Design and Assessment of Lean Manufacturing Systems

THESIS

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CERTIFICATE

This is to certify that the thesis entitled "**Design and Assessment of Lean Manufacturing Systems**", submitted by **Anand G., ID. No. 2004PHXF007P** for award of Ph.D. Degree of the Institute embodies original work done by him under my supervision.

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Dedicated to

My Beloved Parents
Smt. G. Lalitha & Shri. S. Gurumurthy

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Abstract

The Lean Manufacturing Systems (LMS) has attracted serious attention among the practitioners and researchers in the recent years. The principles and practices of Lean Manufacturing (LM) were not only implemented in the manufacturing organisations, but also in service organisations. Although numerous articles dealing with the theory and practice of LM have been published, ironically, not many organisations have been successful in implementing the LMS and demonstrate a significant improvement in performance similar to that of Toyota Motor Corporation (TMC). Many researchers have pointed out that one of the reasons for the same is that there is an improper understanding among the practitioners regarding LMS. However, implementing a change management programmes like LMS requires a thorough understanding about the 'constituents of LMS', 'performance measures of LMS', 'implementation procedure of LMS' and 'assessment of LMS'. In addition, it is also necessary to analyse 'whether implementation of LMS is justified'. However, it is believed that such fundamental issues are not yet addressed completely in the literature of LM. Hence, there is a need to study the design and assessment of LMS.

In this research, a detailed literature review is carried out to understand the current status of LM and to identify the research gaps. To resolve some of the research gaps, comparative analysis of various LM frameworks and frequency analysis of the LM elements is performed based on which a conceptual framework for LMS and an implementation framework for LMS is proposed. The proposed frameworks are validated using a case study. Similarly, a frequency analysis is carried out for to identify the performance measures of LM based on which a new Performance Measurement System (PMS) framework for LMS was proposed by modifying the balanced score card approach. The proposed PMS framework for LMS is validated by comparing the

identified performance measures with the performance measures identified from the existing case studies that are available in the literature. Subsequently, various multi-attribute decision-making models such as analytic network process, preference ranking organisation method for enrichment evaluations and performance value analysis are developed for the justification of LMS for a case organisation, while simulation models are developed for the design of LMS for various case organisations such as a shop floor that manufactures brake linings using a batch production system, a cell that produces spiral and crown wheels (gears) using a mass production system and a factory that fabricates doors and windows using a job shop production system. Later, the graph theoretic model is developed for the assessment of the roles and responsibilities of human resources during the implementation of LMS, while a benchmarking process is developed for the assessment of LMS in a case organisation. Thus, it is believed that these contributions would enable better understanding of LMS by the practitioners and also pave way for many Indian industries to design and assess the principles and practices of LMS and achieve significant competitive advantage over other industries from abroad.

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Chapter 1
Introduction

1.1 Overview

The term "Lean Production (LP)" was introduced by the researchers: Womack, Jones and Roos from the Massachusetts Institute of Technology (MIT), USA, in the year 1990. They published their findings of the landmark study titled "International Motor Vehicle Program (IMVP)", which investigated the manufacturing management practices in the motor industry involving 52 vehicle assembly plants in 14 different countries across the world in the form of a book titled "The Machine that Changed the World" (Womack, *et al.*, 1990). However, the principles and practices explained as a part of LP were prevalent even before the introduction of this term by the MIT researchers. To understand the same, the history has to be traced back to the period of World War II. During the 1950s, after the demolition of Japan in World War II, a number of Japanese companies led by Toyota Motor Corporation (TMC) set out to bring their performance up to the standards set by the Western world. By visiting the manufacturing plants of the successful organisations in the West and by following the teachings of production experts such as Ohno and Shingo and quality gurus - Juran and Deming, Japanese manufacturers developed new ways of improving manufacturing performance that enabled them to make a step change in both quality and productivity. It enabled them to overtake their competitors in the West and Toyota became widely recognized as the most efficient volume car manufacturer in the world (Todd, 1995). Toyota came out with a unique production system called "Toyota Production System (TPS)", which was fundamentally different from the traditional production systems that prevailed in the Western manufacturing plants.

Since, then numerous studies were made by the researchers from the West to understand this unique production system. Some of the authoritative books written by the Japanese experts such as Shingo (1981), Monden (1987), Ohno (1988) and Western experts such as Schonberger (1982), Hall (1983), Harrison (1992) fuelled the interest among the academicians and practitioners to understand about TPS. Every author used different names to refer the TPS. For instance, Shingo (1988) used the term 'Stock-less Production', Harrison (1992) named it as 'JIT Manufacturing / Production', while Monden (1993) referred to it as 'Toyota Management System'. Numerous algorithms and mathematical models were developed to study the kanban system, push/pull system, mixed model manufacturing, etc. Oliver *et al.* (1998) commented that the Japanese management practices have become the Holy Grail for many industrialists especially in the US and Europe, as they start to lose the markets to the Japanese manufacturers. They explained that the Japanese manufacturing methods generated a great interest among the industrialists and noted that during the 1980s, wide-scale implementation of JIT production system were reported in the UK. However, many of the implementations were not successful. Slowly, with the opening up of world markets, the Japanese manufacturers especially the TMC moved outside Japan and established their production system in Western countries and demonstrated successfully the implementation of TPS.

However the evolution of TPS has been very slow. It is only after the study of Womack *et al.* (1990) that TPS got a significant attention among the practitioners worldwide. This study made the western industries to realise that the concept/philosophy of TPS or JIT goes beyond productivity and inventory, as the authors presented their results from the perspective of supply chain, product development, operations and competitive priorities. Even though the proponents were emphasising that the same principles can be applied to both shop floor and non-shop floor activities, the practitioners were implementing the

LM concepts mainly in the manufacturing and operations. Hence, the growth and acceptance of lean beyond the bounds of both manufacturing and post-production efficiencies reaching into all departments and time frames of business was very slow. One of the reasons for the same can be attributed to the fact that the researchers Womack *et al* (1990) initially explained the concepts of LM mostly from the perspective of manufacturing without describing much about its application in other business processes of an organization. However, later in the year 1994, Womack and Jones (1994) extended the concept of LM across different functions of an organisation and coined a new term called “Lean enterprise”. To demonstrate this, Womack and Jones (1996) described a case study of Lantech, a wrapping machine producer and discussed about the application of the five tenets of LM, which lead to unimaginable results in every aspect of its business. Since then, publications dealing with application of LM in other functions of the organisation such as product development (Haque and James-Moore, 2004), purchasing (Garg and Deshmukh, 1999), distribution (Reichhart and Holweg, 2007), etc. slowly emerged. However, the number of publications describing the application of LM beyond the bounds of manufacturing is still less. Apart from this, some researchers such as Levy (1997) have attempted to extend the LM concepts and principles beyond an organisation which resulted in the birth of lean supply chain. Similarly, researchers also discussed about the implementation of LM in service sectors too, which resulted in the development of various buzz words such as ‘lean software development’ (Poppendieck and Poppendieck, 2003), ‘lean service’ (Swank, 2003), etc. In addition to this, some researchers have combined the principles and concepts of LM with other change management programmes/philosophies such as six-sigma and Total Productive Maintenance (TPM) and established their new concepts and principles through various new terms such as lean six-sigma (Arnheiter and Maleyeff, 2005), lean TPM (McCarthy and Rich, 2004), etc.

1.2 Need for the Research

Thus from a brief overview described earlier, it can be found that, LM has been the 'talk of the world' in the last two decades and numerous works have been reported on LM in different countries across the globe. Similarly, a cursory search in the internet using a popular search engine such as www.google.com with the use of search terms such as 'lean manufacturing', 'lean production', 'JIT manufacturing', 'just in time manufacturing', 'Toyota production system', etc. reveal the following results as shown in Table 1.1.

Table 1.1: Results of the internet search (Source: http://www.google.com)

S. No.	Search terms	Results (in no. of web pages) as on 30.8.2008	
		From the web	From India
1.	Lean manufacturing	3,010,000	18,500
2.	Lean production	744,000	4,180
3.	Toyota Production System	380,000	1,930
4.	JIT manufacturing	28,600	339
5.	JIT production	21,900	189
6.	Just in time production	145,000	694
7.	Just in time manufacturing	94,700	1,030
8.	Just-in-time manufacturing	94,700	1,030
9.	Just-in-time production	156,000	698

A cursory analysis of Table 1.1 reveals that the term LP and LM are more famous than the rest of the search terms such as JIT production JIT manufacturing, TPS, etc. as evident from the number of web pages. Apart from this internet search, there are more than 100 journals (both national and international), which reports about various studies in LM. Around 2000 books on LM and related aspects are published. A cursory search on the website www.amazon.com (as on 30 August 2008) reveals that about 1900 titles related to LM and about 2,700 titles related to LP are published and available for sale.

Out of which around 230 books have the term “lean manufacturing” or “lean production” in the title. Recently, Black (2008) has written a book on implementing lean production.

On the other hand, in India, similar to the global results, the terms such as LP and LM have also gained more importance than rest of the search terms as evident from Table 1.1. Although, LM is gaining so much importance and attention in recent times, the level of importance and practice within India among the academicians and the practitioners is very less. The result in terms of the number of web pages shown in Table 1.1 and the number of books authored by Indian researchers and practitioners are significantly less when compared to the rest of the world. Only a very few researchers such as Korgaonker (1992) has written a book on ‘just in time’ manufacturing. Apart from this, it has been observed that many organisations, even in India and around the world, which are attempting to implement LM, are failing in their attempts to implement the same successfully. For instance, Mohanty *et al.* (2007) noted that

> *“many of the companies that reported initial gains from lean implementation often find that improvements remain localized, and the companies are unable to have continuous improvements going on. One of the reasons is that many companies or individual managers who adopted lean approach have incomplete understanding and, as a result, could not be able to gain all the benefits as Toyota enjoys”.*

Similarly, Bamber and Dale (2000) too found that there are two main stumbling blocks to the LM application namely, the redundancy programme and a lack of employee education in the concept and principles of lean production. Under such a circumstance, it becomes imperative to carry out a research and explore about LM. Furthermore, the design of manufacturing system is a complex task and it is crucial to the future of any company. Therefore, implementing Lean Manufacturing Systems (LMS) requires a thorough understanding about the ‘constituents of LMS’, ‘performance measures of LMS’, ‘implementation procedure of LMS’ and ‘assessment of LMS’. In addition, it is also necessary to analyze ‘whether implementation of LMS is justified’. However, it is believed that such fundamental issues are not yet addressed completely in the literature. Hence, there is a need to study the design and assessment of lean manufacturing systems, in which an attempt is made to address some of the fundamental issues related to design and assessment of LMS to eliminate or reduce the problem of ‘improper understanding of LM’ by the practitioners and academicians.

1.3 Objectives of the Research

The objective of the research is to study the design and assessment of lean manufacturing systems. The objective will be achieved by carrying out the following:

- Detailed literature review to understand the current status of LM and identify the research gaps
- Comparative analysis of various LM frameworks and frequency analysis of the LM elements to develop a conceptual framework for LMS and an implementation framework for LMS, which will be validated using a case study
- Frequency analysis for the design of performance measures of LM to propose a new Performance Measurement System (PMS) framework for LMS based on the Balanced Score Card (BSC) approach. The proposed PMS framework for LMS will be validated by comparing the identified performance measures with the performance measures identified from existing case studies that are available in the literature
- Development of the Multi-Attribute Decision-Making (MADM) models such as Analytic Network Process (ANP), Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE) and Performance Value Analysis (PVA) for the justification of LMS for the case organisation
- Development of the simulation models for the design of LMS for various case organisations such as a shop floor that manufactures brake linings using a batch

production system, a cell that produces spiral and crown wheels (gears) using a mass production system and a factory that fabricates doors and windows using a job shop production system

- Development of a Graph Theoretic (GT) model for the assessment of the roles and responsibilities of Human Resources (HR) during the implementation of LMS
- Development of benchmarking process for the assessment of LMS in a case organisation

1.4 Arrangement of the thesis

Chapter 2 discusses the literature review. Chapter 3 describes the proposed frameworks for lean manufacturing systems. Chapter 4 enumerates the development of a performance measurement system for lean manufacturing systems. Chapter 5 describes the justification of lean manufacturing systems. Chapter 6 details the development of simulation models for the design of lean manufacturing systems. Chapter 7 demonstrates the assessment of lean manufacturing systems. Finally, Chapter 8 summarizes the research contributions with conclusions.

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Chapter 2
Literature Review

2.1 Introduction

Since the publication of the book 'The machine that changed the world' authored by researchers from the Massachusetts Institute of Technology (MIT), USA in the year 1990, the applications of LM has been on the rise worldwide. One of the reasons for the same is globalisation. The globalisation phenomenon has resulted in opening up of new markets, which in turn gave rise to ever-demanding customers and ever-spiralling competition from domestic and international players. Hence, the organisations are attempting to implement the LM principles and concepts to remain competitive. Apart from the manufacturing sector, other sectors such as software services, health care, construction, etc. are also attempting to implement LM in recent times. Naturally, many papers addressing various issues have been published in the literature related to LM.

There are many review papers available in the area of Just In Time (JIT) manufacturing/production. For instance, researchers such as Sohal *et al.* (1989), Golhard and Stamm (1991) and Keller and Kazazi (1993) have provided a general review on the literature related to 'JIT manufacturing systems'. Apart from this, many review papers related to individual components of JIT production system were also published. Stamm and Golhar (1993), Waters-Fuller (1995), Garg and Deshmukh (1999), Gunasekaran (1999) reviewed the literature related to JIT purchasing. Duclos *et al.* (1995) reviewed the current practices of JIT in services, while Joo and Wilhelm (1993) reviewed the various quantitative approaches that are used in JIT manufacturing. On the other hand, Corbett and Yucesan (1993) reviewed exclusively on model-based approaches in studying pull systems, while Honold (1997) reviewed the literature related to employee empowerment. Berkley (1992) reviewed the literature on kanban production control and recently, Sendil Kumar and Panneerselvam (2007) presented a literature review on Kanban system in which they surveyed about 100 papers.

But it is ironical to note that not many review papers are available since the introduction of the term LM. It is almost 18 years since the new term called ‘Lean Production (LP)’ or ‘Lean Manufacturing (LM)’ came into being. Hence, it is necessary to have a review of literature to trace its development and identify the milestones in the research journey. Till now, there is only one review paper in the field of LM. It was published by Filho and Fernandes (2004) in the Gestao & Producao journal, published by Departamento de Engenharia de Producao of Universidade Federal de Sao Carlos. This paper is published in Portuguese language. On the other hand, Landsbergis *et al.* (1999) reviewed the literature related to surveys and case studies from various industrial sectors such as auto industry, health care industry and telecommunications, which dealt with the impact of new work systems on job characteristics, injuries, and illness to understand about the potentially major health effects of current employment and industrial trends. But, this paper provided only a review on the impact of work organisation due to LM, which is just one of the issues associated with LM transformations.

Thus, it can be concluded that no review paper, which provides a general review of LM especially in English, is available. Similarly, not many review papers that describes about the individual aspects of LM such as a review on Value Stream Mapping (VSM) and its application or a review on application of LM in various sectors (barring that of Landsbergis *et al.*, 1999), etc. are available in the literature. Hence, an attempt has been made to provide a comprehensive literature review in the field of LM.

2.2 Taxonomy for the Lean Manufacturing Literature

Since the research in LM is progressing in many directions, it is necessary to categorize and group the papers in the literature for easy understanding. Hence, based on the themes and issues, a classification scheme for the LM literature is proposed as shown in Figure 2.1

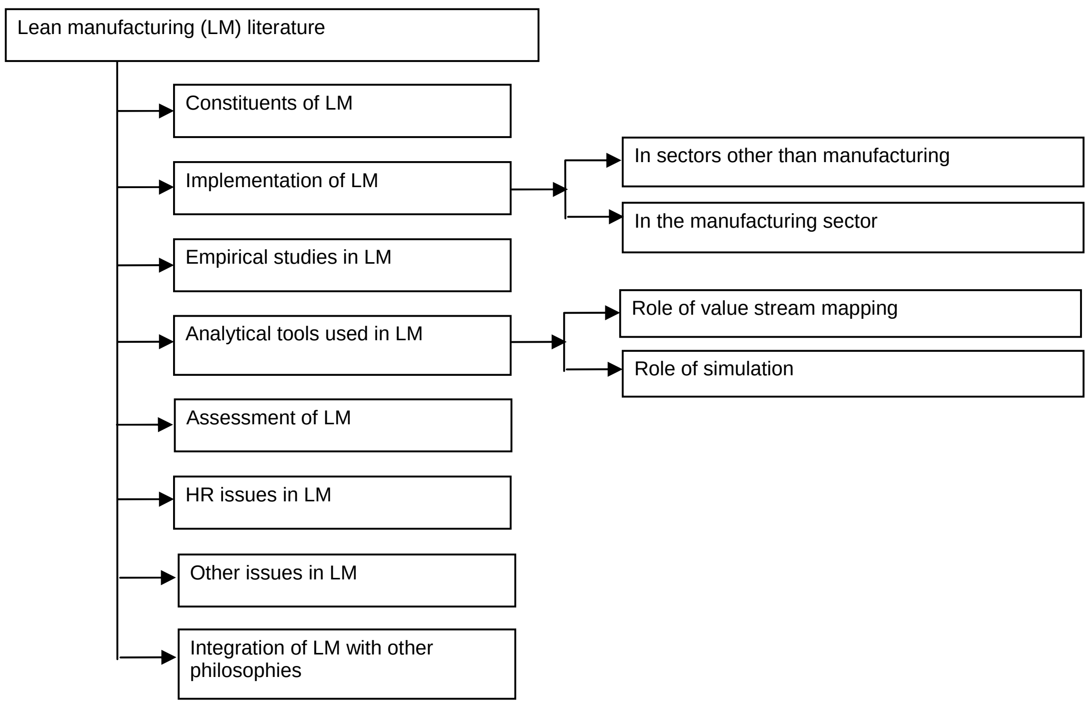

Figure 2.1: Proposed classification scheme for the LM literature

2.2.1 Constituents of lean manufacturing

Smeds (1994) described the constituents of LM as follows:

> *"The LM principles include the integration of production activities into self-contained units along the production flow. These units produce flexibly, with short throughput times and high quality similar parts or whole products. Flexible manufacturing technology and a group of multi-skilled operators with a high degree of autonomy and self-regulation characterize these production cells. They are mainly controlled by cell output in a simple pull mode: just in time for the need of the next "customer".*

Feld (2001) noted that LM consists of five primary elements: manufacturing flow, organisation, process control, metrics/performance measures and logistics and classified various sub elements under these main elements. On the other hand, Shah and Ward (2003) identified about 21 elements of LM from a literature review and classified the same into four bundles, namely, JIT, Total Productive Maintenance (TPM), Total Quality Management (TQM) and Human Resource Management (HRM). Similarly, Pavansakar *et al.* (2003) developed a classification scheme for about 101 LM tools. Treville and Antonakis (2006) noted that the benefits of LM can be achieved over time through a combination of synergistic and mutually reinforcing practices. They grouped those LM practices into several complementary sub-systems including (but not limited to) JIT manufacturing, TQM, TPM, Kaizen (continuous improvement), Design For Manufacturing and Assembly (DFMA), supplier management and HRM practices under the ‘respect-for-workers’ umbrella, which serves as the glue to hold the overall system together. Similarly, many researchers have identified the elements of LM and proposed different frameworks, which integrated all these LM elements. For instance, Womack and Jones (1996) portrayed a descriptive framework for LM in the form of definition and implementation steps. They refer them as the main tenets of lean, which includes the following: 1. specify value, 2. identify the value stream, 3. create flow, 4. let the customer pull and 5. pursue perfection. But, many researchers have chosen to portray a framework through diagrams or graphical representations. A brief review about the existing LM frameworks is presented in Table 2.1. It can be found that various frameworks are available, which are proposed by various researchers/consultants/ organizations. A complete review of all the existing LM frameworks is not feasible, but as far as possible, most widely published and relevant frameworks are reviewed.

Table 2.1: A brief review about the existing LM frameworks

S. No.	Name of the Framework	Author(s)	Remarks
1.	Framework depicting the components necessary for applying lean manufacturing principles	Jina *et al.* 1997	They proposed a framework to suit the High Variety Low Volume (HVLV) situation which has three interrelated components: product design geared to logistics and manufacture; organizing manufacturing along LM principles and integrative supplier relationships. These three components are held together by agile, process-oriented organizational capabilities supported by consistent measures which form the centerpiece for the framework. They have classified various elements under these four major components.
2.	Framework showing the brief summary of LM	Davies and Greenough, 2003	They expressed that they could not identify a strategy for generic lean practice implementation or a comprehensive list of lean activities for maintenance. They referred to a LM framework developed by Bicheno (2000), which is a summary of the central theme of lean thinking based on the five lean principles and fifteen characteristics of lean.
3.	Framework depicting various lean activities	Davies and Greenough, 2001	In another study developed a lean practice template, which they claim to be comprehensive enough to fairly represent lean activities possible within a company and in particular for the maintenance function.
4.	Concepts of LM	Karlsson and Åhlström, 1995	He noted that LP consists of five different parts: lean product development, procurement, manufacturing, and distribution, as well as the lean enterprise. The authors were focusing more on LM among the different parts and proposed a framework based on the following concepts of LM (elimination of waste; continuous improvement; zero defects/JIT; pull instead of push; multi-functional teams; decentralized responsibilities/integrated functions and horizontal and vertical information systems). With this framework, they have analyzed the impact of these LM concepts on remuneration system.
5.	Conceptualization of lean production	Karlsson and Åhlström, 1996a	They developed an operationalized model based on the description in the book “The machine that changed the world” written by Womack *et al.* (1990), which can be used to assess the changes taking place in an organization due to introduction of LP. They developed this model for the managers to use it as a tool to follow progress in their efforts towards achieving lean production.
6.	Theoretical concept of the lean enterprise	Karlsson and Åhlström, 1997	They proposed a lean enterprise framework, in which on the input side of the lean enterprise concept lean procurement is in place, where the principles of organized networks and knowledge input were considered important from a strategic perspective. On the output side is the lean distribution in which one of the principle is that a firm is a part of a global network that ensures actual customer orders trigger the production of goods instead of forecasted sales. Production against customer orders is made possible through the implementation of LM principles. Finally, the lean enterprise relies heavily on partners. This implies collaboration in networks with specialists in different areas, including competitors.

S. No.	Name of the Framework	Author(s)	Remarks
7.	Small and medium sized firms as lean enterprises	Karlsson and Åhlström, 1997	They have also extended the framework of lean enterprise for small firms, in which they and have made the following changes: global supply and special sources of development under lean procurement, global distribution and customers in product system under lean distribution and complimentary product firms as partners.
8.	Framework for LM with a process view of implementation	Åhlström and Karlsson, 2000	They investigated 'when does delayering of the organization take place during manufacturing improvement?' They claimed that existing research on sequences of manufacturing improvement initiatives have a weakness of not having a process view of implementation. Hence they developed a framework for LM from the perspective of process of adoption. They discussed briefly about the content of the LP framework apart from depicting the major actions taken by a case company.
9.	A lean production model for the assessment of LM	Sanchez and Perez, 2001	They developed and tested a framework called "an integrated checklist" to assess manufacturing changes towards LP. They proposed a check-list with 36 indicators that was developed according to the LP principles proposed Karlsson and Åhlström (1995).
10.	The lean automotive vision model	James-Moore and Gibbons, 1997	They noted that models which exist to collect all the information available on operational practices and performance that constitute LM and place them into a unifying framework are somewhat complex. Hence as the first step of their research to assess the status of a case organisation called SVG company, they developed a model which can act as a template and guide during the data collection process. The key aspect of their framework is the reinforcement of the linkages between drivers in the business environment and the strategic responses to the business environment. Hence, the core business processes, practices adopted and finally the appropriate key measurement attributes used either as a control or as a means of comparing performance are consequent on the environment drivers.
11.	The generic framework for the management of change towards a lean enterprise	Smeds, 1994	She proposed a generic framework for the management of change towards lean enterprise. It starts from a strategic vision and an overall umbrella strategy that guide the separate change projects. It then follows in a participative manner through the generic phases: analysis and model of the present state, identification of problems and opportunities, experimentation and selection of future state, implementing the change, and stabilizing the new mode of operation. The idea of continuous improvement is included in the generic framework, which she feels that a spiral of organizational learning is created.
12.	The lean production model	Oliver *et al.*, 2002	They noted that there are claims being made that Japan is no longer regarded as the economic paragon as it was assumed to be 10 to 15 years ago. They wanted to assess the prediction that Japan's car companies would start to behave in ways indistinguishable from their Western counterparts, when long term growth comes to an end. Hence, they performed an empirical analysis for which they prepared a questionnaire. The questionnaire covered seven main areas: plant performance; plant characteristics; process control; work organization; problem solving and improvement; relations with suppliers; and relations with customers.

S. No.	Name of the Framework	Author(s)	Remarks
13.	Tools of LM	Adams *et al.*, 1999	They quoted a framework for LM from the Lean Manufacturing Handbook. Figure 2.14 illustrates a framework which represents the tools of LM. They asserted that foundation of LM is established by the tools such as: 5S, 5-Whys, visual factory, focus groups, quality tools, pokayoke, etc. over which other tools such as TPM, Single Minute Exchange of Dies (SMED), takt time, cells, one piece flow, kanban are assembled. According to their framework, if all these elements of LM are implemented, then the organization can achieve a world-class status in operations.
14.	A lean enterprise	Czarnecki and Loyd, 2001	They proposed a framework, which looks similar to that of Adams *et al.* (1999) in terms of structure. However, there are many differences in terms of the tools listed. For example, tools such as standardized work, Point-Of-Use-Storage (POUS), quality at the source, teams, kaizen, VSM, etc. were not addressed by Adams *et al.* (1999). There is no description about the logic of arranging the tools as foundation, pillars, etc.
15.	Six steps to implement lean	Airbus, 2004	Airbus used a six step process to implement LM. Various lean elements have been classified under each of the six steps and to move from one step to another, the elements within each step should be implemented.
16.	Lean Engineering Principles	Garcia and Drogosz, 2006	Garcia and Drogosz (2006) used a term called “lean engineering” to describe Toyota’s product development. They presented a case study about a company called Tenneco in which the framework of Lean Engineering or Lean Product and Process Development proposed by Morgan and Liker (2006) was implemented. They explained that the three elements (skilled people, tools & techniques and process) must be integrated to create a high-performance Product & Process Development (PPD) System. They noted that: “To create a lean product development system, we must start by creating a lean process. Once a lean process is well defined, we can then implement the correct lean tools & technology to support the process and develop the skilled people needed to work in the process”.
17.	The house of lean	Nolan *et al.*, 2006	They described a case study in which one of the business divisions of Esterline technologies - Korry Electronics is implementing LM using a framework called “the house of lean” developed by Dennis (2002). Dennis (2002) explained that “the foundation of the lean system is stability and standardization. The walls are just-in time delivery of parts of products and jidoka, or automation with a human mind. The goal (the roof) of the system is customer focus: to deliver the highest quality to the customer, at the lowest cost, in the shortest lead time. The heart of the system is involvement: flexible, motivated team members continually seeking a better way”.
18.	Lean production as linked functions within in an enterprise approach	Cook and Graser, 2003	They discussed about the interrelationship between different functions in a lean organization and depicted the same in the form of a framework. They explained that the complexity in LM arises from lean principles cutting across the whole enterprise. For example, issues of concern during design and development can directly affect the manufacturing process, such as the ease of assembling parts into the final configuration. JIT delivery requires the development of close ties with suppliers apart from keeping inventory low, which has significant effects on the factory floor. Hence they developed a framework of LM which shows the interrelationships of the various activities needed to manufacture a product and how all must be managed to improve overall operating efficiency.

S. No.	Name of the Framework	Author(s)	Remarks
19.	The house of TPS	Liker and Lamb, 2000	They discussed about two frameworks. In the first framework, the TPS has been depicted as a house. They explained the logic behind the TPS framework, which are as follows: • The reason for the house metaphor is that a house is a kind of system. Without a strong foundation, strong pillars and a good roof, the house will fail. • The goals of TPS are illustrated in the roof - quality, cost, and delivery through shortening the production flow by eliminating waste. • The two main pillars of TPS are JIT and built-in quality, which are mutually reinforcing. Creating a JIT flow will leads to increased quality. Without the inventory buffers of mass production, JIT systems will fail if there are frequent quality problems that interrupt the flow. • The TPS house must sit on a foundation of extreme stability. For example, machine downtime in one operation will quickly propagate through the whole value stream because the inventory buffers are so small. Products that are not well designed to be manufactured will hang up the system at troublesome operations and prevent a well-orchestrated flow. • At the center of LM are people who must bring the system to life by continually improving it. The Japanese term kaizen literally means “change for the better.” And without people who are committed to improving the process, and aligned with management’s goals the discipline needed to run a LM system will quickly falter.
20.	Framework for lean ship building	Liker and Lamb, 2000	In the second framework, they translated the house of TPS into a shipbuilding model. It included all the elements of TPS but shown within a shipyard with a ship in dry-dock as the center-piece. They have compared these two frameworks and stressed that “one of the strengths of the house version compared to the ship building model is that the house clearly depicts a system – i.e. if any element is missing, the house will collapse. The shipyard figure does not reflect this as clearly.” However, they discussed about the lean ship building model element by element with sufficient ship building examples and finally concluded that lean is a system and the elements cannot be cherry picked one at a time.
21.	Framework of Chrysler Operating System	Flinchbaugh, 1998	He described about a framework called as Chrysler Operating System (COS), which is built based on the LM principles. The framework is said to be composed of core beliefs and values that determine the enablers, sub-systems, support processes, tools, measurement, and results. The four primary sub-systems of the COS are: human infrastructure, levelled and balanced schedules, value-added activities and robust, capable, and in-control processes. All these sub-systems contain most of the elements described under the umbrella of LM. He mentioned two important points related to this framework: • First, it shows how LP is much more than simply implementing a couple of tools such as kanban or 5S’s. Furthermore, it is a system of interrelationships. • Second, it should not be considered as a manual for implementing LP, but to help users understand COS as a system and provide a new language for that system.

S. No.	Name of the Framework	Author(s)	Remarks
22.	The just-in-time thinking principles	Santos *et al.*, 2006	Santos *et al.* (2006) in their book titled "Improving Production with Lean Thinking" have discussed about the framework proposed by Kobayashi to describe how Ohno and Shingo tried to achieve the goal of "delivering the right material, in the exact quantity, with perfect quality, in the right place just before it is needed". To achieve this goal, they developed different methodologies, which have been captured by Kobayashi in his framework.
23.	The 20 keys to workplace improvement	Kobayashi, 1990	Similarly, Santos *et al.* (2006) also described about another framework proposed by Kobayashi, (1990), which explained about the 20 keys to workplace improvement. In this framework, the 20 keys are arranged in a circle which shows the relationship between the keys and their influence on the three main factors: quality, cost, and lead time. They also highlighted that arrangement in the circle is not categorical, as some keys offer benefits in more than one factor. Apart from that, there are four keys outside the circle. Out of which (keys 1, 2, and 3) must be implemented before the rest.
24.	Theoretical framework for LM implementation	Motwani, 2003	He commented that LM implementation will result in changing the business processes of companies. They referred to Kettinger and Grover (1995) who stated that any significant Business Process Change (BPC) requires: a strategic initiative where top managers act as leaders in defining and communicating a vision of change; an organizational environment willingness to learn; culture readiness; balanced network relationships; technology leveragability and knowledge sharing; and prescribed process management and change management practices. These concepts have been put in the form of a framework by them. Motwani have adapted this BPC framework and proposed a theoretical framework for LM implementation and validated the same by applying it to a case company (a medium-size automotive manufacturing corporation located in the Midwest region of the USA) to determine if they facilitate or inhibit the success of LM.
25.	A conceptual framework for successful JIT implementation	Wafa and Yasin, 1998	They identified the factors that hinder the successful implementation of JIT philosophy in manufacturing environments. Hence, they developed a questionnaire and conducted a field study by sending around 700 questionnaires to nation-wide US businesses. Based on the results of the field study, they have identified 23 variables, which were clustered into four categories that facilitate JIT (management, workers, process and suppliers) and presented it in the form of a conceptual framework for successful JIT implementation.
26.	Organization learning framework for LM	Flinchbaugh, 2003	According to this framework, vision drives mental models and also affects the systemic structures. Apart from that, it also determines the patterns of behaviour which result in the events. The framework also provides information about how an organization wants to make a leap. According to him, all articles and teaching limit lean to a set of patterns and events. He explained that events come mostly in the form of solutions such as Andon systems, work cells, error-proofing or kanban and commented that these solutions fit certain problems or needs, thereby only affecting only at the 'event level' of the company. When an organization moves one step up in leverage, then they can see the patterns of behaviour that are expected through LM such as continuous flow, JIT and continuous improvement. He commented that lean improvement efforts across companies and industries begin and end at this level of the framework.

S. No.	Name of the Framework	Author(s)	Remarks
27.	The lean manufacturing house	Flinchbaugh, 2003	He referred to the research by Harvard Professors H. Kent Bowen and Steven Spears who were able to codify the "rules" that true TPS thinkers used when designing, operating or improving their systems and modified the same for ease of understanding and memorization. The four modified rules are: • Structure every ACTIVITY • Clearly CONNECT every customer – supplier • Specify and simplify every FLOW path. • IMPROVE through experimentation at the lowest level possible towards the ideal state. He claimed that these "rules are a major contribution to the understanding of lean and helps organization to move up one more step towards systemic structures in the leverage hierarchy. The next rung on the hierarchy of leverage is mental models which were defined as the principles or beliefs, upon which managers think, make decisions and view the world. While the rules help to design better business systems, mental models are needed to help with the people systems". In regards to lean, this is defined by five principles: • Directly observe work as activities, connections and flows. • Systematic waste elimination. • Establish high agreement of both what and how. • Systematic problem solving. • Create a learning organization. These five principles have been represented in the form of a framework similar to the house of TPS.
28.	The essential elements of lean production	Katayama and Bennett, 1996	They examined the role and significance of LP within the context of the current industrial and economic environment in Japan. They utilized case studies of four manufacturing plants and illustrated that Japanese companies can no longer rely on concepts developed during the 1980s. In order to remain competitive they must adapt to developments in the market and a changing industrial relations climate, for which they have proposed another production system called "Adaptable Production Systems". While discussing about the LP, they explained about the essential elements and represented it in the form of a framework. While explaining about the key feature of LM, they said that fewer resource inputs are required by the manufacturing system (less material, fewer parts, shorter production operations, less unproductive time needed for set-ups, etc.) and at the same time there is pressure for higher output performance to be achieved (better quality, higher technical specifications, greater product variety, etc.). This should result in greater customer satisfaction which in turn provides the opportunity for the lean company to gain a market share larger than those of its competitors. They also support that within the automobile industry, the consequence of creating lean system of production has been demonstrated best by Toyota.

S. No.	Name of the Framework	Author(s)	Remarks
29.	Lean production as outcome and process	Lewis, 2000	He attempted to establish what impact LM has had on the overall competitive positions of the adopting firms. He proposed a framework representing LP as outcome and process, which illustrated these twin aspects by representing them both as a transformation process. He supported it with the help of extant theory and suggested that it is necessary to separate LP as an outcome from the organizational initiatives that are traditionally associated with it as a change process.
30.	Lean – A framework	Hines *et al.*, 2004	They claimed that LM when applied to sectors outside the high-volume repetitive manufacturing environment has its limitations. Hence they suggested a range of other approaches to counter variability, volatility and variety. They suggested that from a strategic point of view, one can integrate other approaches (particularly the tools they offer) without contradicting the core objective of lean – i.e. to provide customer value. In other words, any concept that provides customer value can be in line with a lean strategy, even if lean production tools on the shop-floor, such as kanban, level scheduling, or take time, are not used. They described a framework representing this aspect which also referred to the concepts relating production capacity, quality, responsiveness of the manufacturing system, demand variability, availability of production resources, and production control approaches. They also noted that these concepts are not part of the LP methodology, but can be used in support of a wider lean strategy. They also described the following example: “if the focus within lean thinking is to create capacity by removing waste then it can also be achieved with the application of improvements in overall equipment effectiveness (OEE)”. They claimed that such contingent application of tools and methods from Six-Sigma (SS) and the Theory of Constraints (TOC) are also useful additions in LM. These additional perspectives help to create a more rounded and focused tool-set for applying lean in order to create capacity at the constraint resources. They concluded that the distinction of lean thinking at the strategic level and LP at the operational level is crucial to understand lean as a whole in order to apply the right tools and strategies to provide customer value.

It should be remembered here that these frameworks do not form a definitive list, but it is only a representative sample of the most common ones that are mentioned and proposed in the literature.

2.2.2 Implementation of lean manufacturing

A literature review revealed that a plethora of case studies exist, which describes the LM implementation in a wide variety of industrial sectors in addition to the manufacturing sector. Hence, the reviewed case studies are classified as follows:

2.2.2.1 Implementation of lean manufacturing in sectors other than manufacturing

Bowen and Youngdahl (1998) noted service business tend to adopt production line thinking and suggested that the service providers must shift their production line paradigm along with the changes happening in the manufacturing. They presented this concept using the case study of Taco Bell, a fast food manufacturer. They discussed about the service-driven model developed by Taco Bell and highlighted that there exists lot of similarities between LM and the service driven model. Jones *et al.* (1999) discussed the application of LM principles in British Telecom (BT) and described the application of some of the LM elements such as value stream analysis, root cause analysis, etc. to transform BT into a lean communication service provider. Swank (2003) described a case study of Jefferson Pilot Financial, a full service insurance company, which implemented the principles and concepts of LM in an attempt to differentiate itself in the eye of its customers. She discussed about the use of various LM tools such as processing mapping (by placing linked processes nearer), layout change (by eliminating loop backs), takt time, line balancing (to balance the load in the processing stages of insurance), visual management, etc for improving the various processes in the insurance service.

Smart *et al.* (2003) argued about the need to change the lean mindset and re-engage a broader perspective both at the level of strategic purpose and organisational configuration. They hinted that within the theory of organisation design, an additional complementary alternate set of ‘high reliability’ design principles have to be used. They presented a model of the same and explained it with the help of a case study describing the rail track and the Hatfield accident. Apte and Goh (2004) used an example of insurance claims handling process to illustrate how the LM principles can be applied to information intensive services. Since such services do not have significant amount of inventory, they noted that minimising cycle time plays the same role as reducing inventory. They explained that a slightly different but parallel set of metrics should be used to evaluate the performance of the system after the implementation of LM principles to information intensive services. Mohan and Iyer (2005) analysed the experiences of 16 companies that utilized lean construction principles, during the period of 1990 to 2003 and found that a total of 41 lean principles were applied, resulting in a total of 29 benefits. They eliminated those principles that were used less than average times and thereby identified 11 major lean construction principles and 6 major benefits. On the other hand, Kim *et al.* (2006) discussed some of the basic philosophy and principles of LM methods and described how these concepts can be applied in the health care environment. Sreedharan and Liou (2007) elaborated a case study of implementing LM principles to a university rapid manufacturing laboratory. They started with the application of VSM to identify gaps between the current and future state maps and discussed about the LM techniques to achieve the future state map.

Thus, these case studies substantiate the fact the principles and philosophies of LM can be applied across any type of industries even though its birth is in an automotive industry. Apart from this, it can be found that most of the studies are reported in the last

5 years, which clearly shows that implementation of lean principles in service sector is a recent phenomenon.

