5} & \mathbf{8.6} & \mathbf{5.3} \\ \mathbf{5.6} & \mathbf{3.7} & \mathbf{6.9} & \mathbf{8.4} & \mathbf{7.1} \\ \mathbf{5.6} & \mathbf{4.6} & \mathbf{3.2} & \mathbf{6} & \mathbf{4.6} \\ \mathbf{5.8} & \mathbf{4.2} & \mathbf{5.6} & \mathbf{7.4} & \mathbf{5.2} \\ \mathbf{5.1} & \mathbf{2.8} & \mathbf{4.3} & \mathbf{7.8} & \mathbf{5.9} \end{bmatrix}$$

Index pertaining to the supplier relationship for company (B) enabler is given by:

$$\boldsymbol{I_1 = W_1 \times R_1}$$

$\mathbf{I_1} = (\mathbf{5.71}, \mathbf{4.66}, \mathbf{5.15}, \mathbf{7.76}, \mathbf{5.77})$

Using the same principle, the following indices have been calculated for remaining lean enablers for company (B) as in Table 6.9

**Table 6.9 Indices of the Enablers for Company (B)**

**$\boldsymbol{E_i}$ = Experts participated in the assessment**

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ |
|---|---|---|---|---|---|
| $I_1$ | 5.71 | 4.66 | 5.15 | 7.76 | 5.77 |
| $I_2$ | 7.44 | 5.23 | 5.32 | 8.6 | 5.98 |
| $I_3$ | 6 | 3.65 | 5.6 | 8.85 | 6.55 |
| $I_4$ | 7.55 | 6.14 | 7.45 | 8.81 | 7.49 |
| $I_5$ | 8.72 | 6.92 | 7.61 | 9.71 | 8.12 |

***Step (4) Computing PSS Leanness Index for Company (B)***

The PSS leanness index for company (B) was computed using the following equation:

$$\boldsymbol{I = W \times R}$$

The PSS leanness index for company (B) has been computed as:

Overall weight $\mathbf{W} = (\mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2})$

Overall assessment vector $\mathbf{R} = \begin{bmatrix} \mathbf{5.71} & \mathbf{4.66} & \mathbf{5.15} & \mathbf{7.76} & \mathbf{5.77} \\ \mathbf{7.44} & \mathbf{5.23} & \mathbf{5.32} & \mathbf{8.6} & \mathbf{5.98} \\ \mathbf{6} & \mathbf{3.65} & \mathbf{5.6} & \mathbf{8.85} & \mathbf{6.55} \\ \mathbf{7.55} & \mathbf{6.14} & \mathbf{7.45} & \mathbf{8.81} & \mathbf{7.49} \\ \mathbf{8.72} & \mathbf{6.92} & \mathbf{7.61} & \mathbf{9.71} & \mathbf{8.12} \end{bmatrix}$

Company (B) PSS leanness index has been calculated as:

$$\boldsymbol{I} = \boldsymbol{W} \times \boldsymbol{R}$$

$$\mathbf{I} = (\mathbf{7.257}, \mathbf{5.377}, \mathbf{6.243}, \mathbf{8.83}, \mathbf{6.803})$$

$$\mathbf{I} = \frac{\mathbf{1}}{\mathbf{5}}(\mathbf{7.257} + \mathbf{5.377} + \mathbf{6.243} + \mathbf{8.83} + \mathbf{6.803})$$

$$\mathbf{I} = \mathbf{6.902}$$

The PSS leanness index computed for company (B) is approximately 6.9

All the indices and weights calculated for company (B) enablers and criteria are presented in Figures 6.25, 26, 27, 28, 29 and 30 respectively. For company (B), the most important enabler is management leanness with a relative importance of 30% and an index of 6.5. While, supplier relationship is the least important enabler with a relative importance of 10%, as well as, it has the lowest index of 5.8. An analysis of company (B) performance will be presented later in this chapter.