2.2.2.2 Implementation of lean manufacturing in the manufacturing sector

Even though LM principles are applied in non-manufacturing sectors, the number of LM implementations in the manufacturing sector is much higher. For instance, Benders and van Bijsterveld (2000) explained that LP was adopted as a 'fashionable concept of management' in German industries. They relied on the frequency analysis of key words that appeared in 'OnLine Contents' database and provided empirical evidence that the LP debate was more intensive in Germany than in many other industrialised countries including USA, UK and the Netherlands. This study too supports the claim made by the proponents of LM, who argued that LMS has a universal applicability. However, some researchers such as Cooney (2002) questioned the universality of lean and emphasised that it cannot replace the traditional manufacturing systems such as craft and mass production. Similarly, Dankbaar (1997), who compared the basic elements of LP and Socio-Technical Systems Design (STSD) with the characteristics of the traditional Fordist system of mass production, argued that LP can hardly be considered as an alternative to mass production but on the contrary extends the life of mass production methods. He also mentioned that LP does appear to contain some building blocks for the innovative production systems that are expected to prevail in the 21st century. On the other hand, a review of the following case studies provides a different picture. Burcher *et al.* (1996) proposed a methodology to assist repetitive batch manufacturers in the adoption of certain aspects of the lean production principles. The proposed methodology concentrated on the reduction of inventory through the setting of appropriate batch sizes by taking into account the effect of sequence-dependent setups and the identification and elimination of bottlenecks. Parry and Turner (2006) described three case studies about Rolls Royce, Airbus and Weston Aerospace in UK that has been practicing LM. Seth and Gupta (2005) used the VSM, a LM technique to achieve productivity improvement at the supplier end (motorcycle frames manufacturer) for an auto industry in India, while Dhandapani *et al.* (2004) presented a case study of a steel company that applied some aspects of lean thinking and have explained that per annum production costs can be reduced by 8% of turnover, while capital equivalent to 3.5% of turnover can be released through the removal of inventory. Table 2.2 provides a brief review describing the implementation of LM in various manufacturing industries. However, to present a better understanding of the literature dealing with the cases of LM implementation, a classification scheme (taxonomy) is established based on the type of production process. Thus from this table, it can be found that there are adequate evidences, which support the claim that the LM practices have a universal appeal. Furthermore, these cases substantiate that LM has been implemented in project shops (aerospace industries), in a discrete mass production industry (auto-component supplier) and also in a batch production environment (steel mills), which contradicts the statement of Dankbaar (1997) that 'LM extends the life of mass production'. Rather LM really transforms the traditional production systems with its unique tools, techniques, practices and procedures. Apart from this, it can be found that the number of case studies in the category of project or continuous production is very less, while that in mass production category is more. The number of cases in the remaining two production systems (job shop and batch) lies in between the project and mass production systems. Similarly, as mentioned by Karlsson and Åhlström (1997) most of the case studies are from automotive sector, comprising of component suppliers and automobile manufacturers. Nearly 45% (i.e., about 16 out of 36) of the reviewed studies are from the automobile sector, which again proves that the industries in automotive sector have embraced the principles and philosophies of LM more than any other sectors. The number of case studies dealing with LM implementation in SMEs is very less.

Table 2.2: A brief review describing the implementation of LM in various manufacturing industries

S. No.	Classification scheme	Industry type	Author(s)	Remarks
1.	Project shop	Ship building	Storch and Lim, 1999	They explored the potential application of one of the LM principles - 'flow' to the shipbuilding industry. They noted that the basis for the establishment of lean thinking in shipbuilding is the appropriate application of group technology through the use of a product-oriented work breakdown structure. They also discussed that a well-balanced line and perfect timing are to be used along with the above techniques.
2.		Traditional aerospace manufacturing	Bamber and Dale, 2000	They reported the findings of a research study on the application of LP methods to a traditional aerospace manufacturing organization. They mentioned that the aerospace company initiated a lean approach to production using the Kawasaki Production System (KPS) in the early 1990s. During the course of study they identified two main stumbling blocks to the application, namely, the redundancy programme and a lack of employee education in the concept and principles of lean production. They also noted that a number of the methods of lean production were found not to be as effective as in the motor manufacturing environment.
3.		Aerospace component suppliers	Crute *et al.*, 2003	They discussed the key drives for LM in aerospace and examined the assumption that cross-sector transfer of LM is difficult. They studied two plants Site A and Site B, which belonged to the same company and the second/third tier component suppliers within the aerospace industry. They identified that change strategies, culture, product focus, commitment and consistency of top management and time and space for performance improvement are considered as factors that influence LM implementation.
4.	Job shop	Specialist machinery manufacturers	Jina *et al.,* 1997	They proposed an approach for implementing LM principles within a typical High Variety Low Volume (HVLV) situation, which includes various techniques such as use of common parts, modular design, multi-functional teamwork, ABC analysis and integrative supplier relationships. They concluded with examples of the application of these principles in two very different types of HVLV organization – one a very low volume manufacturer in the aerospace sector, and the other a manufacturer of low to average volumes (in the low thousands) of specialist machinery.
5.		Capital equipment	Mottershead, 2001	He described about the implementation of LM in Electro Scientific Industries, Inc. (ESI), which supplies capital equipment to high-tech companies throughout the world. He explained that the equipments are produced in relatively low volume, but has a high complexity and high unit cost. Furthermore, the machines were produced by one person building each machine from start to finish, resulting in lot of problems, which made ESI to implement LM. He discussed about the implementation of tools and techniques such as pull system, kaizen, visual factory, etc and reported about the benefits and improvements in the performance.

S. No.	Classification scheme	Industry type	Author(s)	Remarks
6.		Secondary wood products	Czabke, 2007	He studied the documented cases of lean implementation in the United States and German secondary wood products industries to identify the successes, failures and challenges to implementation. He used qualitative and quantitative measures to document and compare the individual case studies and concluded that lean thinking can make companies in the secondary wood products industry more profitable.
7.		High-mix, low-volume traditional manufacturing (Aerospace component)	Dudley, 2005	He studied the opportunities for the application of LM tools in Rutherford Aerospace, Ravenna facility - a high-mix, low-volume traditional manufacturing factory floor setting. The manufacturing processes involve traditional machining operations, however, the part complexity with more than 400 part numbers, along with scheduling complexity and demand unpredictability resulted in huge amount of wastes. He utilised the VSM and associated analytical tools such as Pareto analysis, product-process matrix to streamline the flow of products on the floor with a focus on reducing inventory and improving quality.
8.	Batch production	Rough mill	Gumbo *et al.*, 2006	They investigated the implementation of LM in the rough mill and assessed the performance measurement and metrics at both the rough mill and overall business level through benchmarking. They collected data from a nationwide survey of secondary wood processing facilities and found that 1) the average secondary wood products manufacturer holds a combined total of greater than 500,000 board feet in dry lumber and ripped-chopped parts inventory; 2) the average order-to-delivery lead time is 23 days; 3) a statistically significant difference of approximately 10 days was detected when comparing mean lead times between companies involved in LM (19 days) and those not involved in LM (28 days); and 4) rough mill related barriers to LM implementation included performance measurement, machinery constraints, and inability to control "off spec" production.
9.		Die casting industry (SME)	Kumar *et al.*, 2006	They proposed a Lean Sigma framework to reduce the defect occurring in the final product (automobile accessories) manufactured by a die-casting process in a SME in India, which is engaged in designing and manufacturing various types of precision machined components using pressure and gravity die-casting processes. The proposed framework integrated lean tools (current state map, 5S System, and TPM) within Six Sigma DMAIC methodology to enhance the bottom-line results and win customer loyalty. They noted that implementation of the proposed framework shows dramatic improvement in the key metrics such as process capability index, mean and standard deviation of casting density, yield, and overall equipment effectiveness (OEE) apart from providing a substantial financial savings.

S. No.	Classification scheme	Industry type	Author(s)	Remarks
10.		Printing Technologies	Scott, 2007	He enumerated about the bottom up approach, which was deployed through a structured lLean conversion programme at Linx Printing Technologies in the UK, which involved lean conversion of six value streams. This is compared and contrasted with the preferred top-down method taught by Shingijutsu, a Japanese consultancy which adopts more of a systems level approach to the lean transformation process. Finally, he explained the reason for why the lean thinking philosophy has been taught one way by Japanese and is being practiced in another in the west. He commented that the difference is due to the variation in the thinking process of East Asians and Westerners.
11.		Forging	Sahoo *et al.*, 2008	They addressed the implementation of lean philosophy in a forging company called R K Forging, which produces forgings for railways, oil and gas, and the machine tool sector, apart from producing precision forging components for the automobile sectors. They constructed the present and future states of value stream maps of radial forging production flow lines to improve the production process by identifying waste and its sources. Furthermore, Taguchi's method is pursued here to minimize the forging defects produced due to imperfect operating conditions, apart from reducing WIP and setup time.
12.	Mass production	Automobile industry	Rehder, 1994	He noted that different HRM practices are developed in the automobile industry across the world as evident from the Saturn in USA, Uddevalla in Sweden and the Japanese LP systems. They compared and contrasted the HRM practices of these three production systems and concluded that new forces for change can be expected to continue to accelerate in this decade and beyond, forging a great need for creative, new, flexible organisations and management systems.
13.		Automobile industry	Braiden and Morrison, 1996	They discussed about the implementation of LM tools and techniques in one of the two car assembly plants located in Oshawa, Canada. They noted that Motor Compartment Automated Monorail System (AMS) process is currently running at only 75% of its scheduled production capacity resulting in bottlenecks. Hence to improve this process, LM principles were utilized, which increased the uptime.
14.		Automotive components	Mabry and Morrison, 1996	They described about the introduction of LM in the Delphi Chassis Systems, especially in the pilot area – Linovia Modular Strut department. Various concepts such as process flow, layout, material flow, ergonomics, workplace organization, people-focused activities and supporting software development were implemented in an integrated manner, which resulted in 50% production improvement for the current monorail system.

S. No.	Classification scheme	Industry type	Author(s)	Remarks
15.		Automotive components	Sohal, 1996	He described the experiences of Trico Australia, a SME, which manufactured windscreen wiper systems for the automotive industry. He explained about the application of various tools and techniques of LM such as setup time reduction, kanban, layout, standarisation, etc. and reported about the substantial operational and business benefits to the company during the second half of the 1980s.
16.		Auto component supplier	Kasul and Motwani, 1997	They discussed a case study of a medium-size manufacturing corporation located in the mid-west region of the United States, which is a tier one automotive supplier of electromechanical components. They described the implementation of most important elements of TPS (such as one-piece flow, standard work, standard setup, kanban, etc.), the strategies used by the company for implementing TPS, and the significant benefits that were accrued in manufacturing operations and total inventory values.
17.		Automotive assembly plants	Kochan, 1998	He reviewed the new automotive assembly plants in Europe and described the LP techniques that are implemented in Daimler-Benz, NedCar and Skoda. They also described about the automation, which was extensively used in these assembly plants and explained how it played a major role in LM implementations.
18.		Auto component supplier	Soderquist and Motwani, 1999	They reported about the implementation of LM in an automotive supplier firm located in the RhoÃ ne-Alpes region of France, which produces and supplies all kinds of technical fastening devices for leading carmakers such as Peugeot, Renault, Ford, General Motors and Volvo. They analysed how the case organisation confronted the challenge and adopted quality management-related concepts of LP in its operation by analysing lean quality management in six domains: top management support-leadership policy, customer relationships, product design process, process flow management, continuous improvement and market outcomes.
19.		Automotive components	Motwani, 2003	He discussed about a successful LM implementation experience at a medium-size automotive manufacturing company located in the Midwest region of the USA, which is a tier one supplier of electro mechanical components. He examined the factors that facilitated and inhibited the success of the LM at the case organisation apart from enumerating the strategies and benefits obtained.
20.		Truck manufacturing company	Wallace, 2004	He attempted an understanding of the nature of relationship between team-based forms of work and LP within a framework which recognised the increasing importance of organisations attached innovation – i.e., a hybrid system of learning from the best practice of other organisations. He also assessed the implementation of LM paradigm in Volvo do Brazil.

S. No.	Classification scheme	Industry type	Author(s)	Remarks
21.		Continuous product line of a tyre manufacturing plant	Mukhopadhyay and Shanker, 2005	They dealt with the implementation of the kanban system in a continuous product line of a tyre manufacturing plant. They described a practical approach to the design of kanban card, kanban board, container size, the number of kanban, operating rules, day-to-day scheduling of machines using kanban and the necessary changes in a wage system to support its acceptability by workers on the shop floor.
22.		Auto component supplier	Seth and Gupta, 2005	They explained the use of VSM as a technique to achieve productivity improvement at the supplier end, who manufactures motorcycle frames for an auto industry called XYZ Limited. They developed both the current and future ('as is' and 'to be') states of the supplier shop-floor scenarios and analysed the performance of the organisation along with takt time calculations. Finally, they reported about the gain in production output per person, reduction of work in process and finished goods inventory affecting productivity due to LM implementation.
23.		Truck production	Berg and Ohlsson, 2005	They utilised a case study approach to understand the production process of Volvo Truck Production Plant at Wacol, Brisbane, Australia. They identified various wastes in the production process and developed a LM implementation strategy that Volvo could use during the implementation.
24.		Robotic assembly cell in automotive component manufacturer	Abduelmula *et al.*, 2005	They presented a new productivity model and a methodology based on LM techniques for improving the productivity of a robotic-press manufacturing cell at AG Simpson Automotive Systems. They discussed about the tools and techniques such as preventive maintenance, job rotation, quick changeover procedure, standardisation, two bin system, layout change, etc. which were implemented in the cell resulting in a 72% productivity increase.
25.		Automotive industries	Mohanty *et al.*, 2007	They attempted to understand and highlight major concerns and issues preventing the companies in the automotive industry to replicate Toyota's performance using a questionnaire approach. They studied large auto manufacturing companies including both original equipment manufacturers (OEMs) and tier one (and few tier two) suppliers representing a broad cross-section of the auto industry in USA, UK, and India and finally identified the various factors that affect LM implementation in India.
26.		Automotive industry	Lee and Jo, 2007	They noted that over the past 40 years, Hyundai has developed its own production model, Hyundai Production System (HPS) initially emulating TPS, followed by re-interpreting and modifying TPS to adapt to the company's unique circumstances. Their study revealed that the adoption of TPS involves a complex evolutionary process of organizational learning and interpretation. They hinted about the possibility of various paths toward LP and demonstrated that both external and internal factors combine to form a complicated causal chain, influencing the 'mutated' emulation of TPS and generating a certain pattern of path-dependence in the evolutionary trajectory of a particular production model.

S. No.	Classification scheme	Industry type	Author(s)	Remarks
27.		Automotive component assembly line	Domingo *et al.*, 2007	They analysed the internal material flow in an assembly line of combustion injection valves in the Bosch GMB factory in Alcala´ de Henares (Madrid), which follows the Bosch Production System methodology. They developed a handling system in a small space, capable of solving the problems of accumulated intermediate stocks of parts by adopting the milk-run handling system, while verifying the advances by means of lean metrics such as dock-to-dock time and lean rate. They utilised the data from VSM to develop a timetable and routing analysis for the milk-run to improve materials flow.
28.	Continuous production	Paper industries	Lehtonen and Holmström, 1998	They presented the results of a national research project on the logistics situation of the Finnish fine paper industry. They analysed the present situation and suggested new logistics solutions based on JIT philosophy for improved performance in outbound logistics. They used multiple case studies, which include both Nordic and Central European paper mills as well as producers of fine paper, speciality paper and bulk grades like newsprint and super-calendared paper.
29.		Steel manufacturing	Brunt, 2000	He presented the ongoing investigations on developing a methodology for mapping value streams and supply chains. He noted that VSM proposed by Rother and Shook can be used to map the value stream of only a single firm. Hence, he developed a VSM for the entire SC by creating a picture of the value stream for a product across three companies – steel producer, steel service centre and first tier component supplier.
30.		Metal forming	Lee and Allwood, 2003	They noted that LM studies have focused on implementation in assembly type processes such as in the automobile industry, but LM in continuous process industries such as metal forming is not straight forward. They discussed how LM can be applied in the temperature dependent process using a simulation study.
31.		Mining environment	Dunstan *et al.*, 2006	They examined the application of LM in a mining environment based on various case studies. They described about the implementation of certain LM elements that are applicable in these industries and noted that health and safety related incidents were reduced from 154 to 67; absenteeism was reduced by 3.4% to 1.8%, while about $2 million (Australian) were saved during the year 2006.
32.		Textile	Goforth, 2007	She attempted to determine which lean principles are appropriate for implementation in the textile industry and developed a road map in the form of a model for implementing LM in the textile firms. She studied and collected data from 11 textile companies in US that has implemented LM and identified 24 different tools and principles of lean for use in the textile and apparel industry apart from identifying the common barriers.

S. No.	Classification scheme	Industry type	Author(s)	Remarks
33.	SMEs	Durable articles	Gupta and Brennan, 1995	They described the implementation of JIT in a small manufacturing company that produces small durable articles for the catering industry. They described the overall flow of the process and discussed about the work design and inventory reduction activities that were carried out. Further, they compared the pre-implementation and post-implementation conditions of the company based on the measures such as production capacity, lead time, space savings, etc.
34.		Automotive components	Gunasekaran and Lyu, 1997	They dealt with the implementation of JIT in a small company in Taiwan that produces different kinds of automobile lamps such as rear combination lamps and front turn signal lamps. They described about the implementation of various JIT tools such as 5S, TQM activities, TPM, standardisation, process improvements and layout changes apart from discussing the benefits obtained by the case organisation.
35.		Electronic office equipment manufacturer	Karlsson and Åhlström, 1997	They undertook a clinical approach by conducting a case study in a Sweden-based international firm called as “Office Machines” that produces mechanical and electronic office equipment. They analysed the strategies and external networks of Office Machines and compared them with the theoretically derived principles of the lean enterprise. Finally, they concluded that most of the principles contained in the lean enterprise are applicable to the SMEs.
36.		Numerically controlled bagging machines	Abdul-Nour *et al.*, 1998	They utilised a project management approach in order to implement some elements of the JIT philosophy in a small-sized manufacturing firm that produces a variety of numerically controlled bagging machines for loose materials such as wood shavings, ashes, etc. They described the implementation of various tools and techniques such as standardization, Use of Computer Aided Design (CAD) system, modular Bill Of Materials (BOM), Critical Path Method (CPM), motion and time study, layout change, constant work-in-progress (CONWIP), etc.
37.		Automotive components	Gunasekaran *et al.*, 2000	They presented a case study of Valeo, a French company located in England that produces wiper systems for the automotive industry in the UK. He noted that the case organisation produces a wide variety of low volume parts for various customers in a job shop environment. They attempted to improve the productivity of two cells through the implementation of LM tools such as 5S, Hoshin exercise, U shaped layout, autonomous inspection, kaizen, etc.
38.		Small bicycle manufacturing company	Grewal, 2008	He described the implementation of VSM in a small manufacturing firm called XYZ bicycle manufacturing company located near Ludhiana, India. He explained in detail about the mapping of activities within the firm, identifying opportunities for improvement, undertaking the improvement programmes apart from listing out the benefits obtained.

Only 6 papers are available, which specifically mentioned about the implementation of LM in SMEs, However, if some of the industries dealing in metal forming, die casting etc. are included, it may increase to 8 which is again comparatively less. The number of papers describing LM implementation in Indian industries is very less. Out of the 36 papers reviewed, only 6 papers dealt with LM implementation in Indian industries. Similarly, a cursory review of these Indian case studies reveals that even in India, LM is predominantly getting applied only in the automobile sector.

Hines *et al.* (2004) traced the growth of LM from its introduction to its current stage and commented that LM has emerged from being a production strategy into a philosophy. Similarly, the application of principles and concepts of LM has also gone beyond the bounds of both manufacturing and post-production. But, it is a more recent phenomenon. Hence, not many papers are available, which describes the application of LM in other functions/department of an organisation such as research and development (new product development), purchasing and distribution (supply chain management) and other business functions. However, the available literature is briefly discussed below:

2.2.2.2.1 Implementation of lean manufacturing in new product development

The term Lean New Product Development (LNPD) was first introduced in the book – “The machine that changed the world” (Womack *et al.*, 1990). Since the focus of the book was on manufacturing and assembly processes, LNPD did not deserve much attention among the companies to foresee it as an efficient product development methodology. Hence, the number of literature in this area is very less. McManus and Millard (2002) noted that LNPD helps companies to develop a seamlessly flowing product development value stream with minimal waste, defined and pulled by the customer. Smith and Reinertsen (1991) identified the application of JIT manufacturing philosophy (a component of lean) in the NPD process. They described how ‘pull’ approach can be applied to information and if it is established in a development team only the downstream persons can ask for whatever information they need. Cusamano and Nobeoka (1998) detailed the differences between LNPD and a traditional NPD process, which clearly shows that LNPD has better advantages over the traditional NPD process. Karlsson and Åhlström (1996b) conceptualised LNPD as involving the following elements: supplier involvement; cross-functional teams; simultaneous engineering; a focus on integration of activities instead of coordination; strategic management; visions and objectives instead of detailed specifications; and black box engineering (where suppliers are responsible for developing complete modules for the product, often without detailed specifications). Meybodi (2005) had shown that the principles of JIT in manufacturing can also be used to improve NPD and such successful JIT manufacturing organisations were able to develop new products with 67% fewer design changes, 61% less development time, 74% more frequency, 45% less development cost and 36% less manufacturing cost. But till now, no literature is available to provide a step-by-step approach in the form of a systematic framework to make the existing NPD process leaner. This fact was also supported by Haque and James-Moore (2004), who stated that

> *“the lean concept (based on current published literature) does not provide the details needed to improve New Product Introduction (NPI)/NPD; instead, it provides a high-level contextualised (in terms of customer value) approach to process improvement.”*

2.2.2.2.2 Implementation of lean manufacturing in supply chain

The concept of Lean Supply Chain (LSC) evolved in 1994, when the proponents of LM – Womack and Jones (1994) envisioned the concept of ‘lean enterprise’. The proponents realised that applying lean principles to achieve individual breakthroughs can be linked up and down the value chain to form a continuous value stream that creates, sells and serves a family of products; thereby, the performance of the whole stream can be raised to a dramatically higher level. They proposed the five tenets of lean and to implement these five tenets, they advocated the use of various LM elements. Recently, Vitasek *et al.* (2005) defined LSC as “a set of organisations directly linked by upstream and downstream flows of products, services, information and funds that collaboratively work to reduce cost and waste by efficiently pulling what is needed to meet the needs of individual customers”. Vonderembse *et al.* (2005), who classified SCs into three types, namely, the LSC, ASC and LASC, explained that standard products, which tend to be simple and have limited amounts of differentiation, should be produced by LSC. He observed that the most promising result of an effective LSC management is long-term cost reduction via product or process reengineering by forming closer relationships with key suppliers.

To review the past research related to LSC, the definition of Karlsson and Åhlström (1996a) is used to classify the available literature. They viewed LM as lean development (Research and Development or R&D) + lean procurement (supplier involvement) + lean manufacturing + lean distribution. Among the components of the lean enterprise, a plethora of literature dealing with LM is available, while very few papers that concern with lean development are available. The review regarding these two categories was already carried out in the earlier sections. The literature relating LSC has been classified into three broad areas, namely, lean procurement/supply (upstream activities), lean distribution (which includes downstream activities such as warehousing, transportation, retailing, etc.) and the integration of LSC activities. Table 2.3 shows the taxonomy for the literature related to LSC.

Table 2.3: Taxonomy for the literature related to LSC

S. No.	Taxonomy	Authors	Area of Application	Remarks
1.	Lean supply/ procurement	Ha and Kim, 1997	An integrated approach for implementation of JIT purchasing	They addressed the necessity of integration between the buyer and supplier for the effective implementation of the JIT system. They developed an integrated lot-splitting model that facilitates multiple shipments in small lots and compared it with the existing approach in a simple JIT environment of single-buyer-single-supplier under deterministic conditions for a single product. They found that the optimal policy adopted by the integrated approach can provide a strong and consistent cost minimising effect for both the buyer and supplier over the existing approach.
2.		Fynes and Ainamo, 1998	Buyer-seller relationships in LSC	They presented a lean supply model that combines the essence of learning with the buyer-supplier relationship. Furthermore, they discussed a case study of the Irish subsidiary of Apple Computers and two of its local suppliers, in which they studied how organisations learn and unlearn, apart from discussing how the relationships represent the co-existence of competition and cooperation.
3.		Garg and Deshmukh, 1999	Attributes for JIT purchasing	They reviewed and classified the literature on JIT purchasing. They also identified the attributes in JIT purchasing and carried out a survey of the attributes in the Indian context to find the relative importance of such attributes.
4.		Michaels, 1999	Strategies and tactics for LSC	He described a case study of an initiative launched by Large Aerospace Company (LAC) in 1995 to transform an aerospace machined parts SC, which consists of many small businesses having a high-cost mass production into a low-cost lean production. He discussed the strategies and tactics that were used to bring about the desired changes and analysed the business practices, cultural and behavioural factors that contributed to the success and failures.
5.		Liker and Wu, 2000	Supplier development for LSC	They discussed how Japanese manufacturers in the USA achieved LSC by ensuring that their suppliers also adopted LM. They also explained that the Japanese manufacturers invested heavily on supplier development activities and taught LM to the suppliers. To support their contention, they gave a brief description of the supplier development activities of Honda and Toyota. Furthermore, using an empirical approach, they compared the performance of the suppliers serving US auto plants and the suppliers serving Japanese-owned auto plants with respect to various factors such as scheduling and shipping, LM practices at the supplier's line, transportation arrangements, etc.

S. No.	Taxonomy	Authors	Area of Application	Remarks
6.		Buzby *et al.*, 2002	Quotation process	They presented a case study to show the application of LM principles to the administrative function of the quotation process. In addition, they also demonstrated that electronic solutions are the best remedies for streamlining the quotation process to reduce the total cycle time. They mapped the current quotation process and identified the potential waste areas in the procedure of processing the Request For Quotes (RFQ). They also found various solutions, which required the use of various IT tools.
7.		Kaynak and PagÁn, 2003	JIT purchasing techniques and its effect on technical productive efficiency	They analysed the technical productive efficiency effects of implementing JIT purchasing techniques in the US manufacturing industry, which was modelled using a stochastic frontier production function that explicitly accounts for JIT purchasing-induced efficiency effects. They suggested that characteristics that are internal to the organisation, such as top management commitment to implementing JIT purchasing, are related to higher productive efficiency, while external characteristics such as supplier value-added or transportation issues do not appear to be associated with increasing productive efficiency.
8.		Yang and Pan, 2004	Inventory model for strategic alliance between vendor and the purchaser for profit sharing	They mentioned that JIT production plays a crucial role in SC environments and presented an integrated inventory model to minimise the sum of the ordering/setup cost, holding cost, quality improvement investment and crashing cost by simultaneously optimising the order quantity, lead time, process quality and the number of deliveries while the probability distribution of the lead time demand is normal. They noted that this integrated inventory model is useful, particularly for JIT inventory systems, where the vendor and purchaser form a strategic alliance for profit sharing.
9.		Kumar and Dao, 2005	Impact of JIT purchasing practices on firm performance	They identified an integrated list of JIT purchasing practices and examined the impact of these practices on the firm performance, apart from exploring the influence of the firm size and ownership type on the implementation of JIT purchasing. They developed a framework and tested it on a sample of 54 companies located in Vietnam and found that the size and ownership of firms indeed affected the level of adoption of JIT purchasing practices in Vietnam. They also noted that firm performance is not strongly affected by JIT purchasing implementation.
10.	Lean distribution	Christensen, 1996	Transportation in JIT distribution	He discussed the findings of an industry working group that examined time-sensitive distribution, otherwise known as JIT distribution, as part of the Freight Transport Association's response to the transport debate. He concluded that JIT does not cause extra lorry traffic, but actually reduces the number of lorry movements if it is supported by improvements in technology and vehicle utilisation. He provided examples from the industry to illustrate the developments, benefits to the environment and customer service.

S. No.	Taxonomy	Authors	Area of Application	Remarks
11.		Spencer *et* al., 1996	Logistics support for JIT implementation	They hypothesised that manufacturers believe that logisticians share their understanding of JIT; however, this belief was not supported by their findings from their research. They found that the logistics respondents appear to view JIT as it was viewed by manufacturing during early JIT exploration – primarily as an inventory reduction technique and concluded that it is unlikely that the full value of JIT is being realised within logistics.
12.		Jones *et al.*, 1997	Lean logistics	They briefly explained Toyota's downstream SC processes, such as delivery, ordering, warehousing, dealership, etc. They also proposed the seven tools which have to be used along with VSM and demonstrated the application of these tools using a case study of an industrial distributor in the UK.
13.		Taylor, 2002	Lean in distribution	He observed that many changes are occurring in the SC that are creating opportunities to apply lean concepts throughout manufacturing, distribution and logistics, due to which the traditional arenas of manufacturing and distribution will merge and bring new value-added processes into distribution. He stressed that lean in distribution is limited, but will grow substantially with market demands and an increased understanding of successful applications.
14.		Reichhart and Holweg, 2007	A framework for lean distribution	They reviewed and synthesised the previous contributions to lean principles towards defining a framework for lean distribution. Furthermore, they undertook an in-depth case study of a vehicle manufacturer's efforts to implement a lean vehicle distribution system, based on which they identified and quantified some of its key benefits. They explained the conflict between lean distribution and lean production and commented that the attainment of responsiveness in order to reduce wastes from the distribution system requires substantial commitment across the entire organisation. They noted that such efforts may also lead to excess flexibility and the attainment of capabilities that are misaligned with the actual market requirements.
15.		Kiff, 2000	Lean dealership	He explained that the concept of lean dealership centres on a 'customer account manager', who proactively manages the consumer's needs for after-sales of all types, thereby managing demand and removing wastes from the system. He noted that this approach will enable the dealer to exchange ineffective, costly, direct marketing and advertising for value-adding contacts from which the consumer and manufacturer directly benefit, thereby creating a virtuous circle. He also explained how the five tenets of LM can be applied in the dealer process, apart from identifying the wastes.
16.		Green and Inman, 2005	JIT selling	They explained that a JIT selling strategy requires the following: the implementation and execution of selling tactics that build value throughout the selling process based on organisational capabilities to deliver near-zero defect quality, near-zero variance quantity and precise on-time delivery and the subsequent adoption of selling tactics that develop single-source, on-site relationships with customers.

S. No.	Taxonomy	Authors	Area of Application	Remarks
17.		Womack and Jones, 2005	Lean consumption	They described lean consumption as streamlining the systems for providing goods and services and making it easier for customers to buy and use them, which enables the organisation to learn more about their customers strengthen customer loyalty and attract new customers. They have defined six simple principles to establish lean consumption.
18.	Integration of SC activities	Levy, 1997	Lean production in an international value chain	He noted that the rapid flow of goods and information required by LP is costly and difficult to achieve. He observed that the lead times are longer and the inventory levels are higher in international SCs compared to domestic SCs. He also tentatively suggested that some elements of LP facilitate and support globalisation. Furthermore, he described a case study and noted that the reduction of defects and engineering change orders to very low levels helped stabilise the computer company's SC and enabled it to accelerate the transfer of production of new products offshore. Finally, he concluded that LP may be more difficult and expensive in the international context, but it may still be worthwhile.
19.		Claycomb *et al.*, 1999b	Total system JIT	They incorporated JIT selling as one of the dimensions of total system JIT and investigated its effect on the inventory, organisational structure and financial performance outcomes.
20.		Vokurka and Lummus, 2000	JIT in SCM	They proposed a comprehensive JIT approach comprising of JIT manufacturing, JIT purchasing, JIT selling and JIT information strategies, which will support the efforts to manage at the SC level.
21.		Harrison *et al.*, 2002	Status of lean thinking in SCs	They conducted an empirical study to assess the status of lean thinking in the SCs of UK aerospace organisations and found that two groups emerged from the survey: those having an SC strategy as part of their corporate strategy and those who do not. The former group demonstrated that an SC strategy is important in achieving competitive advantage and investment in SC infrastructure is necessary, apart from developing the capabilities of JIT delivery, re-tiering and rationalising their supplier bases.
22.		Taylor, 2006	Model of an integrated supply chain	He proposed an initial model of an integrated SC based on the application of lean principles and demonstrated how the Value Chain Analysis (VCA) technique has highlighted the opportunities for strategic change in the UK agri-food SC.

From this table, it can be found that the number of papers addressing the individual application of lean/JIT for downstream activities such as warehousing, distribution, retailing, selling, etc., are very less when compared to the papers addressing the upstream activities. Green and Inman (2005) noted that while the literature related to the JIT philosophy is extensive, there are currently only two published papers written by Germain *et al.* (1994) and Claycomb *et al.* (1999a) that specifically discussed and measured the JIT selling construct. Naturally, the current research in LSC is more focused on upstream activities (i.e., lean supply and lean production), while due importance has not been given to the downstream activities of the SC. It was also supported by Reichhart and Holweg (2007), who commented that a detailed account of the operational and organisational difficulties of extending the pull beyond the factory is still amiss. They even quoted other researchers, such as Andrews and Shioji, who noted that even the 'lean' Japanese vehicle manufacturers have not achieved the lean transformation of their distribution systems. The same can also be concluded by comparing the number of available papers that address the upstream and downstream activities. For instance, four review papers (Stamm and Golhar, 1993; Waters-Fuller, 1995; Garg and Deshmukh, 1999; Gunasekaran, 1999) that are related to JIT purchasing are available, while review papers that are related to the application of JIT/LM to the downstream activities of SC or the integration of all activities in an SC as a whole is very less. Thus, these observations provided necessary evidence to the claim that the concepts and theory of LSC are not yet fully developed.

2.2.2.2.3 Implementation of lean manufacturing in other business functions

Apart from R&D, purchasing and distribution, it has also reached into all the departments or business functions, as evident from the following cases:

- **Management accounting:** Åhlström and Karlsson (1996) studied how the management accounting system has to change along with the changes happening in an organisation due to LM implementation. They utilised a clinical approach by being the observers during the change in an organisation and proposed what should be done for the management accounting system to support LM implementation. Modarress *et al.* (2005) noted that the objectives of advanced techniques such as JIT, LM, TQM, etc. have been to reduce cost, improve quality, reduce cycle time, and increase flexibility on the factory floor. However, support systems such as finance and cost management have generally not kept pace with the level of corresponding operational changers being implemented. Hence, they presented a case study of kaizen costing as practiced by Boeing Commercial Airplane Company, Interiors Responsibility Centre (IRC) Division. They defined kaizen costing as continual small incremental product cost improvements in the manufacturing phase, as opposed to the improvements in the design and development phase and the management will set the cost reduction targets for the product. They described a method used to set kaizen costs which will provide relevant cost data to support LM decisions.

- **Role of maintenance**: Sullivan *et al.* (2002) illustrated an equipment replacement decision problem within the content of LM implementation. In particular, they demonstrated how the VSM suite of tools can be used to map the current state of a production line and design a desired future state. Further, they provided a roadmap for how VSM can provide necessary information for analysis of equipment replacement decision problems.
- **Role of marketing:** Piercy and Rich (2004) investigated the shortcomings of the value definitions contained within the lean enterprise concept and proposed that an opportunity exists for the strategic integration of marketing activities and lean operations to provide marketers with access to a tool kit for quality and efficiency improvements, whilst at the same time resolving shortcomings in the lean

enterprise to improve organisational effectiveness in the market place. They also discussed about the tactical criticisms of the lean concepts apart from highlighting the deficiency of defining the customer value without any marketing perspective.

2.2.3 Empirical studies in lean manufacturing

Researchers around the world have conducted number of empirical studies utilising the survey methodology. Numerous surveys exist in the field of LM and address a wide variety of issues. Hence, based on the area it addressed, a classification scheme has been established for the papers dealing with surveys. Table 2.4 shows the taxonomy for the papers describing the empirical studies in LM. It can be found that most of the surveys are either conducted in the continents of Europe or America/Canada. About 9 studies are from US/Canadian industries, while about 8 studies are from Europe. Among the empirical studies conducted in Europe, about four surveys were carried out in UK. Very less empirical studies are carried out about the LM implementation in Asia. Around three studies relied on data from multiple countries, which of course include the data collection only from US, UK and Japan. Similarly, most of the survey studies are carried out in either automobile sector or in auto-component sectors.

2.2.4 Analytical tools used in lean manufacturing

Many researchers have utilised various analytical tools in the field of LM. Some of the tools such as VSM are used to transform an organisation from its current situation into a lean manufacturer. While tools such as simulation are used to study how kanban systems will work, how mixed model manufacturing can be implemented, etc.

Table 2.4: Taxonomy for the papers describing the empirical studies in LM

S. No.	Taxonomy	Authors	Industry	Sample size	Remarks
1.	Lean Implementation	Sohal and Egglestone, 1994	Multiple industrial sectors in UK	51	They investigated the extent to which LP has been implemented within Australian organisations, the structural changes that took place due to LP and the future trends in LP. They concluded that about 81% of the organisations adopted LP and discusses about the different organisation changes happened especially in supplier relationships, organisation structure, multi skilling, etc.
2.		Oliver *et al.*, 1994	Automotive components industries from different countries	18	They studied the performance and management practices of 18 auto components plants, nine of which were located in the UK and remaining nine are in Japan. They compared the performance of these plants and used quantitative measures to test the use of LP techniques among the high performers. Five of the plants located in Japan, displayed high performance on measures of productivity and quality and noted that these plants achieve such superior performances due to the LP.
3.		Winfield and Kerrin, 1996	Automotive components industries in East Midlands, UK	60+12	They conducted a survey to study the impact that Toyota’s European transplant operation is having on businesses in the region of East Midlands. They identified the changes happening in both supply chain firms and non-supply chain firms in moves towards adopting LM. They concluded by examining a series of case studies and examined how Toyota supply chain firms appear to have evolved quite distinct ways of managing manufacturing change, in handling subsequent human resource problems and in developing and training their management.
4.		Oliver *et al.*, 1996	Automotive components industries from different countries	71	They examined the relationship between LP and performance empirically using the data from a benchmarking study of 71 plants of automotive components supplier. They concluded that the top performing plants (and their suppliers and customers) showed consistently better process control than the lower performing plants. In particular, they noted that UK plants did not perform very well in terms of either quality or productivity.
5.		Shah and Ward, 2003	Multiple industrial sectors in US	1748	They examined the effects of three contextual factors – plant size, plant age and unionisation status on the likelihood of implementing 22 manufacturing practices that are key facets of LP. Further, they categorised these 22 practices into four bundles and investigated their effect on operational performance. They concluded that there is a strong support for the influence on the plant size on LP implementation, whereas the influence of unionisation and plant age is less and there is a significant improvement in operational performance due to these four bundles of practices.

S. No.	Taxonomy	Authors	Industry	Sample size	Remarks
6.		Christiansen *et al.*, 2003	Multiple industrial sectors in Denmark	65	They conducted a survey of 63 Danish companies, which were divided into four strategic groups. These groups are investigated for their relationships between strategic groups, implementation of LM and operational performance. They concluded that the consideration of strategic groups can improve the understanding of companies' operational performance and their LM practice implementation.
7.		Achanga *et al.*, 2006	Small and Medium Sized Enterprises (SMEs)	13	They presented the critical factors that constitute a successful implementation of LM within manufacturing SMEs. They conducted site visits of 10 SMEs and 3 large organisations that have implemented LM and interviewed key personnel involved in lean implementation. They identified leadership, management, finance, organisational culture, skills and expertise, etc. as the critical factors for successful implementation of LM.
8.		Bonavia and Marin, 2006	Ceramic tile industry in Spain	76	They conducted a survey to determine the degree of use of some of the most representative LP practices in the Spanish ceramic tile industry, their relationship with plant size and their effect on the operational performance of the companies in that sector. They concluded that there is one set of practices that have been scarcely implemented, while another set of practices which are fairly widespread among the companies in this particular sector. Further, they noted the degree of their respective use depends on the firm's size.
9.	Organisational issues	Forza, 1996	Electronics, auto supplier, machinery and mechanical sectors in Italy	43	This examined the differences between traditional plants and LP plants with the help of a theoretical framework based on the work organisation practices that are directly required by JIT and TQM approaches and those practices that are strongly influenced by HRM. They concluded that there may be a priority order between various work organisations practices apart from highlighting the areas of differences and in-differences between lean and non-lean plants.
10.		Conti *et al.*, 2006	Machinery, appliances and electronics, motor vehicles, instruments in UK	21	They conducted a multi-industry empirical study of the relationship of job stress to a range of lean practices. They utilised a Karasek job stress model to link the effects of job demands, job control and social support. They utilised a questionnaire and concluded that LP is not inherently stressful, with stress levels significantly related to management decisions in designing and operating LP systems.

S. No.	Taxonomy	Authors	Industry	Sample size	Remarks
11.		Lewchuk and Robertson, 1996	Automotive components sector in Canada	16	They studied the working conditions of the workers and the tradeoffs between productivity improvements and the conditions of working life. They conducted an empirical survey based on a survey of 1670 workers employed in the independent automotive components sector in Canada. They performed site visits apart from administering two survey instruments, in which one instrument focused on workload and health issues and the other on training, skill, control and other workplace issues. They concluded that working conditions in the Canadian automobile components sector paints an unattractive picture of working life. Workloads are high and increasing, health risks are high and increasing, work is stressful and becoming more stressful. They tested the thesis put forward by supporters of LP that under the new system of work organization, workers will be asked to work smarter, will have more control over working conditions and will become problem solvers. But they found that their study do not support this hypothesis. Compared with workers in traditional Fordist style plants, those at lean companies reported their workload was heavier and faster.
12.		Boyer, 1996	Metal working industries, machinery, electric and electronic equipment and transportation in US	202	He noted that the skills and knowledge embodied in the workforce are a critical element of LP. Hence, he focused on an examination of the relationship between a company's commitment to LP and the actions taken by management to develop the skills, knowledge, and training of its workforce by analyzing the programmes of the investment in the quality leadership, user of small groups or teams for problem solving, training and workforce empowerment. He conducted questionnaire survey and concluded that those industries, which investigated in building a strong supporting infrastructure will obtain significant competitive advantage and those who invest in infrastructure shows adequate commitment towards LP.
13.	Measurement of leanness	Soriano-Meier and Forrester, 2002	UK ceramics tableware industry	30	They presented a research instrument for measuring the degree of leanness possessed by manufacturing firms by performing a quantitative assessment for the various components of leanness. They utilized the model developed by Karlsson and Åhlström (1996) that operationalises the principles of lean production and the model developed by Boyer (1996) for the measurement of managerial commitment to lean production to define the leanness. Further, they utilized the statistical models such as regression analysis, ANOVA etc. to quantify the terms such as 'Degree of Leanness (DOL)', 'Degree of Commitment (DOC)', 'Degree of Adoption (DOA)', etc.

S. No.	Taxonomy	Authors	Industry	Sample size	Remarks
14.		Kojima and Kaplinsky, 2004	Auto components sector in South Africa	50	They addressed the questions of how can the degree of progress in the adoption of LP be measured? and what factors determine the rate of adoption LP? by investigating the South African auto components sector. They devised a method for assessing the extent to which firms have achieved global best practices through introducing new manufacturing practices apart from developing a comprehensive quantitative assessment of performance and practice through Lean Production Index (LPI). They constructed the LPI based on three sub-indices, namely, a flexibility index, a quality index and a continuous improvement index. They used the LPI to test a number of hypotheses which helped them to explain the dramatic improvement in competitive performance of the South African auto industry.
15.		Cumbo *et al.*, 2006	Secondary wood products manufacturing companies in US	258	They investigated the implementation of LM in the rough mill and analyzed the performance measurement and metrics at both the rough mill and overall business level. They benchmarked key manufacturing as well as overall business-related metrics for which, they collected data from a nationwide survey of secondary wood processing facilities. They found that 1) the average secondary wood products manufacturer holds a combined total of greater than 500,000 board feet in dry lumber and ripped-chopped parts inventory; 2) the average order-to-delivery lead time was calculated at 23 days; 3) a statistically significant difference of approximately 10 days was detected when comparing mean lead times between companies involved in LM (19 days) and those not involved in LM (28 days); and 4) rough mill related barriers to LM implementation included performance measurement, machinery constraints, and inability to control "off spec" production.
16.		Ray *et al*, 2006	Wood products industries in US	12	They conducted an exploratory research to develop a methodology for quantitative and objective assessment of the leanness of any wood products operation. They utilized the 'Factor analysis', which described the patterns of relationships among quantifiable predictor variables, with the goal of identifying variables that cannot be directly measured, such as the leanness of a company. Using this technique, they identified a factor model and developed a factor score, or 'Lean Index'. They conducted a study that is similar to BM in which nine wood products companies participated and they found that the average Lean Index is demonstrated to be 5.07, ranging from a low of 2.33 to a high of 12.00. Finally, based on the quantified standards of LP developed in this study, they concluded that (1) primary wood products operations are inherently leaner than secondary wood products operations; (2) process throughput variables explain approximately twice the total variance of all consumed resources, compared to process support variables; and (3) energy consumption is shown to be the single most significant contributor to the leanness of any wood products company.

S. No.	Taxonomy	Authors	Industry	Sample size	Remarks
17.	Lean assessment	Sanchez and Perez, 2001	Automotive and industrial machinery manufacturing organisation in Spain	41	They developed and tested an integrated checklist to assess manufacturing changes towards LP Using the results from the survey of manufacturing plants located in the Spanish region of Aragon, they analyzed which LP indicators are more used to assess the company's improvements in heir production systems and the determinants on the use of these indicators.
18.		Brox and Fader, 2002	Auto-parts manufacturer in Ontario, Canada.	60	They provided an empirical evidence to support the idea that JIT manufacturing environments are, in fact, more productive than their non-JIT counterparts. They used the plant-level cross section data from auto-parts manufacturing firms and utilized the Full Information Maximum Likelihood (FIML) econometric method to estimate and cost and the share equations and thereby compare the performance difference between JIT and non-JIT counterparts.
19.		Doolen and Hacker, 2005	Electronics manufacturer in US	27	They reviewed the existing lean assessment tools and developed an instrument to assess both the number and the level of implementation of a broad range of lean practices in an organization. They conducted an exploratory study of electronic manufacturers in the Pacific Northwest to validate the same. They analyzed the impact of LM elements on different functional areas of an organization, the average implementation of LM elements in each of these functional areas and the list LM elements that are commonly implemented and least implemented among the electronic manufacturers. Furthermore, they compared how small companies and large companies have performed with respect to these parameters.
20.		Taj, 2005	Multiple industrial sectors in China	65	He evaluated the current state of manufacturing in some selected plants in electronics, telecommunication/wireless, and computer industries in the Republic of China. He used a spreadsheet-based assessment tool developed by Strategos Inc., to evaluate nine key areas of manufacturing, namely inventory; team approach; processes; maintenance; layout/handling; suppliers; setups; quality; and scheduling/control. Participants were asked to answer questions for each area and a score is given for each response in the assessment. Scores are then totalled for each of the nine areas and finally a lean profile chart is created to display the current status of the plant and the gap from their specific lean targets. They identified that there exists a somewhat significant gap from the LM target, but have also identified opportunities for improvement.
21.	LM and environment protection	Rothenberg *et al.*, 2001	Automobile assembly plants in US and Japan	31	They examined the relationship between LM practices and environmental performance as measured in terms of air emissions and resource use based on surveys. They concluded that lean management and reduction of air emission of volatile organics compounds are associated negatively. On the other hand they found some linkages between lean practices and resource efficiency.

S. No.	Taxonomy	Authors	Industry	Sample size	Remarks
22.		King and Lenox, 2001	Multiple industrial sectors in US	17499	They attempted to examine the relationship between LP practise and environmental performance. Hence, they conducted an empirical analysis of the environmental performance of 17499 US manufacturing establishments from the year 1991 to 1996. They concluded that those establishments that adopt the quality management standard ISO 9000 are more likely to adopt the environmental management standard ISO 14000. Furthermore, they found strong evidence that LP as measured by ISO 9000 adoption and low Toxic Release Inventories (TRI) is complementary to waste reduction and pollution reduction.
23.	Other issues	Wu, 2003	First-tier automotive suppliers in US	137	He empirically examined the connection between LP and various aspects of the logistics system and found that significant performance/practice differences exist between lean suppliers and non-lean suppliers. He performed a comparison analysis using the Analysis of Covariance (ANCOVA) of various factors such as the supplier's production practices, storage and management practices, etc. and concluded that even given the same organisational constraints and resources, lean suppliers gain significant competitive advantages over non-lean suppliers in production systems, distribution systems, information communications, containerisation, transportation systems, customer-supplier relationships and on time staging/delivery performance.

On the other hand, tools such as benchmarking are used for assessment purpose. In this section, the papers dealing with these analytical tools are reviewed briefly.

2.2.4.1 Role of value stream mapping

Rother & Shook (1999) has discussed in detail about the VSM. According to them, a value stream is comprised of all the actions (both value and non-value added) that are required to bring a product or a group of products from raw materials to the arms of the customer. On the other hand, VSM is a pencil and paper visualisation tool that shows the flow of material and information as a product makes its way through the stream. VSM is done in two steps. The first step is to draw the current state VSM, which provides a snapshot of how things are being done currently, and the second step is to draw the future state map to show how things are supposed to be done. Several application of VSM has been described in the literature. Hines *et al.* (1999) described VSM as "a type of specific process benchmarking where the initial performance of a particular process is not externally compared but is internally compared with how good that process itself could be." They also described the application of VSM to the development of supplier network around a prominent distributor of electronic, electrical and mechanical components. Brunt (2000) discussed in detail about VSM, the standard symbols of VSM and the methodology for constructing current state and future state VSM. Apart from this, he also demonstrated how VSM can be used to map the entire processes along the supply chain from steel-making (i.e. raw material) to steel component supplier. Özkan *et al.* (2005) illustrated how VSM and its associated tools can be used to design a desired future state aligned with LM principles at a shop floor of an automotive industry while, Seth and Gupta (2005) discussed about the application of VSM for lean operations and cycle time reduction in an Indian steel company. On the other hand, Emiliani and Stec (2004) presented how VSM can be used to determine leadership beliefs, behaviours and competencies. Recently, Serrano *et al.* (2008)

presented the results of a project whose main purpose is to evaluate the real applicability of VSM to redesign disconnected flow lines based on manufacturing environments with a diversity of logistical problems. They used a multiple case study approach and concluded that VSM can be used as redesign tool for manufacturing apart from enumerating the differences between theoretical concepts proposed by VSM and their real-world practical applications. Thus, it can be found that VSM has been used in both manufacturing and service industries. However, its application is more predominant in manufacturing. In recent times, it is also getting applied in other areas such as leadership and SCM.

2.2.4.2 Role of simulation

Many researchers have presented simulation studies in the field of LM/JIT manufacturing. For instance, Detty and Yingling (2000) developed a simulation model to quantify the benefits of the lean system (relative to the existing system) and they found that:

- Average time parts spent in system reduced by 55%
- Model changeover time reduced in the assembly cells from 11 to 3 minutes
- Average inventory throughout the system was reduced as shown below:
    - 70% lower warehouse inventories;
    - 75% reduction in assembly cell inventories;
    - 100% reduction in pre-assembly and kitting inventories; and
    - 10% reduction in finished goods inventory.
- Floor space requirement was reduced by:
    - 37% in warehouse area due to reduced maximum inventory levels;
    - 51% in exchange area from lower maximum inventory requirements etc.

Savsar and Al-Jawini (1995) discussed in detail about the simulation analysis of JIT production. Patterson *et al.* (2002) analysed the JIT performance of a printing shop using simulation. Halpin and Kueckmann (2002) explored the relationship between simulation, lean thinking and lean construction and used simulation as a means for evaluating the benefit of using lean construction techniques. Thus these studies supports the claim of Martinez and Bedia (2002), who noted that “computer simulation can be a valuable tool in designing, implementing or changing JIT practices in a production system”. Similarly, Chu and Shih (1992) commented that though several methodologies have been used in studying JIT production, simulation has attracted the attention of many researchers and practitioners. They also conducted a review to synthesize the related literature and examined how extensively and sufficiently simulation has been used in studying JIT. They classified the available literature based on model configuration (single-line multi-stage and multi-line multi-stage), kanban (one or two kanbans), distribution and random variables, simulation languages, experimental factors, performance measures, statistical related issues etc. Though, a detailed literature review of simulation is not the main focus of this section, a different taxonomy has been proposed for classifying the available simulation literature related to LM/JIT by taking a cue from Chu and Shih (1992). Table 2.5 shows the taxonomy for the literature related to simulation studies in JIT/LM. It can be found that most of the simulation studies in JIT/LM deal with: calculating the number of kanbans, analysing the scheduling algorithms during mixed model manufacturing, comparing the performance of push/pull systems, etc. Hence, various categories such as kanban, push/pull, mixed model manufacturing, etc. were established. Since the emergence of LM, many studies focused on combining simulation with VSM. Hence, in addition to the above categories, a separate category has been added to deal with literature related to VSM and simulation.

Table 2.5: Taxonomy for the literature related to simulation studies in JIT/LM

S. No.	Classification scheme	Author(s)	Remarks
1.	Kanban	Albino *et al.*, 1992	They utilised a discrete-event simulation to model a single-product, multi-stage manufacturing line with resource failures and controlled by a two card kanban system. They evaluated several performance measures such as throughput time, WIP and backorder level to determine optimum operating policies given resource failures. They simulated different maintenance policies in order to better understand their impact on overall system performance.
2.		Mejabi and Wasserman, 1992a	They noted that during JIT implementation, some subsystems continue to retain their 'push' characteristics and hence an effective simulation software language must offer the flexibility to model JIT elements, while preserving the traditional features for modelling push elements. So, they proposed a control paradigm for implementing the 'pull' control structure of JIT systems. It is based upon the concept of 'kanban satisfaction' which is used to provide the control structure which permits the pulling of material to take place. They extended these concepts to describe the modelling requirements for interfacing JIT modules with traditional push systems.
3.		Mejabi and Wasserman, 1992b	They mentioned that simulation languages which are in use today lack the proper modelling features for efficient simulation of JIT processes. Hence, they proposed new language constructs to provide the required features, which are implemented as an extension of an existing simulation language (SIMAN). They explained that these new constructs are based upon the kanban satisfaction paradigm and they described the format of the new constructs apart from describing its implementation in detail.
4.		Askin *et al.*, 1993	In this paper, they have considered workcenters that produce multiple part-types and addressed the issue of the number of kanbans needed for each part type by minimising the sum of inventory holding cost and backorder cost. They developed a stochastic model using simulation and derived the steady-state results for the cases of a few and many part types. They also modified their model for the case of expediting the backorders.
5.		Christenson and Dogan, 1995	They introduced a simulation generator for dual-card, kanban-controlled flow shops, which eliminates modelling and the coding stages of simulation analysis. They noted that the generator is capable of simulating multi-product, multi-stage flow shops with multiple kanban cards (withdrawal and production order kanbans) having variable container sizes. It has an easy to use data-driven environment, which allows users to develop, edit, save and execute models without requiring any programming skills as it can generates codes in SIMAN simulation language.
6.		Frein *et al.*, 1995	They analysed the influence of design parameters (such as the one that control total WIP of the stage and the other that determines the target in terms of number of products that must be produced, which needs to be stored at the output of the stage) on the efficiency of generalized kanban control policies. The goal is to provide insights, as well as general rules for providing a better understanding of generalized kanban control policies.
7.		Savsar, 1996	He presented the results of a simulation study of two different kanban withdrawal policies on performance measures of JIT production control method such as throughput rate, station utilization and total WIP levels. He also conducted simulation experiments to determine the effects of processing time variability, number of different types of kanbans allowed at each station and production line length on the above-mentioned performance measures with the assumption of gamma and Erlang distributions for the processing times of stations.

S. No.	Classification scheme	Author(s)	Remarks
8.		Andijani, 1997	He investigated the trade-off between the average throughput rate (to be maximized) and the average system time (to be minimized) using a multi-stage serial production line system with materials in the system controlled by kanban discipline. Simulation results are presented to evaluate the production system performance in terms of two conflicting objectives for a fixed total number of kanbans over a given number of serial workstations.
9.		Huang *et al.*, 1998	In this paper, they performed a simulation analysis to compare three production control systems implemented in a cold rolling plant having a semi-continuous manufacturing environment. Based on the simulation results, they found that the CONWIP production control system is the most efficient of these as it can greatly decrease the WIP, average inventory and average inventory costs, while providing a higher throughput rate and facility utilisation.
10.		Gupta and Al-Turki, 1998a	They studied the effect of a sudden breakdown of a material handling system on the performance of the Traditional Kanban System (TKS). In addition, they also proposed a newly developed kanban system called as Flexible Kanban System' (FKS), which dynamically and systematically manipulates the number of kanbans in order to offset the blocking and starvation caused by these factors during a production cycle and compared the overall performances of the TKS and FKS by considering a variety of cases.
11.		Gupta and Al-Turki, 1998b	They introduced a newly developed systematic methodology to manipulate the number of Kanbans in the FKS in order to reduce the effect of anticipated surge in demand and interruptions caused by planned maintenance in a stochastic processing times environment. Using the simulation model, they demonstrated that FKS is able to reduce order completion time and backlog while minimizing the ending inventory in comparison with TKS.
12.		Gupta *et al.*, 1999	They introduced a newly developed system, which they refer as the FKS to cope up with uncertainties due to planned/unplanned interruptions. They demonstrated the superiority of the new system by considering four case examples covering various uncertainties. By conducting numerous simulation studies, they compared the overall performance of the FKS with that of the traditional JIT system. In all the cases they have considered, the performance of the FKS was indeed, superior to that of the traditional JIT system.
13.		Haslett and Osborne, 2000	They reported on the results from a simulation model of the local rules used by managers in the operation of kanban system. In this case, local rules were used to optimize chances of survival by deflecting senior management criticism of potential stock outs in the system.
14.		KÖchel and NielÄnder, 2002	They demonstrated how simulation optimization, especially simulation and genetic algorithms, can be used to solve complex design and control problems with regard to multistage systems with Kanban control. They provided a description of the Kanban control mechanism for multistage systems and a general optimization problem for Kanban systems. They used the simulator KaSimIR (Kanban Simulation Imaging Reality), developed at Chemnitz University of Technology for the simulation of very general Kanban systems and the evolutionary optimization tool LEO (Laboratory for Evolutionary Optimization) for optimizing the same.
15.		Cave and Nahavandi, 2004	They verified a new Kanban specific simulation language as well as a high-speed execution engine through the simulation of a single stage single part type production line. They modelled the single stage single part KCS with exhaustive enumeration of the decision variables of container sizes and number of Kanbans and used the following performance measures: 95% Confidence Interval (CI) of container Flow Time (FT), mean line throughput as well as the Coefficient of Variance (CV) of FT and Cycle Time (CT) to analyse them.

S. No.	Classification scheme	Author(s)	Remarks
16.	Push/Pull	Kimura and Terada, 1981	They formulated the pull system and gave a model simulation of fluctuation in production and inventory through the whole process in terms of system parameters such as lot size, lead time, etc.
17.		Sarker and Fitzsimmon, 1989	They observed the effects of variability of operator performance and/or the unequal distribution of task times on the performance of push and pull systems and how the manager can decide which production technique to adopt.
18.		Wang and Xu, 1997	In order to test the performance of the hybrid push/pull production control strategy proposed by Hodgson and Wang, they developed a simulation model for a flow-shop manufacturing systems. They conducted different simulation runs for the different description equations that represent the different strategies of material flow control and found that the recommended hybrid push/pull strategy is still the best one of all strategies for general mass product manufacturing systems.
19.		Grosfeld-Nir *et al.*, 2000	They developed a simulation model to study push and pull strategies to control multistage production systems with random processing times. They developed a framework to compare multistage production systems based upon WIP and throughput (TP) trade-off. They found that often push outperforms pull, i.e. push systems accumulate less WIP than pull systems while maintaining higher TP. They also found that WIP linearly increases in the number of stages and that WIP is not affected by variation in processing time in pull systems, while in the case of push systems, they found that the release of material into the system in deterministic time intervals greatly improves performance.
20.		Beamon and Bermudo, 2000	They developed a hybrid push/pull production control algorithm primarily based on a JIT approach, but used dependent demand aspects of manufacturing resources planning (MRP II) to manage the intermediate inventories. They tested it in a multi-stage, multi-line, assembly-type repetitive manufacturing environment using a simulation model to understand its performance based on output, lead time and WIP. The simulation results showed that the algorithm was effective in minimizing WIP while sustaining output capacity, with relatively little sacrifice in total lead times from the best observed values.
21.		Li, 2003	He conducted a simulation experiment to compare the effects of applying the core JIT concepts on the performances of push and pull systems especially in a job shop environment. He found that it is essential that a suitable shop layout and part flow type are adopted for either a push or a pull system based on the extent of set-up time reduction effected by cellular manufacturing. In addition, he also highlighted that although a push system was always superior to a pull system in the simulated job-shop environment, the performance difference between the two systems was small.
22.	Layout	Sarker and Harris, 1988	They noted that for a perfectly balanced line (an ideal situation), the JIT (pull system) production system holds no inventory in between the stages. But in reality, because of the differences in stage operation times due to the variability of the operator's performance and/or unequal distribution of task times, the production line experiences various types of problems. Hence, they studied the effects of this imbalance of stage operation times in a JIT production system.

S. No.	Classification scheme	Author(s)	Remarks
23.		Chakravorty and Atwater, 1995	They compared the performances of lines designed using the line balancing and JIT approaches. A simulation model was developed for both forms of line design. In addition to the two line design approaches, two other independent variables were introduced to observe their impact on the cycle time of each line.
24.		Welgama and Mills, 1995	They described methods of addressing design problems faced by a leading chemical company in Australia when changing from traditional manufacturing system to JIT. They employed simulation using the SIMAN simulation language for analysing the performance of alternative cell designs in terms of materials handling requirements; estimating the operator work loads under the new system and determining the reorder levels in order to operate the JIT system successfully.
25.		Smet and Gelders, 1997	They described a real-life case study that was conducted in the repair department of a truck cabin factory and described how bottlenecks were determined for both the present layout and for a proposed layout change. They noted that as several product flows `intertwine', they caused deadlock phenomena, which made modelling a complex task. Further, using a sensitivity analysis, they evaluated the effects of different types of waste, such as machine breakdowns, inadequate buffer size and production time variance.
26.		Taj *et al.*, 1998	They demonstrated how simulation can be used to examine the feasibility of converting an existing manufacturing system into a cellular manufacturing system at a component manufacturer for an automotive company. They noted that though simply changing the layout into cells can provide benefits, they are offset by a high level of required investment, which arises due to poorly matched cycle times, machine downtimes, long changeovers, etc. They concluded that changes in material handling and machine designs are necessary to increase cell performance.
27.	Small lot production / Production Smoothing	Aigbedo and Monden, 1996	They noted that for most JIT systems, Product Usage Smoothing (PUS) would only be of practical significance, if it helps to achieve Sub-assemblies and parts Usage Smoothing (SUS). Hence, they conducted a simulation experiment for two-level sequence scheduling for JIT assembly lines and used the SUS objective value as the metric. The results showed that in a comparatively higher percentage of cases (relative to single-level SUS objective scheduling), better sequences are produced, which can be reasonably considered as statistically significant.
28.		Berkley, 1996	He investigated the effect of container size on average inventory and customer service levels in a two-card kanban system processing multiple part types. He varied the container size and the number of kanbans in tandem so that total WIP inventory capacity remains constant during the simulation and found that smaller containers lead to smaller average total inventories. He also noted that surprisingly, smaller containers do not always lead to poorer average customer service.
29.		Yang and Deane, 2002	They conducted a computer simulation experiment to test the proposed lot size reduction models and their solution heuristics and to investigate the relationships between the lot size decisions and other important production factors, such as setup time reduction, product mix selection, and job queuing time performance.

S. No.	Classification scheme	Author(s)	Remarks
30.	Mixed model production	Sumichrast *et al.*, 1992	They statistically compared several procedures such as two 'goal chasing' heuristics, an algorithm developed by Miltenberg, a time spread method developed by the authors that smoothes the work load at each assembly line station, and the familiar batch sequencing procedure frequently used in practice for sequencing products on a mixed-model assembly line in a JIT production system, using simulation analysis. These five sequencing procedures were evaluated with respect to four measures of assembly line such as inefficiency, work not completed, worker idleness, worker station time and a measure of variability in uniform component usage.
31.		Yavuz and Satir, 1995	They studied the kanban-based operation of a mixed model manufacturing line using a hypothetical manufacturing line. They described the general structure, major components and operational characteristics of the line and developed the simulation model for the same. They also described the parameters of the base model apart from discussing the experimental design features with respect to simulation related issues, performance measures, statistical analysis, etc.
32.		Sumichrast and Clayton, 1996	They reviewed some of the most promising sequencing techniques on a simulation model which includes both a paced, mixed-model assembly line and a JIT fabrication shop feeding the assembly line. They examined how sequencing methods have been evaluated and suggested procedures which are tied more directly to performance. They commented that the most common measure of the performance of a sequencing method, the sum of squared deviations from linear component usage is flawed and concluded that, in the environment studied direct measures of system productivity are more useful.
33.		McMullen, 1998	He presented a heuristic for sequencing mixed-model production schedule for assembly lines when JIT production is an objective, and setup requirements are present. The heuristic examined a sequence and determined an objective function value based upon the parts usage rate and the number of setups involved. He altered this sequence to find a better sequence in terms of the objective function via Tabu Search. This technique is applied to several problems, and the resulting sequences are simulated to determine production performance measures of production make-span, system time and average WIP inventory level.
34.		Buckhin, 1998	He observed that the throughput evaluation of a mixed model assembly line, where the arrival sequence of items is randomly distributed is a very difficult task. Hence he conducted, a six-stage validity study of five alternative performance measures by making a comparison between calculated performance measures for throughput for different simulation results using the Spearman correlation coefficient. He found that the performance measure based on the probability of a station becoming a bottleneck is highly correlated with simulation results and identified it to be the best measure in almost all experiments.
35.		Merengo *et al.*, 1999	They simulated the manual, mixed-model assembly lines and proposed a new balancing and production sequencing methodologies for minimizing the rate of incomplete jobs (in paced lines and in moving lines) or the probability of blocking/ starvation events (in unpaced lines); (2) reducing WIP and minimizing the number of stations on the line; apart from providing a uniform parts usage.

S. No.	Classification scheme	Author(s)	Remarks
36.		Zeramdini, *et al.*, 2000	According to them, under a JIT pull system the sequencing of products requires the satisfaction of two main goals: (1) keeping a constant rate of usage of parts, and (2) smoothing the workload at work stations to avoid line stoppages. Hence, they proposed a two-step approach. During the first step they considered the goal (1) by applying a benchmark heuristic, while in the second step they focused on goal (2), by investigating the effectiveness of a spacing-constraint based approach, commonly used in the automotive industry, in comparison with a more general time-based one. Based on the simulation of final assembly lines, they found that the benchmark heuristic represents an appropriate choice for step one (based on a new performance measure that represents a lower bound on variation in parts utilization), while for the second step, related to workload smoothing, the spacing-constraint based method presents better achievement than the time-based one.
37.		Hasgül and Büyüksünetçi, 2005	This paper described the development of simulation models for a mixed model production line in a refrigerator company, as the decision makers were interested in determining the bottlenecks before changing the traditional line to a mixed model production line. They also evaluated the performance such as number of units produced, waiting time, cycle time, time in the system etc. and compared the traditional production environment with the assembly lines in a mixed model production environment. They found that mixed model production was better than traditional layouts.
38.		Klampfl *et al.*, 2006	They noted that mixed-model assembly lines create new challenges regarding assembly line planning and balancing. Hence, they studied the problem of how to allocate stock within the work-cells so that non-value added operations such as walking and waiting are minimized during the workstation layout optimization. They presented three different optimization formulations and gave an example of an optimized workstation layout based on simulation.
39.	General/other issues	Occea and Yokota, 1991	They described the modelling of an AGV system (AGVS) in a JIT environment. They emphasised the influence of a 'JIT perspective' throughout the model by introducing threshold values for both input and output queues, performance measures that emphasized lower inventories in addition to transport efficiency and a new dispatching rule that implements better inventory and transport control in the simulation model. Analysing the results of the simulation experiments, they found that the dispatching rule is shown to perform better in a JIT environment than previously developed AGV dispatching rules in both transport and logistic criteria.
40.		Muralidhar *et al.*, 1992	They studied how the selection of the distribution used to describe processing times in JIT simulations will affect the results. Three distributions, namely the truncated normal, the gamma, and the log-normal distributions was used to model the processing time in the simulation models and they found that no significant difference in the performance of the simulation. Further they recommended the gamma distribution as it specifically meets the requirements for describing processing times in the JIT environment apart from being computationally efficient.
41.		Linn and Xie, 1993	They investigated the effect of job sequencing rule on delivery performance of an Automated Storage Retrieval System (ASRS), which is used as a valve warehouse to support a pull-based kanban-driven assembly line. They used a computer simulation to examine the interaction of the sequencing rules with other control variables and assessed various performance measures such as on-time delivery, work loss, inventory, etc.

S. No.	Classification scheme	Author(s)	Remarks
42.		Adams *et al*., 1999	They noted that simulation offers a powerful tool to support the continuous improvement process and presented two case studies in support of it.
43.		Takahashi and Nakamura, 1999	They proposed reactive JIT ordering systems (i.e., the Kanban system and the concurrent ordering system) for the unstable changes in demand to realize an agile control for multi-stage production inventory systems. They also proposed a reactive controller of buffer size for the JIT ordering systems and in the proposed systems. The unstable changes in demand are detected with the exponentially weighted moving average charts, and the buffer size at each inventory point was controlled for reacting to the detected unstable changes. Finally, they analysed and compared the performances of the proposed JIT ordering systems with each other by simulation experiments.
44.		Detty and Yingling, 2000	They used the simulation to assist in the decision to implement LM principles at an existing assembly operation. Models are developed for the existing assembly system, as well as for a new system (of similar capacity), that employs these principles. In addition to the manufacturing processes, the associated warehousing, inventory management, transportation and production control/scheduling systems are included in the model to enable the quantification of LM's impact on the total system. Simulation experiments measure each system's resource requirements and performance, thereby quantifying benefits to be derived from applying the shop-floor principles of LM.
45.		Croci *et al.*, 2000	They developed a simulation model of a real automated Printed Circuit Board (PCB) assembly system to compare several workforce management contexts differing in the number of workers in the crew, the way tasks are assigned to operators and the way operators are assigned to machines in the shop and concluded with some useful directions on work-force management in automated systems, highlighting how job enlargement issues typical of lean production philosophy have great relevance in determining the best workforce management.
46.		Patterson *et al.*, 2002	They demonstrated a case study of a printing press in a medium sized UK based academic publishers, where the engineers were planning to implement a JIT production planning system. Before implementing, they investigated the performance of the printing press (such as number of sheets printed, average WIP, number of jobs completed, number of books produced and production time) under a variety of operating conditions using the simulation models. To their surprise, they found that operating the printing press with JIT control would not produce economic performance improvements due to constraints applied by the printing process.
47.		Martinez and Bedia, 2002	They commented that existing simulation software enables users to generate modules that represent partial aspects of a JIT system. These modules, adequately modified and integrated, give researchers and practitioners the possibility to create complex models that can be applied to a variety of JIT systems or JIT production environments. Hence, they created a modular simulation tool, based on the modular capabilities of Witness. As a module example, they presented the feeder double-kanban line module, which represents one of the core aspects of a JIT manufacturing system and finally, they demonstrated the module integration by modelling a U-shaped line.
48.	VSM	Dennis *et al.,* 2000	They utilised simulation in conjunction with VSM to improve the performance of British Telecommunications PLC (BT). They demonstrated the transformation from current state to future state for a service industry.

S. No.	Classification scheme	Author(s)	Remarks
49.		McDonald *et al.*, 2002	They described an application of VSM coupled with simulation to a dedicated product line in an engineer-to-order motion control products manufacturing plant and demonstrated the use of simulation to answer questions that could not be addressed only using the static view provided by VSM.
50.		Comm and Mathaisel, 2005	They investigated whether LM principles, which are more suitable for capital-intensive manufacturing in the US, be applied to a labour-intensive textile firm in China. They collected a real-life data from a family-owned manufacturing plant, Orient Handbag Limited, in Fujian, china and developed a simulation model using Arena. They found that by applying lean principles, Orient's production efficiency for one of its most trouble-some textile products could be improved.
51.		Huang and Liu, 2005	They demonstrated the use of rough set theory after the current state VSM to identify where lean control is required. They developed a simulation in Arena to model a factory of Taiwan-funded enterprise in mainland China that produces oval-gear flow meters to understand the effect of implementing lean control approaches in the factory. They used five scenarios of the simulation model to arrive at the global optimisation of lean control.
52.		Abdul Malek and Rajgopal, 2007	They described a case where lean principles were adapted for the process sector for application at a large integrated steel mill. They also used VSM to identify the opportunities for various lean techniques and developed a simulation model to contrast the ‘‘before’’ and ‘‘after’’ scenarios in detail, in order to illustrate to managers potential benefits of LM.

2.2.5 Assessment of lean manufacturing

Only a handful of papers related to assessment are available in the literature of LM. Based on the focus of the papers, a classification scheme has been established as shown below:

- Papers that deal with assessment of LM and its related areas in a group of organisations based on empirical studies
- Papers that deal with assessment of LM and its related areas in an individual organisations

Papers that deal with assessment of LM and its related areas in a group of organisations based on empirical studies: Since, the papers under this category rely on survey methodology; they are already discussed in Table 2.4. As seen in Table 2.4, some of the assessment studies focused on assessing issues based on the perspective of HR. They dealt with the assessment of issues such as work organisation, quality of work life, etc., using the survey methodology. On the other hand, researchers such as Doolen and Hacker (2005) and Taj (2005) utilised surveys to perform the assessment of LM – i.e., assessment of implementation of LM elements in a particular sector or comparing the implementation of LM in different sectors of industries. There are some papers by researchers such as Soriano-Meier and Forrester (2002), Kojima and Kaplinsky (2003), Ray *et al.* (2006), etc., which dealt with the development of a quantitative measure such as lean index or degree of leanness based on surveys.

Papers that deal with assessment of LM and its related areas in individual organisations: Karlsson and Åhlström (1996a) developed an operationalized model, which can be used to assess the changes taking place in an effort to introduce LP.

Based on the book authored by Womack *et al.* (1990), they summarized the important principles contained within lean production to find measurable determinants of what constitutes such a system in a manufacturing company. Finally, the model was tested and concurrently developed in a clinical research project in a manufacturing firm producing mechanical and electronic office equipment. Nightingale and Mize (2002) described the Lean Enterprise Self-Assessment Tool (LESAT) developed by Lean Aerospace Initiative (LAI). It utilizes maturity matrices that measure 54 lean practices consisting of lean transformation/leadership, life cycle processes and enabling infrastructure processes. Five maturity levels were defined from least capable (1) to world class (5) for each item. One of the important features of LESAT is that it is developed by the academicians based on the experience gained through LM implementations in various organisations. In addition to this, there are many other assessment tools that are developed by various consultants. For instance, a spreadsheet based assessment tool developed by Strategos Inc. was used by Taj (2005) to assess the organisation before implementing LM to update the management about ‘how much the organisation can improve by implementing LM?’ and ‘what can be done by implementing LM?‘. The consultants also used such assessment tools after completing the LM implementations to demonstrate ‘what is the current status in LM implementation?’ and ‘what other tools need to be implemented?’, etc. For instance, the most widely accepted benchmark of lean competence - the Shingo Prize (2003) lists fifteen different measures in five different categories as the basis for lean measurement. The common feature of all these existing assessment tools is that they are based on questionnaires and check list, which explore different areas of a company’s manufacturing practices. Furthermore, they can be used as a self assessment tool by the organisations that has implemented LM or about to implement LM.

Apart from this, various other forms of methodologies were also proposed to perform assessments. Srinivasaraghavan and Allada (2006) remarked that contemporary lean assessment tools that are designed to evaluate a company's status of lean implementation provide only a qualitative analysis and do not provide any clear direction of where the improvement efforts should be directed. Hence, they proposed a complementary methodology to assist contemporary lean assessment tools that will provide a quantitative measure of leanness by benchmarking other exemplar lean industries along with specific pointers for improvements based on cost considerations. They proposed a Mahalanobis Taguchi Gram Schmidt System (MTGS) based methodology consisting of four steps. The first three steps consist of data collection using contemporary lean assessment tools, standardizing the data, and using the standardized data for calculating the Mahalanobis Distance (MD) by the using the MTGS method. The fourth step helps to identify the direction of improvement for a given set of capital constraints. They have demonstrated their methodology using an example.

Rawabdeh (2005) investigated the waste in a job shop environment and proposed an assessment method aimed at helping companies to identify the root causes of wastes. He developed a 'waste matrix' to quantify in a percentage form the relationships among wastes and represents a probability that a certain type of waste will affect others or be affected by others. Further, an assessment questionnaire was employed to allocate the source of waste and to differentiate between the levels of waste. The waste matrix and the assessment questionnaire were incorporated in the assessment method to rank the existing waste in a job shop. He claimed that the developed model serves as guidelines for simplifying the search of waste problems and identifies opportunities for waste elimination. He utilized a case study to validate the model, in which the results of the assessment and the real situation concur. Comm and Mathaisel (2000) noted that BM can be used to assess and benchmark lean practices especially in the production and operation military aerospace products. They mentioned that leanness is a relative measure and BM can be used to measure the relative value of one's leanness. They presented six overarching characteristics and some of the supporting metrics, which needed to be considered in the development of BM instrument, which can be used to assess whether or not an entity is lean. One of the advantages of BM over other assessment methods is that, it not only assesses which LM elements are implemented and what is the best-in-class performance, it also highlights the best practices and the performance gap.

Voss *et al.* (1994) commented that BM and self-assessment is being used increasingly by industry as a tool to help identify "best practice" apart from identifying the areas for improvement. They noted that the impact has been particularly striking in the quality management area, as the Malcolm Balridge National Quality Award (MBNQA) has been used by many companies in US and Europe for both benchmarking and self-assessment, leading to great improvements in quality practices and performance. Even Comm and Mathaisel (2000), who described the development of an eight-step paradigm to implement lean principles and practices emphasized on the application of BM as the fifth step in their paradigm. Earlier in Table 2.3, some of the BM studies by researchers such as Lewchuk and Roberston (1996) and Cumbo et al. (2006) were already discussed in detail as they are based on surveys. Yasin *et al.* (2004) examined several facets of the implementation of JIT using a two-tiered empirical approach, which included a field study and a mailed survey. They surveyed around 277 respondents, which included 130 manufacturing organizations, 61 service organizations and 86 public sector organizations in the USA. They suggested some areas where BM can be utilized by the various organization types to alleviate potential problems in the JIT implementation process. For instance, they mentioned that for best practices in operations and procedure modifications, supplier relationship etc., the service sector and public sector should benchmarking against manufacturing industry leaders, while in the case of customer relationship, the manufacturing firms and public sector firms should benchmark against service firms. In the case of labor related problems, the manufacturing and service firms should benchmark against public sector firms. Knuf, (2000) explored the use of BM in transforming a conventional organization into a lean enterprise. He noted that during this transformation, the management of knowledge and the practice of continuous learning and improvement figure prominently. Hence, in this study, he distinguished various forms of BM and then addressed the issues in knowledge management, information seeking and use, the diffusion of innovations, resistance to change, benchmarking strategies and practices, and benchmarking teams and protocols, apart from a critique of its limitations.

Thus, in this section, a review of various tools for assessment of LM is presented. It can be found that some of the tools are quantitive in nature, while some of them are qualitative. Similarly, some of the studies utilised the empirical data to compare and assess the degree of LM implementation among the surveyed companies, while some studies reported about the use of assessment tools such as check list, self-assessment, waste matrix, benchmarking, etc. to assess individual organisations.

2.2.6 Human resources issues in lean manufacturing

The success of any organisational change management programme is dependent on the people. However, in the case of LM too, HR plays a major role; as a review of literature revealed that many issues relating to HR and LM have been addressed. Some of the papers Boyer (1996), Conti *et al.* (2006), etc. were already discussed in earlier sections. Forrester (1995) examined the implications on HR strategy due to the policies of lean processes and highlighted the major areas of transition for HR, which include organisational style and structure (with a focus on teams, empowerment, culture etc.), role and selection in job style and flexibility (which includes flexible job, roles and responsibilities, performance management), training, problem solving and innovation, industrial relations and pay and head-office implications. Taking a cue from this paper, a categorisation scheme for the literature relating HR and LM is established based on the major areas it addressed. Table 2.6 shows the taxonomy for the literature relating HR and LM. From this table, it can be found that the researchers have analysed the impact of teamwork, training and learning, work design, motivation, etc. in a LM environment. However, most of the papers were focusing on the issues related to work organisation in a LM environment.

2.2.7 Other issues in lean manufacturing

Apart from the above classification, there are some papers, which addressed some of the unique issues. For instance, Emiliani (2006) provided a historical account regarding the role of the Connecticut businesses and business leaders in the spread of lean management throughout the USA. He noted that the Connecticut businesses and business leaders' played an important role in the discovery and dissemination of lean management in America since 1979, external to Toyota and its affiliated suppliers. However, they concluded that most management practitioners during that time did not understand an important principle called 'respect for people' which hindered the efforts to practice lean management. Naylor (2000) made an attempt to determine whether Japanese practices can be successfully transferred abroad or whether they are culturally bound.