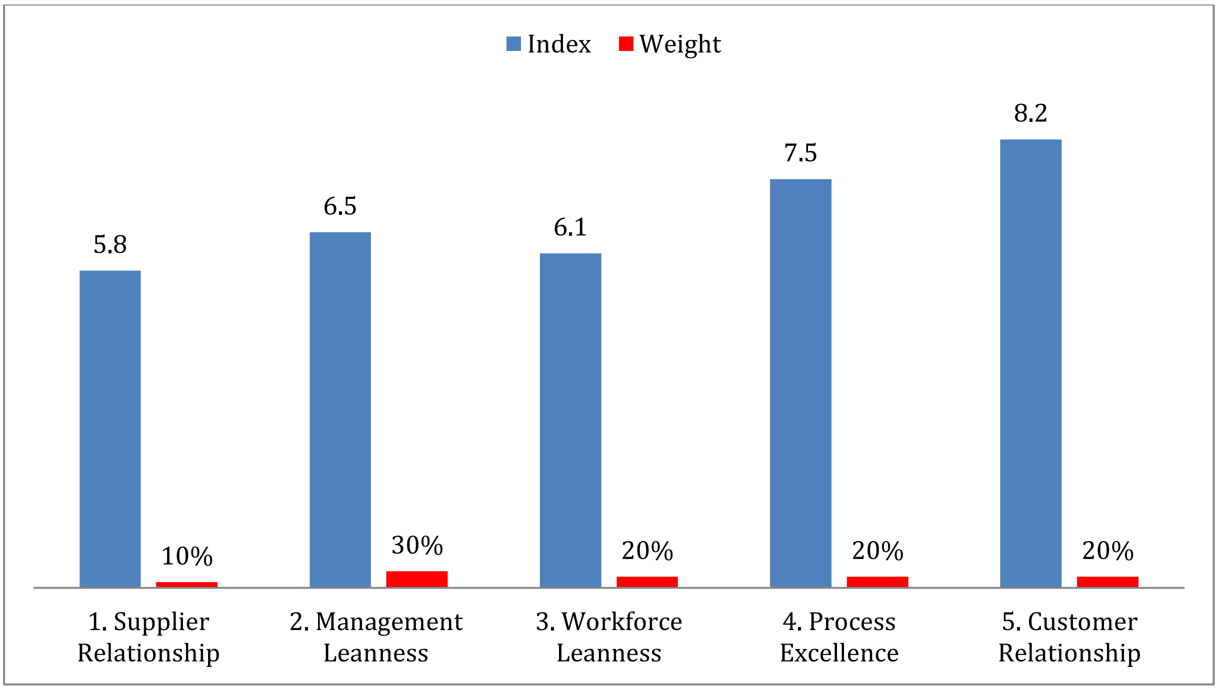



**Figure 6.25 Weights and Indices for Company (B) Enablers**

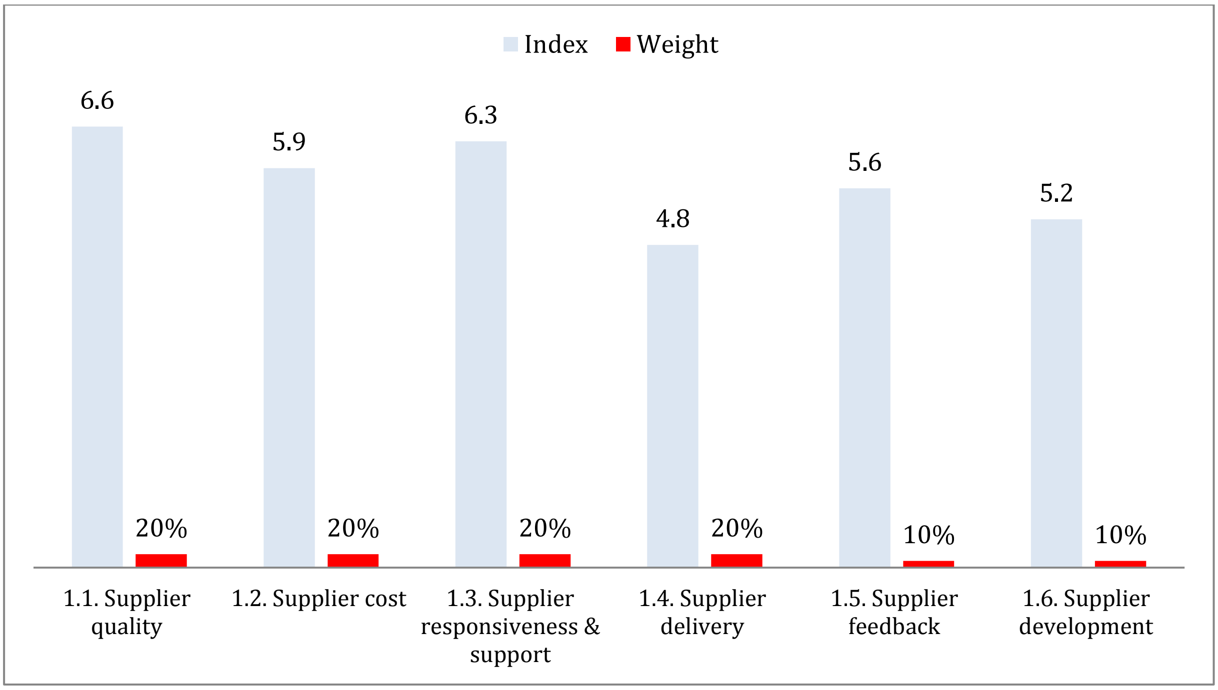



**Figure 6.26 Weights and Indices of Supplier Relationship Criteria (Company B)**

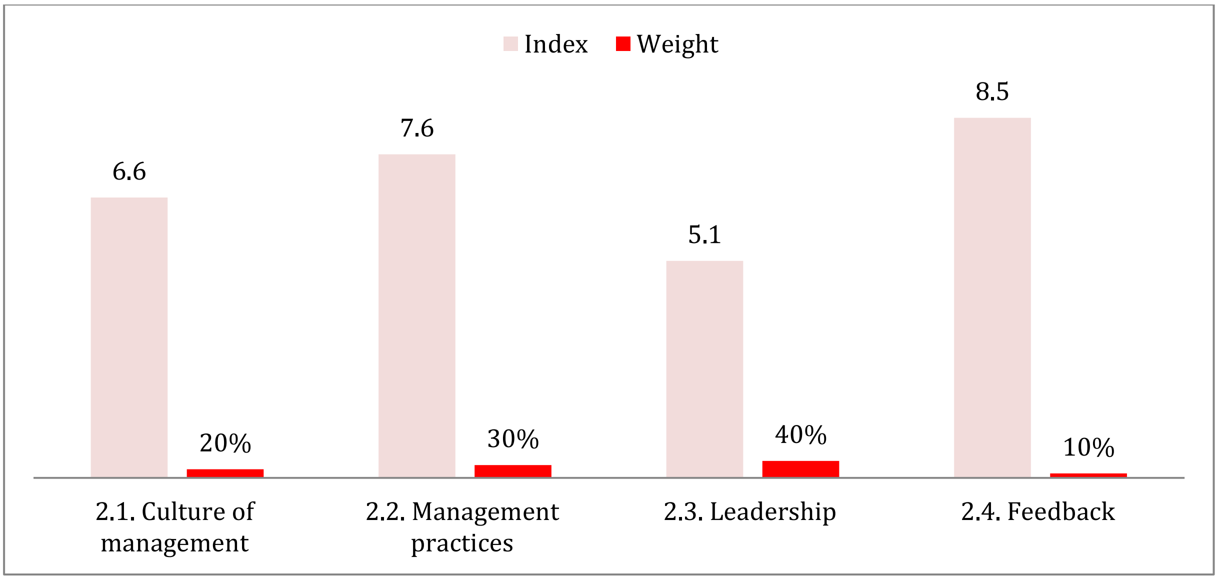



**Figure 6.27 Weights and Indices of Management Leanness Criteria (Company B)**

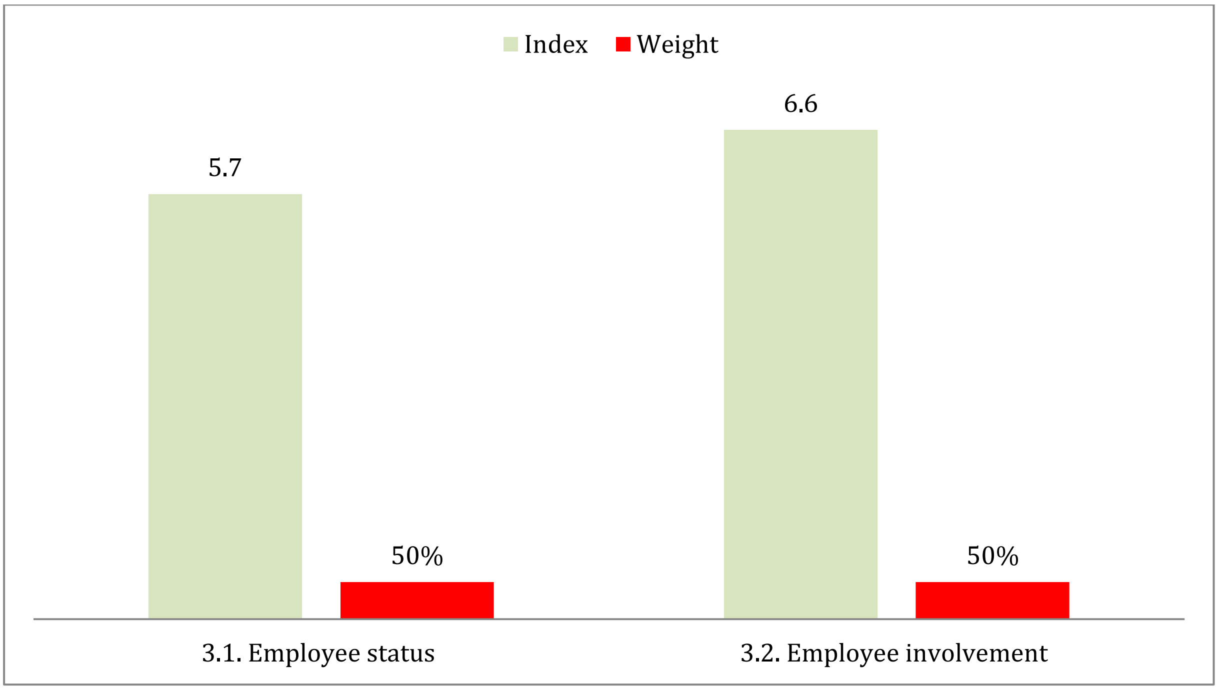



**Figure 6.28 Weights and Indices of Workforce Leanness Criteria (Company B)**

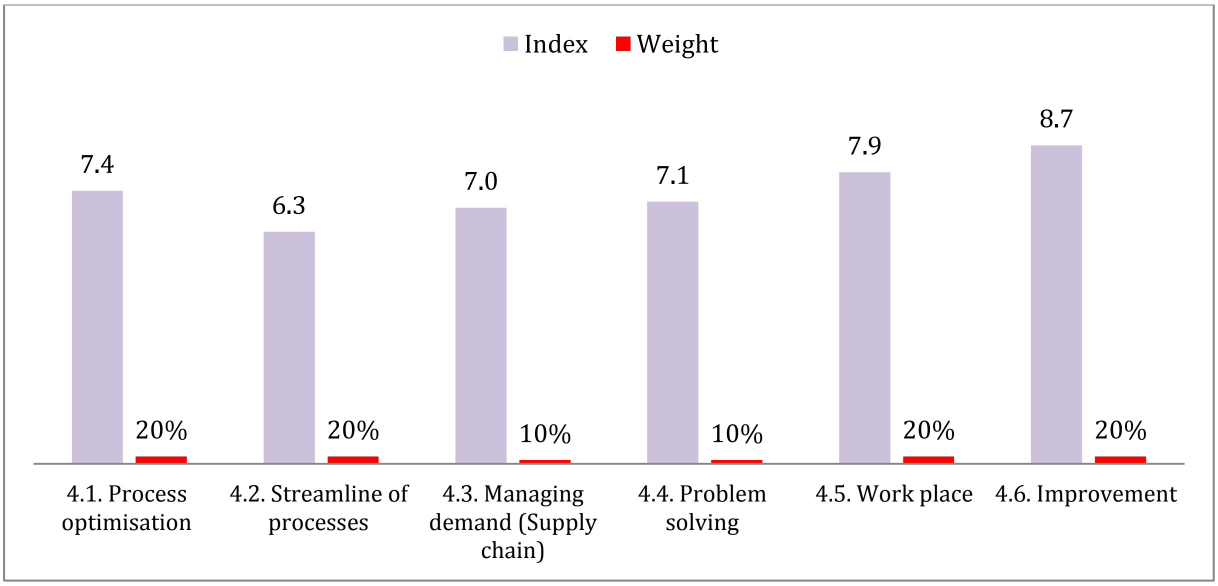



**Figure 6.29 Weights and Indices of Process Excellence Criteria (Company B)**

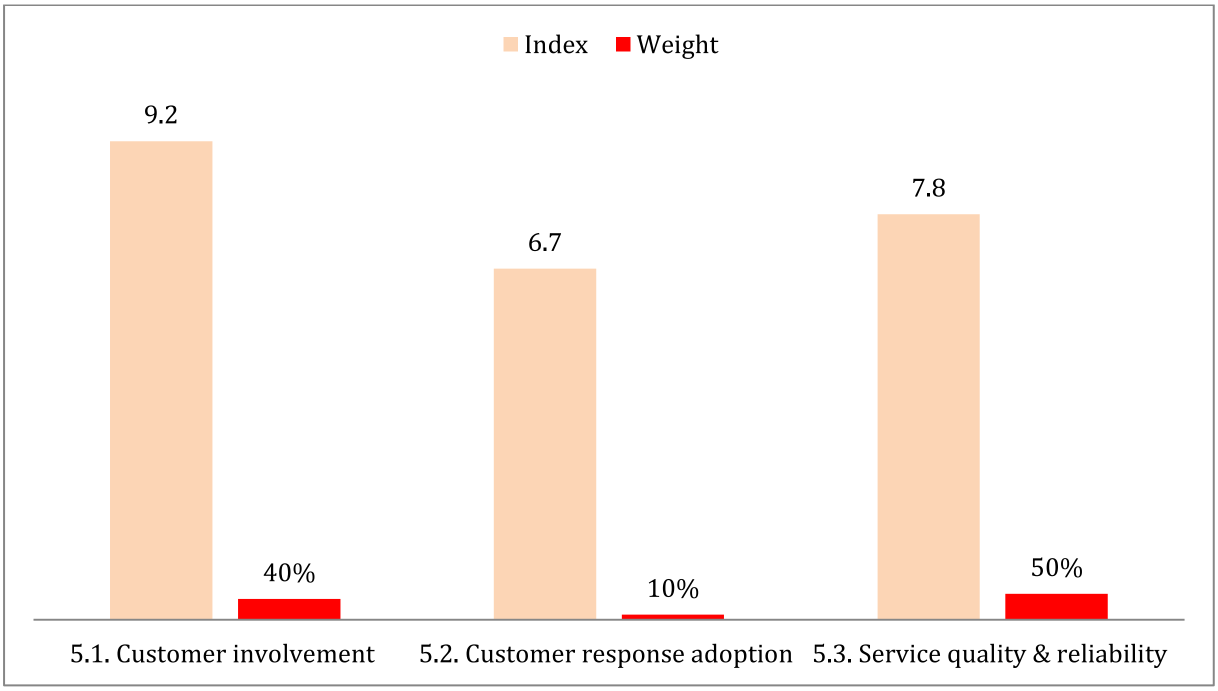
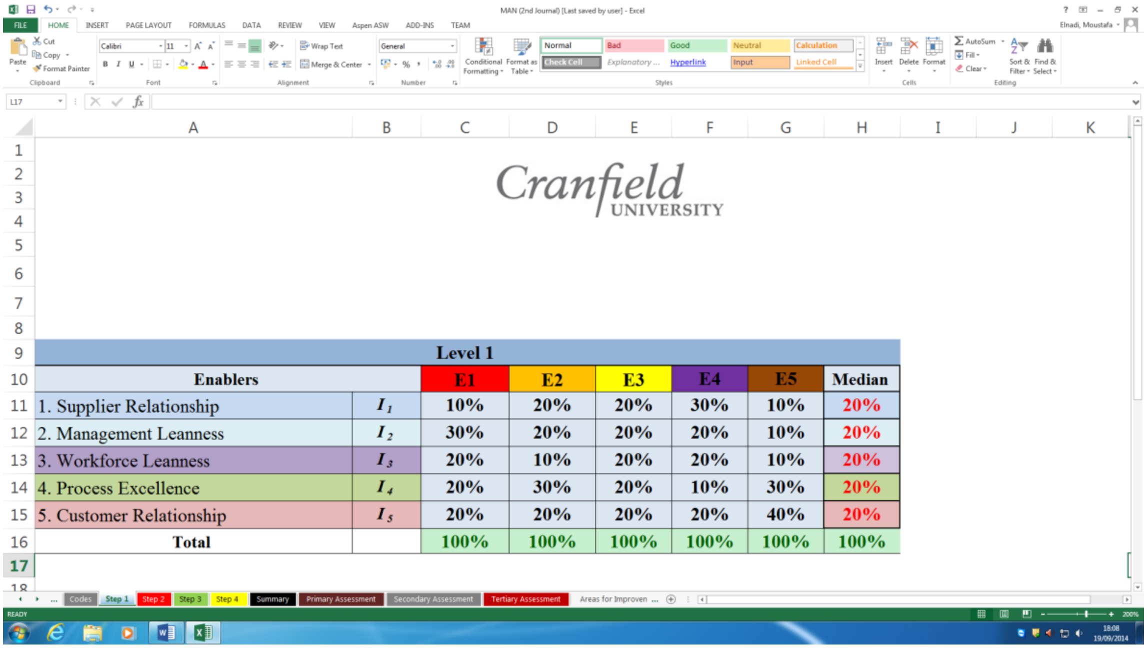



**Figure 6.30 Weights and Indices Customer Relationship Criteria (Company B)**

### 6.4.2.3 Assessment of Company (C) PSS Leanness

***Step (1) Computing the relative importance (weight) for each enabler, criterion, and attribute***

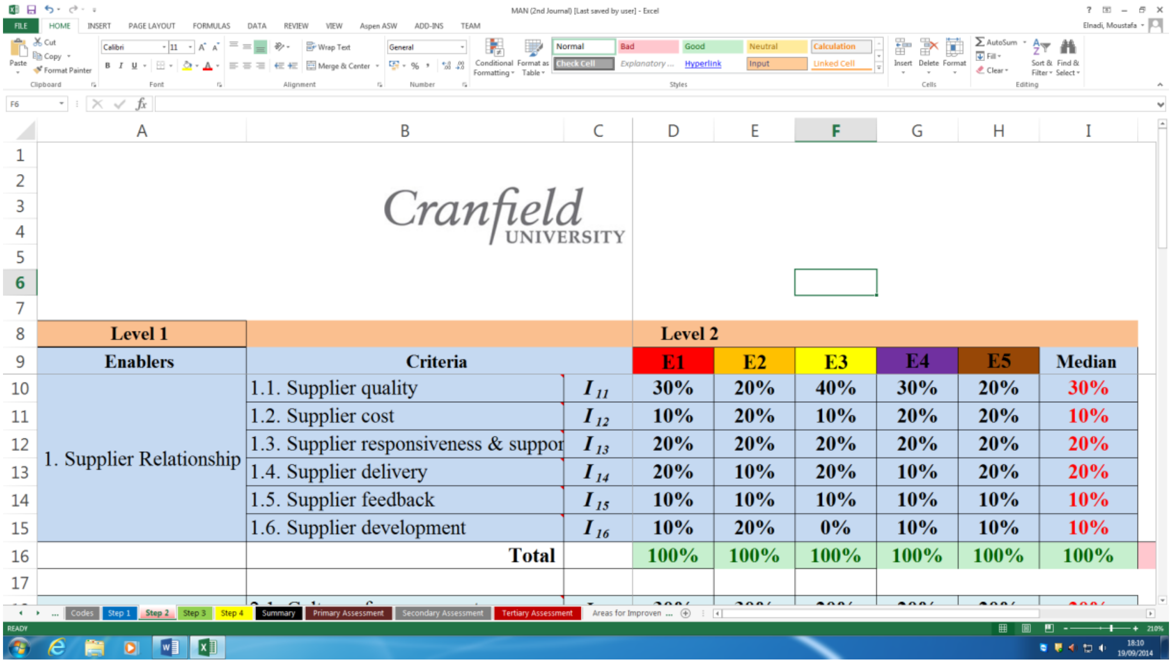
By calculating the median for each enabler, the relative importance of each enabler was computed. For example, the relative importance given by the experts for the supplier relationship enabler was: 10%, 20%, 20%, 30% and 10%. By using the median, the relative importance (weight) for supplier relationship was 20% as presented in Figure 6.31. Using the same procedures, the relative importance for the remaining enablers was computed.



| Level 1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Enablers | | E1 | E2 | E3 | E4 | E5 | Median |
| 1. Supplier Relationship | $I_1$ | 10% | 20% | 20% | 30% | 10% | 20% |
| 2. Management Leanness | $I_2$ | 30% | 20% | 20% | 20% | 10% | 20% |
| 3. Workforce Leanness | $I_3$ | 20% | 10% | 20% | 20% | 10% | 20% |
| 4. Process Excellence | $I_4$ | 20% | 30% | 20% | 10% | 30% | 20% |
| 5. Customer Relationship | $I_5$ | 20% | 20% | 20% | 20% | 40% | 20% |
| Total | | 100% | 100% | 100% | 100% | 100% | 100% |

**Figure 6.31 The Relative Importance of Company (C) Enablers**

Moving to the second level in the assessment, the relative importance for each criterion was computed using also median. For example, the weights given by company (C) experts for the supplier quality criterion were: 30%, 20%, 40%, 30% and 20% as shown in Figure 6.32. Thus, the relative importance of the supplier quality criterion was calculated to be 30% using median.

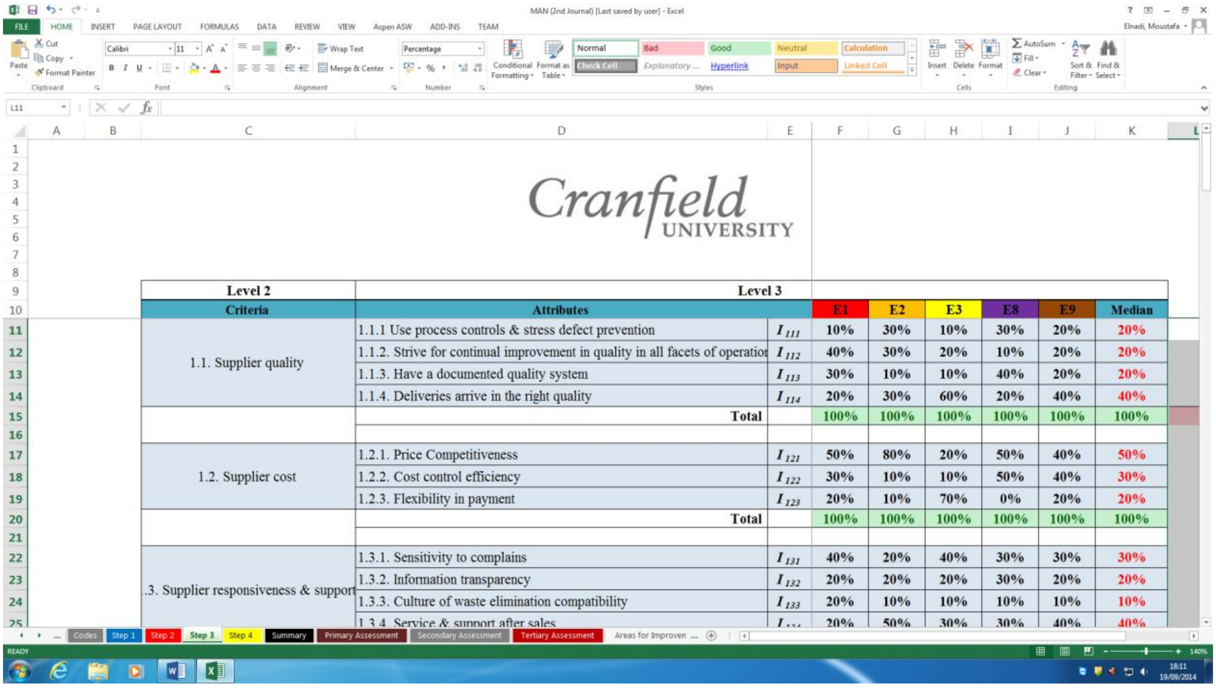


| Level 1 | Level 2 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Enablers | Criteria | | E1 | E2 | E3 | E4 | E5 | Median |
| 1. Supplier Relationship | 1.1. Supplier quality | $I_{11}$ | 30% | 20% | 40% | 30% | 20% | 30% |
| | 1.2. Supplier cost | $I_{12}$ | 10% | 20% | 10% | 20% | 20% | 10% |
| | 1.3. Supplier responsiveness & suppor | $I_{13}$ | 20% | 20% | 20% | 20% | 20% | 20% |
| | 1.4. Supplier delivery | $I_{14}$ | 20% | 10% | 20% | 10% | 20% | 20% |
| | 1.5. Supplier feedback | $I_{15}$ | 10% | 10% | 10% | 10% | 10% | 10% |
| | 1.6. Supplier development | $I_{16}$ | 10% | 20% | 0% | 10% | 10% | 10% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |

**Figure 6.32 The Relative Importance of Company (C) Criteria**

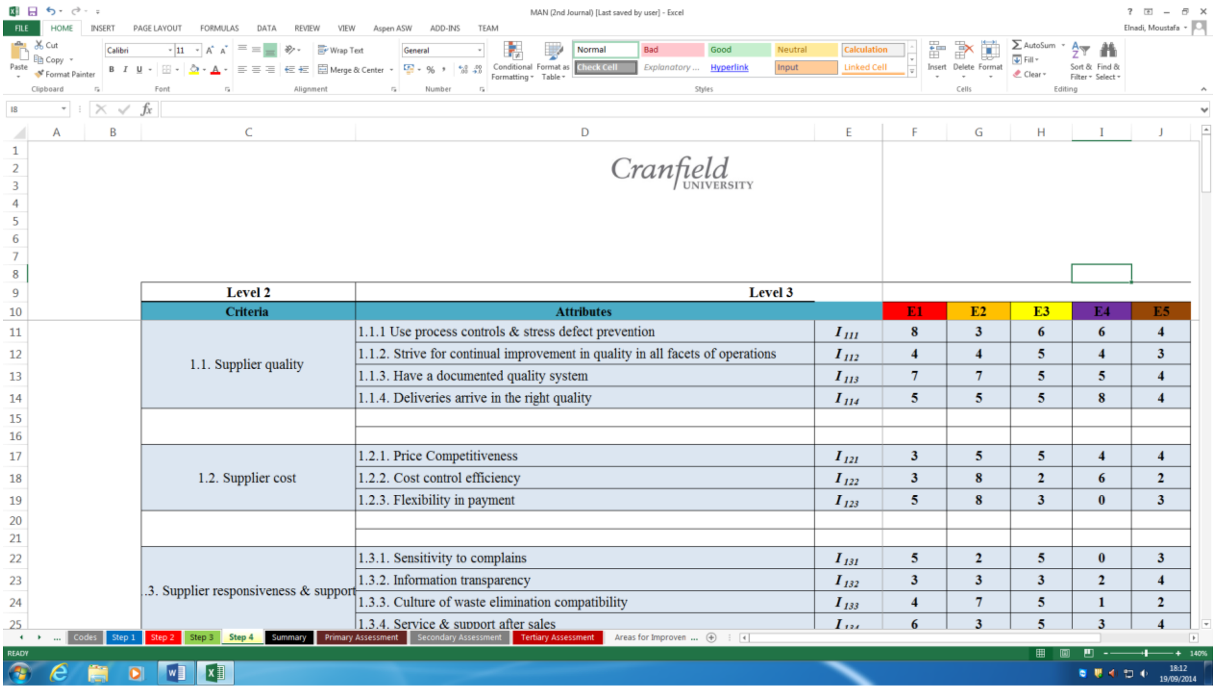
Using the same procedures, the relative importance (weight) for each attributes was calculated as shown in Figure 6.33. Finally, all the assessment scores provided by each expert were collected as presented in Figure 6.34

Table 6.10 presents a summary of the relative importance (weights) computed for the enablers, criteria and attributes and all the assessment scores of each attribute collected from company (C) experts.



| Level 2 Criteria | Level 3 Attributes | | E1 | E2 | E3 | E8 | E9 | Median |
|---|---|---|---|---|---|---|---|---|
| 1.1. Supplier quality | 1.1.1 Use process controls & stress defect prevention | $I_{111}$ | 10% | 30% | 10% | 30% | 20% | 20% |
| | 1.1.2. Strive for continual improvement in quality in all facets of operatior | $I_{112}$ | 40% | 30% | 20% | 10% | 20% | 20% |
| | 1.1.3. Have a documented quality system | $I_{113}$ | 30% | 10% | 10% | 40% | 20% | 20% |
| | 1.1.4. Deliveries arrive in the right quality | $I_{114}$ | 20% | 30% | 60% | 20% | 40% | 40% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |
| 1.2. Supplier cost | 1.2.1. Price Competitiveness | $I_{121}$ | 50% | 80% | 20% | 50% | 40% | 50% |
| | 1.2.2. Cost control efficiency | $I_{122}$ | 30% | 10% | 10% | 50% | 40% | 30% |
| | 1.2.3. Flexibility in payment | $I_{123}$ | 20% | 10% | 70% | 0% | 20% | 20% |
| | Total | | 100% | 100% | 100% | 100% | 100% | 100% |
| .3. Supplier responsiveness & support | 1.3.1. Sensitivity to complains | $I_{131}$ | 40% | 20% | 40% | 30% | 30% | 30% |
| | 1.3.2. Information transparency | $I_{132}$ | 20% | 20% | 20% | 30% | 20% | 20% |
| | 1.3.3. Culture of waste elimination compatibility | $I_{133}$ | 20% | 10% | 10% | 10% | 10% | 10% |
| | 1.3.4. Service & support after sales | $I_{134}$ | 20% | 50% | 30% | 30% | 40% | 40% |

**Figure 6.33 Weights of Company (C) Attributes**



| Level 2 Criteria | Level 3 Attributes | | E1 | E2 | E3 | E4 | E5 |
|---|---|---|---|---|---|---|---|
| 1.1. Supplier quality | 1.1.1 Use process controls & stress defect prevention | $I_{111}$ | 8 | 3 | 6 | 6 | 4 |
| | 1.1.2. Strive for continual improvement in quality in all facets of operations | $I_{112}$ | 4 | 4 | 5 | 4 | 3 |
| | 1.1.3. Have a documented quality system | $I_{113}$ | 7 | 7 | 5 | 5 | 4 |
| | 1.1.4. Deliveries arrive in the right quality | $I_{114}$ | 5 | 5 | 5 | 8 | 4 |
| 1.2. Supplier cost | 1.2.1. Price Competitiveness | $I_{121}$ | 3 | 5 | 5 | 4 | 4 |
| | 1.2.2. Cost control efficiency | $I_{122}$ | 3 | 8 | 2 | 6 | 2 |
| | 1.2.3. Flexibility in payment | $I_{123}$ | 5 | 8 | 3 | 0 | 3 |
| .3. Supplier responsiveness & support | 1.3.1. Sensitivity to complains | $I_{131}$ | 5 | 2 | 5 | 0 | 3 |
| | 1.3.2. Information transparency | $I_{132}$ | 3 | 3 | 3 | 2 | 4 |
| | 1.3.3. Culture of waste elimination compatibility | $I_{133}$ | 4 | 7 | 5 | 1 | 2 |
| | 1.3.4. Service & support after sales | $I_{134}$ | 6 | 3 | 5 | 3 | 4 |

**Figure 6.34 Assessment Scores for Company (C)**

**Table 6.10 Weights and Assessment Scores for Company (C)**
**Refer to Table 6.2 for Enablers, Criteria and attributes**

**Legend:** $\boldsymbol{I_i}$= Enabler index; $\boldsymbol{I_{ij}}$ = Criterion index; $\boldsymbol{I_{ijk}}$ = Attribute index; $\boldsymbol{E_i}$ = Experts participated in the assessment; $\boldsymbol{W_{ij}}$ = Attribute weight; $\boldsymbol{W_i}$ = Criterion weight; $\boldsymbol{W}$ = Enabler weight

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_8$ | $E_9$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_1$ | $I_{11}$ | $I_{111}$ | 8 | 3 | 6 | 6 | 4 | 0.2 | 0.3 | 0.2 |
| | | $I_{112}$ | 4 | 4 | 5 | 4 | 3 | 0.2 | | |
| | | $I_{113}$ | 7 | 7 | 5 | 5 | 4 | 0.2 | | |
| | | $I_{114}$ | 5 | 5 | 5 | 8 | 4 | 0.4 | | |
| | $I_{12}$ | $I_{121}$ | 3 | 5 | 5 | 4 | 4 | 0.5 | 0.1 | |
| | | $I_{122}$ | 3 | 8 | 2 | 6 | 2 | 0.3 | | |
| | | $I_{123}$ | 5 | 8 | 3 | 0 | 3 | 0.2 | | |
| | $I_{13}$ | $I_{131}$ | 5 | 2 | 5 | 0 | 3 | 0.3 | 0.2 | |
| | | $I_{132}$ | 3 | 3 | 3 | 2 | 4 | 0.2 | | |
| | | $I_{133}$ | 4 | 7 | 5 | 1 | 2 | 0.1 | | |
| | | $I_{134}$ | 6 | 3 | 5 | 3 | 4 | 0.4 | | |
| | $I_{14}$ | $I_{141}$ | 8 | 6 | 6 | 7 | 5 | 0.4 | 0.2 | |
| | | $I_{142}$ | 7 | 5 | 7 | 6 | 4 | 0.3 | | |
| | | $I_{143}$ | 6 | 3 | 6 | 2 | 3 | 0.2 | | |
| | | $I_{144}$ | 3 | 5 | 2 | 1 | 2 | 0.1 | | |
| | $I_{15}$ | $I_{151}$ | 8 | 3 | 4 | 3 | 5 | 0.3 | 0.1 | |
| | | $I_{152}$ | 7 | 3 | 2 | 5 | 2 | 0.3 | | |
| | | $I_{153}$ | 9 | 3 | 2 | 4 | 6 | 0.4 | | |
| | $I_{16}$ | $I_{161}$ | 6 | 3 | 1 | 0 | 2 | 0.1 | 0.1 | |
| | | $I_{162}$ | 3 | 3 | 3 | 4 | 4 | 0.3 | | |
| | | $I_{163}$ | 3 | 5 | 4 | 7 | 5 | 0.3 | | |
| | | $I_{164}$ | 5 | 7 | 4 | 8 | 5 | 0.3 | | |
| $I_2$ | $I_{21}$ | $I_{211}$ | 2 | 2 | 2 | 1 | 4 | 0.2 | 0.2 | 0.2 |
| | | $I_{212}$ | 1 | 3 | 2 | 2 | 4 | 0.3 | | |
| | | $I_{213}$ | 4 | 4 | 4 | 2 | 5 | 0.5 | | |
| | $I_{22}$ | $I_{221}$ | 1 | 5 | 4 | 7 | 3 | 0.2 | 0.3 | |
| | | $I_{222}$ | 6 | 3 | 6 | 5 | 4 | 0.2 | | |
| | | $I_{223}$ | 1 | 3 | 6 | 2 | 5 | 0.4 | | |
| | | $I_{224}$ | 2 | 5 | 5 | 3 | 4 | 0.2 | | |
| | $I_{23}$ | $I_{231}$ | 3 | 5 | 4 | 2 | 6 | 0.1 | 0.3 | |
| | | $I_{232}$ | 0 | 6 | 4 | 6 | 4 | 0.1 | | |
| | | $I_{233}$ | 4 | 4 | 6 | 3 | 4 | 0.4 | | |
| | | $I_{234}$ | 7 | 5 | 6 | 4 | 6 | 0.4 | | |
| | $I_{24}$ | $I_{241}$ | 5 | 4 | 6 | 4 | 6 | 0.5 | 0.2 | |
| | | $I_{242}$ | 5 | 5 | 5 | 3 | 6 | 0.5 | | |

| $I_i$ | $I_{ij}$ | $I_{ijk}$ | $E_1$ | $E_2$ | $E_3$ | $E_8$ | $E_9$ | $W_{ij}$ | $W_i$ | $W$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $I_3$ | $I_{31}$ | $I_{311}$ | 4 | 7 | 6 | 3 | 6 | 0.2 | 0.5 | 0.2 |
| | | $I_{312}$ | 4 | 6 | 6 | 5 | 5 | 0.2 | | |
| | | $I_{313}$ | 1 | 2 | 2 | 0 | 3 | 0.1 | | |
| | | $I_{314}$ | 3 | 5 | 6 | 4 | 2 | 0.3 | | |
| | | $I_{315}$ | 2 | 3 | 6 | 2 | 3 | 0.2 | | |
| | $I_{32}$ | $I_{321}$ | 4 | 6 | 6 | 5 | 6 | 0.3 | 0.5 | |
| | | $I_{322}$ | 4 | 5 | 2 | 4 | 2 | 0.5 | | |
| | | $I_{323}$ | 7 | 7 | 5 | 7 | 4 | 0.2 | | |
| $I_4$ | $I_{41}$ | $I_{411}$ | 6 | 3 | 6 | 5 | 3 | 0.4 | 0.2 | 0.2 |
| | | $I_{412}$ | 7 | 4 | 4 | 4 | 5 | 0.4 | | |
| | | $I_{413}$ | 3 | 3 | 4 | 7 | 4 | 0.2 | | |
| | $I_{42}$ | $I_{421}$ | 1 | 1 | 2 | 3 | 1 | 0.2 | 0.2 | |
| | | $I_{422}$ | 2 | 2 | 4 | 2 | 1 | 0.3 | | |
| | | $I_{423}$ | 5 | 5 | 5 | 4 | 4 | 0.3 | | |
| | | $I_{424}$ | 5 | 5 | 4 | 6 | 3 | 0.2 | | |
| | $I_{43}$ | $I_{431}$ | 2 | 4 | 5 | 5 | 6 | 0.3 | 0.1 | |
| | | $I_{432}$ | 2 | 2 | 6 | 7 | 3 | 0.2 | | |
| | | $I_{433}$ | 3 | 2 | 2 | 7 | 5 | 0.2 | | |
| | | $I_{434}$ | 2 | 7 | 4 | 3 | 2 | 0.3 | | |
| | $I_{44}$ | $I_{441}$ | 5 | 3 | 2 | 1 | 3 | 0.3 | 0.2 | |
| | | $I_{442}$ | 3 | 3 | 2 | 3 | 2 | 0.2 | | |
| | | $I_{443}$ | 5 | 3 | 4 | 4 | 3 | 0.3 | | |
| | | $I_{444}$ | 4 | 2 | 4 | 2 | 4 | 0.2 | | |
| | $I_{45}$ | $I_{451}$ | 7 | 2 | 5 | 6 | 4 | 0.4 | 0.1 | |
| | | $I_{452}$ | 6 | 6 | 5 | 4 | 6 | 0.2 | | |
| | | $I_{453}$ | 5 | 6 | 6 | 7 | 3 | 0.4 | | |
| | $I_{46}$ | $I_{461}$ | 7 | 7 | 3 | 8 | 7 | 0.3 | 0.2 | |
| | | $I_{462}$ | 3 | 2 | 4 | 1 | 3 | 0.3 | | |
| | | $I_{463}$ | 4 | 1 | 2 | 1 | 2 | 0.2 | | |
| | | $I_{464}$ | 2 | 1 | 2 | 2 | 1 | 0.2 | | |
| $I_5$ | $I_{51}$ | $I_{511}$ | 4 | 6 | 5 | 4 | 5 | 0.6 | 0.2 | 0.2 |
| | | $I_{512}$ | 7 | 4 | 5 | 6 | 3 | 0.4 | | |
| | $I_{52}$ | $I_{521}$ | 5 | 2 | 5 | 5 | 2 | 0.3 | 0.3 | |
| | | $I_{522}$ | 5 | 6 | 4 | 3 | 3 | 0.2 | | |
| | | $I_{523}$ | 3 | 5 | 4 | 6 | 3 | 0.5 | | |
| | $I_{53}$ | $I_{531}$ | 7 | 5 | 6 | 4 | 4 | 0.6 | 0.5 | |
| | | $I_{532}$ | 6 | 8 | 5 | 4 | 4 | 0.2 | | |
| | | $I_{533}$ | 8 | 7 | 5 | 6 | 3 | 0.2 | | |