Table 2.6: Taxonomy for the literature relating HR and LM

S. No.	Classification scheme	Author(s) and year	Remarks
1.	Work organisation	Rehder, 1994	He noted that different HRM practices are developed in the automobile industry across the world as evident from the Saturn in USA, Uddevalla in Sweden and the Japanese lean production systems. They compared and contrasted the HRM practices of these three production systems and concluded that new forces for change can be expected to continue to accelerate in this decade and beyond, forging a great need for creative, new, flexible organisations and management systems. As a consequence, he predicted that further radical initiatives will be taken up in the years ahead, with mass production and the traditional assembly line no longer features as a prominent part of the works systems of the automobile industry in the future.
2.		Camuffo and Volpato,1995	They utilised a case study of Fiat Auto and concluded that the newly designed HRM policies, on one hand, was resisted by the unions (who have not been involved in the design process) and by segments of the workforce, while on the other hand, they were hindered by existing organisational features and personnel practices, which, in turn, were key success factors during the 1980s.
3.		Forza, 1996	She concluded that LP plants seem to use more teams for problem solving, take employees' suggestions more seriously, rely more heavily on quality feedback both for workers and supervisors, document production procedures more carefully and have employees able to perform a greater variety of tasks including statistical process control.
4.		Emilani, 1998	He made comparisons between common batch and queue manufacturing methods and the typical behaviours exhibited by people in the workplace, which are known to be deficient in their ability to establish trust and gain commitment. Further he studied how individuals can consistently behave in ways that create value, with the goal of eliminating waste in both intra and interpersonal relationships and developed a new model for leadership and organisational behaviour based upon the philosophy and practice of LP.
5.		Niepce and Molleman, 1998	They utilised the nine design principles formulated by a researcher called Cherns to evaluate LP from an STS with respect to work design issues. They concluded that the two concepts differ most with respect to their definition of system boundaries, the assumptions about workers, the control mechanisms and their value bases. But they found that the way control is exercised in each concept is closely related to the production structure and has far-reaching consequences for the HR policies practiced.
6.		Landsbergis *et al.,* 1999	They noted that only few studies have examined the impact of LM on occupational injuries or illnesses or job strain. They commented that increased work pace and limited autonomy (job strain) coupled with the expansion of lean work principles (e.g., an understaffed, flexible labor force; little job security; and overtime) throughout the workforce could produce dramatic increases in the incidence of hypertension and Cardio Vascular Diseases (CVD).

S. No.	Classification scheme	Author(s) and year	Remarks
7.		Biazzo and Panizzolo, 2000	They argued that the way work organization in LP environments is assessed depends heavily on the choice of the variables that are adopted to ascertain the degree of innovation in the workplace. They also commented that many studies evaluate the change in work organization observing only those elements which are functional for the JIT production principles, while excluding crucial dimensions that characterize the working situation from the worker's perspective. Finally, they concluded that only a research approach which is able to give "thick descriptions" of work places can reveal the "reality of working" within lean production systems.
8.		Mehta and Shah, 2005	They proposed a framework and hypothesized that the LP practices, along with environmental and organisational contingencies, affect the work design characteristics that influence employee and organisational outcomes.
9.	Teamwork	Schuring, 1996	He emphasised that group work is one of the main features of LP and explained that work groups within the LP concept are based on the use of standard operating procedures (SOPs) and have a clear hierarchy with close supervision, while the work groups based on a socio-technical design have a certain degree of autonomy in the choice of work methods. He analysed two cases representing the above-mentioned extreme designs of work group and concluded that both approaches to teamwork lead to "operational autonomy".
10.		Camuffo and Micelli, 1997	They conducted a field study of three European car makers (SEAT in Spain, Renault in France and FIAT in Italy) and concluded that the adoption of Japanese manufacturing techniques provided a key regulating role for the first line supervisors. They commented that this regulation was not just a matter of commanding and controlling but rather of communication, negotiation, empowerment and incentives
11.		Tranfileld *et al., 1999*	They explained that LP seeks to harness the potential of employees through teamwork to achieve the collective goals of quality, efficiency and customer service. They also argued that those companies which fail to place team working within a strategic context, or underestimate the degree and nature of change required, are likely to face substantial difficulties particularly in implementation and later in sustaining their change programmes.
12.		Hummels and de Leede, 2000	They offered a description of the two main concepts of a self managing team and considered their introduction into the world of automobile construction using two examples: Volvo's production plant at Uddevala and NUMMI plant in California. They concluded that both concepts do have shortcomings and explained that the meaning and value of the concepts are related to the context in which the systems are implemented.
13.		Kuipers *et al.,* 2004	They addressed the question of whether it is production design or team development that explains business performance and the quality of working life utilising a case study of the Volvo truck plant in Umea (Sweden) that is redesigning from socio-technical based assembly to line-assembly. They concluded that good design of the production structure is necessary, but not sufficient for good performance; team development is just as important, although it requires a favourable context.

S. No.	Classification scheme	Author(s) and year	Remarks
14.	Training and learning	Scott *et al.,* 2001	Using a socio-cultural framework, they described how the production discourse surrounding LP interacted with attempts to introduce reflective action and learning into that environment. They found that action learning practices were accommodated to a certain extent into the work routine during times of production stability, but were largely abandoned during times of crisis. They also noted that there was evidence of individual personal and professional development achieved in this setting, while there was little evidence to date of organizational development.
15.		Smith *et al.,* 2003	They investigated the impact of five common new management practices: team working, TQM, LP, Business Process Re-engineering (BPR) and the learning organisation, as well as a number of other organisational factors and these practices were modelled against eight measures of the organisation of training in enterprises. They concluded that organisational change, as represented by the five new management practices had a significant impact on the organisation of training.
16.		Allwood and Lee, 2004	They modified the learning curve to describe problem solution times; incorporating forgetting effects and treating both general skill and specific skills related to a particular problem and used the resulting model in a simulation of a serial flow shop subject to a range of interruptions. The results showed that the run-ratio generally increases as operators learn more rapidly and forget more slowly, and decreases as the number of problem types increase. They concluded that effect of job rotation schemes is always to reduce the run-ratio.
17.		Politt, 2006	He explained about how culture change among employees of a UK manufacturer was brought about by an award-winning training on the principles of LM.
18.	Motivation	Karlsson and Åhlström, 1995	They conducted an exploratory study and concluded that remuneration serves both as an obstructing and a facilitating force depending on its design.
19.		Koh *et al.,* 2004	They examined whether LM practices interact with the compensation system and information system to reduce production costs using a recursive partitioning model. They concluded that lower production costs can be achieved if LM practices are used along with the incentive compensation plans.
20.		Treville and Antonakis, 2005	They have proposed an extended Job Characteristics Model (JCM) to explain about the intrinsic motivation in the LP context
21.		Worley and Doolen, 2006	They utilised qualitative methods to study the relationships between management support, organisational communications, and LM implementation using a case study of an electronics manufacturing company in the north western USA. They concluded that management support impacted the LM implementation both negatively and positively. Apart from this they also found moderate support for improved communication in the organisation attributable to the lean implementation

S. No.	Classification scheme	Author(s) and year	Remarks
22.	Others	Deshpande and Golhar, 1996	Their study was meant to identify important workforce characteristics, recruitment sources and selection instruments used by JIT firms apart from evaluating the degree of change in training, compensation, employee retention, problems faced by HRM managers and labour relations practices in the firms since JIT implementation. They identified the following as important workforce characteristics: multi-skilled workforce, worker flexibility, quantitative skills, communication skills, problem solving skills, ability to work in groups, ability to inspect their work, self-discipline and concern for firm's success.
23.		Scarbrough and Terry, 1998	They presented the evidence on the management of the labour process at Rover and Peugeot-Talbot. They analysed the existing studies of Japanization in terms of two major theoretical models called the 'diffusion model' and 'bolt on model'. Then, they compared these models with the empirical evidence obtained from the two companies apart from outlining an 'adaptation model' for change.
24.		Koufteros and Vonderembse, 1998	They examined the impact that organisational structure has on the ability of the firm to initiate and implement JIT based on the theoretical support and developed a series of propositions for the relationships between the level of JIT attainment and organisational structure, which they represented it in the form of a theoretical model.
25.		Kinnie, *et al.,* 1998	They attempted to answer these questions: "What is the relationship between downsizing and the concept of lean organisation? Is downsizing always lean? What are the consequences faced by employees due to downsizing?" Finally they concluded that downsizing is rarely lean but often mean and hence frequently associated with failure.
26.		Ahlstrom and Karlsson, 2000	They examined when delayering (i.e., reduction of organizational hierarchy) of the organization takes place during the manufacturing improvement activities such as LM. They utilized a clinical study and participated in the LM implementation of the case organization. Based on the observations and comparing it with the existing operations management theory, they concluded that it is important to delayer the organization earlier during the manufacturing improvement activities as it will create a platform for further improvement.
27.		Radnor and Boaden, 2004	They outlined the concept of 'corporate anorexia', which refers to the inability to utilize or balance effectively the facets/resources of the organization. They identified the characteristics of such anorexic organizations using the case studies. They developed a set of questions based on the review of literature and applied the same to the case studies in order to understand the process of change undergone by an organization when becoming lean and the extent to which this may result in corporate anorexia.

He identified the conditions under which the Japanese management practices have been successfully utilised by the Western companies and concluded that western managers must avoid copying the Japanese practices blindly and should be encouraged to become aware of why certain Japanese approaches are successful. He noted that one of the factors which limit the successful transfer of Japanese methods abroad is the fact that corporate governance in Japan is quite different from many other countries. Lewis (2000) attempted to understand what impact LM has had on the overall competitive position of adopter firms. He combined the normative and critical theory with empirical material drawn from three case studies and argued that lean production can underpin competitive advantage if the firm is able to appropriate the productivity savings it creates. Further, he notes that being 'lean' can curtail the firm's ability to achieve long term flexibility.

Barker (1994) noted that a major problem with JIT philosophy and a fuzzy approach to waste elimination is the lack of structured method. Hence, he provided a structured path to LM with analysis of the supply chain, component production and assembly operation being possible to aid business process re-engineering and benchmarking. He used a time-based value adding frameworks to design the LMS. Katayama and Bennett (1996) examined the role and significance of LP within the context of the current industrial and economic environment in Japan. They explained about the contemporary pressure on Japanese companies and detailed how they are demanding a response to the new conditions through the concept of 'Adaptable Production System'. They utilised the experiences of four Japanese manufacturing plants to support their proposed systems. De Toni and Tonchia (1996) showed that the pursuit of excellence and the organisational change required by lean production leads to a management-by-process organisation, which influences the performance measurement system (PMS). They presented a case study of Zanussi-Electrolux – the largest European producer of domestic appliances, which has introduced management by process into most of its plants. They explained that management by process gives rise to network of independently focused sub-factories, each with its own management criteria and responsibilities, but strictly linked together according to the customer/supplier logic.

Lin and Hui (1997) examined the adaptability of the Japanese style lean organisation system and the traditional American style mass organisation system under changing environments. They modelled the key structural aspects of the two organisations in a problem solving context from an organisational design perspective using computational methods. They utilized organisational level performance in terms of decision making accuracy and severity of errors as an indicator of organisational adaptability under conditions where the task environment shift between predictable or unpredictable or vice versa. They concluded that both organisations have their respective advantages under different task environments and they adapt to environmental shifts in different forms. Lin and Hui (1999) compared the relative performance of the lean and mass organisation systems under different market environments and organisational operating conditions based on the perspective of management coordination. They developed a computer model and conducted simulation experiments to train the model for one type of market environment, in which the organisation encounters all 19683 possible problems in the market environment and learns from the feedback. After the training period, the two organisations are put into real time situation with 1000 randomly drawn problems and the results are recorded and compared. They concluded that the success of either organisation system depends not only on the organisation's structural characteristics for management coordination, but also on internal and environmental conditions. Based on the results, they also cautioned the companies from rushing into lean management practices. Mathaisel (2005) addressed the question of 'whether lean transformation should be incremental or enterprise wide?'. To answer the same, he developed a Lean Enterprise Architecture (LEA) concept for an enterprise-wide transformation, which utilised a multi-phase approach structured on the transformation life cycle phases. He discussed about case examples and discusses about the application and benefits of LEA. Finally, he noted that additional case studies are needed to benchmark the performance of the LEA against incremental lean implementations. Recently, Bhasin and Burcher (2006) presented a conceptual paper, which probed the contemporary view towards lean and illustrated that the implementation record of LM suffers because the aspiring lean enterprise fails to encapsulate that lean is a philosophy rather than another strategy. They reviewed the literature related to LM to find the answers for the following:

- What are the objectives of lean enterprise?
- What are its technical and cultural requirements?
- What are its strategic implications?
- What will be the benefits? and
- What is the procedure for implementing LM?

Finally, they noted that lean is a philosophy and a cocktail of factors are needed for its success. They further explained that not only is it necessary to implement most of the technical tools but an organisation's culture too needs transformation.

2.2.8 Integration of lean manufacturing with other philosophies

Some of the researchers have integrated LM with other philosophies such as TOC, TPM, etc., as evident from the following:

- **Integration of Theory of Constraints (TOC) and LM**: Taj and Berro (2006) presented a case study of an automotive assembly plant, which demonstrated productivity improvement through the application of LM and TOC concepts. The TOC concepts were used in identifying the bottlenecks in the plant that limits the throughput, while LM helped in identifying the wastes. They applied the tools of TOC and LM to improve the productivity of robotic welding operation lines.

- **Leagile Manufacturing**: Krishnamurthy and Yauch (2007) presented a case study to determine whether the concept of leagilty could be applied to a single corporation with multiple business units and whether a decoupling point would be necessary to distinguish the lean and agile portions of the enterprise. They also proposed a theoretical model of leagile manufacturing for describing the leagile infrastructure and presented new research questions. Finally, they found that there exists a decoupling point that separates the lean and agile operations of the case organisation.
- **Integration of lean management and six-sigma**: Arnheiter and Maleyff (2005) eliminated some of the misconceptions regarding Six-Sigma (SS) and lean management and compared them using the available literature. They proposed the six tenets of Lean Six-Sigma (LSS) apart from summarizing the nature of improvements that may occur in organisations that practice lean management or SS and the corresponding improvements that an integrated program could offer. Andersson *et al.* (2006) described the similarities and differences between the concepts including an evaluation and criticism of TQM, SS and LM. They concluded that there is a lot to gain if organisations are able to combine these three concepts, as they are complimentary.

2.3 Research Gaps

In section 2.2.1, a brief review of papers describing what constitutes LM was presented. Even though a plethora of framework exists in the field of LM, none of them have provided:

- A comprehensive listing of principles, practices, tools and techniques (elements) of LM
- A description about the
  - Responsibility of the internal stakeholders (shop floor associates, engineers, managers and top management) of the organisation in implementing LM elements. In other words, what activities should they do in achieving lean? Which LM elements should be implemented by them?
  - Relationship between the LM elements and the competitive priorities of an organisation.
- A comprehensive listing of performance measures for LM

Section 2.2.2 presented a review of papers that describe about the implementation of LM. It was found that lot of case studies exist in the literature, which discussed about the implementation of LM in manufacturing sector and also in sectors other than manufacturing. A review of LM implementation in manufacturing sector revealed that it can be implemented in any organisation irrespective of the type of manufacturing system. Another important observation from the review of these case studies is that none of the paper has discussed in detail about:

- Sequence of implementing each elements of LM. In other words, there is no order of implementing LM elements. For instance, some organisation starts the LM implementation with VSM, while some organisation implements 5S first then proceeds to implement other elements. These studies reveal that there is no procedure or sequence available to implement the LM elements.
- Pre-requisites that need to be completed before implementing certain LM elements

- Role of each operations and its supporting functions of an organisation in implementing LM. i.e. Which LM elements should be implemented by each functions that are related to operations?

Apart from this, a review of papers about the implementation of LM beyond the boundaries of shop floor revealed that not much work has been done in the field of LNPD or in LSC. In the case of LNPD, none of the papers have described clearly about:

- Various wastes that occur in NPD process and how they are related to the wastes in LM
- Tools and techniques which can be used in a NPD process to make it leaner
- Step-by-step approach for implementing the five tenets of LM in the NPD process

Similarly, a review of literature related to LSC revealed that most of the papers were focused on the individual aspects of LSC. However, a typical LSC involves integrating all the upstream and downstream activities into a coherent whole and only very few papers are available that addressed the concept of applying LM principles to the whole of SC. Apart from these potential areas for research, there are some fundamental issues, which are yet to be addressed properly. For instance, none of the papers available in the literature discussed in detail about the following:

- Theoretical basis of LSC
- Elements of LSC
- A step-by-step approach for implementing the five tenets of LM in SC processes

On the other hand, a review of papers on reported empirical studies/surveys in the field of LM in Section 2.2.3 revealed that many surveys are based on the data collected from automotive sector, comprising of automobile plants and auto-components suppliers. Apart from this, the following research gaps can be found:

- Not many papers are available that describe about the surveys from other industrial sectors such as consumer goods sector, process industries or project shops
- Another significant observation is that there is no empirical study about the implementation of LM in Indian industries.
- In addition to these gaps, such empirical studies should also focus on the addressing the following issues: what is the impact on the downstream departments such as warehousing, distribution, logistics etc. due to the implementation of LM principles? In other words, what is the impact on the supporting departments of operations, when LM is implemented in the shop floor?

Section 2.2.4 reviewed the application of different analytical tools in the field of LM. It revealed that VSM has lot of shortcomings and hence, in recent times, simulation has been used along in conjunction with VSM. However, the literature related to simulation in LM and JIT still suffers from the following issues:

- Many simulation studies have been carried from the early 1990s to present are addressing the areas of kanban, pull/push, mixed model assembly/production, inventory control (small lot production), etc. But adequate importance is not given to other JIT/LM elements such as layout change, pokayoke, visual management, process improvements, multi-machine activity (job enlargement), automation, floor space reduction, etc.
- Similarly, most of the studies are focused on analysing one or few issues such as finding the optimal size of kanbans or developing a schedule for mixed model

assembly or analysing the performance of push/pull systems. Only a very few studies have been undertaken considering a combined implementation of JIT/LM elements.

- Furthermore, most of the simulation models are focusing on manufacturing operations only, while supply chain and other business operations are often ignored.

Section 2.2.5, which discussed about the assessment in LM, revealed that some papers on assessment relied on surveys, while the rest of them utilised some unique methodologies such as Mahalanobis Distance (MD), simulation, waste matrix, etc. However, the following research gaps were identified:

- Most of the papers, which attempted to develop a quantitative measure such as lean index or degree of leanness, were based on surveys and data from multiple organisations, while not many papers are available, which discussed a numerical quantitative index for LM assessment in individual organisation.
- Similarly, a review of papers related to BM in LM revealed that the number of papers relating BM and LM are comparatively less, when the long history of LM and BM is considered. Similarly, it can be found that most of papers that relate BM and LM are based on empirical approaches. However, till now:
    - No paper is available in the literature that utilised BM for performing the assessment of LM without relying on empirical studies.
    - Furthermore, none of the papers discussed about the utilization of a well-defined BM models such as that of Xerox, Motorola, etc.

In section 2.2.6, the papers relating the role of HR and LM reviewed. A classification scheme for the same was also established and the papers were classified according to the areas it addressed. The papers were classified in to the following categories: Work organisation, teamwork, training and learning, motivation and others. But the following issues are not yet addressed properly:

- None of the authors have described in detail about the roles and responsibilities of different categories of HR while implementing the LM elements. In other words, no paper has clearly identified which elements of LM should a particular category of HR carry out in a LM environment?
- Similarly, very few papers exist which focus on assessing or evaluating the roles and responsibilities of HR in a LM environment. In other words, none of them has addressed the following fundamental question: 'how effectively does each category of HR have contributed in implementing LM?' or 'how effectively does each category of HR have implemented a particular element of LM?'
- Another important aspect in the evaluation of roles and responsibilities of HR is that implementing LM is not merely a series of mechanical tasks but requires a set of human interactions between different categories of HR. In other words, each category of HR cannot function independently and it is dependent on other categories for the successful implementation of LM. These issues of interactions and dependencies have not been covered extensively till now. Hence, it is necessary to utilise an assessment tool, which can take care of the issue of interdependency.

Although many research gaps have been identified from this review, this thesis will focus on the resolving only some of the research gaps, which are listed below:

- Lack of a comprehensive listing of LM elements and a description about the relationship between the LM elements and the competitive priorities, stakeholders, decision levels, and different functions of the operations department.

- Lack of a step-by-step approach for implementing LMS.
- Lack of a comprehensive listing of performance measures for LMS.
- Lack of simulation studies that considers a combined implementation of JIT/LM elements, instead of one or few elements
- Non availability of a simulation study that provides adequate importance to other JIT/LM elements such as layout change, pokayoke, visual management, process improvements, multi-machine activity (job enlargement), automation, floor space reduction, etc. during the design of LMS.
- Lack of description regarding the roles and responsibilities of different categories of HR while implementing the LMS
- Non availability of an assessment or evaluation method for the roles and responsibilities of HR during the implementation of LMS and
- Lack of an assessment method utilising benchmarking for the assessment of LMS of the entire organisation.

2.4 Conclusions

Thus, in this chapter, various research papers pertaining to LM, which are published in renowned national/international journals and conferences, were reviewed. It was found that the research in LM is progressing in many directions. However, a review paper in English is still not available in the literature of LM to track the milestones in the evolution of LM. Hence, an attempt has been made to carry out a comprehensive review of papers related to LM or LP. As a first step, a classification scheme was proposed for the literature of LM to provide a better understanding. It was found that a lot of papers described about the frameworks of LM. Similarly, a lot of case studies and survey papers exist in the literature of LM. Necessary taxonomies were established for the same and it was found that the number of papers reporting about the implementation of LM in manufacturing sector is much higher than that of LM implementations in service. A review of papers related to the application of analytical tools in LM revealed that simulation has got significant attention among the researchers. About 50 papers were identified and the taxonomy was established based on its application for resolving the problems in LM. Similarly, a review of papers dealing with the assessment in LM showed that some of the papers utilised an empirical approach based on survey to assess the LM implementation, while many papers reported about the quantitative and qualitative tools such as 'waste matrix' and benchmarking for assessment. On the other hand, papers relating HR and LM are also available in plenty. A classification scheme for the same based on the 'theme' of the paper is also established. It was found that many papers addressed the issues of work organisation in the LM environment.

Thus, it is hoped that this comprehensive review and the associated classification schemes will act as a milestone in the history of LM development as there was no review papers available in the literature of LM till date barring the paper written in the Portuguese language. Finally, the research gaps were identified under each category and the research gaps, which will be considered for this thesis is described briefly. An attempt will be made in the forthcoming chapters to resolve these research gaps.

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Chapter 3

Development of Frameworks for Lean Manufacturing Systems

3.1 Introduction

The difficulties that manufacturing organisations face in today's marketplace are fierce with shifts in customer demand, increased variation in products and demands for perfect quality. To counter this, manufacturers have realized the need to continuously improve their operations to compete successfully. Such a phenomenon started in the late 1970s and early 1980s, when previously unchallenged American industries lost substantial market share to Japanese industries in both US and world markets. To regain the competitive edge, those companies that lost market began to adopt various 'improvement programs' that were highly successful in Japan. One such 'improvement program' is the Toyota Production System (TPS) or Just-In-Time (JIT) or Lean Manufacturing System (LMS). Since then, many companies have implemented Lean Manufacturing (LM) in recent years. Among which only a few companies have achieved significant benefits. The reason for this situation can be attributed to 'improper understanding of LM and its concepts by the managers and employees of the organization'. Mohanty *et al.* (2007) too supported this statement and noted that

> *"many of the companies that reported initial gains from lean implementation often find that improvements remain localized, and the companies are unable to have continuous improvements going on. One of the reasons is that many companies or individual managers who adopted lean approach have incomplete understanding and, as a result, could not be able to gain all the benefits as Toyota enjoys".*

Hence, in this chapter, an attempt has been made understand what constitutes LM and what are the principles, practices, procedures, tools and techniques (in short they will be called as 'elements') of LM by proposing a conceptual framework for LMS. Similarly, an attempt has made to understand how to implement LMS and what is the step-by-step approach to implement different LM elements during the design of LMS by proposing an implementation framework for LMS.

3.2 Development of a Conceptual Framework for Lean Manufacturing Systems

Aalbregtse *et al.* (1991) explained that a framework provides a clear picture of the leadership goal for the organization apart from presenting the key characteristics of the to-be style of business operations. Yusuf and Aspinwall (2000) described a framework as “a prescriptive set of things to do”. They noted that one should design and develop a framework representing the modus operandi, the systems to be developed, the activities to be carried out and the ultimate vision of the new style of management in the organization. Hakes (1991) noted that framework helps in translating a theory into practice through some systematic means. From an organisation perspective, the framework can be defined as “a guiding torch that helps a manager in providing necessary direction during the change management programmes that are implemented in an organisation”. It explains either ‘what constitute a change management programme’ or it may discuss about ‘how to carry out the implementation of change management programmes’. It may consist of various elements or blocks, which an organization needs to follow or adopt, when it tries to implement a change in the current way of functioning. In addition to this, Aalbregtse *et al.*, (1991) noted that a framework is needed to:

- Illustrate an overview of a philosophy or change process to be adopted so as to communicate a new vision of the organization
- Force the management to address a substantial list of key issues which otherwise might not be addressed
- Give an insight into the organization’s strengths and weaknesses

A review of literature in Chapter 2 already revealed that many LM frameworks have been proposed by various researchers, consultants and practitioners. The list of existing LM frameworks identified from the review is shown Table 3.1. Although a plethora of frameworks are available in the literature, it is ironical to note that practitioners still have an improper understanding of LM. Hence, it is hypothesised that the existing frameworks have several shortcomings. Hence, to identify the shortcomings, a comparative analysis of these frameworks is required. However, before carrying out such an analysis, it is necessary to answer some of the most frequently asked questions regarding these frameworks.

3.2.1 Frequently asked questions regarding the frameworks

Which framework will be applied to what type of industries?: It must be noted here that the identified frameworks are assumed to be 'more generic in nature' (except that of Jina *et al.*, 1997) because consultants will be providing consultancy on LM implementation based on their framework to various industries (whether it is a large- or medium- or small-scale industry or it might be industries in different sectors such as automobile, electronics, machineries etc.) in different parts of the world. If it is not generic in nature, it cannot be applied uniformly across the vast spectrum of industries. Similarly, the researchers would have proposed the framework based on an empirical survey comprising of response from various sectors of industries. Hence, considering these reasons, the discussion on the context of use for each framework is avoided.

Whether the identified frameworks are dependent on the operational environment or not?: It is a known fact that any change management programmes cannot be copied from one organisation to organisation rather it needs to be adapted to the situation/environment prevailing in the implementing organisation. For example, the JIT production system which was successful in Toyota cannot be exactly replicated in another auto industry. However, many companies have implemented JIT/TPS, in which JIT/LM elements are implemented in a customized manner based on the prevailing internal and external environment. For instance, Mohanty *et al.* (2007) described about the differences in implementation of LM principles in an auto industries across US, UK and India. This study clearly supports the claim that implementation of JIT/LM will depend on the operational environment. If a small scale industry implementing LM is considered, the management may not devote a portion of its resources in developing various algorithms/scheduling rules to establish a full-fledged mixed model assembly line, rather may rely on batch production with reduced batch size. Similarly, instead of a 'kanban system' or full-fledged Enterprise Resource Planning (ERP) software, these companies may use a cost effective packages such as Microsoft Excel, Access and Word for various activities such as: production planning and control, documenting the equipment problems and solutions, collecting equipment data, etc. Thus, it can be concluded that the utilisation of framework for LM also depends on the operational environment. However, for effective implementation of LM, some step-by-step approach should be followed. For instance, small lot production and kanban system can be implemented only if setup time has been reduced, the quality level of the assembly line and suppliers are improved. However, a detailed step-by-step methodology for the implementation of LM is still lacking in the literature.

3.2.2 Taxonomies for the existing frameworks

Yusuf and Aspinwall (2000), when reviewing the Total Quality Management (TQM) frameworks questioned whether or not a TQM model is equivalent to a TQM implementation framework and identified the differences between them. They noted that "a model answers the question of 'what is TQM', with the overall concept or elements put down together, whereas a framework answers 'how to' questions and provides an overall way forward". Thus, they divided the TQM frameworks into two categories, namely models and implementation frameworks. Taking a cue from the definitions of model and framework proposed by Yusuf and Aspinwall (2000), the reviewed LM frameworks were categorized as 'design/conceptual' frameworks (i.e., it refers to the 'model' category) and 'implementation' frameworks as shown in Table 3.1. The following inferences can be drawn from Table 3.1:

- Majority of the frameworks reviewed fall under the category of 'design/conceptual frameworks' and attempted to provide answers to questions such as: 'what constitute LM?' and 'what are the elements of LM?' For instance, the framework titled "the house of lean" proposed by Dennis (2002) lists out the elements of LM.
- Although so many frameworks are available under the category of 'design/conceptual frameworks', which describe about the various elements of LM, none of them have provided a complete list of LM elements. For example, in "the house of lean" framework proposed by Dennis (2002), elements such as successive check, self check, job rotation, delivery at point of use, supplier relationship, etc. are not listed.
- On the other hand, the number of frameworks under the category of 'implementation frameworks' is very less. Apart from this, none of the frameworks, except that of Åhlström and Karlsson (2000) provided a description of 'what sequence to be followed while implementing the LM elements?' In other words, questions such as: 'which elements of LM should be implemented first and which elements should be implemented at the end? What is the prerequisite for implementing the LM elements?' are not addressed by the existing frameworks.
- Apart from the above categories of frameworks, there are four frameworks, which can neither be grouped under the category of 'design/conceptual

frameworks' nor under the category of 'implementation frameworks'. For example, "the framework for lean engineering" or "the lean production as outcome and process" neither specify any LM elements nor it provides a description of how to implement LM. Hence, they are placed under a separate category called 'general frameworks'.

- Finally, a framework by Kobayashi falls under both the categories, as it provides a list of LM elements apart from providing a sequence of implementation.

Similar to the study of Yusuf and Aspinwall (2000), Deros *et al.* (2006) reviewed some of the benchmarking frameworks and classified them as academic/research based models and consultant/expert based models. The same categorization scheme has been extended further by including another category called organization/industry based models for classifying the LM frameworks. A brief definition for each categorization scheme is shown below:

- **Academic/research based frameworks**: These are the frameworks, which are developed by academicians and researchers mainly through their own research, knowledge and experience. In these models, the academician/researcher tends to look at it from the theoretical and conceptual aspects, which may or may not have been implemented or validated through real-life application/implementation.
- **Consultant/expert based frameworks**: These frameworks are developed based on the personal opinion and judgment acquired through experience in providing consultancy to organizations embarking on lean initiatives. These frameworks would be adequately tried and validated through implementation in the client's organization. Hence these frameworks tend to be more practical oriented.

Table 3.1: List of existing LM frameworks and its associated taxonomies

S. No.	Framework for LM	Author	Classification scheme	
1.	Concepts of lean manufacturing	Karlsson and Åhlström, 1995	D	A
2.	Conceptualization of lean production	Karlsson and Åhlström, 1996a	D	A
3.	The components necessary for applying lean manufacturing	Jina *et al.*, 1997	D	A
4.	The lean automotive vision model	James-Moore and Gibbons, 1997	D	A
5.	Theoretical concept of the lean enterprise	Karlsson and Åhlström, 1997	D	A
6.	Small and medium sized firms as lean enterprises	Karlsson and Åhlström, 1997	D	A
7.	The 20 keys to workplace improvement	Kobayashi, 1990	D	C
8.	Lean manufacturing tools	Adams *et al.*, 1999	D	A
9.	Lean enterprise	Czarnecki and Loyd, 2001	D	A
10.	The lean production model	Oliver *et al.*, 2002	D	A
11.	Central theme, principles and characteristics of lean thinking	Bicheno, 2000	D	C
12.	Lean shipbuilding	Liker and Lamb, 2000	D	C
13.	The Toyota Production System	Liker and Lamb, 2000	D	O
14.	A lean reference framework	Davies and Greenough, 2001	D	C
15.	A lean production model	Sanchez and Perez, 2001	D	A
16.	House of lean	Dennis, 2002	D	C
17.	Lean production in an enterprise approach – Linked functions	Cook and Graser, 2003	D	C
18.	Lean – A framework	Hines *et al.*, 2004	D	A
19.	Generic framework for the management of change towards a lean enterprise	Smeds, 1994	I	A
20.	A conceptual framework for successful JIT implementation	Wafa and Yasin, 1998	I	A
21.	Framework for LM with a process view of implementation	Åhlström and Karlsson, 2000	I	A
22.	Chrysler operating system	Flinchbaugh, 1998	I	O
23.	Six steps to implementing lean	Airbus, 2004	I	O
24.	Organizational learning framework	Flinchbaugh, 2003	I	C
25.	The lean manufacturing house	Flinchbaugh, 2003	I	C
26.	Just in time thinking principles	Kobayashi, 1990	D + I	C

S. No.	Framework for LM	Author	Classification scheme	
27.	The essential elements of lean production	Katayama and Bennett, 1996	G	A
28.	Lean production as outcome and process	Lewis, 2000	G	A
29.	Theoretical framework for LM implementation	Motwani, 2003	G	A
30.	Lean engineering	Morgan and Liker, 2006	G	C

Legend

D - Design/conceptual framework
I - Implementation framework
D + I - Combination of Design/conceptual framework and implementation framework
G - General framework
A - Academic/researchers based framework
C - Consultant/expert based framework
O - Organisation based framework

- **Organization based frameworks:** These are the frameworks, which were developed or proposed by organizations based on their experience and knowledge. They tend to be highly dissimilar, as each organization is different in terms of its business scope, market, products, process, etc.

The reviewed frameworks for LM have been classified based on the above taxonomy as shown in Table 3.1. Analyzing each category, it can be found that

- More than 50% of the frameworks are academic/research based frameworks (17 out of 30 frameworks fall under this category).
- Only 12% of the frameworks are available in the category of organization-based frameworks.
- The remaining 10 frameworks (38%) fall under the category of consultant/expert based frameworks.
- On the other hand, the distribution of academic/research based frameworks (conceptual) and consultant/organisation based frameworks (i.e., frameworks that have been or can be implemented in real-time) is found to be equal, i.e. 13 frameworks are academic/research based while the remaining 13 (3 + 10) frameworks are under the organization based and consultant based category respectively.

3.2.3 A comparative analysis of existing lean manufacturing frameworks

A cursory analysis of the existing LM frameworks revealed a lot of problems and issues. For example, some of the frameworks were very abstract, as it was not providing much information about what constitutes LM. Even though some of the frameworks are providing adequate information about what constitutes LM, the elements of LM defined in each framework are completely different with respect to each other. Hence, to have a better understanding of each framework, a comparative analysis is performed with respect to the certain parameters. A similar attempt was made by Yusuf and Aspinwall (2000) in which they compared different TQM implementation frameworks with respect to the Plan Do Check Act (PDCA) cycle. However, in this case, the parameters used for the analysis are completely different from that study and a brief definition for each of them are provided below:

- **Number of elements:** It represents the count of LM elements in each framework.
- **Purpose of the framework:** This parameter helps to identify how a framework has been utilised by the researchers/consultants/organisations. For instance, a framework will be proposed to represent a view point of a researcher or a practitioner and it may not be utilised during the actual implementation. Such frameworks can be classified as a 'conceptual representation', while some frameworks are used by the researchers or academicians as a supportive element in their research. For example, Oliver *et al.* (2002) proposed the framework called 'the lean production model' to prepare a questionnaire. Hence, such frameworks can be classified under 'supportive representation'. On the other hand, some of the frameworks are put to use in real-time in any organization by the researchers or consultants or organisations. Such frameworks will be grouped under 'real-time representation'.
- **Comprehensiveness:** It is evaluated based on the number of elements of LM that a framework represents/addresses. It is based on the assumption that 'more elements are addressed then more it explains about what constitutes LM'. It will be rated as low, medium and high. The degree of comprehensiveness is evaluated based on the following logic: If the number of elements in a framework is more than 30, then it is considered to be highly comprehensive and when the number of elements is less than 10, then it is said to have very low comprehensiveness. A similar approach was followed by Mishra *et al.* (2006).

- **Abstractness:** It focuses on assessing the clarity of a framework in explaining how to implement LM. In other words, it refers to whether a reader would be able to understand how to implement the LM elements; what is the sequence of implementation; which element to be implemented first and which one should be implemented last, etc. This parameter will also be rated as low, medium and high.
- **Degree of fit with respect to an organization:** This parameter tries to analyze whether a framework provides information about the role of stakeholders in LM environment – i.e. who will be responsible for implementing what elements of LM? It will also be rated as low, medium and high.

The ratings for these frameworks are provided by a team of 4 academicians, who have adequate expertise in the field of LM/JIT. On an average, they had about 10 years of teaching experience and 3 years of industrial experience. Each framework was discussed and analyzed critically based on which the ratings were given after a consensus is reached among the team members. One of the authors was assigned the role of noting down the ratings. Table 3.2 shows the comparative analysis of the existing LM frameworks. The following inferences can be drawn from Table 3.2:

- The number of elements in the reviewed frameworks varies from a minimum 3 to a maximum of 50 elements.
- Analysing the utilisation of frameworks, it can be found that 50% of the frameworks (17 in total) are conceptual in nature, while only 12% (only 3) of the frameworks fall under the real-time category. The remaining frameworks (about 10) fall under the category of supportive representation.

Table 3.2: Comparative analysis of the existing LM frameworks

S. No.	Name of the LM framework	Author	Purpose of the framework	Number of elements	Comprehensiveness	Abstractness	Degree of Fit
1.	The components necessary for applying lean manufacturing	Jina *et al.*, 1997	Supportive	Main – 4	Low	High	Less
2.	Central theme, principles and characteristics of lean thinking	Bicheno, 2000	Conceptual	21	Medium	Medium	Less
3.	A lean reference framework	Davies and Greenough, 2001	Conceptual	21	Medium	Low	Less
4.	Concepts of lean manufacturing	Karlsson and Åhlström, 1995	Conceptual	7	Low	Medium	Less
5.	Conceptualization of lean production	Karlsson and Åhlström, 1996a	Supportive	Main – 5 Sub – 24	Medium	Medium	Medium
6.	Theoretical concept of the lean enterprise	Karlsson and Åhlström, 1997	Conceptual	Main – 3 Sub – 7	Low	High	Less
7.	Small and medium sized firms as lean enterprises	Karlsson and Åhlström, 1997	Supportive	Main – 3 Sub – 5	Low	High	Less
8.	Framework for LM with a process view of implementation	Åhlström and Karlsson, 2000	Real time	15	Medium	Medium	Less
9.	A lean production model	Sanchez and Perez, 2001	Supportive	Main – 6 Sub – 36	High	Medium	Less
10.	The lean automotive vision model	James-Moore and Gibbons, 1997	Supportive	Main – 6 Sub – 44	High	Low	Less
11.	Generic framework for the management of change towards a lean enterprise	Smeds, 1994	Supportive	6	Low	High	Less
12.	The lean production model	Oliver *et al.*, 2002	Supportive	Main – 3 Sub – 13	Medium	High	Less
13.	Lean manufacturing tools	Adams *et al.*, 1999	Conceptual	14	Medium	High	Less
14.	Lean enterprise	Czarnecki and Loyd, 1999	Conceptual	14	Medium	High	Less
15.	Six steps to implementing lean	Airbus (2004)	Real time	Main – 6 Sub – 36	High	Medium	Less

S. No.	Name of the LM framework	Author	Purpose of the framework	Number of elements	Comprehensiveness	Abstractness	Degree of Fit
16.	Lean engineering	Morgan and Liker (2006)	Supportive	3	Low	High	Less
17.	Lean production in an enterprise approach – Linked functions	Cook and Graser (2003)	Conceptual	Main – 4 Sub – 17	Medium	Medium	Medium
18.	House of Lean	Dennis, 2002	Supportive	Main – 6 Sub – 25	Medium	Medium	Less
19.	The Toyota Production System	Liker and Lamb (2000)	Conceptual	Main – 5 Sub – 14	Medium	Medium	Less
20.	Lean shipbuilding	Liker and Lamb (2000)	Conceptual	Main – 5 Sub – 20	Medium	Medium	Less
21.	Chrysler operating system	Flinchbaugh, 1998	Real time	Main – 4 Sub – 50	High	Low	Less
22.	Just in time thinking principles	Kobayashi, 1990	Conceptual	Main – 4 Sub – 10	Low	High	Less
23.	The 20 keys to workplace improvement	Kobayashi, 1990	Conceptual	Main – 3 Sub – 20	Medium	Low	Less
24.	Organizational learning framework	Flinchbaugh, 2003	Conceptual	5	Low	High	Less
25.	The lean manufacturing house	Flinchbaugh, 2003	Conceptual	5	Low	High	Less
26.	Theoretical framework for LM implementation	Motwani, 2003	Supportive	7	Low	High	Less
27.	A conceptual framework for successful JIT implementation	Wafa and Yasin, 1998	Conceptual	Main – 4 Sub – 23	Medium	Medium	Less
28.	The essential elements of lean production	Katayama and Bennet, 1996	Conceptual	Nil	Low	High	Less
29.	Lean production as outcome and process	Lewis, 2000	Conceptual	Main – 3 Sub – 10	Low	High	Medium
30.	Lean – A framework	Hines *et al.*, 2004	Conceptual	Main – 8 Sub – 16	Medium	Medium	Less

Note: Under the column – 'number of elements', Main represents main elements, while sub represents sub elements

- Among the frameworks reviewed, only four frameworks have high degree of comprehensiveness, while at least 10 frameworks have very low comprehensiveness. Most of the frameworks have medium comprehensiveness.
- Similar is the case with the degree of abstractness. Very few frameworks have low abstractness while many of them fall between high and medium degree of abstractness.
- One of the important result from the analysis is none of the framework had shown the relationship (degree of fit) between elements and the internal stakeholders or functions of an organization – i.e. who will be responsible for implementing which element of JIT/LM? i.e., what elements will be implemented by the shop floor associates, what will be implemented by engineers/supervisors and managers?, etc. Among the frameworks reviewed, only two frameworks - conceptualization of lean production (Karlsson and Åhlström, 1996a) and lean production as linked functions in an enterprise approach (Cook and Graser, 2003) have scored medium, which means that these two frameworks attempts to reveal some relationship between lean elements and the internal stakeholders. In the Karlsson and Åhlström's framework the elements have been classified under various function of the organization like product development, procurement, manufacturing, distribution, etc. But these functions are not related. On the other hand, in Cook and Graser's framework, similar approach is followed, but it depicts a linkage between different functions in the organization.

From the extensive analysis of these LM frameworks, it can be concluded that the body of knowledge on LM lacks a framework, which provides a:

- Comprehensive listing of principles, practices, tools and techniques (which will be called as 'elements' from now on) of LM

- Structured framework depicting the comprehensive set of elements as a coherent whole
- Description about
    - What is the responsibility of the internal stakeholders (shop floor associates, engineers, managers and top management) of the organisation in implementing LM? In other words, what activities should they do in achieving lean? Which LM elements should be implemented by them?
    - What is the role of each operations and its supporting functions of an organisation in implementing LM?, i.e. Which LM elements should be implemented by each functions that are related to operations?
    - What is the relationship between the LM elements and the competitive priorities of an organisation?
- Discussion about
    - What is the sequence of implementing each elements of LM?
    - What are the pre-requisites that need to be completed before implementing certain LM elements?

Thus, to provide answers for the above-raised questions, new LM frameworks are required. Hence, two frameworks are proposed – one in the ‘design/conceptual framework’ category by identifying the list of LM elements comprehensively and the other in the ‘implementation framework’ category, which lists out clearly the sequence of implementation of LM elements. Thus, these frameworks will help the practitioners to understand clearly ‘what constitute LM’ and ‘how to implement LM’, thereby attempting to overcome the problem of “improper understanding of LM”. To accomplish this, a frequency analysis is carried out to identify the LM elements for developing the proposed framework under the 'design/conceptual framework' category.

3.2.4 *Frequency analysis of the lean manufacturing elements*

Forza (1996) analyzed the differences in work organisation in Lean Production (LP) and traditional plants and identified a list of 10 LP practices apart from the 12 work organisation practices. On the other hand, Bhasin and Burcher (2006) listed around 12 tools of LM and suggested that companies implementing LM should not embrace one or two isolated tools rather they should practice most, if not all of the 12 tools. Similarly many authors have described about the elements of LM. But it is observed that the literature related to elements of LM suffers from the following issues:

- The number of elements identified by various researchers to represent the philosophy of LM differs considerably.
- Similarly, some of the core elements listed in the authoritative books on LM/JIT was not identified by some of the researchers. For an instance, Shah and Ward (2003) identified around 21 manufacturing practices that are commonly associated with LM based on the literature review. But elements such as Andon (warning light) or Jidoka (Autonomation) is not present in the list, which were identified as 'core elements of JIT' by experts such as Shingo (1981), Monden (1987), Ohno (1988), Korgaonker (1992), etc.

Hence to overcome the above-mentioned issues, a detailed literature search related to LM elements has been undertaken. Based on the collected literature, a frequency analysis (i.e., a meta-analysis) of the LM elements is carried out to identify a comprehensive list of LM elements. A similar approach was followed by Shah and Ward (2003). They compared around 16 papers and identified about 21 elements of LM. As said earlier, the elements identified by the researchers including that of Shah and Ward were not comprehensive. Hence it was decided to improve upon the analysis carried out by Shah and Ward and extended it further by performing a comparative analysis of 24 more papers to identify all possible commonly used lean elements.

The papers which were published post 1990 in leading Operations Management (OM) journals identified by Olson (2000) was considered. Olson (2000) identified a list of top journals in the area of OM, which also included some of the journals pertaining to operations research. However, these journals were eliminated from the search activities. Since, the number of top-notch journals pertaining to OM is less; the search was carried out by visiting the publisher's website instead of using the journal databases. Another reason is that these databases will provide a mega-list of papers from various sources including trade magazines, conference proceedings, etc., which can be avoided by limiting the search activities within the publisher's website. Various terms such as 'lean production', ' lean manufacturing' were used in conjunction with other terms such as 'elements', 'tools', 'principles', etc. to identify the relevant papers. Even though, many journals and conference proceedings were filtered out earlier, the literature from these leading journals itself is vast, as it included papers that deal with JIT, which was quite popular during the 1980s-1990s. Hence, the search was further restricted only to those papers which were published after the introduction of the term LM by Womack *et al.* (1990). Similarly, only those papers that described about 'some elements of LM' were selected apart from the books which provided the theoretical aspects of LM. The reason for utilising the above logic is that Shah and Ward (2003) have already considered the literature exclusively related to JIT/TPS to identify the elements of JIT/TPS.

A word of caution regarding the above literature search is that these papers do not form a definitive list rather represents only a sample of numerous LM papers that exist in the literature as many more papers dealing with LM elements might be available in the recently introduced journals and reputed conference proceedings. A complete review of all these papers in other journals and reputed conference proceedings would be impractical. But as far as possible, the more recent and widely published and acknowledged ones were selected for the analysis. Table 3.3 shows the frequency analysis of the LM elements. It should be remembered that the analysis utilised by Shah and Ward (2003) has been included in the analysis, even though it is not shown in the table. Table 3.3 shows a matrix containing the symbol '*'. A '*' represent that a unique LM element listed row-wise in the left-hand side of the table in column 2 is considered by the authors listed column-wise. The purpose of marking a '*' against the LM elements and authors is to obtain a frequency of occurrence of various elements of LM. This analysis revealed about 108 elements in all. Among these, some elements are mentioned by just one author/researcher. These elements were neglected, which reduced the number of elements to around 70. Among the remaining ones, only those elements which are relevant to the field of LM/JIT are considered as part of LMS. For example, elements such as 'ABC analysis', 'leadership', 'quality management program', etc. are common for any type of manufacturing systems and they are not unique to LM. Hence these elements were eliminated. On the other hand, the element 'service cell agreements' is not considered as it was not relevant to LM. Identification of such relevant and irrelevant elements is carried out based on the judgemental approach and domain knowledge. Apart from these elements, there are some elements, which are said to be the pre-requisites for JIT or LMS. For example, elements such as Supplier Proximity (SPR), Concurrent Engineering (COE), Maintain Spare Capacity (MSC) and Order Based Production (OBS) are required for LMS.

Table 3.3: Frequency analysis of LM elements

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
1	Kanban (at supplier or at manufacturing end)			*	*				*	*			*	*	*			*			*	*	*	*	28	65.1
2	Quick changeover techniques or single minute exchange of dies or setup time reduction										*	*	*	*	*	*				*	*	*	*	*	27	62.8
3	Pull system or pull signal			*	*				*		*				*			*	*	*	*			*	26	60.5
4	Lot size reductions or small lot production (at supplier and in manufacturing)								*	*	*	*		*				*			*	*	*	*	24	55.8
5	Self-directed work teams or cross functional team working			*	*				*	*	*	*	*		*	*	*	*			*		*		23	53.5
6	Continuous improvement program or Kaizen				*					*	*	*			*	*		*	*	*	*	*			22	51.2
7	JIT or continuous flow production or one piece flow or smooth flow														*			*	*		*	*	*		22	51.2
8	Cross-functional or multi skilled work force or multi functional employees or Shojinka				*		*		*	*		*		*		*		*			*			*	21	48.8

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
9	Preventive maintenance or Total Productive Maintenance (TPM)									*		*		*	*	*	*			*		*	*	*	21	48.8
10	Process capability measurements or statistical process control										*		*		*	*	*		*	*			*	*	15	34.9
11	Cellular manufacturing or Group technology			*					*		*	*			*							*	*	*	14	32.6
12	Total quality management									*															13	30.2
13	Multi skilled or cross functional training		*	*			*		*	*	*	*			*		*			*		*	*	*	13	30.2
14	Defects at source (operator checking)						*		*		*	*	*		*	*		*			*		*		12	27.9
15	JIT delivery (at supplier and within manufacturing)			*					*		*	*	*	*							*		*	*	11	25.6
16	Visual control or management or graphical work instructions						*	*			*			*	*			*	*		*	*		*	11	25.6
17	Standardization of work processes							*		*					*	*		*	*		*			*	10	23.3
18	Cycle time reductions or lead time reductions									*								*			*			*	9	20.9
19	Employee participation / Empowerment / responsibility					*	*		*	*						*	*		*		*		*		9	20.9

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
20	Reduction in suppliers or sole sourcing								*	*		*	*	*						*		*	*		9	20.9
21	Long term supplier relationships/partnership/customer-supplier alignment									*				*	*	*	*		*	*		*			9	20.9
22	Suggestion schemes or employee suggestions			*					*		*	*				*			*					*	8	18.6
23	Quality circles				*					*	*					*		*					*	*	8	18.6
30	Defect prevention/Pokayoke ot mistake proofing									*				*	*		*	*	*		*				8	18.6
31	5S or Housekeeping													*	*		*				*	*	*	*	8	18.6
32	Focused factory production																								7	16.3
33	Open and better communication (with employees)									*			*	*	*	*						*		*	7	16.3
34	Planning and scheduling strategies or production smoothing/level loading														*			*			*			*	6	14
35	Job rotation programs or flexible job responsibilities		*								*	*	*											*	6	14
36	Use of problem solving tools				*		*		*	*		*								*					6	14

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
37	Job enlargement or multi machine handling or Nagara System						*			*	*							*							6	14
38	Flat organization structure or restructuring or fewer functional hierarchy								*	*	*	*										*	*		6	14
39	Process activity mapping or value stream or value stream mapping	*													*				*			*	*		5	11.6
40	Andon or warning light system/ Jidoka/autonomation/line stop								*									*			*				5	11.6
41	Mixed model scheduling or process flexibility														*			*			*				5	11.6
42	New process equipment/technologies																						*		4	9.3
43	Reengineered production process or simplification (product and process)									*								*	*						4	9.3
44	Quality accreditation /certification (both supplier and manufacturing)			*									*	*									*		4	9.3
45	Minimization of buffers or elimination of safety stock							*		*	*													*	4	9.3
46	Design for manufacture								*				*			*	*								4	9.3
47	Storage space reduction									*				*									*		4	9.3

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
48	Sharing of information with supplier									*		*		*						*					4	9.3
49	Layout change or U shaped assembly line															*		*						*	4	9.3
50	Workload balancing														*				*					*	4	9.3
51	Automation of manufacturing and support activities (barcoding, order tracking)													*									*		4	9.3
52	Information system or Use of EDI(Electronic Data Interchange), Network etc.													*			*						*		4	9.3
53	Quality management programs																	*		*					3	6.98
54	Safety improvement programs																								3	6.98
55	Process sharing				*											*		*							3	6.98
56	Commanality of parts between products									*	*	*													3	6.98
57	Supplier involvement in design											*	*	*											3	6.98
58	Supplier training or supplier development											*	*									*			3	6.98
59	Rewards and recognition											*	*										*		3	6.98
60	CAD/CAM/Computer Integrated Manufacturing																*						*		3	6.98

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
61	Links with customer for quality															*			*			*			3	6.98
62	Synchronization																	*				*			3	6.98
63	Takt time or takt calculations														*			*							2	4.65
64	Work in process reduction										*												*		2	4.65
65	Standard containers													*					*						2	4.65
66	ABC analysis										*				*										2	4.65
67	Long term employment																*						*		2	4.65
68	Service cell agreements or controlled production servicing														*		*								2	4.65
69	Rolling production plans															*							*		2	4.65
70	Leadership																*					*			2	4.65
71	Use of flexible machines																						*		2	4.65
72	Pacemaker or bottleneck removal					*																			1	2.33
73	Maintenance optimization																						*		1	2.33

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
74	Job design		*																						1	2.33
75	Time study					*																			1	2.33
76	Motion study					*																			1	2.33
77	Use of a 2 bin system								*																1	2.33
78	Co location								*																1	2.33
79	Supermarket																								1	2.33
80	Maintain spare capacity																						*		1	2.33
81	Supplier proximity													*											1	2.33
82	Cross docking													*											1	2.33
83	Simultaneous or concurrent Engineering										*														1	2.33
84	Profit sharing scheme												*												1	2.33
85	Routing analysis														*										1	2.33
86	Lean manager development														*										1	2.33

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
87	Touch labor cross-training skill matrix														*										1	2.33
88	Forward plan														*										1	2.33
89	Workable work														*										1	2.33
90	Operational rules														*										1	2.33
91	Detail schedule adherence															*									1	2.33
92	Respect for humanity																*								1	2.33
93	People management																*								1	2.33
94	Dealer partnership																*								1	2.33
95	Neutral cash flow																*								1	2.33
96	True costs known																*								1	2.33
97	Outward looking																*								1	2.33
98	Financial optimization																*								1	2.33
99	Controlled complexity																*								1	2.33

S. No.	LM elements	Sullivan *et al.* (2002)	Shah and Ward (2003)	Kojima and Kaplinksy (2004)	Crute *et al.* (2003)	Dong *et al.* (2001)	Womack *et al.* (1990)	Mehta and Shah (2005)	Bamber and Dale (2000)	Sohal and Egglestone (1994)	Karlsson and Åhlström (1996a)	Sanchez and Perez (2001)	Lewis (2000)	Wu (2003)	Feld (2001)	Forza (1996)	James-Moore and Gibbons (1997)	Cochran *et al.* (2000)	Davies and Greenough (2003)	Koh *et al.* (2004)	Detty and Yingling (2000)	Bhasin and Burcher (2006)	Taj (2005)	Bonavia and Marin (2006)	Number of authors who have given importance	Percentage of authors who have given importance
100	Integration effective R&D																*								1	2.33
101	Control of 6Ms																*								1	2.33
102	Constancy of purpose																*								1	2.33
103	High supplier quality																*								1	2.33
104	Order based production																	*							1	2.33
105	Easy machine handling																	*							1	2.33
106	Operator loops																	*							1	2.33
107	Kaikaku or step change																					*			1	2.33
108	Competitive benchmarking																								0	0

Hence, these elements were included in the list even though it was referred by only one author. Table 3.4 shows the list of LM elements considered for development of the framework.

Table 3.4: List of LM elements considered for the development of the framework

LM elements	In short
Kanban System	KAN
Single Minute Exchange of Dies	SMD
Pull Production	PUL
Small Lot Production	SLP
Cross Functional Teams	CFT
Continuous improvement program or Kaizen	CIP
One Piece Flow	OPF
Multi Skilled Workforce	MSW
Total Productive Maintenance	TPM
Statistical Process Control	SPC
Total Quality Management	TQM
Multi Functional Training	MFT
Defects at Source (Self inspection)	DAS
Just-In-Time delivery (from suppliers and within workstations)	JIT
Visual Control	VIC
Work Standardization	WST
Cycle time and Lead time Reduction	CTR
Sole Sourcing or supplier reduction	SSO
Long Term Supplier Relationship	LTR
Suggestion Schemes	SUS
Quality Circles	QUC
Pokayoke or Mistake proofing or Defect Prevention	POK
Housekeeping (5S)	HOK
Focused Factory Production	FFP
Communication Between Employees	CBE
Production Smoothing or Load Levelling	PSM
Job Rotation or Flexible Job Responsibilities	JOR
Use of Problem Solving Tools	PST
Job Enlargement or Nagara System	JEL
Flat Organisation Structure	FOS
Value Stream Mapping	VSM
Mixed Model Manufacturing/Scheduling	MMM
New process equipment/technologies	NPE
Product and Process Simplification	PPS
Quality Certification (suppliers and manufacturers)	QUC
Elimination of buffers	ELB
Design for Manufacturing	DFM
Storage Space Reduction	SSP
Information Sharing with Suppliers	ISS
Layout change or U-Shaped Cell	LAY
Workload or Line Balancing	WLB
Automation	AUT
Use of EDI with suppliers	EDI
Safety Improvement Programs	SIP
Process Sharing	PRS
Commonization and Standardization of Parts	CSP
Supplier Involvement in Design	SID

LM elements	In short
Supplier Training and Development	STD
Rewards and Recognition	RRE
Computer Integrated Manufacturing (CAD/CAM/CAE)	CIM
Links with customer for quality	CFQ
Synchronization	SYN
Takt time or takt calculations	TAK
WIP Reduction	WIP
Standardized Containers	STC
Long Term Employment	LTE
Rolling production plans	RPP
Use of Multiple Small Machines	UMS
Successive Checking	SUC
Andon (Warning lights)	AND
Jidoka (Autonomation)	JID
Employee Empowerment	EEM
Employee Participation	EPA
Cellular Manufacturing	CEM
Group technology	GRT
Order Based Production	OBS
Concurrent Engineering	CEG
Maintain Spare Capacity	MSC
Supplier Proximity	SPR

It should be remembered here that these elements do not form a definitive list of LM elements; rather it represents only a sample of numerous tools, techniques, practices and procedures. However these elements represent those which are widely considered and acknowledged by the researchers and practitioners. A cursory review of the Table 3.3 and Table 3.4 may arise many questions for which necessary clarifications have to be provided. Hence, before proposing the frameworks, it is necessary to address some of the commonly asked questions that are listed below:

- **Why the same elements are being repeated as another element in the comparison table?**: For instance, in Table 3.3, item 45 lists ‘minimisation of buffers or safety stock’ while item 64 lists ‘Work in Process (WIP) reduction’ and may give a feel that both are similar and have a same meaning. However, these elements have different meanings. Shingo (1988), while explaining about the cause of inventory has clearly explained that there are two types of delay – namely, process delay and lot delay. According to him, process delay refers to “both lots of unprocessed items waiting to be processed and accumulated excess inventory that sits waiting to be processed or delivered". This is represented as buffer/safety stock. JIT/LM focuses on eliminating wastes, which causes process delays and thereby reduce or eliminate the buffer/safety stocks. On the other hand, he also explained lot delay as: "whenever parts are processed in lots, the entire lot, except for the one piece being processed, is delayed "in storage" in either an unprocessed or a processed state until all pieces in the lot have been processed." These delays are caused due to setup time and hence large lot production happens, which corresponds to WIP. JIT focuses on reducing the setup time and establish small lot production, thereby focuses on eliminating/reducing WIP. Thus, this explanation reveals that item no. 45 and 69 are different. In a similar manner, based on our domain knowledge and a detailed study of the JIT/LM, some elements are combined as one, while some elements are represented separately in the Table 3.4. Due to space limitations, a brief explanation/definition for each element; the logic behind combing certain elements and the logic behind representing some elements uniquely are not presented.

- **Why all new manufacturing practices such as TQM, Total Productive Maintenance (TPM), Concurrent Engineering, etc. are added up simply under the banner of LM?**: It should be understood here that these best practices of contemporary manufacturing are not added just for the sake of it. But the purpose of this effort is to show that all these best practices have been studied in isolation till date. All these contemporary manufacturing practices existed as a coherent whole in the Japanese manufacturing systems. Many researchers have included these philosophies as a part of LM. For example, Koh *et al.* (2004) noted that LM practices have often been referred to by other names, such as TQM, JIT, etc. On the other hand, Shah and Ward (2003) classified the different elements of LM into four practice bundles comprising of

TQM, TPM, JIT and Human Resource Management (HRM). Apart from these literature evidences, it is hypothesized that the concepts of TQM, TPM and JIT are all part of the whole system called TPS. According to the literature, the concepts of TQM, TPM, concurrent engineering etc. even have their origins in various Japanese industries. However it is believed that these elements were all present in TPS. Since researchers have studied TPS or Japanese manufacturing from different perspectives (such as how Japanese manufacturers provide the highest quality product, how the Japanese manufacturers could introduce new products at a faster rate than their counterparts), it is believed that TQM, TPM, JIT etc. were developed as standalone philosophies. However, it is only after the study of TPS by Womack *et al.* (1990) revealed that stand-alone philosophies such as TQM, TPM are also a part of LM. Apart from this, the studies undertaken by various researchers such as Flynn and Sakakibara (1995), who studied the relationship between JIT and TQM and Cua *et al.* (2001), who traced the relationships between TQM, JIT, TPM and manufacturing performance, further support our contention that JIT, TQM and TPM are part of TPS. Even Hines *et al.* (2004) noted that there are different ways of achieving LM and mentioned that even six-sigma and TOC are a notable addition to LM.

The consolidated list of LM elements as shown in Table 3.4 consists of various principles, practices, tools and techniques. But till date, researchers have not provided a clear-cut distinction between principles, practices, tools and techniques and still there exists a lot of confusion regarding such a classification. For instance, Bicheno (2000) classified all the LM elements as tools in his book titled “The lean tool box”. On the other hand, Cochran *et al.* (2000) referred various LM elements as principles. Pavnaskar *et al.* (2003) provided a classification scheme for about 101 LM tools. They classified each and every element according to different levels such as system, object, operation, activity, resource, characteristic and application. As explained in the introduction section, many managers do not have a complete understanding regarding the constituents of LM, which lead to many failed implementations. One of the reasons for the same can be due to this lack of clarity and confusion created in the literature regarding the principles, tools, techniques, practices and procedures. Hence, in the next section, a detailed explanation is provided not only for the above issue, but also regarding the various taxonomies that were developed for LM elements.

3.2.5 Taxonomies for lean manufacturing elements

Some researchers have already proposed taxonomies for JIT/LM elements in the literature. For example, Kupanhy (1995) classified the JIT elements into pure engineering elements, worker's operations/activities and Japanese management-related elements. Shah and Ward (2003) postulated four bundles of inter-related and internally consistent practices, which include JIT, TQM, TPM and HRM. Though such classification schemes exist, they fail to provide a clear-cut understanding of what are the principles, practices, tools and techniques of LM. Apart from this, none of the taxonomies addressed the relationship of LM elements between various aspects of organisation. Hence, the following taxonomies are established for the identified elements of LM based on the perspective of:

- Concepts, principles, practices, tools and techniques
- Competitive priorities
- Stakeholders of the organisation
- Different functions of an organisation

3.2.5.1 Classification of lean manufacturing elements into principles, practices, tools and techniques

Only a very few researchers have attempted to distinguish between the "concepts", "principles", "practices", and "techniques" of LM. Karlsson and Åhlström (1997) explained that

> *"the lean enterprise is a concept, which contains a number of principles. The principles in turn consist of a set of practices, which are the activities undertaken to change the organisation, while the practices in turn consist of a wide array of techniques, which contain actions on a quite detailed level."*

But they did not discuss in detail about the practices, tools and techniques. However, in another study, they listed down the following principles of LM: elimination of waste; continuous improvement; zero defects; pull instead of push; multi-functional teams; decentralized responsibilities/integrated functions and horizontal and vertical information systems (Åhlström and Karlsson, 2000). The LM elements could have been classified based on the principles of Åhlström and Karlsson (2000), but it is believed that some of the principles such as multi-functional teamwork, information systems and decentralization and integrated functions are not exactly principles. Principles are those which differentiate LM as a fundamentally different system when compared to the traditional manufacturing systems. The following paragraphs will discuss in detail about the principles utilised by Toyota Motor Corporation (TMC) in designing their operations, which are fundamentally different from the traditional manufacturing systems/concepts followed by Westerners:

- **Order-based production:** Most Western manufacturers developed their production planning based on the concept of Economic Order Quantity (EOQ) and Economic Manufacturing Quantity (EMQ), which provided a trade-off between ordering cost and inventory holding cost (in terms of procurement) in the case of EOQ or setup time and inventory cost (in terms of manufacturing) in the case of EMQ. The assumption of EMQ is based on the fact that setup time cannot be reduced, while the unproductive costs and time associated with it can be spread across a large volume of production. In the case of procurement/inventory (i.e., EOQ), it was believed that ordering cost cannot be reduced as it is dependent on the distance and transportation cost per unit of distance. Another fact is that if more orders are placed it is possible to obtain the volume discounts from the suppliers. But, the Japanese experts such as Shingo (1988) and Ohno (1988) questioned such logics and attempted to reduce the setup time drastically from hours to minutes through the application of "Single Minute Exchange of Dies (SMED)". Similarly, they focused on identifying suppliers in close proximity and practiced 'sole sourcing'. They avoided the concept of having multiple suppliers for the same component, which provided adequate confidence to the supplier that more orders will be placed to them even in the future. Hence, adequate discounts were also provided by the suppliers. Due to these practices, the ordering cost came down and hence, the trade-off between ordering cost and inventory holding cost become invalid. Apart from this, these unique practices resulted in reduction of lead time and inventory apart from aiding in production of variety of products in smaller lots according to the actual orders instead of forecasted demand.

- **Zero defects:** The Western manufacturers adopted and utilised the concepts of Statistical Quality Control (SQC) and acceptable sampling in a big way. Though these scientific methodologies provided adequate benefits in lieu of 100% inspection, the inventors of TPS did not believe in the concept of "acceptable level of defects". They felt that it will have a cascading effect on the product's quality when it undergoes a series of processes/operations. Hence, they resorted to a 100% inspection system. However, the task of 100% inspection was entrusted with everybody involved in the production in the form of practices such as self-check, successive check and tools such as pokayoke (mistake proofing) systems, instead of thrusting the responsibility on a single person or a team of people in quality department. Thus, they eliminated the concept of acceptable level of defects from their production system and strived to achieve an ideal goal of ‘zero defects’.

- **Elimination of wastes:** In continuation with reduction of setup time and defects, the engineers in Toyota also focused on eliminating unnecessary wastes and actions for which customers are not willing to pay for. They identified the following seven wastes: over production (caused due to excess capacity), inventory (caused due to uncertainties in machines, suppliers etc.), motion (caused due to poor work design practices) over-processing (caused due to unnecessary and redundant processing activities), defects, transportation and waiting. They attempted to eliminate these wastes through the use of “common sense” instead of relying heavily on technology and automation.

- **Focus on continuous incremental improvements:** Apart from eliminating these wastes continuously, the engineers of TPS believed that “small incremental improvements in product, process and systems happening quite frequently” is more beneficial than a one-step improvement - a notion followed by the Western manufacturers. Hence, they focused on improving the product, process and systems by utilising the “common sense” in achieving significant incremental improvements in a most cost-effective manner. For instance, they utilised the practices such as “reduction of fasteners”, “reduction of number of parts”, “use of common parts”, “use of standard parts”, etc., which not only improved the design, but also resulted in reduction in processing times.

- **Respect for humanity:** Another deviation from the traditional production systems is that management of TPS utilised the ‘brain of the workers’ in addition to their ‘legs and hands’ to come up with innovative and creative ideas through practices such as suggestion schemes, quality circle, etc., They believed that those who do the job repetitively knows better about the product, process and systems than the well-educated engineers. This lead to breakdown of hierarchy and provided the workers with necessary empowerment to suggest and devise new ways. Hence, adequate respect was provided to the workers and they were involved in discussion with their superiors too. But, in the case of traditional production systems, a strict top-down hierarchy was followed and the workers were paid only for carrying out physical activities using their hands and legs.

- **Visual management system:** Another important aspect of the TPS is the importance to visual control. For instance, practices such as Andon (Warning light) to indicate the problem in the production area, 5S (Housekeeping practices) to sort, clean and keep necessary items in the workplace with proper labelling, Kanban (a card) indicating the part number, part name, quantity, the preceding operation and subsequent operations, etc. were used. Apart from this, they utilised well-documented work standards, which provided necessary information to any worker about the job he is supposed to do. Though some of these practices were followed in Western plants, adequate importance was not given by them until they realized the importance of this system.

- **Focus on customers:** In traditional production systems, the production will start at the most upstream operation with the raw materials being pushed from the stores to the production area according to the forecast, while the changes in actual demand were not considered directly. On the other hand, the engineers of TPS established a tight link in their production systems such that they produced according to the actual demand of the customers. They established a 'pull' system where operations in the downstream pulled materials from the upstream operation according to the customer's requirement. Such a system enabled them to produce according to the demand of customers (which refers to both internal and external customers).

- **Supplier partnership:** The management of TMC strictly followed the Deming's principle of "extended enterprise" (Mitra, 1998). They considered suppliers as an integral part of the manufacturing system and followed a completely different approach than the Western manufacturers. For example, they followed 'sole sourcing' (having only one supplier for a part or family of parts) and thereby reduced the total number of suppliers; while the Westerner manufacturers relied on multiple suppliers for each part or a family of parts as a contingency measure. The purpose of utilising sole sourcing practice is to reduce the variation in materials supplied. Similarly, the Japanese manufacturers located the suppliers closer to the plant and ensured that materials are supplied in smaller lot through the use of standard containers while the Western manufacturers relied on quantity discounts and EOQ. A detailed description about the characteristics of JIT purchasing and supplier relationship is presented by Garg and Deshmukh (1999).

A cursory review of these principles will reveal that out of eight principles, four of them are similar to that of Åhlström and Karlsson (2000). The remaining three principles identified by Åhlström and Karlsson (2000) were captured in the rest of the four principles listed above. Based on these eight fundamental principles of LM the elements identified from the frequency analysis are classified. Some of these principles are already present in Table 3.4. These elements were separated out as principles and the remaining elements were classified based on these principles. Under each classification (i.e. principle), the elements may correspond to a tool or technique or a practice. However Shingo (1988) clarified the differences between them. According to him, zero defects is a principle and it can be achieved through 100% inspection in the form of practices such as "self-check or self-inspection" and "successive check". However, since these practices are carried out by humans, he believed that mistakes are bound to happen inadvertently. Hence, he suggested the use of pokayoke (fool proofing) as a technique, which will prevent mistakes from happening in these practices. Utilizing the guideline of Shingo (1988), the remaining LM elements were classified into practices, tools and techniques. The taxonomy for LM elements from this perspective is shown in Table 3.5. A cursory analysis of Table 3.5 reveals that there are 8 principles, 23 techniques, 5 tools, while the remaining elements are practices. Further, it can be found that around 14 elements are listed under the principle of 'elimination of wastes', while only 4 elements are listed under the category of 'visual management', which reiterates the fact that the prime objective of LM is elimination of wastes.

3.2.5.2 Classification of lean manufacturing elements according to the competitive priorities

It is a known fact that organisations will implement change management programmes such as TQM, TPM or LM as part of their manufacturing strategy to achieve a significant competitive advantage. In other words, these programmes strive to improve the existing competitive priorities of organisation apart from helping them to focus on new priorities. Hence, it is necessary to understand how these LM elements are related to the competitive priorities. According to Dangayach and Deshmukh (2000), the competitive priorities include: cost, quality, delivery and flexibility. But the same has been extended to include productivity, morale, innovation and competitive advantages. The identified LM elements were classified into eight significant categories as shown in Table 3.5. This taxonomy reveals that LM plays an important role in improving all the competitive priorities, which quashes the general notion that companies implement LM only to achieve cost reduction. If companies implement LM in a proper and systematic manner, it can expect an overall performance improvement in all the competitive priorities simultaneously. It is also supported by analyzing the number of LM elements under each competitive priority. A cursory analysis reveals that about seven elements are grouped under the 'cost category', 11 elements are grouped under 'flexibility', 'quality' and 'delivery' while, 'productivity' has 10 elements. On the lower side, only three elements are listed under 'innovation'.

3.2.5.3 Classification of lean manufacturing elements according to the stakeholders of the organisation

White and Prybutok (2001) traced the relationship between JIT practices and type of production system. However, not many researchers have traced the relationship of JIT/LM practices within a production system. It is a known fact that implementing LM in an organisation successfully is dependent on the various stakeholders such as top management, managers (departmental heads), engineers, supervisors, operators, suppliers and customers. Hence, it is necessary to understand "which elements will be implemented by which stakeholder?" Table 3.5 shows the classification scheme from this perspective, which it is believed that will help in understanding "who will be affected by various LM elements and who will be responsible for using/implementing these elements in an organisation?" It can be found that the shop-floor employees have more responsibility than that of other stakeholders, as they are responsible to carry out or implement about 17 elements of LM. On the other hand, top management too have more responsibilities than other stakeholders such as engineers and managers as top management has to be involved in implementing 14 LM elements. The supplier category however has the lowest number of elements (9), but that does not mean they have lesser responsibility. They too play an important role in successful implementation of LM in an organisation.

3.2.5.4 Classification of lean manufacturing elements according to the different functions of operations in an organisation

Extending the above logic, it is also necessary to understand “how the different elements of LM are related to the different functions of organisation, especially from the perspective of operations department? Any standard text book on ‘Operations Management’ would provide a description about the decision areas or functions of the operations department in an organisation. For example, Russell and Taylor III (2006) identified the different functions or activities (decision areas) carried out by an operations department, which include: operations strategy, product design, process planning, facilities and layout, purchasing, production planning and control, quality control, maintenance, human resources, logistics and supply chain management, etc. The LM elements have been grouped according to the different functions or activities of an operations department of an organisation as shown in Table 3.5. It is evident that each of these functions plays a vital role in the implementation of LM. However, the manufacturing and HRM play an important role, as the number of elements under each category is 16 and 12 respectively. On the other hand, other functions such as process planning, purchasing, production planning and control have equal responsibilities. It seems that maintenance and quality control functions have the least responsibility. One of the reasons for the same is that majority of their activities such as inspection, cleaning, tightening, lubrication, etc. have been entrusted with the shop floor employees and hence their role seem to be lesser.

Table 3.5: Taxonomies for LM elements

S. No.	Principles	Element	In short	Practices (P), Tools (To), Techniques (Te)	Competitive priorities	Stakeholders	Functions or activities of operations
	Elimination of wastes						
1.		WIP Reduction	WIP	P	C	En	PPC
2.		Cycle time and Lead time Reduction	CTR	P	Pr	En	MA
3.		Layout change or U-Shaped Cell	LAY	P	Pr	En	PP
4.		Workload or Line Balancing	WLB	Te	Pr	En	PP
5.		Focused Factory Production	FFP	P	Pr	TM	MA
6.		One Piece Flow	OPF	P	Pr	Ma	PP
7.		Design for Manufacturing	DFM	P	C	Ma	PD
8.		Single Minute Exchange of Dies	SMD	Te	F	En	MA
9.		Process Sharing	PRS	Te	Pr	Sh	MA
10.		Flat Organisation Structure	FOS	P	M	TM	HR
	Zero defects						
11.		Defects at Source (Self inspection)	DAS	P	Q	Sh	MA
12.		Successive Checking	SUC	P	Q	Sh	MA
13.		Statistical Process Control	SPC	To	Q	En	QC
14.		Pokayoke or Mistake proofing or Defect Prevention	POK	Te	Q	En	QC
15.		Quality Circles	QUC	Te	I	Sh/En	QC
16.		Computer Integrated Manufacturing (CAD/CAM/CAE)	CIM	Te	Q	TM	PD/PP/MA
17.		Total Quality Management	TQM	P	CA	TM	QC
18.		Quality Certification (suppliers and manufacturers)	QUC	P	Q	Su	QC
	Order Based Production		SLP				
19.		Just-In-Time delivery (from suppliers and within workstations)	JIT	P	D	Su	PU
20.		Synchronization	SYN	P	Pr	En	PPC
21.		Small Lot Production		P	F	Ma	PPC
22.		Kanban System	KAN	P	D	Ma	PPC

S. No.	Principles	Element	In short	Practices (P), Tools (To), Techniques (Te)	Competitive priorities	Stakeholders	Functions or activities of operations
23.		Rolling production plans	RPP	Te	F	Ma	PPC
24.		Production Smoothing or Load Levelling	PSM	Te	D	Ma	PPC
25.		Use of EDI with suppliers	EDI	To	D	Ma/Su	PPC
26.		Pull Production	PUL	P	D	Ma	PPC
	Customer focus						
27.		Maintain Spare Capacity	MSC	P	F	TM	MA
28.		Use of Multiple Small Machines	UMS	Te	F	Ma	PP
29.		Cellular Manufacturing	CEM	P	F	TM	PP
30.		Group technology	GRT	Te	F	En	PP
31.		Takt time or takt calculations	TAK	P	D	Sh	MA
32.		Value Stream Mapping	VSM	To	CA	TM	PP
33.		Mixed Model Manufacturing / Scheduling	MMM	Te	F	Ma	PP/MA
34.		Commonization and Standardization of Parts	CSP	Te	C	Ma	PD
35.		Concurrent Engineering	CEG	P	CA	TM	PD
	Supplier partnership						
36.		Supplier Proximity	SPR	P	D	Su	PU
37.		Supplier Involvement in Design	SID	P	I	Su	PD
38.		Standardized Containers	STC	Te	D	Su/En	PU/MA
39.		Supplier Training and Development	STD	P	Q	Ma	QC
40.		Long Term Supplier Relationship	LTR	P	D	TM	PU
41.		Information Sharing with Suppliers	ISS	Te	D	TM/Su	PU
42.		Sole Sourcing or supplier reduction	SSO	P	Q	TM	PU
	Visual Control		VIC				
43.		Housekeeping (5S)	HOK	P	Pr	Sh	MA
44.		Andon (Warning lights)	AND	To	Q	Sh	MA
45.		Jidoka (Autonomation)	JID	P	Q	Sh	MA
46.		Work Standardization	WST	P	Q	En	QC
	Continuous improvement						
47.		Use of Problem Solving Tools	PST	To	Q	Sh	QC

S. No.	Principles	Element	In short	Practices (P), Tools (To), Techniques (Te)	Competitive priorities	Stakeholders	Functions or activities of operations
48.		Safety Improvement Programs	SIP	P	M	En	MN
49.		Product and Process Simplification	PPS	Te	C	En	PD
50.		Elimination of buffers	ELB	P	C	Ma	PPC
51.		Storage Space Reduction	SSP	P	C	En	MA
52.		Automation	AUT	Te	Pr	Ma	MA
53.		Total Productive Maintenance	TPM	P	CA	TM	MN
54.		Multi Functional Training	MFT	Te	F	En	HR
55.		New Process or Equipment Technologies	NPE	Te	C	TM	PP
	Respect for humanity						
56.		Long Term Employment	LTE	P	M	TM	HR
57.		Multi Skilled Workforce	MSW	P	F	Sh	HR
58.		Employee Empowerment	EEM	Te	M	Sh	HR
59.		Employee Participation	EPA	P	M	Sh	HR
60.		Rewards and Recognition	RRE	Te	M	TM	HR
61.		Cross Functional Team working	CFT	P	M	Sh	HR
62.		Suggestion Schemes	SUS	Te	I	Sh	QC
63.		Job Enlargement or Nagara System	JEL	Te	Pr	Sh	HR
64.		Communication Between Employees	CBE	P	M	TM	HR
65.		Job Rotation or Flexible Job Responsibilities	JOR	Te	F	Sh	HR/MA

Legend:

P – Practice
To – Tool
Te – Technique

P – Productivity
Q – Quality
C – Cost
D – Delivery
M – Morale
F – Flexibility
I – Innovation
CA – Competitive advantage

Sh – Shop floor associates
En – Engineers
Ma – Managers
TM – Top Management
Su – Suppliers

PD – Product design
PP – Process planning
PU – Purchasing
PPC – Production planning and control
MA – Manufacturing
MN – Maintenance
QC – Quality control
HR – Human resources department

3.2.6 Proposed conceptual framework for lean manufacturing systems

It is believed that the taxonomies discussed above would have provided a clear understanding about the LM elements and its relationship within the organisation. The next task is to provide a structure/framework, which unifies all these elements and practices of LM into a coherent whole. The purpose of this framework is to resolve some of the limitations of the frameworks that are grouped under the 'design/conceptual framework' category. It is found that the number of elements under each framework of this category is varying. Hence, they do not specify clearly what constitute LM. Similarly, there is no consistency in highlighting the LM elements among the existing frameworks. For instance, the framework proposed by Adams *et al*. (1999) and Czarnecki and Loyd (2001) differ considerably in the listing of LM elements, even though they have a similar structure of a house. Hence, based on the comprehensive list of LM elements identified in the earlier section, a framework in the 'design/conceptual framework' category has to be proposed to help the practitioners to understand clearly 'what constitute LM'. A cursory review of the frameworks identified above revealed that the house structure is predominantly used in constructing the frameworks. Hence, the same has been adapted and improved to represent our proposed comprehensive framework. The proposed conceptual framework for LMS is shown in Figure 3.1 and the components of the same are explained below:

- **Foundation:** It refers to a universal pre-requisite which should be present in any organization. These pre-requisites should not be considered as LM practices as they are common for any change management programmes such as TQM, TPM, etc. Also, these pre-requisites cannot be taught or forced on the human resources of the organization, similar to certain LM elements such as successive check, self check, etc. However, they should be developed and nurtured. Good leadership, commitment, culture and human aspects form the foundation.