***Step (2) Computing the index belonging to each criterion***

The index pertaining to each criterion will be calculated using the following equation:

$$\boldsymbol{I_{ij} = W_{ij} \times R_{ij}}$$

For example, the calculation related to supplier quality criterion for company (C) is shown as follows:

Weights pertaining to the supplier quality criterion $\mathrm{W}_{11} = (0.2, 0.2, 0.2, 0.4)$

Assessment scores pertaining to the supplier quality criterion is given by:

$$\mathbf{R_{11}} = \begin{bmatrix} \mathbf{8} & \mathbf{3} & \mathbf{6} & \mathbf{6} & \mathbf{4} \\ \mathbf{4} & \mathbf{4} & \mathbf{5} & \mathbf{4} & \mathbf{3} \\ \mathbf{7} & \mathbf{7} & \mathbf{5} & \mathbf{5} & \mathbf{4} \\ \mathbf{5} & \mathbf{5} & \mathbf{5} & \mathbf{8} & \mathbf{4} \end{bmatrix}$$

Index pertaining to the supplier quality criterion for company (C) is given by

$$\boldsymbol{I_{11} = W_{11} \times R_{11}}$$

$$\mathbf{I_{11}} = (\mathbf{5.8, 4.8, 5.2, 6.2, 3.8})$$

Using the same procedures, the indices pertaining to the remaining lean criteria have been computed as presented in Table 6.11

**Table 6.11 Indices of the Criteria for Company (C)**

**$E_i$ = Experts participated in the assessment**

| | *E1* | *E2* | *E3* | *E4* | *E5* |
|---|---|---|---|---|---|
| $I_{11}$ | 5.8 | 4.8 | 5.2 | 6.2 | 3.8 |
| $I_{12}$ | 3.4 | 6.5 | 3.7 | 3.8 | 3.2 |
| $I_{13}$ | 4.9 | 3.1 | 4.6 | 1.7 | 3.5 |
| $I_{14}$ | 6.8 | 5 | 5.9 | 5.1 | 4 |
| $I_{15}$ | 8.1 | 3 | 2.6 | 4 | 4.5 |
| $I_{16}$ | 3.9 | 4.8 | 3.4 | 5.7 | 4.4 |
| $I_{21}$ | 2.7 | 3.3 | 3 | 1.8 | 4.5 |
| $I_{22}$ | 2.2 | 3.8 | 5.4 | 3.8 | 4.2 |
| $I_{23}$ | 4.7 | 4.7 | 5.6 | 3.6 | 5 |
| $I_{24}$ | 5 | 4.5 | 5.5 | 3.5 | 6 |
| $I_{31}$ | 3 | 4.9 | 5.6 | 3.2 | 3.7 |

| | E1 | E2 | E3 | E4 | E5 |
|---|---|---|---|---|---|
| $I_{32}$ | 4.6 | 5.7 | 3.8 | 4.9 | 3.6 |
| $I_{41}$ | 5.8 | 3.4 | 4.8 | 5 | 4 |
| $I_{42}$ | 3.3 | 3.3 | 3.9 | 3.6 | 2.3 |
| $I_{43}$ | 2.2 | 4.1 | 4.3 | 5.2 | 4 |
| $I_{44}$ | 4.4 | 2.8 | 3 | 2.5 | 3 |
| $I_{45}$ | 6 | 4.4 | 5.4 | 6 | 4 |
| $I_{46}$ | 4.2 | 3.1 | 2.9 | 3.3 | 3.6 |
| $I_{51}$ | 5.2 | 5.2 | 5 | 4.8 | 4.2 |
| $I_{52}$ | 4 | 4.3 | 4.3 | 5.1 | 2.7 |
| $I_{53}$ | 7 | 6 | 5.6 | 4.4 | 3.8 |

***Step (3) Computing the indices belonging to each enabler***

The index pertaining to each enabler will be calculated using the following equation:

$$\boldsymbol{I_i = W_i \times R_i}$$

For example, the calculation related to the supplier relationship enabler for company (C) is given by:

$$\boldsymbol{I_1 = W_1 \times R_1}$$

Weight pertaining to the supplier relationship enabler is given by:

$$\mathbf{W_1} = (\mathbf{0.3, 0.1, 0.2, 0.2, 0.1, 0.1})$$

Assessment scores pertaining to the supplier relationship enabler is given by:

$$\mathbf{R_1} = \begin{bmatrix} \mathbf{5.8} & \mathbf{4.8} & \mathbf{5.2} & \mathbf{6.2} & \mathbf{3.8} \\ \mathbf{3.4} & \mathbf{6.5} & \mathbf{3.7} & \mathbf{3.8} & \mathbf{3.2} \\ \mathbf{4.9} & \mathbf{3.1} & \mathbf{4.6} & \mathbf{1.7} & \mathbf{3.5} \\ \mathbf{6.8} & \mathbf{5} & \mathbf{5.9} & \mathbf{5.1} & \mathbf{4} \\ \mathbf{8.1} & \mathbf{3} & \mathbf{2.6} & \mathbf{4} & \mathbf{4.5} \\ \mathbf{3.9} & \mathbf{4.8} & \mathbf{3.4} & \mathbf{5.7} & \mathbf{4.4} \end{bmatrix}$$

Index pertaining to the supplier relationship for company (C) enabler is given by:

$$\boldsymbol{I_1 = W_1 \times R_1}$$

$\mathbf{I_1} = (\mathbf{5.62, 4.49, 4.63, 4.57, 3.85})$

Using the same principle, the following indices have been calculated for remaining lean enablers for company (C) as in Table 6.12

**Table 6.12 Indices of the Enablers for Company (C)**

**$E_i$ = Experts participated in the assessment**

| | *E1* | *E2* | *E3* | *E4* | *E5* |
|---|---|---|---|---|---|
| $I_1$ | 5.62 | 4.49 | 4.63 | 4.57 | 3.85 |
| $I_2$ | 3.61 | 4.11 | 5 | 3.28 | 4.86 |
| $I_3$ | 3.8 | 5.3 | 4.7 | 4.05 | 3.65 |
| $I_4$ | 4.36 | 3.37 | 3.89 | 4 | 3.38 |
| $I_5$ | 5.74 | 5.33 | 5.09 | 4.69 | 3.55 |

***Step (4) Computing PSS Leanness Index for Company (C)***

The PSS leanness index for company (C) was computed using the following equation:

$$\boldsymbol{I = W \times R}$$

The PSS leanness index for company (C) has been computed as:

Overall weight $\mathbf{W} = (\mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2}, \mathbf{0.2})$

Overall assessment vector $\mathbf{R} = \begin{bmatrix} \mathbf{5.62} & \mathbf{4.49} & \mathbf{4.63} & \mathbf{4.57} & \mathbf{3.85} \\ \mathbf{3.61} & \mathbf{4.11} & \mathbf{5} & \mathbf{3.28} & \mathbf{4.86} \\ \mathbf{3.8} & \mathbf{5.3} & \mathbf{4.7} & \mathbf{4.05} & \mathbf{3.65} \\ \mathbf{4.36} & \mathbf{3.37} & \mathbf{3.89} & \mathbf{4} & \mathbf{3.38} \\ \mathbf{5.74} & \mathbf{5.33} & \mathbf{5.09} & \mathbf{4.69} & \mathbf{3.55} \end{bmatrix}$

Company (C) PSS leanness index has been calculated as:

$$\boldsymbol{I = W \times R}$$

$\mathbf{I} = (\mathbf{4.626}, \mathbf{4.52}, \mathbf{4.662}, \mathbf{4.118}, \mathbf{3.858})$

$\mathbf{I} = \frac{\mathbf{1}}{\mathbf{5}}(\mathbf{4.626} + \mathbf{4.52} + \mathbf{4.662} + \mathbf{4.118} + \mathbf{3.858})$

$\mathbf{I} = \mathbf{4.3568}$

The PSS Leanness Index computed for company (C) is approximately 4.4

All the indices and weights calculated for company (C) enablers and criteria are presented in Figures 6.35, 36, 37, 38, 39 and 40 respectively. For company (C), all the enablers are equally important with a weight of 20%. At the same time the all the indices calculated for all the enablers for company (C) were below the average. The performance of company (C) across all the enablers will be presented in more details in the next section.