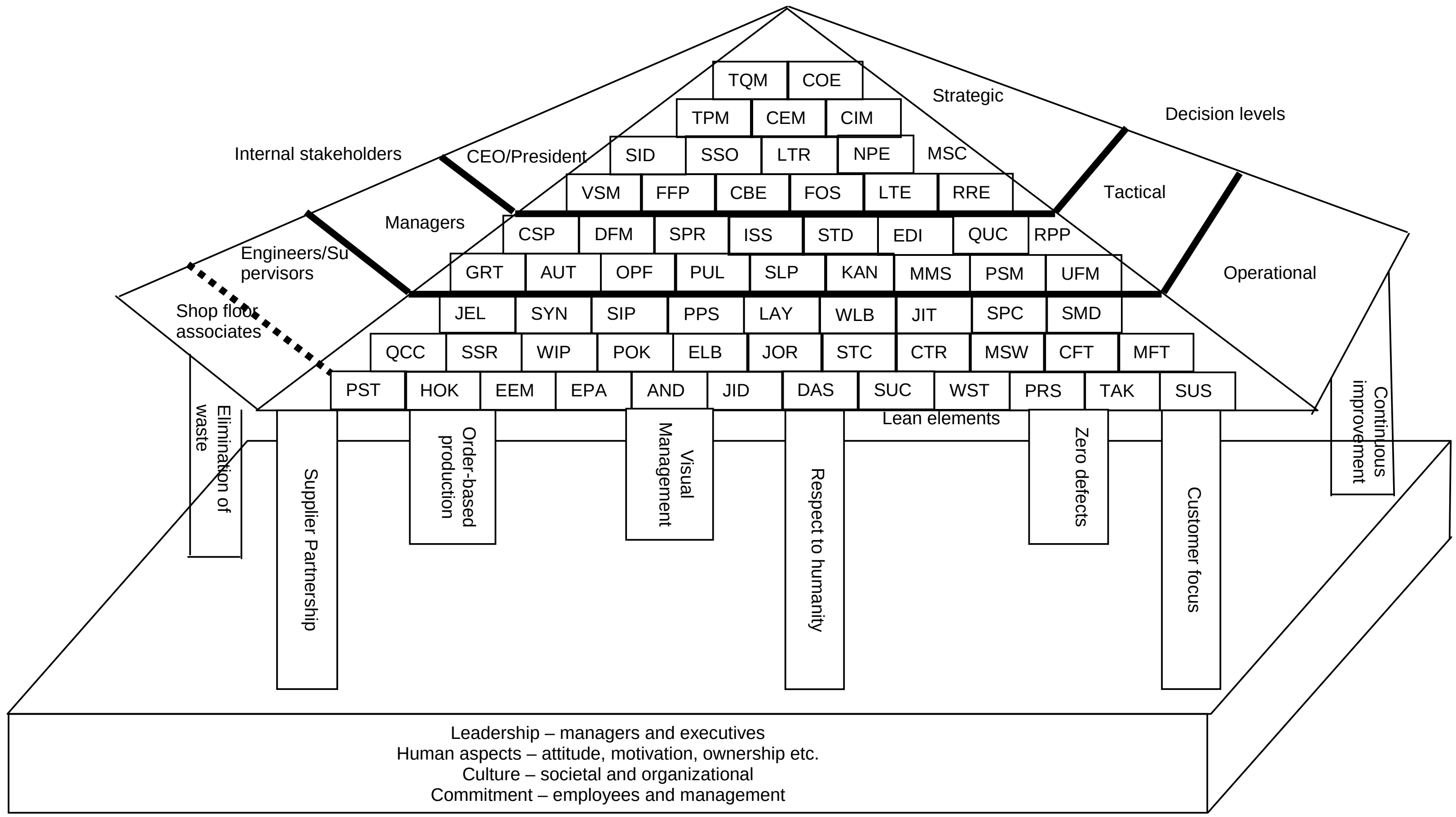

Figure 3.1: Proposed conceptual framework for LMS

PST – Use of problem solving tools HOK – House keeping (5S) EEM – Employee empowerment EPR – Employee participation AND – Andon (Warning lights) JID – Jidoka (Autonomation) DAS – Defect at source (self inspection) SUC – Successive checking WST – Work standardization PRS – Process sharing TAK – Takt time SUS – Suggestion schemes MFT – Multi functional training CFT – Cross-functional teams MSW – Multi-skilled workforce CTR – Cycle time and lead time reduction STC – Standardized containers JOR – Job rotation or flexible job responsibilities	ELB – Elimination of buffers POK – Pokayoke (Mistake proofing) or defect prevention WIP – WIP reduction SSR – Storage space reduction QCC – Quality circles JEL – Job enlargement or Nagara system SYN - Synchronization SIP – Safety improvement programs PPS – Product and process simplification LAY – Layout change or U shaped cell WLB – Workload or line balancing JIT – Just in time delivery (suppliers and within workstations) SPC – Statistical process control SMD – Single minute exchange of dies UFM – Use of flexible machines	PSM – Production smoothing (load leveling) MMS – Mixed model manufacturing/scheduling KAN – Kanban system SLP – Small lot production PUL – Pull production OPF – One piece flow AUT – Automation GRT – Group technology CSP – Commonization and standardization of parts DFM – Design for manufacturing SPR – Supplier proximity ISS – Information sharing with suppliers STD – Supplier training and development EDI – Use of Electronic data interchange with suppliers QUC – Quality certification (suppliers and self) RPP – Rolling Production Plan	VSM – Value stream mapping FFP – Focused factory production CBE – Communication between employees FOS – Flat organization structure LTE – Long term employment RRE – Rewards and recognition SID – Supplier involvement in design SSO – Sole sourcing or supplier reduction LTR – Long term supplier relationship NPE – New process or equipment technologies CEM – Cellular manufacturing TPM – Total productive maintenance TQM – Total quality management CIM – Computer integrated manufacturing (CAD/CAM/CAE) MSC – Maintain spare capacity COE – Concurrent Engineering

Figure 3.1: Proposed conceptual framework for LMS (Continued)

Leadership refers to the ability of managers or chief executives to guide the organization in the right direction both in business as well as in LM implementation. If there is no proper leadership, then there is a high chance that the sub-ordinates will easily oppose the changes and hence an organization cannot progress further in its change process. Similarly, commitment refers to both employee as well as that of managers during the implementation of LM. It is a known fact that whenever any new program or a change is brought out, there will always be a resistance from the employees. It takes quite some time for them to adapt to the changes in the organization. During these transformation period (which can generally vary between 6 months to 1.5 years), the results as shown in the literature may not be achievable. It requires commitment from both managers and employees to implement LM in a proper fashion and should achieve the desired results. Another prerequisite is the cultural and human aspects, which are closely related. Every organization has its own culture (unwritten norms and rules) which should be changed such that it does not hinder the LM implementation. For example, in many traditional organizations, if a machine require some minor repair during production, the operator tend to inform the supervisor, supervisor in turn inform operation's manager, while operations' manager inform the maintenance head and the maintenance head will inform his engineers to rectify the machines. But LM require the operator himself at least to clean, lubricate and check the process parameters apart from performing some basic repairs like tightening, change of threads, etc. However, to have such a cultural change, the human aspects such as attitude, motivation, ownership, etc. should be developed within the employees (engineers, shop floor associates and managers). Hence these elements – leadership, commitment, culture and human aspects have been placed as the foundation.

- **Pillars:** The pillars represent the principles based on which LM has been developed. The basic eight principles are small lot production, zero defects, elimination of waste, continuous improvement, customer focus, supplier partnership, respect for humanity and visual management. Though these pillars are shown separately in the figure, they are inter-related. Organization implementing LM should strive to eliminate the seven wastes through continuous improvement for achieving other principles such as zero defects and small lot production. Similarly, the organization should be more focused on customer to identify what they want and provide a high value in the form of product and services for the price they pay. This can happen only if the wastes are eliminated on a continuous basis for which the role of people and supplier are highly important. The suppliers and people play an important role in transforming an organization to become lean by utilizing their creativity and knowledge supported by various tools and techniques of LM. Thus, it can be found that these pillars are highly interrelated. Hence these pillars are placed over the foundations.

- **Decision levels:** Already in the previous section, the identified LM elements have been classified according to different perspectives. In this framework, the elements are again classified with respect to the decision levels in an organization. Any standard operations management book will provide details about the three decision levels (strategic, tactical and operational) in an organization and its characteristics. Among the identified LM elements, those elements which are predominantly implemented in shop floor generally fall under the category of operational decision level. For example, Jidoka – Autonomation (JID), successive check (SUC), layout change (LAY), etc. are activities that are carried out in shop floor and require the support of shop floor employees extensively. Further these elements/activities will be happening on a day to day or week to week basis in the shop floor and they do not require extensive planning. Similarly, some of the elements such as Automation (AUT), Group technology (GRT), Kanban (KAN), etc. require a good managerial support. Unless the initiatives for these elements are taken from the managerial side (i.e. the department heads), it will not be implemented properly in the organization. These elements are generally implemented on a monthly or quarterly or yearly basis. It requires a certain amount of lead time to implement and may require more investment than the operational elements. In the case of strategic level, most of these elements is dependent on the decisions of top management. For example, Concurrent Engineering, TQM, Long Term Employment (LTE), etc. fall under this category. Implementing these elements require a considerable time in years (about 3 to 5 years) apart from heavy investments. To implement these elements successfully, a strong management commitment is needed. Among the elements, many companies implement those elements listed in the bottom level (operation levels) and claim as lean manufacturer. On the other hand, some companies start off with kanban system and pull production without having other elements in place and fail in their attempts. Hence this framework can provide a better clarity to the practitioners to clearly understand the relationship between decision levels and elements of LM.

- **Role of stakeholders:** The proposed framework also depicts the relationship of various elements of LM with respect to the internal stakeholders of an organization – i.e. shop floor associates, engineers, managers and executives. One of the distinctive features of this framework is that, the operational level of an organization is considered to be composed of shop floor associates (operators) and engineers/supervisors. The framework clearly states which elements fall under the responsibility of which stakeholder. For example, the elements such as suggestion schemes (SUS), process sharing (PRS), etc. are responsibility of the operators. On the other hand, the elements such as layout change (LAY), single minute exchange of dies (SMD), etc are carried out by the supervisors/engineers with the support of operators. Elements such as Automation (AUT), Production Smoothing (PSM), etc. require the responsibility of managers, who will be guiding the team with their engineers. The top management which comprises of Chief Executive Officer (CEO), Presidents, Vice Presidents (VP) will be responsible for elements such as Long Term Relationship (LTR) with strategic suppliers, implementation of Computer Integrated Manufacturing (CIM) like use of CNC machines, CAD/CAM software and hardware tools etc.

3.2.6.1 Logic behind the proposed conceptual framework

The use of pyramid in the proposed model of LM is based on the 'Bottom Of the Pyramid (BOP)' concept proposed by Prahalad (2006). He states that "a huge opportunity for both local and global organizations lies in breaking this code - linking the poor and the rich across the world in a seamless market organized around the concept of sustainable growth and development". Furthermore, he explains that

> *"the real market opportunity here is not just the wealthy few in the developing world, but the vast number of aspiring poor who are joining the market economy for the first time. If we consider the global market as a pyramid, at the very top of the pyramid there exists a small fraction (as a percentage of global population) of customers corresponding to the affluent in developed countries such as the United States. However, the vast emerging consumer base is at the bottom of the pyramid, where 4 billion people reside. The per capita income in this tier is less than $1,500 per year. For well over a billion people, per capita income is less than a dollar per day. The vast majority of those in Tier 4 of the pyramid live in rural villages and urban slums and shantytowns. Educational levels are low to non-existent. These markets are hard to reach - from the point of view of distribution, credit, or communications. This market is often unorganized, local, and limited in quantity and quality of products and services available. Over the next 40 years, the numbers in Tier 4 could swell to 6 billion or more, since the bulk of the world's population growth is expected to come from this segment. Yet, much like the proverbial iceberg, where only the tip is in plain view, this*

massive tier of the World Pyramid has been largely invisible to the corporate sector."

Relating this concept to the decision pyramid of an organization, it can be found that 20% of the employees constituting the top management, managers and engineers are educated and remain at the top of the pyramid, while the rest 80% of the employees (foreman, shop floor associates and other support employees) are at the BOP, who are less educated and earn comparatively lesser than the top 20% of the employees. It is believed that the success of any organization is equally dependent on these 80% of the people in the BOP. Similarly, changing the organization culture or implementing any change management programs successfully depends on BOP. Hence adequate importance in the form of training, learning, etc. should be given to the employees at the BOP. Furthermore, an organization can be successful, if the top management can convince these BOP employees and buy their consensus in implementing the same. This approach has been clearly followed by inventors of TPS, even before the advent of the BOP concept. For instance, elements such as 5S, Andon, Jidoka, suggestion schemes, empowerment, quality circle team, etc. are directed towards the employees under the BOP.

Apart from this, one of the best examples for a stable structure is pyramid. The reason is that lean concepts and elements are considered to be stable. It has withstood the test of time and has shown drastic improvements in Toyota and other organization. Further to some extent, it can even improve the performance of a company temporarily, which has not fully implemented all these elements. But, on the other hand, if an organization is not following the basic principles of lean, but keep adapting one or few of the elements, then one can assume that organization can fail in the near future. Similarly, if an organization does not have any pre-requisites like good leadership, a participative culture and high commitment from managers and employees apart from a positive attitude, high motivation and sense of ownership, then also it will fail in the long run. Based on this argument, the stable structure of pyramid roof is placed over the unstable pillars, which is laid over the foundations.

3.2.6.2 Features and issues of the proposed conceptual framework

The proposed framework is compared with the existing frameworks and it was found that the proposed framework differs considerably. Following are the essential features of the proposed framework, which set it apart from the existing frameworks:

- This framework includes about 60 elements pertaining to LM which was identified from a detailed literature survey.
- Most of the reviewed frameworks contain majority of these elements identified in the proposed framework.
- It clearly distinguishes between pre-requisites, principles and elements (tools, techniques, procedures and practices).
- The framework provides a relationship between the various decision levels of an organization and the elements of LM in addition to the relationship between various stakeholders (internal) of the organization. This feature provides a better understanding for the managers/practitioners thereby eliminates the abstractness and help them view the degree of fit between the organization and elements of LM.
- The number of elements identified in the proposed framework is comparatively higher than the frameworks that were reviewed, which clearly increases its comprehensiveness.
- The framework is self-explanatory and one can easily understand the logic behind it.

On the other hand, the proposed framework suffers from the following drawbacks:

- Though in the proposed framework, about 60 elements have been identified to improve the comprehensiveness and abstractness, some of the elements might have been missed out. It is also supported by Weick (1979) who explained that it is impossible for a framework to be at the same time general, accurate, and simple.
- Similarly, the elements in the proposed framework were identified from a comprehensive literature search. However, the identified elements can be validated by conducting a survey to identify, which elements are more commonly used and which are least used.

The proposed framework addressed only the question of 'what constitute LM'. It fails to address the question of 'how to implement LM'. Hence in the next section, an implementation framework for LMS is described.

3.3 Development of a Implementation Framework for Lean Manufacturing Systems

A review of frameworks in Chapter 2 followed by the taxonomy established in Section 3.2.3 revealed that some of the implementation frameworks for LM are already available in the literature. The comparative analysis in Table 3.3 already revealed that the implementation frameworks neither described a step-by-step procedure of implementation nor they explained the sequence of implementing each and every element of LM. Furthermore, an attempt was made to identify whether any implementation framework has been used in the case studies describing LM. Already a review of papers dealing with the case studies describing LM implementation is carried out in Table 2.3 in Chapter 2. It was found that none of the case studies demonstrated the use of a 'step-by-step procedure' to implement LMS. Furthermore, the sequence of implementation seems to be highly varying and incoherent in each of these cases.

None of the case studies discussed about: what pre-requisites have to be completed before implementing certain elements of LMS. These findings support the hypothesis that there is no proper framework, which helps the managers in guiding and providing a right direction in implementing LMS. In order to fill up this research gap, an attempt has been made to develop an implementation framework for LMS.

The proposed implementation framework for LMS is shown in Figure 3.2. It is developed based on the LM elements that were identified to construct the ‘model’ shown in Figure 3.1, which described ‘what constitutes LMS’. Figure 3.2 shows that there are 10 levels in the implementation of LM. A brief description about each level is given below:

- Level 0 is called as ‘Evaluate stage’. It involves performing an initial assessment of the organization to understand the amount of wastes in the organization. This step can be carried out by an external consultant in LM along with the members of the top management, who can go around the factory and identify NVA activities and quantify the same into cost savings. This step will enable the top management to understand the problem in the organization in a language they understand – ‘money’ apart from ensuring necessary commitment from the top management.
- Level 1 called as ‘Prepare stage’ deals with preparing the organisation for LM implementation. In this stage, the announcement regarding LM implementation can be made to the entire organization including its suppliers to inform about the need for the organization to implement LM, benefits to be obtained apart from an assurance regarding job security and business to the employees and suppliers. Subsequently, a team comprising of members from different functions has to be formed, which will take the responsibility of implementing LM.

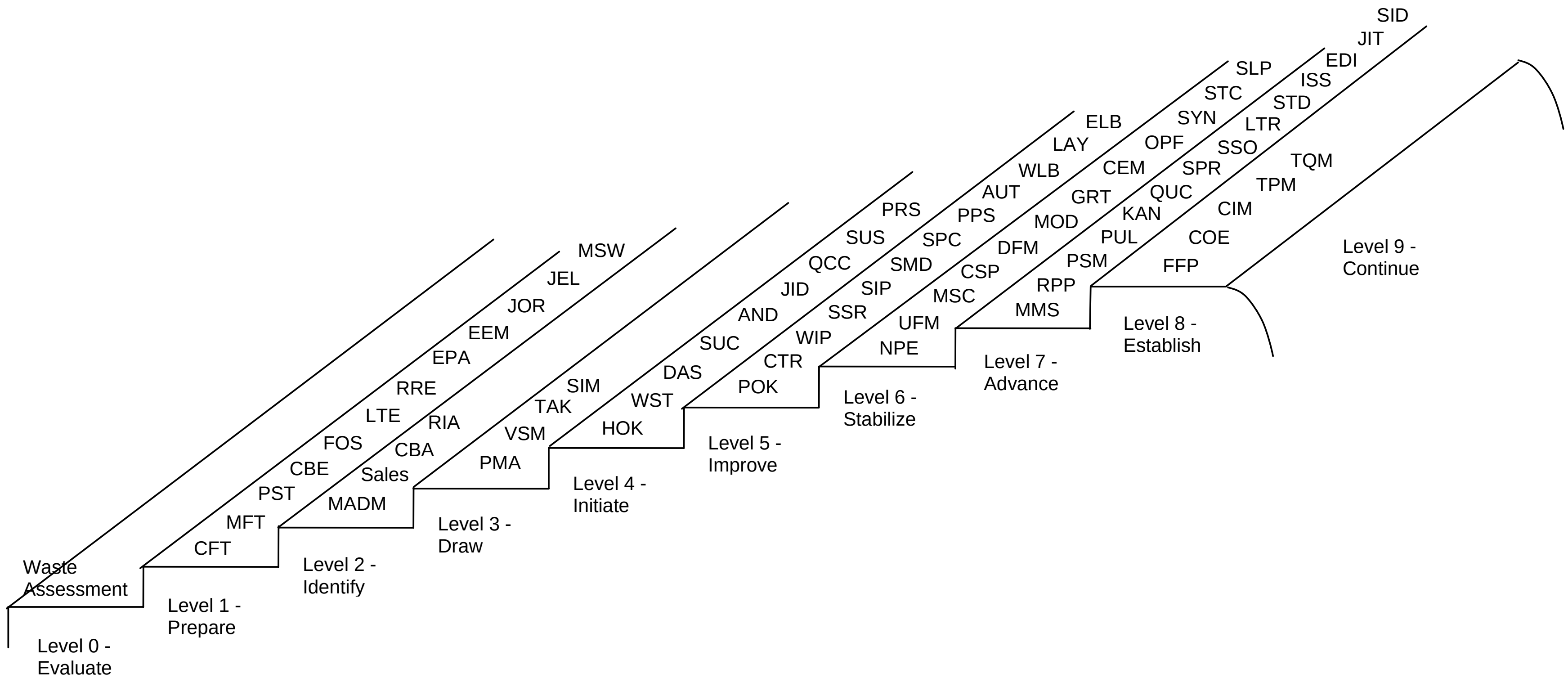

Figure 3.2: Proposed implementation framework for LMS

Once the team is identified, necessary training on LM is arranged for the Cross Functional Team (CFT) and the top management, while training on Problem Solving Tools (PST), team working, personality development, etc. can be provided to the employees in the BOP. The service of the external consultants can be used to provide training. In addition to the team formation and training, the top management is required to implement certain elements such as Communication Between Employees (CBE), Flat Organization Structure (FOS), Long Term Employment (LTE), Rewards and Recognition (RRE), Employee Empowerment (EEM), Employee Participation (EPA) etc., which gives necessary confidence to the employees in the BOP that LM is carried out only for improving the organization and not to rob off their jobs. Similarly, the shop floor associates are made to undergo Job Rotation (JOR) or provided with Job Enlargement (JEL) so that they become multi-skilled. Thus, these elements are considered to be a 'pre-requisites' for successful LM implementation.

- Level 2 is called as 'Identify stage'. It deals with the first tenet of LM – 'Define value'. The value can be defined by identifying the product, which is critical for the organization's survival. This product can be considered as the pilot project for implementing the LM process. The product, which is critical to the organization should be selected based on experience or by evaluating various factors (such as customer requirement, sales/demand, technology used, investments made etc.) using some decision making tools. For example, risk analysis or cost-benefit analysis or Multi-Attribute Decision Making (MADM) models such as Analytic Hierarchy Process (AHP) can be used for the same.
- Level 3 called as 'Draw stage' deals with the second tenet of LM – 'Identify the value stream'. Once the critical product is identified, the next step is to understand its existing manufacturing process. It is accomplished using a process flow chart or a simple flowchart. After mapping the manufacturing

process clearly, it is necessary to understand the complete flow of materials and information, apart from understanding the value added (VA) Non-Value Added (NVA) activities and Required Non-Value Added (RNVA) activities within the process. This can be accomplished by utilising Value Stream Mapping (VSM). VSM is of two types – the current state map and the future state map. During the mapping of current state, relevant data such as cycle time required at each stage, idle/waiting time, the preceding and subsequent operation/activity, number of operators, maintenance time, setup time, etc. are collected. Based on this information, different parameters such as takt time, process ratio or Value Stream Index (VSI) are calculated.

The next step is to draw the future state map, in which the team identifies potential areas of improvements and identifies the necessary LM tools to be implemented. They also estimate how much of wastes can be eliminated by quantifying the same in terms of savings in inventory, operation time, change over time etc. Based on the estimates, a new process ratio is found. This future state VSM acts as a blue print and provides direction for the managers in implementing the LM. Rother and Shook (1999) have discussed in detail about the development of VSM. Apart from this, many researchers such as Hines *et al.* (1999), Ozkan *et al.* (2005), Dhandapani *et al.* (2004), Emiliani and Stec (2004) described the application of VSM. Since VSM is just a snap shot of the shop floor on any particular day, it is considered as static in nature. Hence, researchers such as Detty and Yingling (2000), McDonald et al. (2002), Comm and Mathaisel (2005), Lian and Landeghem (2007) and Abdulmalek and Rajgopal (2007) have used VSM in conjunction with simulation to demonstrate how the organization will look, when it gets transformed by LM. It also provides information about, whether it is possible to implement various LM elements that were identified and helps to quantify what will be benefits, what will be improvement in performance?, etc.

- Level 4 called as 'Initiate stage' deals with the third tenet of LM – 'Create a flow'. It is in this stage, actual LM implementation starts. As described earlier, the LM tools that are directed towards employees (i.e. shop floor associates, supervisors, foreman etc.) in the BOP are implemented first. For instance, it is better to start with 'Housekeeping (HOK)' or 5S because it is easier to implement. Secondly, it improves the productivity and morale apart from providing the confidence to the employees that they are also part of the LM team. Other elements such as 'Work Standardization (WST)', 'Defect At Source (DAS)', 'Successive Check (SUC)' improves the quality and reduces the defect. Implementing these elements require only 'common sense'. On the other hand, elements such as 'Andon (AND)', 'Jidoka (JID)', 'Quality Circles (QCC)', 'Suggestion Schemes (SUS)' etc. requires some training. However, these training can be provided by the engineers and managers, who were already trained. Implementing these LM elements will enable the shop floor associates to find wastes in the manufacturing process. Once, they get used to it, it will become a habit or culture and they tend to identify many suggestions and improvements, which will improve the productivity. Even at this level, many organizations can report a increase in performance, when compared to their traditional way of functioning.

- Level 5 – 'Improve' stage is an extension of the previous stage. However, the elements listed in this stage require the support of both the shop floor associates and the engineers, as implementing some of the LM elements require technical and mathematical knowledge in addition to 'common sense'. Thus, it is required for the shop floor associates and engineers to work in a team. For instance, implementing 'Pokayoke (POK)', 'Single Minute Exchange of Dies (SMD)', ‘Statistical Process Control (SPC)’, ‘Automation (AUT)’, ‘Work Load Balancing (WLB)’, etc. can only be implemented with the support of engineers and shop floor associates. Implementing these LM elements requires training as it may involve changes in the way they are functioning currently. It should be remembered that the managers or departmental head should provide necessary resources, support and motivation to implement these LM elements, even if it results in losing some of the productive working hours. At the end of this level, the organization can see a significant reduction in the seven wastes apart from increase in the performance related to competitive priorities such as productivity, cost, quality, delivery, flexibility, morale, innovation, etc.

- Level 6 is referred as ‘Stabilize stage’, as the improvements that happened in the previous stage stabilize. In this stage, the role of shop floor associates is less however, the role of engineers and managers increases. Apart from implementing the LM elements dealing with the shop floor, it is also necessary to implement LM elements that are related to other areas in the organization. For example, the elements such as ‘Commonization and Standardization of parts (CSP)’, ‘Design for Manufacturing (DFM)’, Modularity (MOD)’, etc. deals with the design and development of products. Hence, the engineers and managers in the Research and Development (R&D) have to implement these elements for the existing products that are identified to provide the value, apart from incorporating it in other products. Similarly, LM elements dealing with production/industrial engineering have to be implemented. For instance, elements such as buying New Product Equipment (NPE), grouping similar products using Group Technology (GRT), forming working cells using Cellular Manufacturing (CEM) concepts, etc. have to be implemented by the industrial engineering team. Implementing these elements require sound engineering knowledge and analytical capabilities. Hence, these elements will be implemented only by the engineers with the support of managers and members of other supporting departments.

- Level 7 corresponds to the fourth tenet of LM – 'Let the customer pull'. In this stage, all advanced elements of LM are implemented. Hence it is called 'Advance stage'. For instance, elements such as Mixed Model Scheduling (MMS), Production Smoothing (PSM), Pull system (PUL), Kanban system (KAN) etc. will be implemented, which is heavily dependent on internal members such as R&D, Production Planning and Control (PPC) apart from the suppliers. In the case of suppliers, elements such as Sole Sourcing (SSO), Long Term Relationship (LTR) between suppliers, Use of Electronic Data Interchange (EDI), Supplier Training and Development (STD), etc. have to be implemented which also requires the support of both purchasing and quality department. It may require reducing the number of suppliers and identify suppliers who are nearer to the organization due to the concept of Supplier Proximity (SPR), which is a pre-requisite for establishing Just-In-Time (JIT) delivery. Similarly, Quality Certification (QUC), Information Sharing with Suppliers (ISS), etc is a must for suppliers, so that JIT delivery can be achieved. Only after implementing the above-said elements, other tools and techniques such as Kanban (KAN), Mixed model production and scheduling (MMS), etc. can be extended to the supplier end. Implementing these elements require a lot of resources and consumes more time. Hence, these elements are considered as advanced elements of LM.
- Level 8 – 'Establish' is an extension of the previous stage. Once the elements in the previous levels are implemented properly, it will be easy for the organization to establish any other advanced management philosophies such as TQM or TPM or Six Sigma. Since, the basic cultural changes among the

employees are brought about in Level 1 and Level 4; it will be easier to implement these philosophies organization-wide.

- Level 9 – ‘Continue’ refers to the last tenet of LM – ‘Pursue perfection’. It focuses on continuous improvement of the existing value stream apart from replicating the same on other value streams of the organization. Once, the pilot project is successful, it can be implemented across various plants of the organization. However, it should be remembered that a proper documentation of the implementation procedure, problems faced, solutions developed, etc. should be made, which will help in faster replication in other value streams or plants.

3.3.1 Features of the proposed implementation framework

Some of the significant features of the proposed implementation framework of LMS in comparison with the existing implementation frameworks are described below:

- A step-by-step procedure is provided for LM implementation. However, it should be noted that the proposed framework is not a ‘cook book’ as the proposed steps may not be uniformly applicable to all types of industries. Under each level, the LM elements, which are suitable for that particular type of organization can be selected and implemented, if necessary pre-requisite elements are already in place. For instance, not all companies can implement kanban system at both the shop-floor and at the supplier’s end. Similarly, it may not be possible to implement it in a company, which is highly integrated with Enterprise Resource Planning (ERP) software such as SAP, BaaN, Oracle, etc.
- **Abstractness**: It eliminates the abstractness, which is one of the major shortcomings in majority of the frameworks reviewed earlier. Furthermore, it clearly explains which element should be implemented in each level and under each tenet of LM, apart from describing the sequence of implementation. In

addition to this, it also identifies the pre-requisites for each level. Hence, it is believed that the degree of abstractness is improved.

- **Comprehensiveness**: The proposed implementation framework is based on the elements of LM identified earlier. Not many frameworks that are available in the literature deal with about 60 LM elements apart from explaining how it should be implemented. Hence, the degree of comprehensiveness is also high.

Thus, it is believed that some of the shortcomings of the existing frameworks have been eliminated.

3.4 Validation of the Proposed Frameworks

The proposed frameworks for LMS are conceptual and needs to be validated. It can be performed either through a clinical approach by deploying the framework in an organisation and studying its performance difference through case studies or by conducting a survey. In this case, a unique approach has been used. Pathak (2006), a student of MS Manufacturing Management degree programme offered by the Distance Learning Programmes Division (DLPD) of BITS, Pilani, has carried out his dissertation in a leading automotive component suppliers company in Maharashtra, India. He came to BITS, Pilani for the Viva-Voce examination, which provided the chance to collect data and other supporting information from his organisation to validate the frameworks. Before the case study is discussed, it must be clearly understood that the above-mentioned frameworks were not implemented in the case organisation. Similarly, every element that is listed in the proposed frameworks is not exactly followed by the company. Rather, many of the elements implemented by the case organisation are available in the proposed conceptual framework, while the logic of implementing various LM elements in the case organisation seems to be similar to the steps involved in the proposed implementation framework. In other words, the case study has been utilised to provide some real-life examples to support the proposed frameworks apart from verifying the assumptions and propositions.

3.4.1 Organisation details

To preserve the confidentiality, the auto component supplier is named as EFG Transmissions Limited (EFGTL). EFGTL is a member of the MNO Group, which manufactures precision machine components and various automotive components. The group employs about 500 people and have a turnover of about US $18 Million. In particular, EFGTL manufactures transmission gear & shaft, engine gears and pump gears. It also manufactures propeller shaft components & assemblies, manifold housing, oil cooler & covers for engines & transmission for the Original Equipment Manufacturers (OEMs) at its two plants. Since, the company has been in the market for last 10 years, it has established the state-of-art machining facilities for gears and precision machined components apart from employing CAD/CAM tools such as IDEAS, PRO-Engineer, Auto CAD and Solid Works for planning the manufacturing process, designing & manufacturing fixtures, etc. (Pathak, 2006).

3.4.2 Problems faced

Currently, EFGTL is manufacturing various types of gears ranging from 30 to 400 mm diameter, shafts up to 600mm length and sleeves up to 250 mm diameter. One of the leading automobile manufacturers in India has outsourced the production of front axle to two of its vendors, to ramp up their production from 60 Nos. to 250 Nos. per day. EFGTL is selected as one the suppliers for these parts and assemblies. After establishing a dedicated line and fine tuning the same, EFGTL could despatch about 78 Nos. of Front Assembly Beam (FAB) and 50 Nos. of beam and stub axle by working for two shifts a day. However, the dedicated line in EFGTL has been designed to produce 250 Nos. of

FAB, while the current level of productivity is only 40% approximately. Hence, the management was interested in improving the line and meet the demand requirements of the customer. They were more interested in implementing LM, because they could streamline their entire processes and reduce the defects with the implementation of quality systems. As a result, both plants of EFGTL have been awarded ISO 9000, QS9000 & TS 16949 certifications (Pathak, 2006).

3.4.3 Solutions – Implementation of lean manufacturing

As part of the LM implementation, a team was formed and they started off with understanding the manufacturing process. They found that only some of the major parts of the FAB assembly, namely, beam, eye, boss, front axle tube and stub axle LH and RH were manufactured in-house. Rest of the parts such as screws, pins, oil seals, nuts, bolts, washer, circlip, bearings, etc. were outsourced or bought directly from other suppliers located nearby. Apart from this, some of the parts are provided by the OEM supplier. In addition to this, the process sequences of the major parts of the FAB assembly were studied. After understanding the manufacturing process, a VSM is developed to identify the current status of production. However, due to space limitations, it is not shown here. As part of the VSM, takt time is calculated as follows: The total production requirement for various components such as eye, stub axle, bracket, etc. is 500 Nos./day. The plant is operating for 2 shifts, with an 8-hour morning shift and an 7-hour night shift. However, within this available time, two 5 minute tea breaks and a 20 minute lunch break are provided. Hence, the total time available is 870 minutes (450 + 420). The takt time is found to be 870/500 = 1.74 minutes or 104.4 seconds. However, the cycle times for making various components were high. Hence, they conducted a time study using video analysis to identify the areas for improvement. They found that lot of wastes is prevalent in the manufacturing processes. For instance, Table 3.6 shows the details of wastes within the machining, fabrication and assembly areas.

Table 3.6: Details of wastes within the machining, fabrication and assembly areas

S. No.	Loss or Idle hours factors	Cumulative loss in %
1.	Break down	40
2.	No material	24
3.	No power	5
4.	No tools and searching time	8
5.	Setting time	5
6.	Kaizen training	15
7.	Loading and unloading time	3

Hence, to eliminate these wastes, the team attempted to implement the following LM elements:

- **5S:** As evident from Table 3.6, it was found that 8% of the total time is spent on searching for tools. Some times, the tools were not available or it was misplaced. Hence, the operator has to wait till the tool is returned by another operator or he has to search from the pile of tools lying over the table. The reason for the same is that, the tools are placed on a table and it was shared between two workstations in the assembly line. To overcome this problem, 5S or housekeeping techniques were implemented. A dedicated trolley with necessary tools for that particular workstation was provided. Hence, the wastes associated with searching for tools or operator movement to fetch tools from other workstations was avoided.
- **Autonomous maintenance:** Since many machines in the machining area are purchased second hand, the breakdowns of these machines were higher due to wear and tear. Hence, to overcome this problem, the operators were made responsible to perform basic maintenance activities such as lubrication, inspection for leakage, tightness in joints, cleaning of the machine and monitoring of the process parameters. These initiatives reduced the breakdown time only to certain extent. However, to eliminate and reduce the breakdown

times, the maintenance department was entrusted with the responsibility of establishing preventive maintenance activities such as scheduled maintenance.

- **Standard containers:** Earlier in the assembly section, the front axle has to be loaded from a pallet as shown in Figure 3.3a. Each time, the operator has to bend and lift the front axle for further assembly. Since, the front axle is quite heavy, frequent loading and unloading resulted in operator's fatigue. Naturally, the productivity got reduced. In addition to this, a fork lift has to be used to move the pallet to the despatch area, where it has to be lifted to be loaded into the truck. All these activities were time consuming. Hence, as a solution, the engineers developed a standard container in the form of a trolley as shown in Figure 3.3b. This trolley can hold a fixed quantity of parts of about 50 Nos., which can be sent to the customer directly by loading it easily on the truck. Additional equipments such as fork lift were avoided as the trolley can be moved without much effort. Apart from this, they also bought various bins to store materials such as eye, bracket, etc. in standard quantities as shown in Figure 3.3c. Such improvement not only reduced the operator fatigue and improved the productivity, but also played a major role in controlling the inventory.

- **Layout change:** When the engineers studied the material movement in the fabrication shop, they found that there were a lot of zig-zag movements. The raw material was entering from one side and the finished product was leaving from the opposite side. Seven gravity conveyors, six trolleys and one stand were used for the material movements, apart from the seven operators, who were involved in the manufacturing activities. To eliminate the transportation waste, a U-shaped layout was designed in such as way that both material entry and exit happen at one location. Furthermore, it reduced the number of operators from 7 to 5 due to reduced movements and also brought down the number of gravity conveyors from 7 to 3 and the trolleys from 6 to 3. The area occupied was also reduced from 63.25 sq. m. to 48 sq. m. Figure 3.4a shows the layout before LM implementation in the fabrication line, while Figure 3.4b shows the layout after LM implementation.

- **Process improvements:** Since the machines were older, the time taken for certain process was higher. To overcome this problem, the top management replaced the old machines with new ones. For instance, in the fabrication section, to perform the cotter pin drilling operation, a new Vertical Machining Centre was bought, which reduced the cycle time significantly. Apart from this, they modified the fixtures to hold the axle assembly. Initially, they used a fixture, which had only one holding point and used a screw arrangement for tightening. This consumed significant time as the screwing activity was considered to be a NVA activity. Hence, instead of screw holder, a spring loaded holders was used to firmly hold the part. Figure 3.5 shows the fixture improvements carried out in the fabrication line.

A closer look at the LM implementation will reveal that after the VSM, the team implemented the following elements, such as 5S, autonomous maintenance, use of standard containers, etc. which can be implemented by shop floor associates. Once they were successful, they proceeded to implement other LM elements such as process improvements and layout changes. These elements were implemented by the engineers with the support of operators. Thus, these sequences support the stages proposed in the implementation framework for LMS.

Before

Figure 3.3a: Pallet to hold front axles

(Source: Pathak, 2006)

Figure 3.3b: Trolley as a standard container for holding front axles

(Source: Pathak, 2006)

After

Figure 3.3c: Use of standard bins for other parts

(Source: Pathak, 2006)

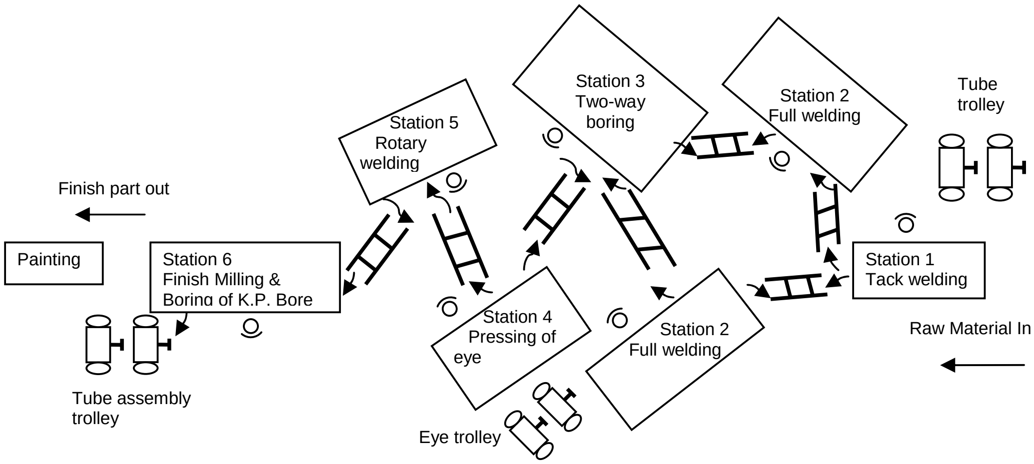

Figure 3.4a: Layout before LM implementation in the fabrication line (Source: Pathak, 2006)

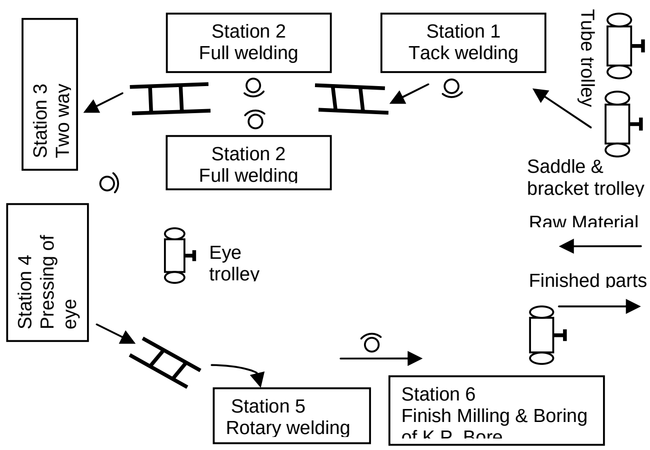

Figure 3.4b: Layout after LM implementation in the fabrication line (Source: Pathak, 2006)

Before LM

After LM

Figure 3.5: Fixture improvements carried out in the fabrication line (Source: Pathak, 2006)

The team started the LM implementation from Level 3 and then implemented other elements in Level 4 and Level 5. Similarly, the LM elements, which are implemented by the case organisation is also present in the proposed conceptual and implementation frameworks. Since, the case organisation has just started off with the LM implementation; other LM elements such as Single Minute Exchange of Dies (SMED), Kanban, Pull system and other supplier related elements in remaining levels of the proposed implementation framework are not yet implemented. However, it might be taken up in the near future and will be implemented soon. Thus, it can be concluded that the case organisation is in the right track to become lean manufacturer, if it implements most of the LM elements, if not all from the proposed frameworks.

3.5 Conclusions

This chapter started with a claim that one of the reasons for not achieving the true benefits of LM by the organization is that the managers and employees do not understand clearly what constitute LM. Hence, to facilitate a better understanding of LM, it was felt that frameworks providing comprehensive information about ‘what constitutes LMS’ and ‘how to implement LMS’ are required. To accomplish this, a brief review of existing LM frameworks was carried out, which resulted in collection of about 30 frameworks. Even though, many frameworks were available, the reasoning of managers not able to understand about LM is an irony. Hence, it was felt that the existing frameworks suffer from various shortcomings. To identify the shortcomings, an in-depth analysis of these frameworks was carried out, during which they were classified as ‘design/conceptual frameworks’ and ‘implementation frameworks’. A cursory analysis revealed that a large number of frameworks fall under the scheme of ‘design/conceptual frameworks’, when compared to the category of ‘implementation frameworks’. Apart from this grouping, the frameworks were also classified into academic/research based, consultant/expert based and organization based frameworks.

It was found that there are more academic/research based frameworks than the frameworks that are more practical and real-life based ones. In addition to these taxonomies, a comparative analysis was carried out, which revealed the following shortcomings: none of the frameworks listed out the important LM elements. Similarly, some of the frameworks were highly abstract or superficial and did not discuss what sequence should be followed in implementing the LM elements.

Hence, as a first step to overcome the shortcomings of the framework in category of 'design/conceptual frameworks', tools, techniques, practices and procedures listed in various research papers and authoritative books on LM were identified by conducting a frequency analysis. At the end of this analysis, around 65 elements of LM were identified, out of which some are considered as principles, some are considered as tools and techniques, while some are practices. Similarly, it was found that some elements can be implemented by the shop-floor associates, while some elements require the support of top management. It was also found that some elements have to be implemented by product design department, while some elements need to be implemented by the purchasing department. However, till date, none of the papers in the realm of LM discussed about these issues. Hence various taxonomies were established for the identified LM elements based on the above perspectives. Another aspect is that these elements cannot be implemented or adopted in a standalone fashion rather a unifying or integrating structure called framework is required. So, a new framework for LMS is proposed, which can be classified under the category of 'design/conceptual frameworks' as per the first categorization scheme, while it can be placed under the category of academic/research based frameworks as per the second categorization scheme. A detailed account of the proposed framework and its features is also provided

Similarly, a framework for implementation of LMS is developed by considering the framework proposed under the category of 'design/conceptual frameworks' as the reference. It provided a step-by-step approach for transforming an organization to become a lean manufacturer. It consists of 10 levels and in each level, the activities that are to be carried out are briefly explained apart from explaining the sequence of implementation of various LM elements. To validate the above mentioned frameworks, a case study of an organisation that is implementing LM was presented. It can be found that most of the elements implemented by the organisation were present in the proposed LM frameworks. Another aspect is that, the sequence presented in the framework for implementation of LMS seems to be matching with the implementation procedure of the case organisation. It should be understood here that all the steps and elements in the proposed frameworks were not followed/implemented by the case organisation, because, they have just started off with the LM implementation. However, it was felt that the proposed frameworks will provide the practitioners with necessary guidelines to improve their manufacturing system and reap the benefits of lean philosophy.

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Chapter 4

Development of a Performance Measurement System for Lean Manufacturing Systems

4.1 Introduction

In recent years, many organisations – be it small-, medium- or large-scale organisations have attempted to become world-class manufacturers by transforming their organisations through principles and philosophies such as Total Quality Management (TQM), Theory of Constraints (TOC), Total Productive Maintenance (TPM), etc. A plethora of study exists that describes the performance improvements of various companies that have undergone such transformations. For instance, McAdam and Bannister (2001) studied a Performance Measurement (PM) framework that measures the impact of the TQM philosophy on fundamental measures of business performance. They undertook a case study approach in an organisation and compared the results of a survey with the business results of the company and found that TQM has had a worthwhile impact. On the other hand, in many transforming organisations, managers tend to feel that they have not achieved the desired benefits after the initial implementation. For instance, Chand and Shirvani (2000) conducted an investigation in collaboration with a first-tier automotive component supplier to determine the Overall Equipment Effectiveness (OEE) of a semi-automated assembly cell in which TPM is implemented. They found that OEE was only 62%, which when compared with the results of world-class performance clearly revealed a lot of gaps.

One of the reasons for such a situation can be attributed to the improper understanding of perceived benefits from proceeding with Performance Measurement Systems (PMS) and its metrics (Bourne *et al*., 2002). Another reason is that many organisations, even after transforming their existing manufacturing systems tend to stick with their traditional way of measurement (financial measures), which prevents them from seeing the desired benefits. According to Tangen (2004), numerous researchers have discussed the limitations of the traditional approach of PM and the problems associated with it. To resolve these issues, many researchers have stressed that both the PMS and its corresponding metrics should evolve in response to the changes happening in the manufacturing systems. Hence, they proposed different PMS and metrics for each of the change management initiatives such as TQM, TPM, TOC, etc. For instance, Gunasekaran *et al*. (2004) have analysed the need for performance measures and metrics for Supply Chain Management (SCM) and proposed a framework for the same. Similarly, Lockamy and Spencer (1998) have studied about performance measurement in a TOC environment. But, until now, there is no paper available in the literature that provides a comprehensive discussion regarding the performance measurement and metrics for organisations that has implemented a Lean Manufacturing System (LMS). Thus, this chapter attempt to fill the gap and provide answers for the following questions:

- What is the current status of PMS and performance measures?
- What are the performance measures that need to be considered in a PMS for organisations that has implemented LMS?
- What is the relationship between the performance measures, competitive priorities, organisation's business processes and the elements of LM?
- How can a comprehensive PMS for LMS be applied in a Small- and Medium-sized Enterprise (SME)?

4.2 Development of a Performance Measurement System for Lean Manufacturing Systems

The literature pertaining to the field of PMS and metrics is very vast and a lot of review papers are already available. Elaborate reviews have been carried out in recent years by Neely *et al*. (2005), Gomes *et al*. (2004) and Marr and Schuma (2003), to name a few. Hence, in this review, only a brief theoretical background about PM is presented. Bourne *et al*. (2002) investigated the success and failure of PMS design interventions by studying around ten companies and concluded that there are two main perceived drivers for the implementation of the PMS (out of a list of five, which includes the benefits of performance measurement, continued top management support, time and effort required, consequence of the activities of the internal or external facilitator and juxtaposition of the PM intervention with other projects) and four perceived factors that block implementation (which include difficulties with data access and information technology systems, time and effort required, difficulties concerned with developing appropriate measures and the personal consequences of PM). Kennerley and Neely (2002) asserted that organisations should have systematic processes in place to manage the evolution of their PMS to ensure that they continue to reflect the organisation's context. Amaratunga and Baldry (2002) emphasised that in order for an organisation to make effective use of the results of performance measurement, it must be able to make the transition from measurement to management. Bourne *et al*. (2000) noted that the recent academic literature and practitioner activities are more focused only on the early stages of the development of the PMS – i.e., development of the conceptual frameworks and processes for designing the performance measures. Hence, they addressed those issues that arise when designing, implementing, using and continuously updating PMS in manufacturing companies. They noted that the development of PMS can be divided into following three main phases:

1. design of the performance measures

2. implementation of the performance measures

3. use and update of the performance measures

These three main phases and the associated steps proposed by Bourne *et al*. (2000) will be used to design and develop the conceptual PMS for LMS. To supplement the theoretical aspects, necessary literature support will be used to bolster the arguments developed during these three phases apart from providing the answer to the first research question – 'what is the current status of PMS and performance measures?'

4.2.1 Design of the performance measures for lean manufacturing systems

This phase consists of two steps. The first step is to identify the key objectives. In this case, the key objective is to develop the performance measures for organisation which is planning to implement or have already implemented LM. The second step is to design the measures. This step will provide the answer to the second research question – 'what are the metrics that need to be considered in a PMS for organisations operating under a LM environment?' Neely *et al*. (1997) expressed that one of the key questions that has to be considered in the development of PMS is 'how specific measures of performance should be designed?' They hinted that designing a performance measure involves much more than simply specifying a robust formula. It includes a variety of factors such as the purpose of the measure, the frequency of measurement, the source of data, etc. They also cautioned that inadequately designed performance measures can result in dysfunctional behaviour. Gomes *et al*. (2006) have shed some light on the current practices of manufacturing PM with a focus on the nature and scope of measures, which the executives tend to use and view to be relevant in their evaluation of manufacturing performance. They studied the PM practices in terms of utilisation, relevance and availability of information for 63 performance measures from a sample of 92 Portuguese manufacturing executives and concluded that there is an underutilisation of measures related to management effectiveness, labour-management relations, innovation, safety, workforce development, natural environment and social responsibility and community. They also explained that the underutilisation of such non-financial measures is by no means unique to the Portuguese manufacturing environment; rather, they are indicative of a general pattern found across different manufacturing cultural settings. On the other hand, Kasul and Motwani (1996) identified and interpreted the performance measures cited in literature and proposed a strategic model of performance measures for WCM. They used a judgemental process for grouping similar world-class organisation requirements and classified those requirements into nine separate categories or factors. Using a similar approach, the performance measures of LMS were identified based on a frequency analysis of the existing literature dealing with the performance measures of LM for designing the performance measures of LMS.

4.2.1.1 Frequency analysis for design of the performance measures of lean manufacturing systems

Pandya and Boyd (1995) studied the financial gains obtained in organisations that have implemented some of the strategies of Japanese manufacturers (i.e., Just-In-Time (JIT)) in UK, using an empirical analysis. Burcher *et al*. (1996) proposed a methodology to assist repetitive batch manufacturers in the adoption of certain aspects of the lean production principles and assessed the organisation based on limited number of performance measures namely, inventory, batch size, and setup time. But until now, no paper is available, which provide a comprehensive listing of performance measures for LM. However, LM has been evolving since its inception. Hines *et al*. (2004) traced the history of LM and discussed its evolution from 1980 to 2000. They explained that it has evolved from focusing on manufacturing and shop floor to various integrated processes, such as order fulfilment and new product development. It was also supported by Karlsson and Åhlström (1996) who insisted that lean ranges from an organisation's product development to its distributional logistics. Under such a situation, it is imperative to understand the performance measures of lean organisations from a broader perspective – i.e., from the perspective of lean enterprise. To accomplish this, a comparative analysis of the existing literature of LM is carried out. A similar approach was utilised by White (1996) to develop the taxonomy for categorising strategy-related manufacturing performance measures. They proposed a framework, which suggested how the taxonomy can be used in selecting strategy related performance measures, either by companies which want to accurately measure manufacturing performance relative to their competitive strategy, or by the researchers who seek to gauge manufacturing performance as part of their manufacturing strategy research. By adapting a similar approach, around 35 papers related to LM are reviewed, from which the performance measures are identified and compared to find which of the measures were more commonly used and which of them were least used. This analysis revealed around 280 elements. Table 4.1 shows the frequency analysis for the design of performance measures of LMS.

A cursory review of the identified elements showed that some of them were very abstract while some represented the LM practices. For example (see Table 4.1), the elements such as ‘labour relations’, ‘task identity’, etc., are very abstract, while elements such as ‘use of bar-coded containers’, ‘order processing’, ‘advance shipping notice’, etc., are examples of LM practices. Such abstract elements and practices were neglected resulting in the elimination of about 80 elements. Some of the remaining elements were highlighted by just one or two authors and the frequency of occurrence of such elements was found to be just 5.8%. Hence, these elements were not considered, which resulted in the elimination of another 110 elements. Some of the remaining elements were very similar. For example, ‘increase in quality’ can be related to the ‘scrap and rework cost’ or ‘number of customer returns’. Hence, such measures were combined into one. Apart from this, some of the performance measures such as number of informative top management meetings with employees, reserve capacity, inventory maintained at customer sites, etc., were left out, even though they were valid. This is due to the fact that Bourne *et al*. (2000) have emphasised that the number of performance measures should be restricted. If we attempt to group all those valid performance measures, then the number of measures may increase up to 140, making it more complicated. From the frequency analysis, some significant findings were made. The most commonly highlighted performance measure is 'work in progress inventory' with a frequency percentage of about 72%, which undermines the fact that researchers and practitioners still consider LM or JIT as an inventory reduction mechanism. Similarly, many authoritative books on JIT or LM such as Korgaonker (1992) and Monden (1983) emphasised that calculating the number of kanbans will help in identifying the inventory level of an organisation. But surprisingly, the analysis revealed that only a very few authors have highlighted 'number of kanbans' as an important measure. The top five performance measures of LM identified from this analysis are: WIP inventory (72%), setup time (67%), customer lead time (50%), finished goods inventory (47%) and batch sizes (42%), which are consistent with the main objective of LM – 'elimination of waste and adding value'. After three rounds of elimination, about 90 performance measures were left out, which were considered for developing the PMS for the LM environment. The consolidated list of performance measures for LMS is shown in Table 4.2.

Table 4.1: Frequency analysis for the design of performance measures for LMS

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al.* (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al.* (2003)	Koh *et al.* (2004)	Sohal (1996)	McDonald *et al.* (2002)	Worley and Doolen (2006)	Arbulu *et al.* (2003)	Sullivan *et al.* (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al.* (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al.* (1997)	Taj (2005)	Burcher *et al.* (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al.* (2002)	Christiansen *et al.* (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
1.	Scrap and rework costs or Value of scrap and rework in relation to sales or reduced/less scrap/Cost of defects	*		*			*		*				*					*			*	*								*			*				10	27.8
2.	Manufacturing cycle time or short cycle time or reduction in cycle time or Processing time	*								*		*			*		*	*		*			*		*				*		*		*			*	13	36.1
3.	First Pass Yield or increased quality/reduction of rejects of finished goods/Scrap rate or Part quality	*						*	*			*							*				*		*					*	*		*		*	*	12	33.3
4.	Labour productivity/efficiency	*		*	*				*	*										*				*	*				*					*	*	*	12	33.3
5.	Unit manufacturing cost or manufacturing cost	*									*		*							*													*				5	13.9
6.	Customer lead time or lead time of customers orders or delivery lead time/lead time or sales lead time or Amount of time spent processing each order	*		*			*					*	*				*		*		*	*	*	*	*				*	*	*		*		*	*	18	50.0
7.	Time spent on engineering changes or Engineering hours												*								*														*		3	8.3
8.	Number of engineering changes																				*																1	2.8
9.	Number of total parts in bill of materials												*												*						*				*		4	11.1
10.	Work in process inventory (days, hours, months etc.)/Amount of work in progress/Reduced work in progress/Amount of buffer		*	*	*	*		*	*			*	*	*	*	*		*			*	*	*	*	*	*		*		*	*	*	*		*	*	25	69.4

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al.* (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al.* (2003)	Koh *et al.* (2004)	Sohal (1996)	McDonald *et al.* (2002)	Worley and Doolen (2006)	Arbulu *et al.* (2003)	Sullivan *et al.* (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al.* (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al.* (1997)	Taj (2005)	Burcher *et al.* (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al.* (2002)	Christiansen *et al.* (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
	stocks																																					
11.	Value of work in progress in relation to sales/Cost of work in progress inventory						*											*										*		*							4	11.1
12.	Finished goods inventory (days, hours, months etc.)/Amount of inventory or reduction in inventory		*	*	*			*	*			*				*			*					*	*			*	*		*	*	*		*	*	17	47.2
13.	Number of kanbans														*										*	*					*						4	11.1
14.	Improvement in return on assets											*																									1	2.78
15.	Reduction in setup time (Setup time reduction effort)/Amount of time needed for die changes Reduction in changeovers or minimization of setup time/Reducing the number of setups/Changeover time/Average overall setup time		*				*			*		*	*	*	*		*	*	*	*	*		*	*	*		*	*	*	*	*	*	*		*	*	24	66.7
16.	Rate of customer returns or sales return or Customer reject rate		*					*					*																				*				4	11.1
17.	Stock turns or Number of inventory rotations or increase in inventory turnover			*			*	*	*	*				*								*		*				*				*		*	*		12	33.3
18.	Production capacity per month/Improved capacity of current facilities or Target operating capacity for machines			*								*								*					*			*									5	13.9
19.	Production or delivery or purchased lot sizes or batch size (Reduced) or Small batches			*			*		*						*					*	*	*	*		*		*		*	*	*					*	14	38.9

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
20.	Value added time or Value added per employee			*											*		*	*				*	*										*				7	19.4
21.	Non value added time/Reduction in non-value added activities/Idle time due to line imbalance/Wait or Queue time			*	*												*								*				*								5	13.9
22.	Number of suggestions or no. of suggestions per employee per year				*		*							*																*		*					5	13.9
23.	Reduction in direct labour/Reduced labour requirement or Reduction in labour cost				*				*														*														3	8.3
24.	Improvements in direct labour utilization											*											*														2	5.6
25.	Improvements in indirect labour utilization											*											*														2	5.6
26.	Reduced paper work								*																		*										2	5.6
27.	Reduced equipment breakdown time or Percentage of time machines are standing due to malfunction or Percentage of unscheduled downtime or low equipment failure or wait time or percentage of uptime or Number of hours machines are standing due to mal function in relation to total machine time				*		*		*		*						*				*		*		*			*		*				*			11	30.6
28.	Reduction in floor space or Reduction is space requirement/Total Productive floor space (in m^2) or Total space in storage and material handling				*			*	*			*		*	*						*		*	*				*	*		*						12	33.3

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
29.	Throughput time or reduction in production lead time or manufacturing lead time								*				*	*	*			*	*		*	*	*	*	*				*				*		*		14	38.9
30.	Reduction in indirect labour								*			*								*																	3	8.3
31.	Reduction in overtime																								*									*			2	5.6
32.	Takt time														*								*								*						3	8.3
33.	Number of flexible workers or skilled workers or multi skilled workers or labour flexibility or Percentage of employees cross trained to perform three or more					*				*	*					*			*	*	*	*	*		*											*	11	30.6
34.	Reduction in plant investment or Reduction in overall cost/Investment commitment										*													*	*												3	8.3
35.	Autonomy					*																															1	2.8
36.	Motivation or motivation for pride of workmanship, quality awards and rewards or improved worker motivation/Compensation policies					*		*	*	*						*												*				*					7	19.4
37.	Job satisfaction					*																															1	2.8
38.	Employee commitment					*																															1	2.8
39.	Job-related strain					*																															1	2.8
40.	Work content/Reduction in the levels of work load variability					*													*																		2	5.6
41.	Labour relations					*																															1	2.8
42.	Work environment conditions					*																															1	2.8
43.	Coordination and collaboration between employees					*																															1	2.8
44.	Technical uncertainty					*																															1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
45.	Degree of coercion					*																															1	2.8
46.	Task identity					*																															1	2.8
47.	Task significance					*																															1	2.8
48.	Feedback					*																															1	2.8
49.	Percentage of common or standardized parts						*										*				*				*										*		5	13.9
50.	Shipping distance or Number of times and distance parts are transported or shipping miles/Reduction in move time/Distance between the supplier and manufacturer						*				*						*							*	*	*	*	*	*	*	*	*					12	33.3
51.	Percentage of preventive maintenance over total maintenance or Predictive and Preventive maintenance coverage						*				*																							*			3	8.3
52.	Percentage of implemented suggestions						*																							*							2	5.6
53.	Savings and/or benefits from the suggestions						*																														1	2.8
54.	Percentage of inspection carried out by autonomous defect control/Workers identify defective parts and stop the line						*													*										*							3	8.3
55.	Percentage of defective parts adjusted by production line workers/requiring rework / Defective products in ppm require rework or scrap/Reduction in defects/Number of defects or In plant defect fallout rate						*	*			*	*	*					*				*						*	*	*			*				11	30.6

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
56.	Improvement in quality											*			*				*				*								*	*	*			*	8	22.2
57.	Number of teams/Number of quality circles or Number of trained multi-functional teams													*								*								*		*				*	5	13.9
58.	Number of people dedicated directly to quality control or Amount of responsibility for quality given to operators						*																							*		*					3	8.3
59.	Percentage of employees working in team or Percentage of employees involved in two or more teams increased teamwork or Percentage of personnel are active members of formal work teams, quality teams or problem-solving teams					*	*	*	*																			*		*							6	16.7
60.	Number and percentage of tasks performed by the teams						*																							*							2	5.6
61.	Percentage of employees rotating tasks within the company						*																														1	2.8
62.	Average frequency of task rotation						*																							*							2	5.6
63.	Percentage of team leaders elected by their own team co-workers						*																														1	2.8
64.	Percentage of parts delivered just in time by suppliers or Percentage of parts delivered directly to the point of use without incoming inspection or storage or lots are delivered just-in-time or Supplier readiness						*				*									*	*							*		*					*		7	19.4

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
65.	Level of integration between suppliers delivery and the company's production information systems						*														*					*	*										4	11.1
66.	Percentage of parts delivered just in time between sections in the production line or Percentage of Work in Progress (WIP) flows directly from one operation to next without intermediate storage or Type specific deliveries just-in-						*																					*		*							3	8.3
67.	Percentage of parts co-designed with suppliers						*										*									*	*										4	11.1
68.	Number of suggestions made to suppliers or Frequency of meetings or communications with the manufacturers						*										*									*	*										4	11.1
69.	The frequency with which suppliers technicians visit the company						*																			*											2	5.6
70.	The frequency with which company's suppliers are visited by technicians						*																			*											2	5.6
71.	Percentage of documents exchanged with suppliers through electronic data interchange or intranets						*																			*											2	5.6
72.	Average length contract with the most important suppliers						*																				*										2	5.6
73.	Average number of suppliers for the most important parts or Dependable rapid suppliers or Are we working with key vendors?						*			*											*																3	8.3

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
74.	Frequency with which information is given to employees						*																							*							2	5.6
75.	Number of informative top management meetings with employees						*																														1	2.8
76.	Percentage of procedures which are written or recorded or documented in the company or Number of Standard Operating procedures (SOP) and regulations					*	*																	*												*	4	11.1
77.	Percentage of production equipment that is computer integrated or Automation or Amount of automation						*			*										*																	3	8.3
78.	Number of decisions employee accomplish without supervisory control						*																														1	2.8
79.	Number of customer complaints												*																								1	2.8
80.	Time spent working with suppliers to improve quality or Supplier Training												*														*										2	5.6
81.	Time spent by plant management staff to quality improvement or Percentage of employees having basic Statistical Process Control (SPC) trainings												*															*									2	5.6
82.	Number of suppliers/Reduction in number of suppliers/Average number of suppliers for each raw material or part												*			*			*		*						*	*				*					7	19.4
83.	Length of product runs/Product on batch or production runs between setups												*	*																*	*						4	11.1

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al.* (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al.* (2003)	Koh *et al.* (2004)	Sohal (1996)	McDonald *et al.* (2002)	Worley and Doolen (2006)	Arbulu *et al.* (2003)	Sullivan *et al.* (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al.* (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al.* (1997)	Taj (2005)	Burcher *et al.* (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al.* (2002)	Christiansen *et al.* (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
84.	Supplier lead time/Inconsistent supplier lead time/Speed of delivery/Delivery lead time/Reduction in delivery time or Supplier punctuality										*				*				*		*		*		*								*		*	*	9	25.0
85.	Gross annual profit (in million Euros) or increased profit margin/Gross profit margin/Profit after tax or Economic Value Added (EVA) operating profit-taxes-cost of capital)					*		*	*							*		*		*				*					*								8	22.2
86.	Total sales or sales or Sales growth							*						*					*					*								*					5	13.9
87.	Annual turnover																										*										1	2.8
88.	On time delivery in percentage/ On-time staging in percentage /On time delivery requirements or Supplier reliability							*			*	*	*		*					*	*					*	*	*					*		*	*	13	36.1
89.	Number of employees or Minimal number of manpower or Reduction in headcount							*						*	*				*	*			*	*	*						*	*					10	27.8
90.	New product development lead time or product development time or engineering hours or Time to market for new products							*					*	*										*					*				*		*		7	19.4
91.	Number of new products introduced/Product variety													*		*				*	*			*					*			*	*				8	22.2
92.	Improved competitive position/Improved time-based competitiveness								*														*	*							*						4	11.1
93.	Improved Equipment Efficiency (OEE) or Overall average availability of equipment								*			*																*									3	8.3

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al.* (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al.* (2003)	Koh *et al.* (2004)	Sohal (1996)	McDonald *et al.* (2002)	Worley and Doolen (2006)	Arbulu *et al.* (2003)	Sullivan *et al.* (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al.* (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al.* (1997)	Taj (2005)	Burcher *et al.* (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al.* (2002)	Christiansen *et al.* (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
94.	Improved administration efficiency								*																												1	2.8
95.	Increased equipment utilization or Shop utilization								*	*															*						*			*			5	13.9
96.	Increased flexibility or Ability to shift output when the product mix changes or Machine flexibility								*																			*							*		3	8.3
97.	Increase in productivity								*			*							*				*	*					*		*	*				*	9	25.0
98.	Reduced raw material or parts/Minimizing the number of parts								*								*				*																3	8.3
99.	Low overheads								*	*																											2	5.6
100.	Reduced Product Cost/Average per unit cost/Price				*				*							*				*	*		*	*			*		*				*				10	27.8
101.	Special purpose equipment and facilities or versatile processing equipment									*																											1	2.8
102.	Close control of materials									*																											1	2.8
103.	Labour utilization									*		*																						*			3	8.3
104.	Improvement in machine availability or Equipment availability											*																						*			2	5.6
105.	Low wage rates and stable union contracts									*																											1	2.8
106.	Maintenance cost as a percentage of total cost or Cost of maintenance hours									*																								*			2	5.6
107.	Ratio of indirect labour to direct labour									*										*										*							3	8.3
108.	High utilization of capacity									*		*																	*								3	8.3

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al.* (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al.* (2003)	Koh *et al.* (2004)	Sohal (1996)	McDonald *et al.* (2002)	Worley and Doolen (2006)	Arbulu *et al.* (2003)	Sullivan *et al.* (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al.* (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al.* (1997)	Taj (2005)	Burcher *et al.* (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al.* (2002)	Christiansen *et al.* (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
109.	Ratio of engineers to mechanics, engineers to assets									*																											1	2.8
110.	Years of experience									*																											1	2.8
111.	Effective communication of standards or job requirements									*	*																										2	5.6
112.	Defect prevention									*																											1	2.8
113.	Effective scheduling									*																											1	2.8
114.	Low turnover of employees/Employee turnover/Personnel Turnover rate/Reduction in labour turnover rate/Annual turnover of employees									*				*		*			*									*									5	13.9
115.	Reduced inventory investment or cost or total inventory									*				*									*		*			*	*			*	*				8	22.2
116.	Adequate training or Have your personnel are thoroughly trained in LM									*									*																		2	5.6
117.	System performance: Reliability in percentage, Failure rates or Product reliability									*																									*		2	5.6
118.	Shop size (number of activities by category)									*																											1	2.8
119.	Equipment requirements									*																											1	2.8
120.	Shop capacity									*																											1	2.8
121.	Outsourcing policies									*																											1	2.8
122.	Reserve capacity or over-capacity availability									*																									*		2	5.6
123.	Effective control of work flow									*																											1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
124.	Integration of design and production									*																											1	2.8
125.	Customer expectations									*																											1	2.8
126.	Customer perceptions or customer perceived quality									*			*																								2	5.6
127.	Company guarantees, warranties etc. or Warranty cost									*			*																				*				3	8.3
128.	Company recovery strategies									*																											1	2.8
129.	Inventory on road (shifts)										*																										1	2.8
130.	Inventory maintained at customer sites										*																										1	2.8
131.	Frequency of die changes										*																										1	2.8
132.	Frequency of preventive maintenance/Time spent on preventive maintenance/Reduction in maintenance time/Preventive maintenance schedule or Maintenance hours applied										*		*						*									*						*			5	13.9
133.	Cost spent on preventive maintenance or Preventive maintenance cost as a percentage of breakdown cost												*																					*			2	5.6
134.	Time spent on quality related training/Average amount of initial training or Amount (in hours) of training given to newly employed personnel												*			*						*								*							4	11.1
135.	Cost spent on quality related training												*																								1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al.* (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al.* (2003)	Koh *et al.* (2004)	Sohal (1996)	McDonald *et al.* (2002)	Worley and Doolen (2006)	Arbulu *et al.* (2003)	Sullivan *et al.* (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al.* (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al.* (1997)	Taj (2005)	Burcher *et al.* (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al.* (2002)	Christiansen *et al.* (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
136.	Percentage of manufacturing process under statistical control or Portion of operations that are controlled with Statistical Process Control (SPC) or Processes are controlled through measuring inside the process												*															*		*						*	4	11.1
137.	Percentage of PM skipped										*																										1	2.8
138.	PM schedule followed										*																										1	2.8
139.	Use of outside warehouse by the plant										*																										1	2.8
140.	Use of colour coding										*																										1	2.8
141.	Use of visual management or aids										*																	*				*				*	4	11.1
142.	Orderly shipping site or housekeeping or Level of housekeeping										*																	*								*	3	8.3
143.	Order processing										*																										1	2.8
144.	Shipment tracking										*																										1	2.8
145.	Advanced shipping notice										*																										1	2.8
146.	Shipment schedule										*																										1	2.8
147.	Production schedule/Adherence to schedule										*																*								*		3	8.3
148.	Use of bar coded containers										*																										1	2.8
149.	Use of returnable containers										*																										1	2.8
150.	Returnable containers provided by the customers										*																										1	2.8
151.	Container size suggested by customer										*									*						*					*						4	11.1

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
152.	Appropriateness of container size										*																										1	2.8
153.	Percentage of shipments delivered daily										*																										1	2.8
154.	Percentage use of additional truck/trailers										*																										1	2.8
155.	Percentage side-loading trucks/trailers										*																										1	2.8
156.	Loading time (mins)										*																										1	2.8
157.	Tightness of pickup time windows (mins)										*																										1	2.8
158.	Percentage on-time pickups required										*																										1	2.8
159.	Percentage on-time pickups achieved										*																										1	2.8
160.	Percentage on-time deliveries required by customer										*																										1	2.8
161.	Percentage of transportation costs of total costs										*																										1	2.8
162.	Percentage of full truck loads filled										*																										1	2.8
163.	Percentage emergency shipping compared with last year										*																										1	2.8
164.	Emergency shipping costs (per million sales) last year										*																										1	2.8
165.	Single product loads										*																										1	2.8
166.	Mixed product loads/Number of product varieties/Number of Mixed models in a line										*				*					*																	3	8.3
167.	In-sequence mixed loads										*																										1	2.8
168.	Point to point delivery										*																										1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al.* (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al.* (2003)	Koh *et al.* (2004)	Sohal (1996)	McDonald *et al.* (2002)	Worley and Doolen (2006)	Arbulu *et al.* (2003)	Sullivan *et al.* (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al.* (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al.* (1997)	Taj (2005)	Burcher *et al.* (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al.* (2002)	Christiansen *et al.* (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
169.	Circuit delivery (milk run)										*																										1	2.8
170.	Compound delivery										*																										1	2.8
171.	Shipments allowed to be unloaded before the scheduled delivery time by customers										*																										1	2.8
172.	Deviation from schedule (1 week before needed) in percentage										*																*										2	5.6
173.	Deviation from schedule (2-3 days before needed) in percentage										*																										1	2.8
174.	Deviation from schedule (1 day before needed) in percentage										*																										1	2.8
175.	Business relationship (years) or Number of years a supplier is associated with the manufacturer or Manufacturers have been supplier since the component was created										*															*	*										3	8.3
176.	Length of contract (years) or long term contract with their manufacturers										*															*											2	5.6
177.	Relationship based on mutual trust										*																										1	2.8
178.	Percentage of suppliers participating in quality certification program or Number of certified suppliers or Supplier having statistical process control										*															*	*	*							*		5	13.9
179.	Sole source in percentage / Number of sole sourcing suppliers										*								*							*	*										4	11.1

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
180.	Percentage of products accepted as good without inspection or Percentage of parts comes from qualified suppliers or In-bound statistical control results										*																*	*							*		4	11.1
181.	Percentage emphasis on delivery performance by customer										*																										1	2.8
182.	Volume commitment/Increase in production volume/Production output or Producing according to demand				*						*			*	*	*				*	*				*	*	*				*	*			*		13	36.1
183.	Business commitment										*																										1	2.8
184.	Detailed technical specification or Product conformance										*																								*		2	5.6
185.	Delivery frequency requirements / Frequency of the deliveries										*		*								*				*	*	*	*			*						8	22.2
186.	Penalties due to late deliveries										*															*											2	5.6
187.	Penalties due to poor quality or Cost of quality or Average quality cost										*													*		*							*				4	11.1
188.	Penalties due to short quantity										*															*	*										3	8.3
189.	Defective products in ppm shipped to customer or Defect rate										*														*							*					3	8.3
190.	Machine mobility										*																										1	2.8
191.	Quality responsiveness (min)										*																										1	2.8
192.	Percentage of late deliveries										*																					*					2	5.6
193.	Percentage of sales to OEMs													*																							1	2.8
194.	Absenteeism													*																		*					2	5.6

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
195.	Reduction in number of workers/employees				*													*									*										3	8.3
196.	Square footage of buildings															*																					1	2.8
197.	Age of machinery															*																					1	2.8
198.	Number of managerial positions or Number of hierarchical levels in the manufacturing organization															*														*							2	5.6
199.	Increase in revenue/Revenue per full time employee															*				*				*													3	8.3
200.	Number of shifts																	*		*			*								*						4	11.1
201.	Production rate or ability to change the production rate or Units per hour																	*		*					*			*				*					5	13.9
202.	Reduced purchased cost or Percentage of material cost to total cost or Material cost																		*							*	*						*		*		5	13.9
203.	Increase in worker morale																		*					*													2	5.6
204.	Expand market share																			*																	1	2.8
205.	Number of hours worked per year or Annual hours per person per year																			*												*					2	5.6
206.	Annual wage per production worker																			*																	1	2.8
207.	Number of layers in the organisation																					*															1	2.8
208.	Customer dissatisfaction/Satisfaction																						*														1	2.8
209.	Number of steps or activities in the assembly line or work flow																						*														1	2.8
210.	Stock out																								*												1	2.8
211.	Machine repair time or Breakdown repair hours																								*									*			2	5.6

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
212.	Line efficiency																								*												1	2.8
213.	Service level																								*												1	2.8
214.	Raw material inventory or stocks of less than one day of production or Reduced incoming materials inventory or Raw material inventory turn rate																								*	*		*			*	*	*		*	*	8	22.2
215.	Lost sales																								*												1	2.8
216.	Organisation type																											*									1	2.8
217.	Job security																											*									1	2.8
218.	Percentage of personnel received at least eight hours of team building training																											*									1	2.8
219.	Number of large scale machines or single-process areas in the plant through which 50% or more of different products must pass																											*									1	2.8
220.	Overall bias of the plant's process selection with respect to scale																											*									1	2.8
221.	Overall bias of the plant's process selection with respect to technology																											*									1	2.8
222.	Availability of documents describing equipment records, records of uptime, repair history and spare parts																											*									1	2.8
223.	Time between re-sourcing of items in months																											*									1	2.8
224.	Percentage of machine operators having formal training in rapid setup sequences																											*									1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
225.	Extent of managers and workers judged based on setup performance																											*									1	2.8
226.	Tooling investment																												*								1	2.8
227.	Workers identify defective parts and do not stop the line																													*							1	2.8
228.	Quality control department identify defective parts and informs production management																													*							1	2.8
229.	Workers take out and adjust defective parts																													*							1	2.8
230.	Adjustment department adjusts defective parts																													*							1	2.8
231.	Measuring is done after each process																													*							1	2.8
232.	Measuring is done only after product is complete																													*							1	2.8
233.	Size of the adjustment and repair area																													*							1	2.8
234.	Sequential just in time possible																													*							1	2.8
235.	Number of stages in the material flow that uses pull (backward requests) in relation to the total number of stages in the material flow																													*							1	2.8
236.	Percentage of the annual requirement value that is scheduled through a pull system																													*							1	2.8
237.	Number of job classifications																													*							1	2.8
238.	Number of different tasks which employees are trained in																													*							1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
239.	Number of different functional areas which employees are trained in																													*							1	2.8
240.	Team leaders rotates among team members																													*							1	2.8
241.	Supervisory tasks performed by the team																													*							1	2.8
242.	Separate supervisory level in the organization																													*							1	2.8
243.	Percentage of employees being able to accept responsibility for team leadership																													*							1	2.8
244.	Percentage of employees having accepted responsibility for team leadership																													*							1	2.8
245.	Number of functional areas that are the responsibility of teams																													*							1	2.8
246.	Number of different indirect tasks performed by the team																													*							1	2.8
247.	Number of different measures used to asses the performance of the teams																													*							1	2.8
248.	Number of areas contained in the information given to employees																													*							1	2.8
249.	Information continuously displayed in dedicated spaces, directly in the production flow. Regular meetings to discuss the information																													*							1	2.8
250.	Oral and written information provided regularly																													*							1	2.8
251.	Written information provided regularly																													*							1	2.8
252.	No information to employees																													*							1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
253.	Time perspective in the information																													*							1	2.8
254.	Number of processes that are mapped to identify value added, non value added activities, bottlenecks etc.																																*				1	2.8
255.	Number of cells																														*						1	2.8
256.	Number of workstations in each cell																														*						1	2.8
257.	Number of customers																															*					1	2.8
258.	Overdue tasks																																	*			1	2.8
259.	Planned and scheduled work orders																																	*			1	2.8
260.	Work orders turnover																																	*			1	2.8
261.	Degree of scheduling																																	*			1	2.8
262.	Breakdown frequency																																	*			1	2.8
263.	Evaluation of preventive maintenance and predictive maintenance																																	*			1	2.8
264.	Length of running																																	*			1	2.8
265.	Emergency man hours																																	*			1	2.8
266.	Emergency and other unscheduled tasks																																	*			1	2.8
267.	Breakdown severity																																	*			1	2.8
268.	Scheduled service cost																																	*			1	2.8
269.	Maintenance cost per unit of production																																	*			1	2.8
270.	Degree of activity overlapping																																		*		1	2.8

S. No	Performance Measures	Shah and Ward (2003)	Kojima and Kaplinsky (2004)	Crute *et al*. (2003)	Dong (1995)	Mehta and Shah (2005)	Sanchez and Perez (2001)	Lewis (2000)	Kumar and Garg (2000)	Comm and Mathaisel (2000)	Wu (2003)	Pavnaskar *et al*. (2003)	Koh *et al*. (2004)	Sohal (1996)	McDonald *et al*. (2002)	Worley and Doolen (2006)	Arbulu *et al*. (2003)	Sullivan *et al*. (2002)	Wafa and Yasin (1998)	Katayama and Bennett (1996)	Jina *et al*. (1997)	Ahlstrom and Karlsson (2000)	Emiliani and Stec (2004)	Bhasin and Burcher (2006)	Chu and Shih (1992)	Gonzalez-Benito (2002)	Garg *et al*. (1997)	Taj (2005)	Burcher *et al*. (1996)	Karlsson and Ahlstrom (1996)	Detty and Yingling (2000)	Oliver *et al*. (2002)	Christiansen *et al*. (2003)	Davies and Greenough (2003)	De Toni and Tonchia (1996)	Bonavia and Martin (2006)	Frequency	Percentage of authors using the measure
271.	Work breakdown structure time adherence																																		*		1	2.8
272.	Carry over																																		*		1	2.8
273.	Prototype cost																																		*		1	2.8
274.	Design man hours (including projects not completed)																																		*		1	2.8
275.	Process capability																																		*		1	2.8
276.	Material Productivity																																		*		1	2.8
277.	Machine Productivity																																		*		1	2.8
278.	Project quality																																		*		1	2.8
279.	Project costs																																		*		1	2.8
280.	Material availability																																		*		1	2.8
281.	Alternative routings																																		*		1	2.8