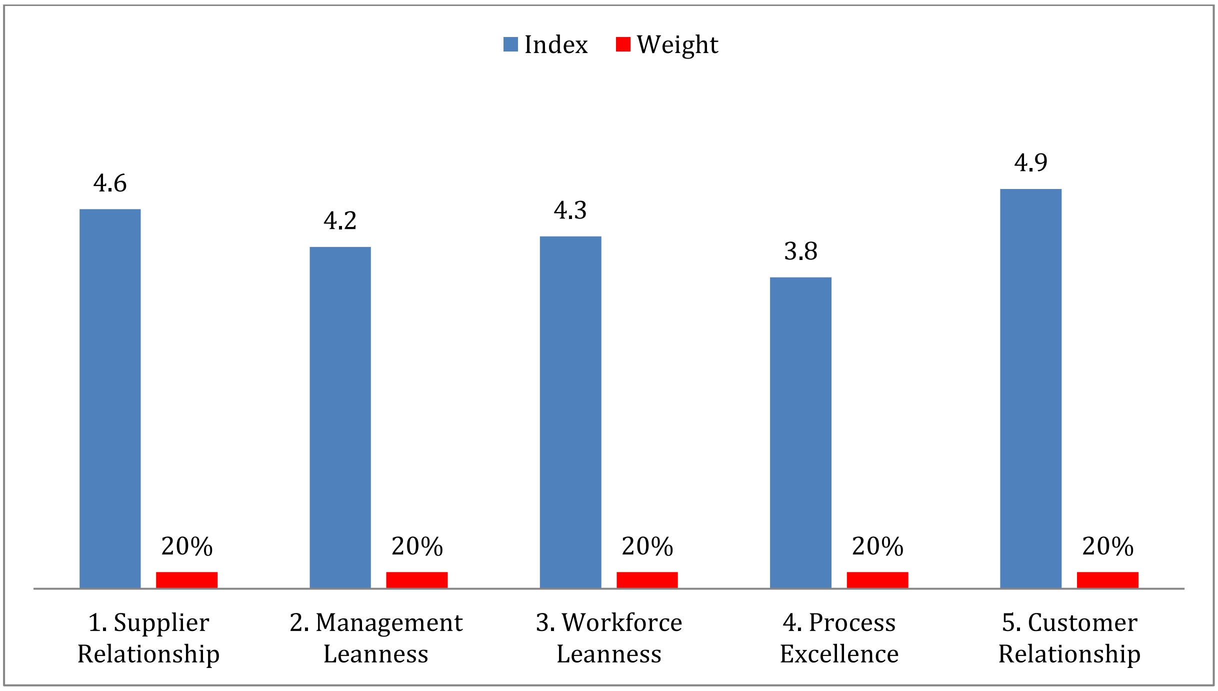



**Figure 6.35 Weights and Indices for Company (C) Enablers**

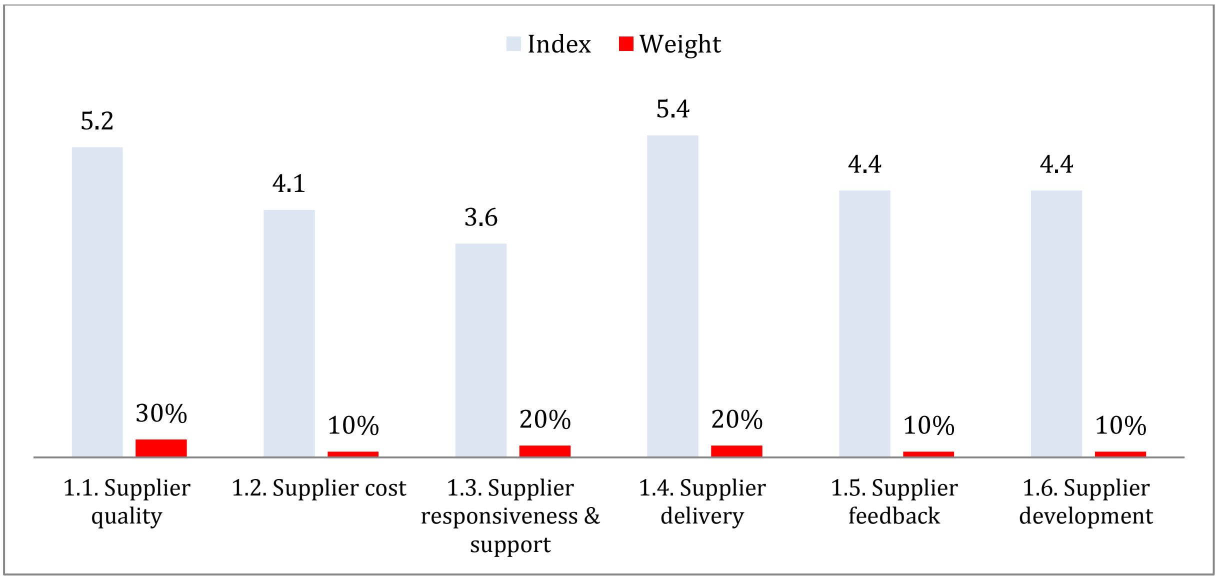



**Figure 6.36 Weights and Indices of Supplier Relationship Criteria (Company C)**

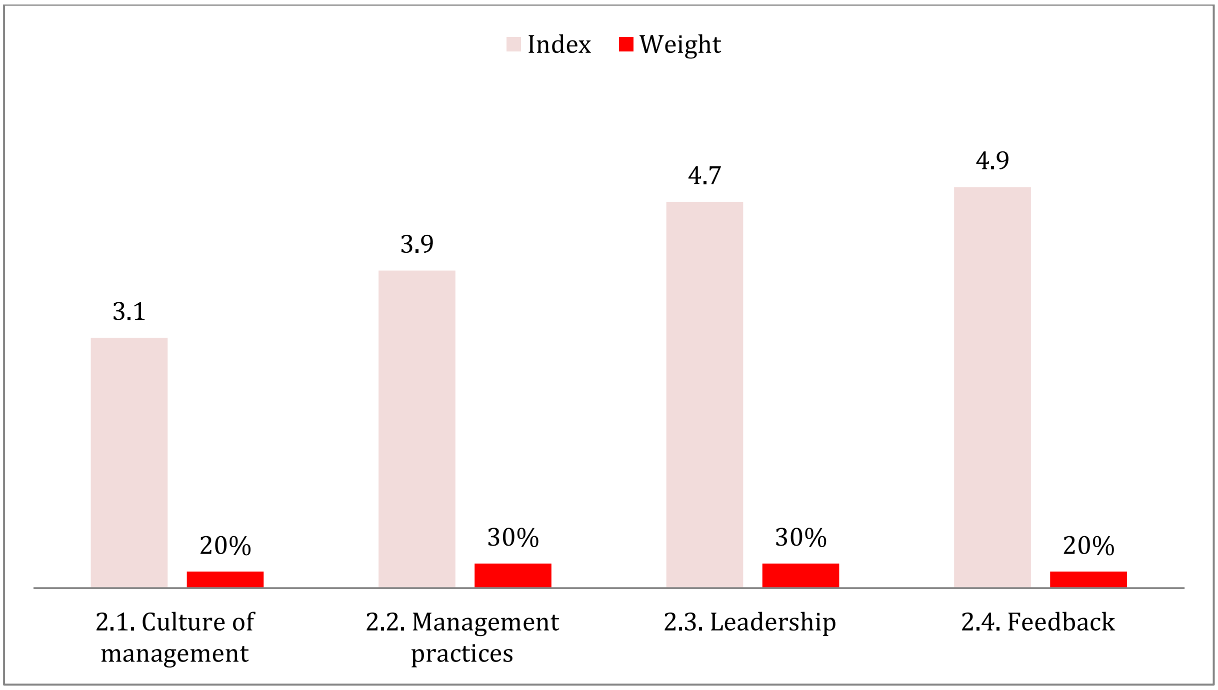



**Figure 6.37 Weights and Indices of Management Leanness Criteria (Company C)**

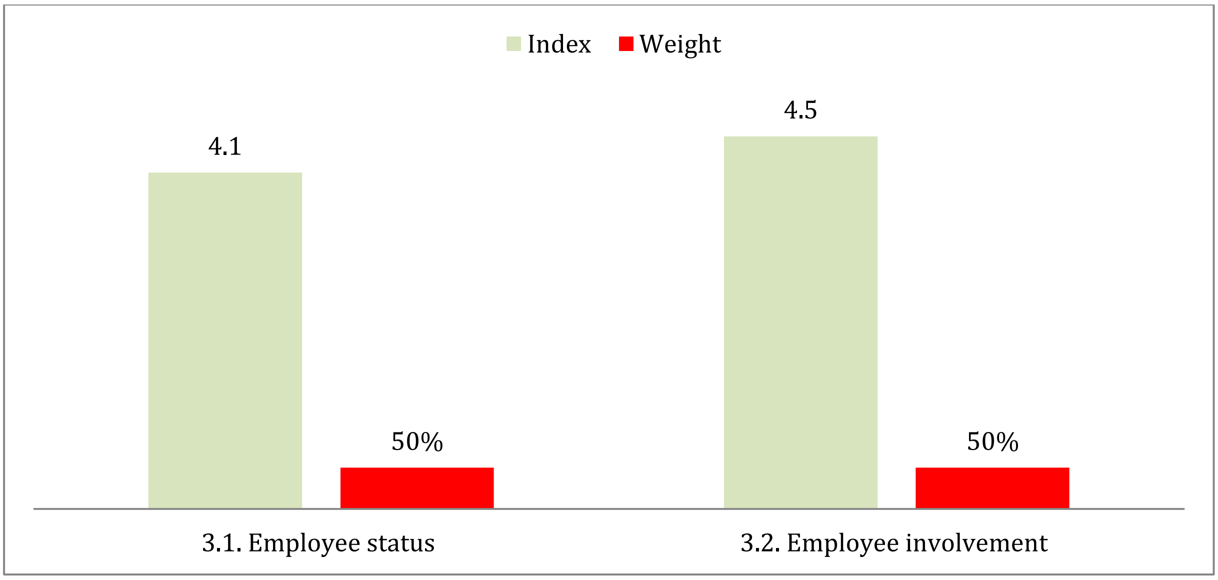



**Figure 6.38 Weights and Indices of Workforce Leanness Criteria (Company C)**

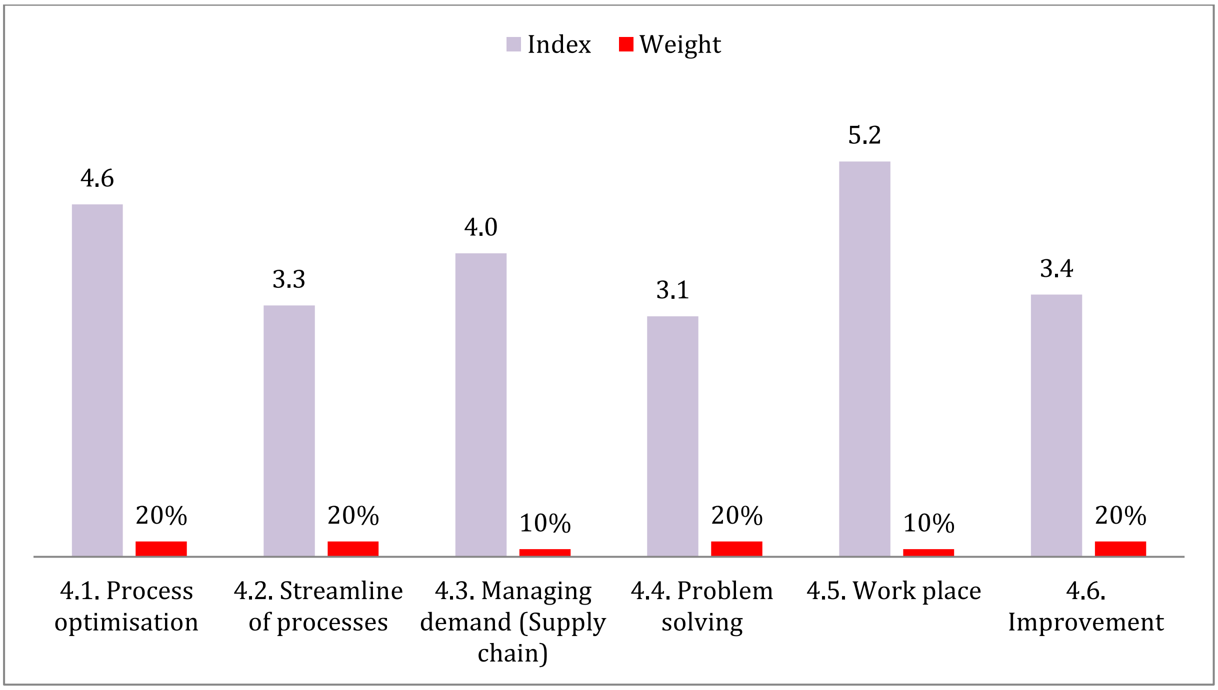



**Figure 6.39 Weights and Indices Process Excellence Criteria (Company C)**

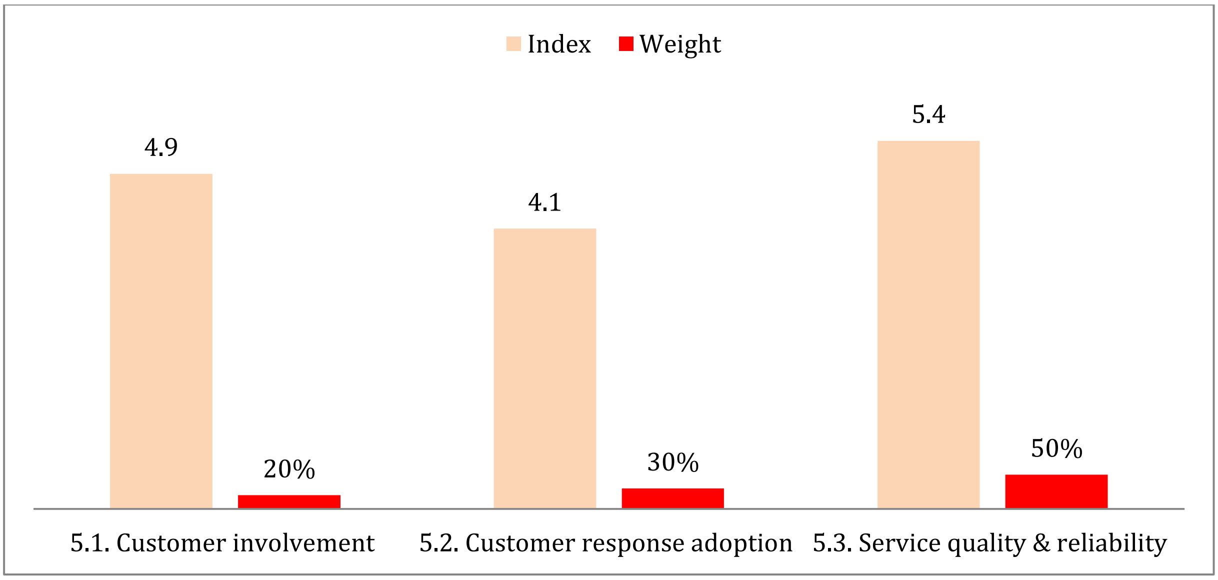



**Figure 6.40 Weights and Indices of Customer Relationship Criteria (Company C)**

## 6.5 Discussion on the Case Studies Results

Based on the assessment conducted for the three companies (A), (B), and (C), it was found that the PSS leanness indices for the three companies are 8.0, 6.9, and 4.4 respectively as mentioned in Table 6.13

**Table 6.13 PSS Leanness Index for the Three Companies**

| Company | PSS Index |
|---|---|
| (A) | 8.0 |
| (B) | 6.9 |
| (C) | 4.4 |

The indices for company (A) and company (B) reveal that the service offering in both companies is lean, but the PSS in company (A) is 11.08% leaner than company (B). The difference between the companies comes from the history of each company in implementing lean practices. As mentioned before, company (A) started its quality journey in the early 90s and lean was integrated and driven as a company strategy, but, company (B) started its lean journey in 2006.

Apart from company (A) and company (B), the PSS leanness index for company (C) was found to be 4.4. This PSS leanness index indicates that the service offering process in company (C) is not lean, this is because company (C) still in the early stages of lean implementation. More discussions about each company are presented in the following sections.

### 6.5.1 Company (A)

The PSS index for company (A) is 8.0, the PSS in company (A) is just about to be extremely lean. Some improvements should be conducted in order for company (A) to shift to the extremely lean category. As presented in Table 6.14 Section (a), company (A) should focus more on the process excellence enabler, where process excellence is highly important for company (A) with a weight of 40% and an index of 7.7

From Table 6.14 Section (e) it is obvious that some enhancements are required in three criteria, namely: problem solving, process optimisation and improvement. This improvement can be achieved by having a well-defined action plan for each problem, using statistical techniques to reduce process variance, encouraging improvement team, and quantification of the seven wastes.

The second enabler that needs some improvement is the supplier relationship. The index of the supplier relationship as mentioned in Table 6.14 Section (a) is 7.8. Supplier relationship can be improved by conducting regular training for suppliers' employees and flexibility in payment for suppliers.

Finally, other areas for improvements may include workforce leanness. This can be done by implementing job rotation system and giving more empowerment for employees to be able to solve customers' problems faster.

**Table 6.14 Comparison Between the Three Companies**

| (a) Enablers | Company (A) | | Company (B) | | Company (C) | |
|---|---|---|---|---|---|---|
| | Index | Weight | Index | Weight | Index | Weight |
| 1. Supplier Relationship | 7.8 | 10% | 5.8 | 10% | 4.6 | 20% |
| 2. Management Leanness | 8.3 | 20% | 6.5 | 30% | 4.2 | 20% |
| 3. Workforce Leanness | 8.1 | 10% | 6.1 | 20% | 4.3 | 20% |
| 4. Process Excellence | 7.7 | 40% | 7.5 | 20% | 3.8 | 20% |
| 5. Customer Relationship | 8.3 | 20% | 8.2 | 20% | 4.9 | 20% |

| (b) Supplier Relationship | Company (A) | | Company (B) | | Company (C) | |
|---|---|---|---|---|---|---|
| | Index | Weight | Index | Weight | Index | Weight |
| 1.1.Supplier quality | 8.1 | 20% | 6.6 | 20% | 5.2 | 30% |
| 1.2.Supplier cost | 7.2 | 10% | 5.9 | 20% | 4.1 | 10% |
| 1.3.Supplier responsiveness & support | 8.2 | 20% | 6.3 | 20% | 3.6 | 20% |
| 1.4.Supplier delivery | 7.8 | 30% | 4.8 | 20% | 5.4 | 20% |
| 1.5.Supplier feedback | 7.8 | 10% | 5.6 | 10% | 4.4 | 10% |
| 1.6.Supplier development | 7.3 | 10% | 5.2 | 10% | 4.4 | 10% |

| (c) Management Leanness | Company (A) | | Company (B) | | Company (C) | |
|---|---|---|---|---|---|---|
| | Index | Weight | Index | Weight | Index | Weight |
| 2.1.Culture of management | 9.5 | 30% | 6.6 | 20% | 3.1 | 20% |
| 2.2.Management practices | 7.4 | 30% | 7.6 | 30% | 3.9 | 30% |
| 2.3.Leadership | 8 | 20% | 5.1 | 40% | 4.7 | 30% |
| 2.4.Feedback | 8.2 | 20% | 8.5 | 10% | 4.9 | 20% |

| (d) Workforce Leanness | Company (A) | | Company (B) | | Company (C) | |
|---|---|---|---|---|---|---|
| | Index | Weight | Index | Weight | Index | Weight |
| 3.1.Employee status | 7.5 | 20% | 5.7 | 50% | 4.1 | 50% |
| 3.2.Employee involvement | 8.2 | 80% | 6.6 | 50% | 4.5 | 50% |

| (e) Process Excellence | Company (A) | | Company (B) | | Company (C) | |
|---|---|---|---|---|---|---|
| | Index | Weight | Index | Weight | Index | Weight |
| 4.1.Process optimisation | 7.6 | 20% | 7.4 | 20% | 4.6 | 20% |
| 4.2.Streamline of processes | 8 | 20% | 6.3 | 20% | 3.3 | 20% |
| 4.3.Managing demand | 8.1 | 10% | 7 | 10% | 4 | 10% |
| 4.4.Problem solving | 7.4 | 20% | 7.1 | 10% | 3.1 | 20% |
| 4.5.Work place | 8.1 | 10% | 7.9 | 20% | 5.2 | 10% |
| 4.6.Improvement | 7.6 | 20% | 8.7 | 20% | 3.4 | 20% |

| (f) Customer Relationship | Company (A) | | Company (B) | | Company (C) | |
|---|---|---|---|---|---|---|
| | Index | Weight | Index | Weight | Index | Weight |
| 5.1.Customer involvement | 8.6 | 40% | 9.1 | 40% | 4.9 | 20% |
| 5.2.Customer response adoption | 8.1 | 30% | 6.7 | 10% | 4.1 | 30% |
| 5.3.Service quality & reliability | 8.1 | 30% | 7.8 | 50% | 5.4 | 50% |

### 6.5.2 Company (B)

The PSS leanness index for company (B) is 6.902. This total PSS leanness index reflects the indices computed for the five main enablers for company (B) as shown in Table 6.14 Section (a). The PSS in company (B) is considered to be lean, but more progress still available. Three main enablers need some improvement in company (B) as presented in Table 6.14 Section (a). These enablers include management leanness, workforce leanness, and supplier relationship with indices of 6.5, 6.1 and 5.8 respectively.

Starting from management leanness because it presents the most important enabler with a weight of 30%, company (B) should give more attention to the leadership style. As shown in Table 6.14 Section (C), leaders should: refer to employees as associate and spend a lot of time coaching, mentoring and leading by example. Also, more focus is required in management practices in terms of the smooth of information flow, process focused management, and team management for decision making.

The second enabler that can be improved is workforce leanness. Workforce leanness index is 6.13 with a relative importance of 20%. Improvement in workforce leanness can be achieved by implementing job rotation system, enhancing culture of continuous improvement, identifying the internal and external customer for each employee, encouraging employees' cooperation and empowerment. With regard to supplier relationship as shown in Table 6.14 Section (b), it can be improved by considering three areas that include: supplier delivery, supplier development and supplier cost. Other areas for improvement may involve some attributes pertaining to process excellence and this can be achieved by adopting value stream mapping, quantification of the seven wastes, optimising the cost of inventory, usage of automated tools to enhance services, and existence of future state maps.

### 6.5.3 Company (C)

Apart from company (A) and company (B), the PSS leanness index for company (C) was found to be not lean with an index of 4.3568. According to company (C), all the enablers are equally important for implementing lean practices in PSS with a relative importance of 20% as shown in Table 6.14 Section (a). Company (C) should work hard in all areas to improve the PSS leanness level. But the focus here will be only on process excellence, because the index computed for process excellence was found to be 3.8 and this presents the lowest index computed for the enablers for company (C). As a starting point for company (C) process excellence can be improved by:

- Adoption of value stream mapping
- Quantification of the seven wastes
- Having extra capacity to handle unpredictable demand
- Training employees on problem solving tools and techniques
- Using of root cause analysis
- Identifying a well-defined action plan for each problem
- Using Kaizen and 5s
- Existence of improvement team
- Existence of future state maps

### 6.5.4 Approval of the results

After computing PSS leanness index and identifying areas for further improvement for the three companies, a presentation to the experts participated in the assessment process of each company was carried out. The aim of this presentation was to discuss the index calculated for each company and areas for further improvement and examine if the results reflect the real situation in each company or not.

In a group discussion in each company, the five experts were asked whether:

- The index computed presents the reality
- The improvement areas reflect the current situation of the company
- There were any missing items or items that should be excluded from the tool

The experts asserted that the index computed for their company reflects the current lean practices in their company. Also, there was an agreement among them on the improvement areas identified for each company. Finally, they did not suggest any modifications on the model and they mentioned that the model is comprehensive and covers all the required elements. For example, the **Business Improvement Manager** of **Company (A)** mentioned:

> *"I am quite happy with the way we implement lean. You can always say it could have been better, but I think we did very well. One of the very appealing sides of the tool is to identify the gap between the current leanness state and the ideal leanness state. The tool can identify what can be improved. We will seek opportunities for improvement".*

Also, the **Continuous Improvement Manager** of **Company (B)** said:

> *"I am proud. The tool is pretty simple, holistic and quick to put into practice. All the suggestions and recommendations are acceptable. Our strength and weak points are much clearer now. Our performance in certain areas was lower than expected, but it will get better. The index proves that we are on the right track".*

Finally, the **CEO** of **Company (C)** stated:

> *"This tool is really helpful. It enables us to assess our performance across different areas. The tool is useful for use to find and diagnose problems. It has the advantage of analysing our performance in each area by cutting problems into bite-sized chunks. We are now aware of the bigger picture of what's going and how we can change it".*

## 6.6 Chapter Summary

In this Chapter, the development and the validation of the PSS leanness assessment model were presented. The PSS leanness assessment model can be used to evaluate and determine the degree of leanness in the service offering process of manufacturing companies, as well as, identifying areas for further improvement.

In Section 6.1, a brief introduction about PSS and lean was highlighted, in addition to, defining the concept of PSS leanness.

In Section 6.2, the research methodology followed for the development and the validation of the model was illustrated. In this section a detailed description of the iterative steps used to develop the model and the process used to apply it was presented.

Section 6.3, has provided insights into the PSS leanness assessment model. This Section, described the structure and the components of the model. The model comprises of three levels, namely: enablers, criteria and attributes. The first level contains five enablers, in the second level there are 21 criteria, and finally the third level consists of 73 attributes. In this section, an explanation of the five main enablers - supplier relationship, management leanness, workforce leanness, process excellence and customer relationship- was provided. Additionally, the assessment process used to calculate PSS leanness index was explained. Also, the equations, as well, as the steps used in computing the PSS leanness level were highlighted.

In section 6.4, the application of the model in three real life case studies was carried out. This section, demonstrated the PSS leanness level for each company.

In Section 6.5, the PSS leanness index was computed for the three companies based on the relative importance and assessment scores provided by fifteen experts from three UK manufacturing companies, five experts from each company. Then, a comparison between the three companies was conducted and areas for further improvements were identified for each company.

CHAPTER 7

# 7 DISCUSSION AND CONCLUSIONS

The aim of this chapter is to provide a synopsis of the research findings and further discuss their implications to the relevant fields. Additionally, the conclusions drawn from this thesis are presented in this chapter. To achieve this aim, this chapter is structured as presented in Figure 7.1.

In Section 7.1, a summary and further discussion of the key research findings described in this thesis is presented, taking each area of the thesis in turn. Section 7.2 discusses the quality and the generalisability of the research findings. The author emphasises the main contributions of this research in Section7.3. An account of how the research findings fulfilled the research objectives is presented in Section 7.4. Section 7.5 identifies the limitations of this study. The final conclusions are presented in Section 7.6. Finally, in Section 7.7, the author suggests areas for future research in the light of this thesis.

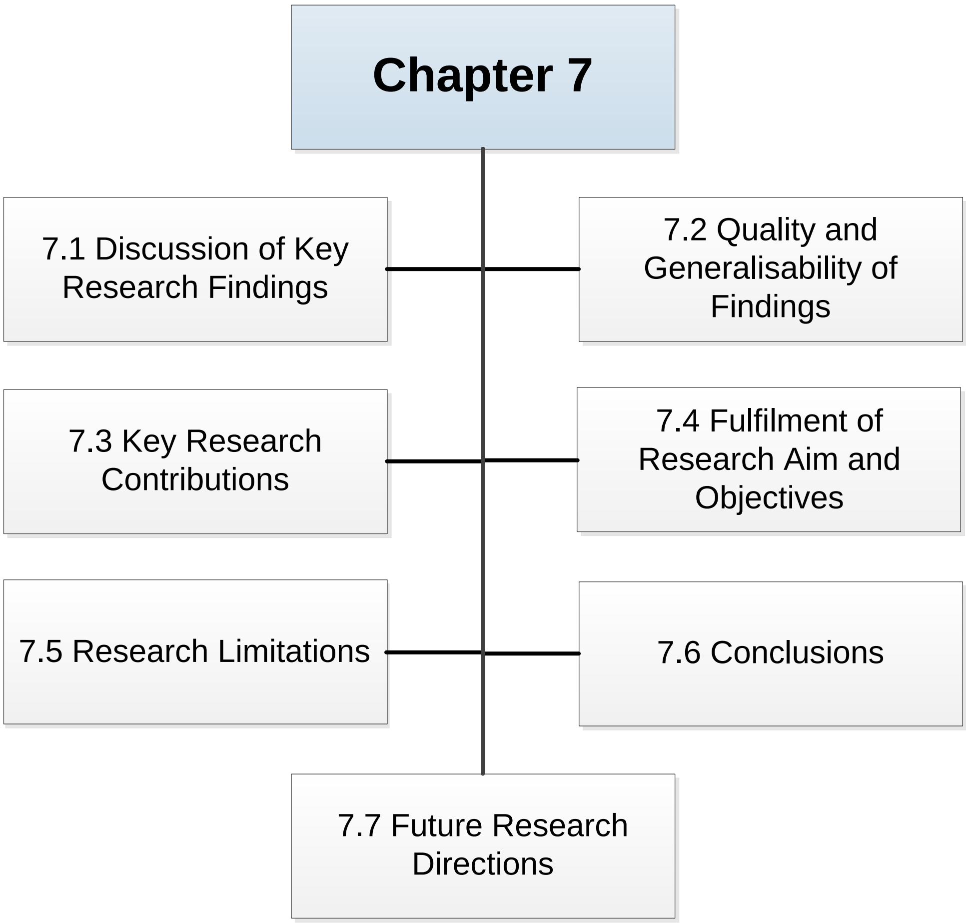



**Figure 7.1 Structure of Chapter 7**

## 7.1 Discussion of Key Research Findings

A discussion of the key research findings and observations is presented in this section. The sequence of the section endeavours to represent the sequence of the work presented within this thesis, facilitating the reader to keep track of it.

### 7.1.1 Literature Review

The review of literature covered the two main areas of this research: Product-Service System (PSS) and lean. In regard to PSS, this review revealed that the research on this topic is growing. Many researchers from different backgrounds have started to investigate, analyse and describe the concept of PSS. PSS promotes the idea of selling value in use via an integrated combination of products and services. It has been regarded by many economic policy makers and researchers as a potential competitive strategy for the manufacturing industry with the aim of improving sustainability and reducing the consumption of materials. This review revealed that most of the research described in the literature makes an attempt to clarify the concept of PSS and differentiate it from other related concepts, identify the barriers of implementing PSS, describe the benefits of implementing PSS, and to develop methodologies for PSS design and development. In spite of the existence of an extensive literature in the area of PSS, it was observed a lack of efforts conducted to determine how the existing service offering process can be enhanced and improved using some business improvements tools and techniques.

From the literature review carried out on the area of lean, it can be seen that the research into this topic is booming, and companies are striving to adopt lean practices in their process. Furthermore, the implementation of lean can be considered difficult and challenging. So, few companies succeed in their lean journey.

It can be observed that lean is about delivering the most value from the customers' perspective while consuming the fewest resources. Also, from the literature reviewed, it was found that lean has been widely applied in both manufacturing and non-manufacturing sectors as this provide organisations with the ability of reducing cost by eliminating non-value-added activities. Thus, lean can be seen as a management strategy that is applicable to all types of organisations either manufacturing or non-manufacturing because it improves business processes.

Most of the previous research carried out in the area of lean focused on the implementation of lean practices mainly on the manufacturing sector. Recently, the popularity of lean is growing exponentially in non-manufacturing sector such as: insurance companies, universities, call centres, restaurants, and hospitals. The literature reviewed in the area of lean revealed that most of the research carried out in the manufacturing sector and non-manufacturing sector makes an attempt to identify: how lean can be implemented, what are the lean tools and techniques that can be employed, how to make processes leaner, what are the challenges of implementing lean and how to overcome these challenges.

Despite the vast research carried out either on lean manufacturing or lean service, few attempts were made to precisely define how lean practices can be implemented in PSS. Little effort has been made on developing a framework for implementing lean in PSS, as well as, little effort has been made on identifying the enablers, challenges, and tools of implementing lean in PSS. Additionally, none of the existing researches have described how lean the PSS is, how lean the PSS should be, and how to achieve the desired leanness level.

### 7.1.2 Research Methodology

As described in chapter 3, the research methodology followed is primarily qualitative. The main weaknesses of qualitative research are potential bias from the participants and from the researcher as well. This bias nature can affect the validity and reliability of results. To mitigate these weaknesses, the author took a number of actions. One of the actions is to use of a variety of methods in the data collection phase. The qualitative nature of the research required a sufficient understanding of the suitable methods to be used when collecting data. The author used face-to-face interviews, focus group, observation, and the companies' documentation. The information captured from different sources was triangulated to minimise bias. Moreover, the author triangulated the data collected by means of semi-structured and structured interviews with different experts from different organisations. In addition, the questionnaires used in this research have always been piloted with a subject expert to ensure its quality and applicability. After collecting and analysing the required data from different sources, the key findings were summarised and presented to the participants in order to reduce the researcher's bias.

### 7.1.3 Lean PSS Implementation Framework

The author, after conducting literature review and a series of face-to-face interviews with experts at three UK manufacturing companies and triangulating it with official documents, managed to identify that the implementation of lean can be considered difficult and challenging and few companies succeed in their lean journey. Thus, there is a need to define a well-planned framework for the successful lean implementation.

While many attempts have been made to create a useful framework for lean implementation in the manufacturing sector and the non-manufacturing sector, none of the existing frameworks have tried to develop a framework for implementing lean in PSS. Based on the findings, a framework for implementing lean in PSS was proposed. The proposed framework will determine the lean tools and techniques that need to be implemented based on the company's current state.

The proposed framework is constructed on three implementation phases. These phases are assessment of the current state, developing a future state, and stabilising the new way of operations. Appropriate practices and tools are proposed and assigned to each phase.

In the assessment of the current state phase, the challenges of implementing lean in the service offering process were identified as discussed in chapters 4 and 5. After identifying the main challenges, the PSS leanness level should be measured using Lean PSS Assessment Model. The model assess the PSS leanness level in terms of five main enablers, these enablers are supplier relationship, management status, employees status, work process, and finally customers relationship as explained in chapters 4 and 6. In the second phase of the implementation framework, areas for further improvements are clear and the improvement proposal is identified with respect to supplier relationship, management status, employees' status, work process, and customer relationship. Finally, in the last phase the new way of operation should be institutionalised, along with continuous improvement practices to take advantage of the initial momentum and push toward the established goals. In this phase, there is an emphasis on measurement and continuous improvement.

### 7.1.4 Determinates of Lean Success and Failure in PSS

After conducting literature review and a series of semi-structured and structured interviews, it was found that the popularity of lean practices in the manufacturing and non-manufacturing sectors is growing every day, as well as, the successful lean implementation is governed and facilitated by certain crucial enablers. To date, the enablers, challenges, and tools for implementing lean practices in the service offering process have not been systematically examined and investigated. Most of the existing studies have derived their enablers, challenges, and tools from either manufacturing or non-manufacturing perspective. Thus, there is a need to propose a set of enablers and challenges which is believed to be more appropriate for PSS.

The transfer and implementation of lean practices in PSS is possible. However, it is important to note that for this transfer and implementation to be achieved with the desired benefits, some enablers have to be in place during the implementation process. There are five main generic enablers namely: management status, work process, customers relationship, employees status, and suppliers relationship. These enablers are considered crucial for implementing lean in PSS. Under these enablers there are 33 factors that deemed to be critical for implementing lean in PSS. Those enablers and factors are important because they can act as guidelines for companies when implementing lean in PSS. Those enablers and factors should be taken into consideration when applying lean in PSS. In addition, a series of inhibitors also appeared which could block the transfer and implementation of lean practices in PSS. Lean can be successfully applied in PSS, provided implementation barriers are understood and overcome. Some of the challenges are the same as in the manufacturing and non-manufacturing sectors such as: resistance to change, management commitment, understanding the concept of lean, and lack of finance. Other challenges are related to the PSS such as: nature of service process, ability to define waste in the service process, and the ability to identify customers and what they value.

Additionally, the appropriate lean tools and techniques for the successful implementation of lean practices in PSS should be identified. There are a wide variety of lean tools, if used in the proper way will lead to the achievement of the desired objectives. Among the most important lean tools that can be used in the implementation of lean in PSS are Kaizen, 5s, Just-in-Time (JIT), Voice of the Customer (VOC), standardisation, 5 whys, and Value stream mapping (VSM).

### 7.1.5 PSS Leanness Assessment Model

Based on literature review it was found that few attempts were made to precisely define leanness in the context of assessing lean status. Even with the massive research carried out either on lean manufacturing or lean services, the definition of leanness was not stated explicitly. Most of the previous studies focused on how to make a process leaner, little effort has been made on determining how lean the process is. In chapter 6 PSS leanness is defined as the degree of the adoption and implementation of the lean practices in the process of providing services to customers. PSS leanness can be considered as an assessment parameter to measure the lean status of the process of providing services to customers. Additionally, in chapter 6 an innovative model to assess the leanness of PSS and provide an index for lean PSS was presented. The model comprises of three levels, namely: enablers, criteria and attributes. The first level contains five enablers, in the second level there are 21 criteria, and finally the third level consists of 73 attributes. The development of the model was carried out through an iterative process. Starting from literature review going through semi-structured interviews with academic researchers involved in lean projects and ended with semi-structured interviews with a number of experts in the field of lean from five UK manufacturing companies.

The rationale behind the formulation of the model is that it represents five major perspectives of lean in PSS, namely: supplier relationship, management leanness, workforce leanness, process excellence and customer relationship. The computation of PSS leanness index goes through successive steps. The assessment of each level depends on the assessment of the preceding level. For instance, the PSS leanness index is the sum of the indices calculated for each enabler. Also, the index of each enabler is the sum of the indices computed for the criteria pertaining to each enabler. Finally, the index computed for each criterion will be determined by the assessment scores for each attribute pertaining to each criterion.

The PSS leanness index discussed in chapter 6 is useful for business improvement. This index provides managers with a real insight into the leanness level of their service offering. Also, it provides managers with a quantifiable measure of how lean their PSS is. The index identifies the gap between the current state and the future state and this helps in determining areas for further improvement. This performance measurement is useful to keep managers aware of things that should address and ensure that they are on the right track.

## 7.2 Quality and Generalisability of Findings

The author throughout the course of this research made every attempt to ensure that the entire process, the attainment and the analysis of the results, were carried out in a methodical and systematic way.

Considerable attention was paid to the selection of the suitable data collection methods and followed a formal research strategy as presented in chapter 3. This was achieved by combining different data collection methods such as: semi-structured and structured interviews, received documents, focus group and case studies. Regarding the case studies, the time available for the researcher was the main limitation. Hence, all the necessary steps were taken so as to select cases, where the experts are accessible, and willing to collaborate with the researcher before and during each case study. Furthermore, when possible, triangulation of data and methods was implemented, whilst also collecting data from multiple organisations for the purpose of gathering a general view from different industries.

Data were collected mainly from three large companies that operate in different industries. The first company is a document management company that produces and sells portfolio of offerings such as: colour and black-and-white printing, publishing systems, multifunction devices, photocopiers, fax machines, and related consulting services. The second one is a specialist train manufacturers that provides a comprehensive range of design, manufacturing, operating and maintenance service for the rail transport. Finally, the third one is specialised in manufacturing commercial heavy vehicles.

The author paid importance to the selection of case companies that operate in different industries in order to ensure the generalisability of the research findings. Thus, the implementation framework along with the assessment model can be applied in other manufacturing industries that deliver PSS business model without any modifications. The proposed lean PSS assessment model was validated via 15 experts working in three different UK manufacturing companies in three different industries. The 15 experts participated in the validation process agreed that the framework and the assessment model is suitable for any manufacturing company that implement or want to implement lean practices in PSS.

The research outputs were qualitatively and quantitatively validated. The identified enablers, challenges, and tools of lean practices implementation in PSS implementation were validated by 15 experts from three companies. They stated that the identified enablers, as well as, the challenges and tools captured by the researcher, represent a comprehensive and well-organised set, which will be valuable to companies when they first attempt to plan for lean PSS implementation. Furthermore, after the group discussion, the 15 experts were prompted to complete a validation questionnaire independently. The analysis of the participants' responses indicated that all of them agreed on the results achieved.

With regard to the assessment model, the model was validated by applying it to compute the PSS leanness level for three UK manufacturing companies and identifying areas for further improvement for these companies. The results indicate that the model is able to assess PSS leanness level effectively and has a practical relevance. After computing PSS leanness index and identifying areas for further improvement for the three companies, a presentation to the experts participated in the assessment process of each company was carried out. The aim of this presentation was to discuss the index calculated for each company and areas for further improvement and examine if the results reflect the real situation in each company or not. The experts asserted that the index computed for their company reflects the current lean practices in their company. Also, there was an agreement among them on the improvement areas identified for each company based on the assessment model results. Finally, they did not suggest any modifications on the model and they mentioned that the model is pretty simple, holistic and quick to put into practice. They mentioned that it is helpful to assess the performance across different area to find and diagnose problems, as it cuts problems into bite-sized chunks. The PSS leanness index computed is useful for business improvement. This index provides managers with a real insight into the leanness level of their service offering. Also, it provides managers with a quantifiable measure of how lean their PSS is. The index identifies the gap between the current state and the future state and this helps in determining areas for further improvement.

## 7.3 Key Research Contributions

The key contributions to knowledge made through this research have been described in this section. This research has significantly contributed to a better understanding of implementing lean principles in PSS. It has introduced a framework that guides manufacturing companies in the implementation process of lean practices in PSS. Furthermore, the key enablers, challenges, and tools of implementing lean principles in PSS were identified. Additionally, the research has introduced a novel lean PSS assessment model that can measure the degree of PSS leanness. The key contributions of this research are summarised as follows:

Literature reported various frameworks that address the implementation of lean practices in the manufacturing and non-manufacturing sectors. None of the existing lean research has attempted to develop a framework for implementing lean practices in PSS. This research offers a framework which can be useful for practitioners seeking to implement lean practices in the service offering process. The lean PSS implementation framework is well-structured, tooled and comprehensive enough to be apprehensive and understandable to the practitioners. In addition the framework covers the identified enablers, factors, and lean tools required for the successful implementation of lean in PSS, as well as, the challenges that may obstacle the implementation process. The proposed framework has integrated an assessment model that provides a quantifiable measure of the PSS leanness level. The framework highlights all the relevant phases that are necessary to consider in the implementation process, offers a description of what these phases entail, and a guideline for the sequence in which these phases should be implemented. It also emphasises what must be done to recognise the desired benefits within short time and ensures continuous improvement. The framework can be used as a guide for manufacturing companies that aim to implement lean in PSS.

To date, the enablers, challenges, and tools of implementing lean practices in PSS have not been systematically examined and investigated. This study is probably the first to provide a set of the enablers, challenges, and tools of implementing lean in PSS. A careful understanding of these vital factors will benefit manufacturing companies that would like to implement lean practices in PSS. These factors enable manufacturing companies to address and deal with when accomplishing lean implementation in PSS. This would help to ensure that essential issues and factors are covered when they are planning implementation of lean practices. Moreover, companies will be aware of the barriers that tend to hinder lean implementation success.

Despite the vast research published on leanness either on the manufacturing or the non-manufacturing, the extent literature fails to provide a method or instrument that can be used to measure the degree of PSS leanness. This research provides a definition of PSS leanness, as well as, an assessment model that can be used to measure the degree of PSS leanness. PSS leanness is defined as the degree of the adoption and implementation of the lean principles in the process of providing services to customers. Moreover this research provides an assessment parameter to measure the lean status of the process of providing services to customers. Accordingly, this research presents a comprehensive and complete lean PSS assessment model that can be employed to identify the degree of leanness in the service offering process. Applying this assessment model helps the implementation of lean in PSS as well as supports the continuous improvement initiatives. The output of this model is an index that: reveals how lean the service offering process is; indicates how lean the service offering process should be; and demonstrates how to achieve the desired leanness level.

## 7.4 Fulfilment of Research Aim and Objectives

The purpose of this section is to show how the aim and objectives of this thesis, defined in chapter 1, have been achieved.

The **first objective** was to understand the current industrial practices and state of the art in PSS and lean. Based on the review of literature and information gathered from multiple UK manufacturing organisations as presented in chapter 2 and chapter 4, the author revealed that:

- The research on the area of lean and PSS is growing, as well as, the implementation of lean practices and PSS among manufacturing companies is gaining considerable importance.
- Most of the research in the area of PSS makes an attempt to clarify the concept of PSS and develop methodologies for PSS design and development.
- There is a lack of efforts conducted to determine how the existing service offering process can be enhanced and improved using some business improvements tools and techniques such as lean.
- Most of the previous research carried out in the area of lean focused on the implementation of lean principles mainly in the manufacturing sector. But, recently the popularity of lean is growing exponentially in the non-manufacturing sector such as: insurance companies, universities, call centres, restaurants, and hospitals.
- It was observed that lean can be seen as a management strategy that is applicable to all types of process either in the manufacturing or the non-manufacturing sectors because it improves business processes.
- Most of the research carried out in the area of lean either in the manufacturing sector or the non-manufacturing sector makes an attempt to identify: how lean can be implemented, what are the lean tools and techniques that can be employed, how to make processes leaner, what are the challenges of implementing lean and how to overcome these challenges.
- There is a lack of efforts conducted to precisely determine how lean practices can be implemented in PSS.
- There is a general lack of standard procedures that describe the implementation process of lean practices in PSS across all the industrial collaborators.

The **second objective** was to determine the key challenges of implementing lean practices in Product-Service System (chapter 5). The author identified that:

- The researcher presented a list of barriers based on previous studies and interviews with industrial collaborators. Eight key challenges were identified; some of these challenges are unique and related to the nature of the service offering process.
- The relative importance of each of these challenges was identified. It was found that the most important challenge that manufacturing companies should take into their consideration when implementing lean in PSS is the nature of the service that differ from the nature of the tangible product.
- The transfer and implementation of lean practices in PSS is possible, provided implementation barriers are understood and overcome.

The **third objective** was to develop a framework for implementing lean practices in Product-Service System (PSS) (chapter 4). After conducting a combination of research methodology approaches including literature review and interviews with industrial collaborators, the author identified that:

- The author developed a framework (chapter 4) that transfer the lean approach used in the manufacturing and the non-manufacturing sectors into the service offering process. The proposed framework identified the main phases that should be followed by manufacturing companies for the successful implementation of lean initiatives in the service offering process. The framework was structured in three phases each requiring different kind of tools and methods, each phase should be completed in a proper way before going to the next phase. The three phases are assessment of the current state, developing a future state, and stabilising the new way of operations. The developed framework has the capability of assessing the leanness level of the service offering process, as well as, identifies the challenges that may hinder the implementation process.
- There are some common factors that are considered crucial for developing a framework for the lean implementation process. These factors include for

example: assessment of the current situation, developing lean implementation team, conducting training programs, management commitment and support, using the best combination of lean tools and techniques, and regular monitoring

- It was observed that there are some basic phases that are required to be followed during the implementation process of lean. These phases include the preparation phase, the design phase, the implementation phase, and the perfection phase.
- The lack of an effective lean implementation methodology and framework is one of the significant reasons behind the failure of the lean practices.
- Many attempts were made to create a useful framework for lean implementation in the manufacturing sector and the non-manufacturing sector, but none of the existing frameworks was comprehensive and can be implemented in all industries.
- While many attempts have been made to create a useful framework for lean implementation in the manufacturing sector and the non-manufacturing sector, none of the existing research tried to develop a framework for implementing lean practices in PSS.

The **fourth objective** was to identify the enablers and factors that assist manufacturing companies to develop and implement lean practices in PSS (chapter 5). The author revealed that:

- From the literature reviewed and the interviews conducted with the industrial collaborators, the author presented the main enablers and factors that assist manufacturing companies to develop and implement lean practices in PSS. By merging some of the existent factors and introducing some new ones, a comprehensive set of enablers and factors were developed for the successful implementation of lean practices in PSS.
- The author identified five main enablers and 33 factors emerging from the main enablers that are considered to be vital for the successful application of

lean in PSS. The main enablers are management status, work process, customer relationship, employees' status and finally, supplier relationship.

- The author identified the relative importance of all the enablers and the factors pertaining to each enabler.
- The most critical enablers are work process and management status. Followed by customer relationship and employees' status. Finally, the least important enabler is supplier relationship.
- Factors such as using Kaizen and 5s and identifying standards for each process present the most critical factors that pertain to the work process enabler.
- With respect to the management status enabler, the most important factors are management commitment; culture of problem prevention and waste elimination; and leadership.
- Using a well-defined voice of the customer is highly important factor to improve the customer relationship enabler.
- Employees' status can be improved by training and empowerment.
- With respect to the final enabler, namely, supplier relationship, the most two important factors are supplier lead time and deliveries arrive on time and in the right quality.
- Successful lean implementation is governed and facilitated by certain crucial factors. A thorough understanding of these crucial factors will benefit the organisations who would like to implement lean principles.
- Most of the existing studies have derived their set of critical success factors (CSFs) from manufacturing and non-manufacturing perspectives. Therefore, they have not really been designed to meet the needs of the service offering process.
- To date, enablers and factors for implementing lean principles in PSS have not been systematically examined and investigated. Thus, it is important to

outline the factors that perceived to be critical for the successful implementation of lean in PSS.

The **fifth objective** was to specify the appropriate lean tools and techniques that can be used to implement lean practices in PSS (chapter 5). The author revealed that:

- The author presented a list of nine lean tools and techniques based on previous studies and interviews with industrial collaborators that can be used to implement lean practices in PSS.
- The author identified the relative importance of each of these lean tools.
- The misapplication of the lean tools in terms of using the wrong tool to solve a problem, or using of single tool to solve all of the problems, or using the same set of tools on each problem is one of the significant reasons behind the failure of the lean implementation.
- The selection of the lean tools depends on the needs of the company. No single set of tools can be suitable for all the companies.
- The lean tools should be implemented in a structured manner and at an appropriate time whilst taking into account their interactions.

The **sixth objective** was to develop an innovative model to asses Product-Service System (PSS) leanness and provide PSS leanness index (chapter 6). The author identified that:

- The author provided a definition of PSS leanness which is the degree of the adoption and the implementation of the lean practices in the process of providing services to customers. PSS leanness can be considered as an assessment parameter to measure the lean status of the process of providing services to customers.
- Through an iterative process, the author presented an innovative model to assess PSS leanness in manufacturing companies. The model comprises of three levels, namely: enablers, criteria and attributes. The first level contains five enablers, in the second level there are 21 criteria, and finally the third level consists of 73 attributes (chapter 6).

- The computed PSS leanness index is useful for business improvement. This index provides managers with a real insight into the leanness level of their service offering. Also, it provides managers with a quantifiable measure of how lean their PSS is. The index identifies the gap between the current state and the future state and this helps in determining areas for further improvement, as well as, it identifies how lean the service offering process should be.
- The leanness measurement gains importance as it indicates the leanness performance of the organisation.
- Even with the massive research carried out either in lean manufacturing or lean services, the definition of leanness was not stated explicitly. Few attempts were made to precisely define leanness in the context of assessing lean status.
- Despite the few studies published on leanness either on the manufacturing sector or the non-manufacturing sector, the existing literature fails to provide a method to measure PSS leanness.

The **seventh objective** was to validate the research results through case studies and experts judgment. To achieve this objective, the following activities were carried out:

- The research outputs were qualitatively and quantitatively validated as explained in chapters 5 and 6.
- The experts stated that the enablers, as well as, the challenges and tools captured by the researcher, represent a comprehensive and well-organised set, which will be valuable to companies when they first attempt to plan for lean PSS implementation. Their views were collected to improve the final findings.
- The lean PSS assessment model was validated by applying it to compute the PSS leanness level for three UK manufacturing companies and identifying areas for further improvement for these companies. The results

indicate that the model is able to assess PSS leanness level effectively and has a practical relevance.

- The assessment model was also validated through experts' opinion from three UK manufacturing companies. Their views were collected to validate and improve the model.

## 7.5 Research Limitations

However, the scope of the research focuses only on large manufacturing companies that apply Product-Service System and keen to implement lean practices in the service offering process, there are some research limitations.

The research limitations are related to the research methodology followed, the proposed lean PSS implementation framework, the determinants of lean success and failure in PSS, and PSS leanness assessment model. Some of these limitations were out of the scope of this research.

With regard to the research methodology as it was explained in chapter 3, the qualitative nature of this research makes it prone to possible bias and problems with validity and reliability. Actions were taken to counteract the potential negative effect of the research methodology. These actions involved: (1) collecting data through multiple methods and techniques; (2) the careful selection of the case studies to make sure that they satisfy the research needs; (3) the rigour selection of the experts that have experience in lean implementation in order to understand the research requirements; (4) conducting interviews with experts from different fields and from different companies from different industries; and (5) presenting all the generated results and findings to the participants to get their feedback and validate the results. However, the three UK manufacturing companies that were studied in this research are large manufacturing organisation. The researcher considered this as another limitation as more cases would be needed to improve the generalisability of the findings.

With regard to the lean PSS implementation framework, the framework can be considered generic and dedicated to manufacturing companies that apply the Product-Service System business model and keen to implement lean practices in their service offering process. The framework does not provide any guidance about how much time and cost are required to implement each phase, as well as, how much effort and resources are required during the implementation process. Another issue that should be considered is to assess the usefulness of the framework in action, through actually using it to plan and manage an entire lean PSS implementation process. All the phases and related activities should be applied in a typical company and monitor the implementation process throughout all the phases.

Regarding the determinants of lean implementation success and failure factors, the semi-structured interviews used in the pilot study provides the opportunity to generate the widest range of responses but also allows for a greater chance of bias. Although, this generally did not have a great impact on the results, the risk was minimised by using structured interviews to identify the relative importance of each enablers, challenges, and lean tool. Moreover, the level of lean implementation of each company may affect the collected data. The amount of time each company had been involved with implementing lean varies from company to company. But, this provides the researcher with the ability to generate the determinants of lean PSS implementation from different angles that reflect different lean implementation experiences. The determinants of lean PSS implementation success and failure have been validated by experts' opinions. To address the issue of bias, the researcher validated the determinants through experts belonging to different fields of expertise including academia and industry. Their collaborative validation reduced any bias of both the researcher's and the experts' opinions.

Another limitation of this respect is that the PSS leanness assessment model did not include any direct financial performance factors. Financial parameters are important factor that need to be measured in the assessment process. Moreover, the assessment model has been validated through three case studies. The researcher identified the case studies from three different industries to describe the application of the developed model in different industrial sectors. Although validation through only three industries appears to be a small quantity, the researcher managed to validate the model through a number of options in each industry and therefore was able to minimise the consequences. Additionally, one limitation that occurred at the validation of the assessment model is that, some of the experts who participated in the validation of the assessment model, also participated in its development and refinement. This could cause bias since their views were already taken into account at the development stage. However, the other experts who were not involved at the development stage reduced the issues of bias.

## 7.6 Conclusions

In conclusion, it may be asserted that this research study has achieved the main aim and its objectives of developing an innovative framework to implement lean practices in PSS with the capability of assessing PSS leanness level. The following points summarise the main conclusions of this research study:

- In today's competitive market, manufacturing companies are more focused on the improvement of core competitiveness. They try to improve and develop their ability for competition through modern manufacturing initiatives and from these initiatives are lean manufacturing and Product-Service System (PSS). Lean and PSS can lead to dematerialisation through reducing the creation of wastes and the consumption of raw materials, cost reduction, improving customers satisfaction by meeting customers' needs better and improving competitiveness through increasing customers value.

- Lean can be seen as a management strategy that is applicable to all types of process either in the manufacturing or the non-manufacturing sectors because it improves business processes.

- There is a lack of efforts conducted to precisely determine how lean practices can be implemented in PSS. Furthermore, in spite of the vast research published on lean manufacturing and lean service, the concept lacks a general accepted definition and it lacks a holistic and unifying measure. Therefore, it becomes necessary for successful lean implementation to develop a standard measure to assess the effectiveness and efficiency of lean implementation.

- This research provides a lean PSS implementation framework. This framework is useful for manufacturing companies seeking to implement lean practices in the service offering process. The lean PSS implementation framework is well-structured, tooled and comprehensive enough to be apprehensive and understandable to the practitioners. In addition the framework covers the main enablers, factors, and tools required for the successful implementation of lean in PSS, as well as, the major challenges that may obstacle the implementation process. The proposed framework has integrated an assessment model that provides a quantifiable measure of the PSS leanness level and can be used as an audit tool. The framework highlights all the relevant phases that are necessary to consider in the implementation process, offers a description of what these phases entail, and a guideline for the sequence in which these phases should be implemented. It also emphasises what must be done to recognise the desired benefits within short time and ensures continuous improvement. The framework can be used as a guide for manufacturing companies that aim to implement lean in PSS.
- The transfer and implementation of lean practices in PSS is possible, as presented through in this research. However, it is important to note that for this transfer and implementation to be achieved with the desired benefits manufacturing companies should:
    - Use a roadmap for the implementation process of lean principles in PSS. Implementations.
    - Understand all the crucial enablers and factors that determine that successful implementation of lean practices in PSS.
    - Remove the factors that tend to hinder and block the process of lean PSS implementation success.
    - Select the best combination of lean tools and techniques that can be used in the implementation process.

- Regularly audit and monitor progress achieved towards the desired lean status to recognise the juncture that it has accomplished.

## 7.7 Future Research Direction

This section describes the potential areas of future work based on this study's findings. There are some potential researches for future work that would be helpful:

- The lean PSS implementation framework need to be actually implemented as this would enhance the usefulness, robustness, and generalisability of the framework and allow for further refinement. All the phases and related activities should be applied in a typical company and monitor the implementation process throughout all the phases.

- More manufacturing companies need to be investigated and to provide a standard roadmap for those companies that desire to implement lean principles in PSS.

- Future work can provide more insights about the cost, time, efforts, and resources required in the implementation of lean practices in PSS. Also, more research can be conducted to identify the cost-benefit analysis of implementing lean principles in the service offering process.

- In the future, more lean PSS enablers, challenges, and tools may be identified to improve the proposed framework. Future studies may shed more light on the factors that shape the various phases of the lean PSS implementation process.

- Studying cases that have failed or did not achieve all of their intended benefits from implementing lean practices in PSS can be considered in the future, to determine the reasons for their failures.

- The developed assessment model has been validated through three companies operating in different industries. In the future, the assessment model needs to be validated and implemented by more manufacturing companies to enhance the generalisability of the model.

- In the calculations of the PSS leanness index, the multi-grade method has been used to compute the PSS leanness index. Other calculation methods have not been considered in this research. In future, it will be necessary to compare the proposed method with other calculation methods such as Analytical Network Process (ANP), Analytical Hierarchy Process (AHP), structural equation model, and artificial neural network.

- Future research can also, develop a decision support system that can be used easily by manufacturing companies to calculate the PSS leanness index. This decision support system will facilitate the accurate evaluation of the PSS leanness. Besides assessing leanness, the decision support system also will enable the identification of improvement areas.

- Future research can include any financial performance indicators in the PSS leanness assessment model.

- Data collected mainly from three UK large manufacturing companies, future work can investigate the implementation of lean principles in the service offering process in SMEs.

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# APPENDICES

## Appendix A SEMI-STRUCTURED QUESTIONNAIRE FOR THE PILOT STUDY

### *I. Introduction*

Thank you for agreeing to participate in this research project that is being conducted at Cranfield University on Lean Product-Service System (PSS), which aims to develop a framework for implementing lean thinking in Product-Service System.

We are initiating a field study to identify the critical factors that determine the successful application of lean thinking in Product-Service System in UK companies.

In return for your help, you will receive a report detailing the findings of the study and potential recommendations.

Your participation will also be acknowledged (unless undesired) and we will provide you with project updates.

Regarding the interview, I'm interested in your view about the implementation of lean thinking in PSS. Therefore, I want to discuss with you questions about the aims, tools, barrier and impact of implementing lean thinking. The interview will last approximately 60 minutes.

### *II. General information*

**Name:**

**Company:**

**Job role:**

**Department:**

## *III. About your company*

**Q1)** What services do you offer to your customers?

**Q2)** Do your service agreements include the opportunity to purchase the rights for product-use instead of the purchase of the product itself?

## *IV. Background and motivation*

**Q3)** What do you associate with the lean philosophy? (What is your personal understanding of lean?)

**Q4)** When did the company start with its lean journey?

**Q5)** Please list the departments and/or areas of your company in which lean philosophy have been implemented.

**Q6)** What is driving your company toward becoming lean?

**Q7)** What were the main objectives of implementing lean in your company?

**Q8)** Does your company implement lean principles in the process of providing services to customers?

**Q9)** If No, do you think that the process of providing services to customers is not suitable for lean? Why?

## *V. Methods and tools*

**Q10)** What would you describe as the main challenges when adopting lean in the company in general?

**Q11)** Which lean tools and techniques are used in the process of providing services to customers?

## *VI. Implementation*

**Q12)** What are the factors contributing to the success of lean strategy in the process of providing services?

**Q13)** What have been the barriers to implementing lean strategy or realising success in the process of providing services?

## *VII. Impact*

**Q14)** What are the quantitative impacts of implementing lean in the process of providing services?

**Q15)** What are the qualitative outcomes of applying lean in service department?

**Q16)** Did the implementation of lean philosophy result in achieving the required objectives?

**Q17)** If no, please indicate the reasons why certain objective did not achieved

**Q18)** Is there any systematic procedure for a continuous evaluation of the quantitative and qualitative impacts? If yes, what are these procedures?

**Q19)** What are the recurring and non-recurring costs have incurred due to applying lean in the process of providing services?

## *VIII. Closure*

**Q20)** Is there any aspect, which you feel is important for the topic and we have not yet covered?

# Appendix B STRUCTURRD QUESTIONNAIRE

1. **What are the main challenges of implementing lean principles in the service offering process?**
   *Please for each of the following challenges listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| List of Challenges | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Lack of management commitment and support | | | | | |
| 2. Resistance to change | | | | | |
| 3. Nature of service | | | | | |
| 4. Understanding lean | | | | | |
| 5. Multi-site of the company | | | | | |
| 6. Identifying customers value | | | | | |
| 7. Overloaded people in the workplace | | | | | |
| 8. Defining waste | | | | | |

2. **What are the main enablers for the successful implementation of lean principles in the service offering process?**
   *Please for each of the following enablers listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| List of Enablers | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Supplier relationship | | | | | |
| 2. Management status | | | | | |
| 3. Employees status | | | | | |
| 4. Work processes | | | | | |
| 5. Customer relationship | | | | | |

**3. What are the main factors pertaining to supplier relationship enabler?**

*Please for each of the following factors listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| **List of Factors** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| 1. Supplier lead time | | | | | |
| 2. Deliveries arrive on time and in the right quality | | | | | |
| 3. Supplier after sales service & support | | | | | |
| 4. Supplier Involvement | | | | | |
| 5. Supplier sensitivity to complaints | | | | | |
| 6. Regular feedback to suppliers on their performance | | | | | |
| 7. Culture of waste elimination compatibility | | | | | |
| 8. Location of key suppliers | | | | | |
| 9. Regular training are conducted for suppliers employees | | | | | |

**4. What are the main factors pertaining to management status enabler?**

*Please for each of the following factors listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| **List of Factors** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| 1. Management commitment | | | | | |
| 2. Culture of problem prevention & waste elimination | | | | | |
| 3. Leadership | | | | | |
| 4. On-going measurement of performance | | | | | |
| 5. Clear understanding that lean is not just about tools but a philosophy | | | | | |
| 6. Daily accountability process | | | | | |
| 7. Participative decision making | | | | | |
| 8. Communication and smooth information flow | | | | | |

5. **What are the main factors pertaining to employees status enabler?**
*Please for each of the following factors listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| List of Factors | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Employees Training | | | | | |
| 2. Employees empowerment | | | | | |
| 3. Strong employee spirit and cooperation | | | | | |
| 4. Flexible workforce | | | | | |
| 5. Multi-skilled personnel | | | | | |

6. **What are the main factors pertaining to work process enabler?**
*Please for each of the following factors listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| List of Factors | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Identifying the purpose of each process | | | | | |
| 2. Identifying standards for the process | | | | | |
| 3. Quantifying the seven wastes | | | | | |
| 4. Using Kaizen & 5s | | | | | |
| 5. Anticipating potential risks for processes | | | | | |
| 6. Adopting value stream mapping | | | | | |
| 7. Setting an action plan for each problem | | | | | |

7. **What are the main factors pertaining to customer relationship enabler?**
*Please for each of the following factors listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| List of Factors | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Customers involvement | | | | | |
| 2. Customers feedback on quality, cost and delivery performance | | | | | |
| 3. On time delivery to customers | | | | | |
| 4. Identifying customer touch points | | | | | |
| 5. Usage of a well-defined VOC | | | | | |

8. **What are the most appropriate lean tools that can be used to implement lean principles in the service offering process?**
*Please for each of the following tools listed below, tick the box that indicates your opinion of its importance to your company* ***(1 = last Important, 2 = less Important, 3 = Important, 4 = Very Important, 5 = Crucial)***

| List of Tools | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1. Just-in-time (JIT) | | | | | |
| 2. 5s | | | | | |
| 3. Kaizen | | | | | |
| 4. Voice of the customer | | | | | |
| 5. Standardisation | | | | | |
| 6. 5 whys | | | | | |
| 7. Value stream mapping | | | | | |
| 8. Key performance indicators (KPIs) | | | | | |
| 9. Benchmarking | | | | | |