Table 4.2: List of performance measures for LMS and its associated taxonomies

S. No.	Performance measures of LM	Taxonomies			
		Competitive priorities	**Elements of LM**	**Perspective**	**Internal business process or department**
1.	Scrap and rework costs	Cost	TQM	Financial	Finance and accounting
2.	Manufacturing cycle time	Productivity	CTR, WLB, LAY, NPE, FFP	Internal business process	Operations
3.	First pass yield	Quality	POK, TQM	Internal business process	Quality control or assurance
4.	Labour productivity	Productivity	NPE	Internal business process	Operations
5.	Manufacturing cost per unit	Cost	PPS, MOD, CSP	Financial	Finance and accounting
6.	Customer lead time	Delivery		Customer	Top management
7.	Time spent on engineering changes	Innovation	COE	Internal business process	Research and development
8.	Number of total parts in bill of materials	Innovation	PPS, MOD, CEM	Internal business process	Research and development
9.	WIP inventory	Flexibility	WIP, KAN,SLP, PSM, FFP	Internal business process	Production Planning and Control
10.	Value of WIP in relation to sales	Cost	KAN, FFP	Financial	Finance and accounting
11.	Finished goods inventory	Flexibility	KAN, SLP, PSM, FFP	Internal business process	Production Planning and Control
12.	Number of kanbans	Delivery	PUL, KAN	Internal business process	Production Planning and Control
13.	Setup time	Flexibility	SMD, PSM	Internal business process	Operations
14.	Rate of customer returns	Quality	TQM	Customer	Quality control or assurance
15.	Number of inventory rotations	Productivity		Internal business process	Production Planning and Control

S. No.	Performance measures of LM	Taxonomies			
		Competitive priorities	Elements of LM	Perspective	Internal business process or department
16.	Production capacity	Flexibility	MSC, NPE, FFP	Internal business process	Production Planning and Control
17.	Batch size	Flexibility	SLP	Internal business process	Production Planning and Control
18.	Value added time	Productivity	WLB, VSM, FFP	Internal business process	Operations
19.	Non value added time	Productivity	WLB, LAY, VSM, FFP	Internal business process	Operations
20.	Number of suggestions per employee per year	Innovation	SUS, PST, RRE, EPR, TQM	Innovation or Learning	Human resource or Personnel
21.	Reduction in direct labour	Morale	LTE, FOS	Internal business process	Human resource or Personnel
22.	Percentage of unscheduled downtime	Productivity	TPM	Internal business process	Maintenance
23.	Total productive floor space	Cost	SSR,FFP	Financial	Operations
24.	Throughput time or manufacturing lead time	Delivery	DFM, FFP	Internal business process	Supplier development or purchasing
25.	Reduction in indirect labour	Morale	LTE, FOS	Internal business process	Human resource or Personnel
26.	Takt time	Delivery	PUL	Customer	Production Planning and Control
27.	Percentage of employees cross trained to perform three or more jobs	Flexibility	MSW, JOR	Innovation or Learning	Human resource of Personnel
28.	Reduction in overall plant investment	Cost		Financial	Finance and accounting
29.	Number of awards and rewards provided for workers	Morale	EEM, PST, RRE, EPR, TQM	Internal business process	Human resource or Personnel
30.	Percentage of common or standardised parts	Innovation	PPS, CSP, CEM	Internal business process	Research and development
31.	Average distance between the supplier and manufacturer	Delivery	JIT, SPR	Supplier	Supplier development or purchasing

S. No.	Performance measures of LM	Taxonomies			
		Competitive priorities	Elements of LM	Perspective	Internal business process or department
32.	Percentage of preventive maintenance over total maintenance	Quality	TPM	Internal business process	Supplier development or purchasing
33.	Percentage of inspection carried out by autonomous defect control	Quality	DAS, TQM	Innovation or Learning	Quality control or assurance
34.	Percentage of defective parts adjusted by production line workers	Quality	SUC, TQM	Internal business process	Quality control or assurance
35.	Number of teams	Morale	CFT, QCC, RRE, EPR, TQM	Internal business process	Human resource or Personnel
36.	Percentage of employees working in team	Morale	EPR, RRE	Internal business process	Human resource or Personnel
37.	Percentage of parts delivered directly to the point of use from supplier without incoming inspection or storage	Delivery	JIT, QUC, SLP, LTR, TQM	Supplier	Supplier development or purchasing
38.	Level of integration between suppliers delivery and the company's production information systems	Delivery	JIT, EDI, ISS, LTR	Supplier	Supplier development or purchasing
39.	Percentage of parts delivered just in time between sections in the production line	Delivery	JIT, PUL, OPF, SLP	Internal business process	Production Planning and Control
40.	Percentage of parts co-designed with suppliers	Delivery	PRS, STD, LTR, SID, SSO	Supplier	Supplier development or purchasing
41.	Number of suggestions made to suppliers	Quality	ISS, STD	Supplier	Supplier development or purchasing
42.	Average number of suppliers for the most important parts	Quality	LTR, SSO	Supplier	Supplier development or purchasing
43.	Percentage of procedures which are written or recorded or documented in the company	Quality	WST, TQM	Innovation or Learning	Quality control or assurance
44.	Percentage of production equipment that is computer integrated or automated	Flexibility	JEL, AUT, SIP, CIM	Internal business process	Operations
45.	Number of suppliers	Delivery	SSO	Supplier	Supplier development or purchasing
46.	Length of product runs	Delivery	DFM	Internal business process	Production Planning and Control

S. No.	Performance measures of LM	Taxonomies			
		Competitive priorities	Elements of LM	Perspective	Internal business process or department
47.	Supplier or delivery lead time	Delivery	JIT	Supplier	Supplier development or purchasing
48.	Gross annual profit	Cost		Financial	Top management
49.	Total sales	Cost		Financial	Top management
50.	Percentage on time delivery	Delivery	JIT, LTR	Supplier	Supplier development or purchasing
51.	Number of employees	Cost	LTE	Financial	Human resource or Personnel
52.	Time to market for new products	Innovation	DFM	Customer	Research and development
53.	Number of new products introduced	Innovation	GRT, CEM	Customer	Research and development
54.	Improved time-based competitiveness	Productivity		Customer	Top management
55.	Improved overall equipment efficiency (OEE)	Productivity	TPM	Internal business process	Maintenance
56.	Equipment utilisation	Productivity	MSC, NPE	Internal business process	Maintenance
57.	Increased flexibility	Flexibility	UFM, PSM, NPE	Internal business process	Top management
58.	Increase in productivity	Productivity		Internal business process	Top management
59.	Reduced product cost or price	Cost	PPS, MOD, CSP	Financial	Finance and accounting
60.	Labour utilisation	Productivity	LAY, LTE, FOS	Internal business process	Human resource or Personnel
61.	Ratio of indirect labour to direct labour	Productivity	LTE, FOS	Internal business process	Operations
62.	Utilisation of capacity	Productivity	MSC, NPE	Internal business process	Production Planning and Control

S. No.	Performance measures of LM	Taxonomies			
		Competitive priorities	Elements of LM	Perspective	Internal business process or department
63.	Employee turnover rate	Morale	LTE	Internal business process	Human resource or Personnel
64.	Reduced inventory investment	Cost	KAN	Financial	Finance and accounting
65.	Warranty cost	Cost	TQM	Financial	Finance and accounting
66.	Frequency of preventive maintenance	Productivity	AUM, NPE, TPM	Internal business process	Maintenance
67.	Amount (in hours) of training given to newly employed personnel	Morale	MFT	Innovation or Learning	Human resource or Personnel
68.	Percentage of manufacturing process under statistical control	Quality	SPC, TQM	Internal business process	Quality control or assurance
69.	Use of visual management or aids	Productivity	VIC, CBE	Customer	Operations
70.	Level of housekeeping	Productivity	HOK	Internal business process	Maintenance
71.	Adherence to schedule	Delivery	CBE, LTR	Supplier	Production Planning and Control
72.	Container size	Delivery	STC,	Supplier	Production Planning and Control
73.	Number of mixed models in a line	Flexibility	MMS	Internal business process	Production Planning and Control
74.	Number of years a supplier is associated with the manufacturer	Delivery	LTR	Supplier	Supplier development or purchasing
75.	Number of certified suppliers	Quality	JIT, QUC, LTR	Supplier	Supplier development or purchasing
76.	Number of sole sourcing suppliers	Quality	LTR, SSO, TQM	Supplier	Supplier development or purchasing
77.	Percentage of products accepted as good without inspection	Quality	JIT, TQM	Internal business process	Quality control or assurance
78.	Increase in production volume	Productivity	NPE, FFP	Internal business process	Top management

S. No.	Performance measures of LM	Taxonomies			
		Competitive priorities	Elements of LM	Perspective	Internal business process or department
79.	Frequency of the deliveries	Delivery	JIT, SLP, LTR	Supplier	Supplier development or purchasing
80.	Cost of poor quality	Cost	TQM	Financial	Finance and accounting
81.	Penalties due to short quantity	Delivery	JIT, TQM	Supplier	Supplier development or purchasing
82.	Defective products in ppm shipped to customer	Quality	TQM	Customer	Quality control or assurance
83.	Reduction in number of workers/employees	Morale	LTE, FOS	Internal business process	Human resource or Personnel
84.	Increase in revenue	Cost		Financial	Top management
85.	Number of shifts	Productivity		Internal business process	Operations
86.	Production rate	Productivity	LAY, DFM, NPE, TPM, FFP	Internal business process	Operations
87.	Reduced purchase cost	Cost	LTR, SSO	Financial	Finance and accounting
88.	Raw material inventory	Flexibility	ELB, KAN, SLP, PSM, FFP	Internal business process	Production Planning and Control
89.	Overtime	Productivity		Internal business process	Production Planning and Control
90.	Percentage of people involving in stopping the line due to problems	Morale	JID, AND, RRE, EPR, TQM	Internal business process	Human resource or Personnel

Note: A detailed list of abbreviations and its associated expansions for the elements of LM are presented in Chapter 3.

4.2.2 *Implementation of performance measures for lean manufacturing systems*

This section corresponds to the second phase of the PMS development methodology proposed by Bourne *et al*. (2000). Kennerley and Neely (2002) stated that the objective of the PMS frameworks is to help organisations define a set of measures that reflect their objectives and assess their performance appropriately. They commented that PMS frameworks should be multidimensional and should strike a balance between both financial and non-financial measures. Utilising these guidelines and the objectives, the PMS framework for LMS is developed. A review of literature on PMS revealed a plethora of frameworks. Tangen (2004) has already reviewed different frameworks of PMS and expressed that on one hand, the new approaches to PMS have solved some of the limitations of the traditional way of measuring performance; while on the other hand, these modern frameworks are all trying to limit the number of performance measures to avoid information overload and guard against sub-optimisation. He also identified several weaknesses of the existing PMS frameworks.

Since a review of existing PMS frameworks is already available, a classification scheme (taxonomy) is established, as it helps in understanding the nuances of the various PMS frameworks apart from differentiating them. Table 4.3 shows the taxonomy for PMS frameworks. The frameworks are classified under the following three categories:

1. **General frameworks of PMS:** This category deals with research papers that explain the fundamentals of performance measurement. It includes the basic frameworks of PMS such as performance pyramid, Balanced Scorecard (BSC), etc.

Table 4.3: Taxonomy for PMS frameworks

S. No.	Category	Name of the framework	Author	Remarks
1.	General frameworks of PMS	Integrated dynamic PMS	Ghalayini and Noble (1996)	They addressed the changing basis of PM apart from discussing the limitations of traditional performance measures and the characteristics of recently developed performance measures, in which they described the attempts to incorporate time-based issues and continuous improvement. They also reviewed the concepts of the Strategic Measurement Analysis and Reporting Technique (SMART) system, the Performance Measurement Questionnaire (PMQ) and the Balanced Scorecard (BSC) which have been developed for the integrated PM. They assessed the advantages and disadvantages of each of these systems and proposed the development of integrated dynamic PMS.
2.		Dynamic PMS	Bitici *et al.* (2000)	They have explored the use of IT based management tools to a self-auditing 'dynamic PM', which would ensure that an organisations' PMS remains integrated, efficient and effective at all times Using the newly developed framework of dynamic PMS, they addressed the question – whether the existing knowledge, expressed in the form of models and frameworks is sufficiently advanced to create a truly dynamic PMS. They reviewed the dynamic PMS framework against available models and frameworks and validated the same using a case study. They concluded that the proposed model of dynamic PMS extends the notion of performance measurement into a control loop to include correction action.
3.		Framework describing the forces shaping the evolution of the measurement systems	Kennerley and Neely (2002)	They also supported that the measurement systems should be dynamic but they criticised that very few organisations appear to have systematic processes in place for managing the evolution of their measurement systems, because of which, a new measurement 'crisis' has been caused with organisations implementing new measures to reflect new priorities, but failing to discard measures reflecting old priorities resulting in uncorrelated and inconsistent measures. Hence they developed a framework describing the forces that shape the evolution of the measurement systems used by different organisations. The framework was developed based on the following change management issues – drivers for change and barriers to change. Based on these two issues, they identified the factors that force the organisation to change the measures and its PMS and the factors that prevent the organisation from changing the PMS. They validated the framework through a multiple case study approach.
4.		A consistent PMS	Flapper *et al.* (1996)	They presented a systematic method for designing a consistent PMS to be used in practice, where explicit attention was paid to the relations between performance indicators. They defined consistent PMS as a system that covers all aspects of performance that are relevant for the existence of the organisation as a whole apart from offering management quickly the

S. No.	Category	Name of the framework	Author	Remarks
				insight into how well the organisation is performing its tasks and to what extent the organisational objectives are realised. They also provided a new classification scheme for the performance indicators and validated their PMS using a case study of a Dutch company.
5.	PMS frameworks for various change management initiatives utilising world class manufacturing philosophies and practices	PMS for Business Process Reengineering (BPR)	Kuwaiti and Kay (2000)	They argued that a PMS is a prerequisite to the introduction of Business Process Re-engineering (BPR) as the PMS play a major role during the phase of introducing change. They examined the relationship between the congruence of PMS and the concepts of empowerment, integration and strategic alignment by collecting data from 301 respondents in 19 manufacturing and 30 financial companies in Bahrain. They conducted reliability and validity analysis, factor loading, and correlation analysis and based on these analyses, they found that PMS and strategic alignment are strongly related, empowerment is moderately related and integration showed a weak relationship.
6.		Quality-focused PMS	Lockamy (1998)	He provided a normative model for the development of quality-focused PMS, which is based on the results of a study of six firms identified as “world class” by academic and practitioner experts. His study focused on the relationship between division and plant PMS designed to support the firms’ strategic objectives and to facilitate organisational coordination. Each of the six firms identified quality improvement as a strategic objective and devised various approaches for assessing their quality performance. He claimed that the model developed based on empirical findings from these six studies, will provide a foundation for further development of quality-focused PMS theory.
7.		PMS for SCM	Gunasekaran *et al.* (2004)	They analysed the need for performance measures and metrics in a supply chain. They have identified the measures and metrics in the areas of planning, sourcing, make/assembly decisions, delivery, and customer service level.
8.		Integrated PM framework for auditing and enhancing PMSs for a world-class manufacturer	Medori and Steeple (2000)	They developed a framework for auditing and enhancing PMS for a world class manufacturer. They mentioned that ‘to be a world class and be classified as a world class manufacturer, manufacturing organisations need to have a number of critical ingredients: one such ingredient is that of an appropriate PMS. They reviewed different PMS, but found that none of them have provided guidance for the actual selection and implementation of selected performance measures. They commented that the currently available frameworks have not given adequate consideration to the existing measurement systems followed in an organisation. Hence to resolve these issues, they have identified a list of financial and non-financial performance measures for world-class manufacturers, which was segregated by six competitive priorities and developed a six stage ‘integrated PM’ framework.

S. No.	Category	Name of the framework	Author	Remarks
9.		PMS for JIT	Crawford and Cox (1990)	They conducted a study to understand how performance is evaluated in JIT operations. They developed a series of ten propositions for constructing the PMS for JIT, which are concerned with the performance criteria, standards, measurement techniques and reporting methods that are appropriate in JIT environments. They stated that these propositions are a first step towards establishing a framework for understanding JIT performance evaluation. They utilised a case study approach and studied in detail about 6 companies to examine the PMS developed by the implementers, who were addressing the problem of performance evaluation in the JIT environment.
10.		Framework for the performance measures of WCM	Digalwar and Metri (2005)	They commented that even though the concept of World-Class Manufacturing (WCM) is well understood, neither practitioner nor academics agree upon, or know, how WCM can be measured in totality. Hence they provided a theoretical framework for the performance measures of WCM. They used the first two steps of Churchill's model and a thorough synthesis of the literature to identify the following eleven performance measures of WCM – top management commitment, customer service, price/cost, quality, facility control, speed, innovation and technology, flexibility, vendor and material management, global competitiveness, environmental health and safety.
11.		A strategic model of PM in world-class operations	Kasul and Motwani (1996)	They identified and interpreted the performance measures cited in literature and proposed a strategic model to identify the status of an organisation on the road to global supremacy. They used a judgemental process for grouping similar world-class organisation requirements and classified those requirements in to nine separate categories or factors. They noted that the model can be very useful for developing a programming model which an organisation can use to implement proactively and manage world-class organisations.
12.		PM in TOC environment	Lockamy and Spencer (1998)	They studied about PM in Theory of Constraints (TOC) environment. They commented that TOC is a means to achieve manufacturing excellence but only a little research has been published exploring the implications of TOC in relation to performance measurement. They observed that TOC research till date has focused on the production planning and scheduling methods (known as drum- buffer-rope and buffer management), rather than on an examination of the PM methods. They explained that the discussion on TOC and PM was advocatory in nature lacking empirical results. Hence they have examined the results of the use of TOC performance measures in an actual manufacturing setting for comparison with the existing literature. Based on this, they have generated proposition for future TOC PM research.
13.		PMS for LM using management	De Toni and Tonchia (1996)	They emphasised that the organisational change required by lean production leads to a management-by-process organisation, and that management by process influences the PMS. They supported their premise using a case study of Zanussi-Electrolux – the largest

S. No.	Category	Name of the framework	Author	Remarks
		by process		European producer of domestic appliances, which has introduced management by process into most of its plants. They provided a detailed analysis of the organisational change due to LM and its effects on PM. They noted that among the different processes in a manufacturing organisation, three can be considered fundamental: product development; manufacturing (material processing); logistics (material handling) and for each of these three processes, they have identified the main organisational variables and PM variables. The PM variables include the most critical performance dimension (T = time performance, C = cost performance, Q = quality performance), the number of objects to be measured and the costs and frequency of measuring etc.
14.		PMS for firms implementing JIT	Upton (1998)	He investigated the use of PMS in firms implementing JIT. He noted that 'the use of efficiency variances may encourage production for inventory rather than demand and a possible consequence of the use of this type of measure is that inventories of work in process and finished goods will accumulate, which is contrary to the goal of waste elimination, a central theme of the JIT philosophy'. Hence, based on this premise, he anticipated that JIT users will focus more on non-financial performance indicators, such as supplier on time delivery and supplier quality and less on traditional/financial measures such as labour and machine efficiency. He hypothesized the following: – JIT firms are expected to use non-financial indicators to a greater extent than non-JIT firms – Greater use of non-financial performance measures is correlated to organisation performance. To confirm this, he surveyed a sample of New Zealand manufacturing companies to examine the nature of their production environments, performance measurement systems and organisation performance.
15.		PM framework for measuring the impact of TQM philosophy	McAdam and Bannister (2001)	They studied an example of a PM framework which measures the impact of TQM philosophy on fundamental measures of business performance. They undertook a case study approach in an organisation and compared the results of a survey to the business results of the company and found that TQM has had a worthwhile impact. They observed that if the basic fundamentals of TQM are properly applied then, as the TQM process matures, all the business indicators will show steady improvement with time, as found in the case company. For instance, they explained about the impact brought about by a sustained effort from all employees, whether they are direct operators or support staff, which reduced the percentage of scrap parts. In the same manner, they have analysed performance measures like scrap cost per hour, product variation, production order size, on time delivery, customer complaints etc.

S. No.	Category	Name of the framework	Author	Remarks
16.	PMS frameworks for individual functions within an organisation	PMS for maintenance	Kutucuoglu *et al.* (2001)	They noted that the aim of the maintenance function is to contribute towards an organisation's profit by bringing the need for maintenance operations to be in harmony with corporate business objectives. To accomplish this, the PMS are crucial to those organisations having a stake in maintenance, to ensure that they are not in conflict with the overall business needs. Hence they analysed the role of PMS in maintenance, with particular reference to developing a new PMS using the Quality Function Deployment (QFD) technique. They identified the key factors for an effective PMS based on a literature review. They examined the common PMSs for maintenance and based on the principles of an effective PMS they discussed about the PMSs application to the maintenance function. Further, they developed a framework embracing these key facets and discussed its practical implications, in the light of its application within a SME.
17.		A process-based approach for measuring supply chain performance	Chan and Qi (2003)	They have proposed a process-based approach to map and analyze the performance of practically complex supply chain network. They have developed a process-based PMS in which a method called performance of activity was used to identify the performance measures and metrics of supply chain.
18.		Integrated Production Performance Measurement System (IP2MS) for the operations	De Toni *et al.* (1997)	They proposed an original Integrated Production Performance Measurement System (IP2MS) for the operations. IP2MS is based on a model, which is capable of examining simultaneously several production performances of different operation centres of a firm. They have obtained a quantitative and homogeneous appraisal of the production performances, based on both objective measures and subjective judgements. They explained that the proposed IP2MS utilizes data from the manufacturing planning and control system (MPCS) and from the ABC system. The data from the MPCS are used to express a judgement on the "cost performances" (such as machine efficiency, amount of rejects and waste, etc.) and on the "non-cost performances" (such as adherence to scheduling, throughput time, etc.), while the data from the ABC system are used to weigh the performance of each single operation centre. The have tested their proposed model empirically in some significant medium-large enterprises of Northern Italy.
19.		PM for logistics research	Chow *et al.* (1994)	They utilised a literature review to examine the various ways in which "performance" has been defined, the data collection methods, data sources, and the measures that have been used in and industrial and academic circles. They identified and discussed about the potential sources of performance data of logistics. They proposed a PM framework for logistics, which incorporates various possible dimensions of performance in a single envelope, which highlighted the numerous interdependencies and conflicts between the goals. Further they

S. No.	Category	Name of the framework	Author	Remarks
				commented that logistics performance measures can be classified in to hard and soft measures. They explained that hard performance measures such as net income or order fill rate are typically impersonal, accurate and easy and inexpensive to collect. Similarly, measures such as net income and accounting ratios such as Return On Investment (ROI) are useful ways of capturing profitability, and will often be easy and inexpensive to collect, particularly where logistics is treated as a profit centre. On the other hand, they also recommended that qualitative variables such as attitudes or perceptions can be included apart from utilising quantitative techniques for conducting research on logistics performance measurement.
20.		PMS for a virtual engineering team	Hacker and Lang (2000)	They discussed the process and issues involved in developing a PMS for a virtual engineering team working within a high technology environment. Further, they developed the PMS utilising a case study in which the engineering team were consisting of members from many different sites across the world with a unique role in maintaining standardized manufacturing processes at the lowest possible cost. Since the team was facing many challenges including communication barriers, culture differences, as well as different reporting structures within each individual site, the authors developed a PMS to focus the team on the key actions affecting performance instead of the issues getting in the way. The PMS linked the team's objectives to its mission and identified the critical actions associated with each objective.

2. **The PMS frameworks for various change management initiatives:** This category includes PMS frameworks that are developed particularly for change management initiatives such as TQM, TOC, etc., which discuss how the performance measures were identified for that particular initiative, how they should be implemented, etc.

3. **PMS frameworks for individual functions within an organisation:** In this group, papers dealing with the PMS that are developed for particular functions of an organisation are grouped. For instance, it may include frameworks that discuss the performance measures for logistics, product development, etc.

Neely *et al*. (2005) concluded that the performance measurement and PMS should change according to the changes happening in organisations. But from the review of PMS frameworks, it is found that there is no paper available in the literature until now that discusses how the organisation should achieve this objective when it undergoes change with the application of LM principles. In addition to this, it is found that PMSs has been developed for individual functions within the organisation. But it is hypothesized that when an organisation undergoes a transformation by adopting changes such as TQM, TPM, LM, etc., all the functions within the organisation will be affected. Hence, a PMS should include PM and metrics for the organisation as a whole and not for individual functions alone. In other words, the PM and metrics for individual functions should be integrated into a coherent whole, and a holistic approach should be followed in developing the PMS. Rolstadås (1998) discussed about the concept of enterprise PM, which supported the hypothesis. He described the TOPP and European Network for Advanced Performance Studies (ENAPS) models for enterprise PM. He explained that the TOPP model adopted a business process approach, in which an organisation's processes such as sales, marketing, production, product development, supplier development, etc., have been classified into primary processes, secondary processes and development processes. Under each of these processes, various performance indicators were identified. He commented that the ENAPS model also follows the same approach to a certain degree. ENAPS classifies the processes followed in organisation into four business processes and two secondary processes, and performance is measured at three levels of performance indicators – enterprise level, process level and function level, in which a total of 117 indicators were used. Based on this premise, a PMS for LM will be developed with a holistic approach.

According to the taxonomy established above, the framework to be proposed for LM will fall under the second category, i.e., ‘PMS framework for change management initiatives’. Hence before proposing the framework for LM, it is necessary to:

- check whether the identified performance measures satisfy the competitive priorities of an organisation
- understand what is the relationship of the performance measures with the different elements of LM
- analyse what is the relationship of the performance measures with the different business processes of an organisation

Thus this section will answer the third research question – ‘what is the relationship between performance measures and competitive priorities, the organisation’s business processes and the elements of LM?’

4.2.2.1 Relationship between the performance measures and competitive priorities

Noble (1997) listed out the following as competitive priorities for any organisation: quality, dependability, delivery, cost efficiency, flexibility; and innovation, while Medoir and Steeple (2000) identified quality, cost, flexibility, time, delivery and future growth as competitive priorities of an organisation. But it is hypothesized that an organisation that is implementing LMS will focus on the following as competitive priorities: productivity, quality, cost, delivery, morale, flexibility and innovation. Hence, based on these competitive priorities, the taxonomy for the identified performance measures of LMS is established as shown in Table 4.2. They were classified under each of the competitive priorities using a judgemental approach. A similar taxonomy was also developed by White (1996). But, the proposed taxonomy is different from that of White (1996) in the following ways: the number of competitive priorities considered in the proposed taxonomy is seven, while White considered only five (excluding morale and innovation). Similarly, White developed the taxonomy for strategy-related performance measures for manufacturing, whereas, in this case, it was established for performance measures related to LM.

4.2.2.2 Relationship between performance measures and elements of lean manufacturing

Another important aspect in designing the PMS is to understand the relationship between the performance measures and the activities or processes involved in the change initiatives. To accomplish this, a relationship between the identified measures and different elements of LM should be established, for which the conceptual framework of LM developed in Chapter 3 is utilised. Based on this conceptual framework of LMS, the relationship between performance measures and elements of LM is established as shown in Table 4.2.

4.2.2.3 Relationship between performance measures and business processes

Rolstadås (1998), while discussing the TOPP system, has explained about the performance measures for 20 specific areas within the enterprise, such as marketing, design, technological planning, product development, production planning and control, manufacturing/assembly, financial management, personnel management, information technology and improvement processes. Similarly, to provide a better clarity, the performance measures of LMS were classified according to the business processes of a typical organisation, which is shown in Table 4.2.

4.2.2.4 Proposed performance measurement system framework for lean manufacturing systems

Many researchers have identified that BSC is the most commonly used framework for performance measurement. For instance, Marr and Schuma (2003) concluded that BSC seems to be the most influential and dominant concept in the field of PM. Hence, the proposed framework for LM will be developed based on the concepts and framework of BSC. According to Tangen (2004), the BSC proposes that a company should use a balanced set of measures that allows top managers to take a quick but comprehensive view of the business from four important perspectives and provide answers to the following four fundamental questions:

1. How do our shareholders see us (financial perspective)?
2. What must we excel in (internal business perspective)?
3. How do our customers see us (the customer perspective)?
4. How can we continue to improve and create value (innovation and learning perspective)?

However, in this case, the BSC has been suitably modified and adapted to suit the requirements of LM. In the proposed framework of PMS for LMS, the perspective of suppliers is also incorporated. In other words, the proposed framework attempts to provide answer to another fundamental question – how do our suppliers see us (the supplier perspective)? This perspective is essential because, when organisations become lean or JIT manufacturers, they expect their supplier (at least their critical suppliers) to follow the lean/JIT principles. Further, the success of a lean/JIT manufacturer is heavily dependent on the capability of its supplier to be lean. Emiliani (2000) explained that, in recent times, many large manufacturing companies managed in the Western tradition seek to obtain alignment with first-tier suppliers (which are predominantly SMEs) by engaging them in activities to improve their production capabilities, i.e., companies considered as leaders in lean production have long realised that the entire supply chain (or supply networks), not just first-tier suppliers, must mirror their production practices in order for JIT systems to function properly. To support this, he presented the strategies and methods used by Pratt & Whitney, a manufacturer of gas turbine engines, for a three-year period (1996–1998), to develop the network of suppliers that produce small machined parts to undergo lean transformation. So, it becomes imperative to suitably modify the conventional BSC framework to incorporate the supplier's perspective. Figure 4.1 shows the proposed PMS framework for LMS, which is developed by modifying the conventional BSC. As shown in Figure 4.1, the performance measures identified earlier were categorised according to the each perspective of BSC, which is shown in Table 4.2.

4.2.2.5 Features of the proposed performance measurement system framework for lean manufacturing systems

A cursory analysis of the proposed framework reveal that the framework also utilises most of the traditional performance measures such as gross profit, total sales, revenue, inventory cost, etc., which are highly financial in nature. Similarly, most of the commonly used performance measures, which are traditionally used by various organisations, are also present in the proposed framework. Hence if an organisation wishes to implement LM, it need not discard the existing PMS completely rather it can build upon its existing PMS by adding suitable performance measures selected from the proposed framework.

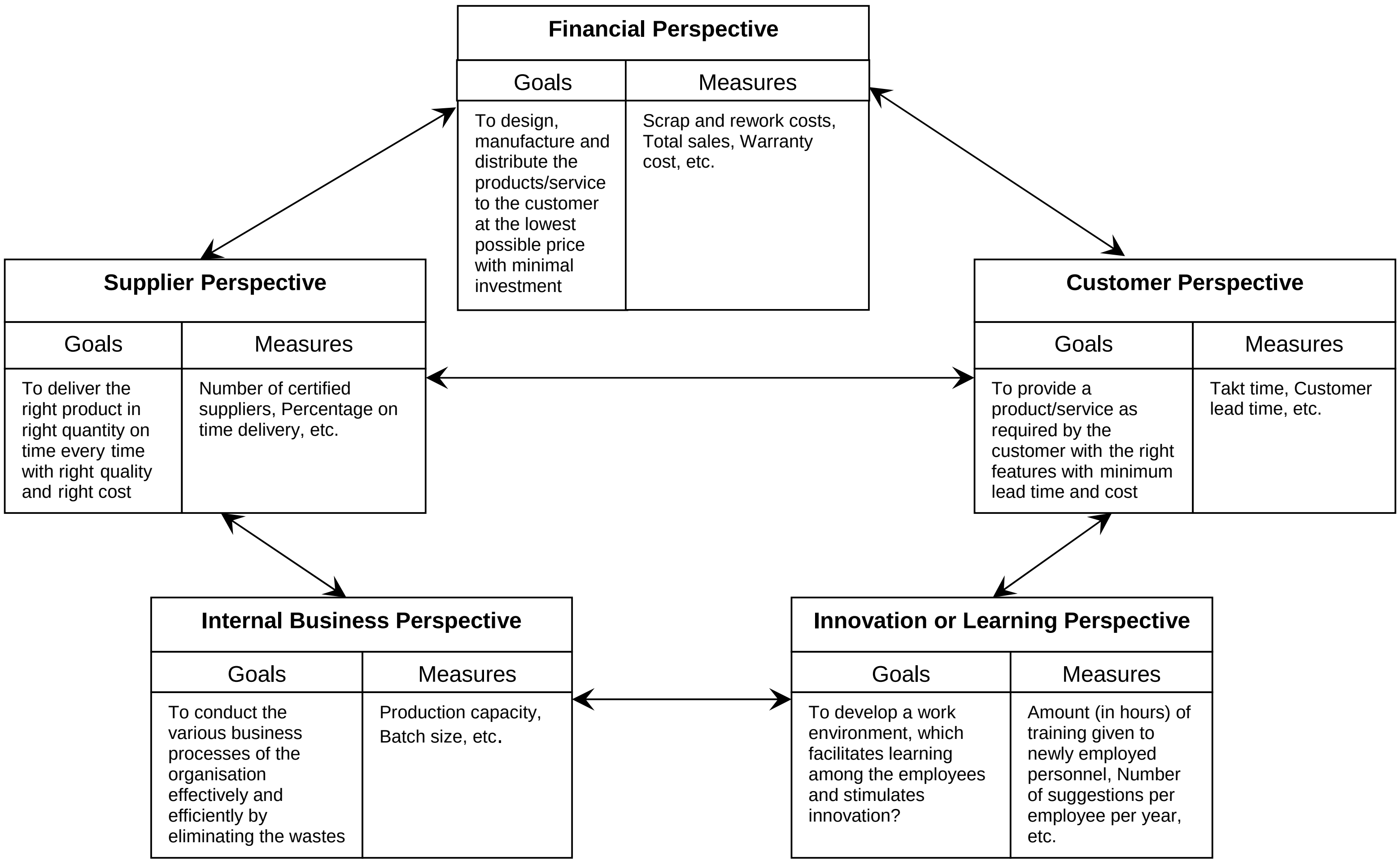

Figure 4.1: Proposed PMS framework for LMS

Apart from this, some of the important features of the proposed PMS framework for LMS are:

- It consists of about 90 performance measures, which can be utilised across the entire organisation which is implementing LM or has already implemented LM.
- It has taken into consideration the role of every stakeholder of an organisation. Hence, it provides an opportunity to assess their contribution in implementing LM.
- It tends to have more non-financial performance measures, which was also supported by Gunasekaran *et al*. (2000), who clarified that only simple non-financial performance measures would be most appropriate especially for SMEs.
- It has only very few qualitative performance measures compared to the quantitative performance measures.
- It attempts to provide a comprehensive coverage of performance measures for all functions within an organisation.

In earlier studies, performance measures were developed for individual functions within an organisation operating under a LM environment. For instance, Haque and Moore (2004) discussed the measures of performance (metrics) for the new product introduction process in the aerospace industry. They defined seven key metrics for enterprise-wide application and another eight metrics for process- or product family-specific application. Davies and Greenough (2003) discussed a case study about a lean manufacturer operating in the automotive sector that aims to measure the performance of the maintenance function. In all these papers, only the performance measures for individual functions under LM environment were identified. But, the proposed framework provides a comprehensive list of performance measures for most of the commonly available functions within an organisation, thereby supporting the concept of lean enterprise proposed by Womack and Jones (1996).

4.2.3 *Use and update of the performance measures for lean manufacturing systems*

This is the third and final phase of the PMS development methodology proposed by Bourne *et al.* (2000). But the steps associated with this phase are not completely followed, because the proposed framework is conceptual and it is not yet validated. Similarly, the concept of updating the performance measures is not dealt with, as it can be taken up only after the real-time implementation of the proposed framework. On the other hand, the applicability aspects (i.e., its use) of the new PMS for LM have been described from a theoretical perspective based on the literature support by evaluating the use of performance measures, particularly in SMEs.

A review of literature revealed few case studies which demonstrated the application of LM and JIT in SMEs. For instance, Gunasekaran and Lyu (1997) dealt with the implementation of JIT in a small company in Taiwan that produced different kinds of automobile lamps. In a recent study, Achanga et al. (2006) utilised a combination of comprehensive literature review, industrial visits to ten SMEs based in the east of the UK, apart from interviews of the key personnel and observation of the companies' practices, to highlight the degree of LM implementation and utilisation within these companies. Such case studies were reviewed to identify the performance measures of LM that were used in the SMEs. Table 4.4 shows the details of performance measures of LMS applicable in small- and medium-sized enterprises. Analysing these performance measures, it is found that most of the performance measures used by SMEs are also present in the proposed PMS for LMS, except a couple of measures such as schedule achievement (number of jobs done/number of jobs to be completed) and process capability (Gunasekaran *et al*., 2000). But a close look at these 'outliers' reveals that it can be considered equivalent to the measures such as, 'schedule adherence' and 'percentage of manufacturing process under statistical process control' identified in the proposed PMS.

Table 4.4: Details of performance measures of LMS applicable in small- and medium-sized enterprises

Gupta and Brennon (1995) • Production capacity • Travel time or distance travelled • Container size • Space savings • Production cycle time • House keeping • Customer lead time • Higher productivity	Gunasekaran and Lyu (1997) • Breakdown rate • Reduction in WIP inventory • Reduction in finished goods inventory • Reduction in raw material inventory • Improvement in quality • Improvement in productivity • Reduction of throughput time • Elimination of unnecessary activities (non value added activities) • Lower manufacturing cost
Karlsson and Ahlstrom (1997) • Use of sole sourcing • Distance of supplier • Supplier relationship	Abdul-Nour *et al*. (1998) • Standardization of component • Reduction of parts in BOM • Distance traveled within the assembly line • Cycle time reduction • Number of kanbans • Manufacturing lead time reduction
Gunasekaran *et al*. (2000) • Cycle time reduction • Labor productivity (output per person) • Productivity • On time delivery • Schedule achievement • Number of changeovers • Overtime needed • Number of complaints • Different number of products • Automation • Process capability	Seth and Gupta (2005) • Number of employees • Labor productivity (Output per person) • Value added time • Production lead time • WIP inventory • Finished goods inventory • Cycle time • Takt time • Overall product cost

Similarly, most of the performance measures identified from the frequency analysis were similar to the ones identified by Sharma *et al*. (2005), who conducted a survey of Indian SMEs from three western states of India to identify the important factors in performance measurement from the SME's point of view. Thus, it can be hypothesised that the proposed PMS framework of LMS can also be utilised with ease in SMEs. An interesting point to be noted here is that not all measures identified in the proposed framework should be used in the industries. Rather, the proposed framework can be customised suitably for use in either large companies or SMEs, by selecting the measures from Table 4.2, as per their LM implementation strategy. For example, if a SME implements Single Minute Exchange of Dies (SMED) and 5-S, it can use setup time, degree of housekeeping as performance measures apart from their existing measures such as profit, turnover, revenue, etc.

4.3 Conclusions

This chapter started with a claim that ‘there is no comprehensive PMS and metrics available for organisation that has implemented or about to implement the principles of LM’. Hence, the focus of this chapter is to propose a conceptual framework of PMS for LMS. To accomplish this, a literature review has been carried out, which helped in identifying the methodology for developing a PMS, which had three phases. In the first phase, to design the performance measures of LM, a frequency analysis of 35 papers related to LM is carried out and a comprehensive listing of 280 performance measures are identified. After subsequent analyses, around 90 performance measures are selected, which was used for developing the PMS for LMS. As part of the second phase of implementing the performance measures, the taxonomy for the identified performance measures for LMS based on the competitive priorities is established apart from establishing the relationship between performance measures and elements of LM. The performance measures of LMS are also classified with respect to the different business processes of an organisation. After such classifications, the PMS for LMS is proposed based on the most commonly used framework for PMS – the BSC, which was modified suitably to include the perspective of suppliers. Though the third phase of the methodology has not been completely implemented, the case studies pertaining to implementation of JIT or LM in SMEs were reviewed to analyse the performance measures that were used by various SMEs. From this review, it was found that most of the performance measures identified from the case studies were also present in the proposed framework. Thus, it can be concluded that the proposed framework can be suitably applied in either a large organisation or a SME by customising the same, depending upon the circumstances and implementation of LM practices or elements. However, it should be remembered here that the proposed PMS framework for LMS is highly conceptual and it is developed based on the theoretical deliberation available in the literature. Hence, there exists a lot of scope to further this research:

- To get a realistic view of the performance measures, an empirical survey within the companies that have implemented LM can be carried out as it would help in validating the identified performance measures. Apart from this, it would have revealed which of the measures are highly followed, which are least followed and which of the measures are missing.
- Similarly, in addition to the survey, the proposed PMS framework can be validated by conducting a case study.

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Chapter 5

Justification of Lean Manufacturing Systems

5.1 Introduction

The decision of selecting a suitable manufacturing system is highly strategic in nature. It requires a detailed analysis from multiple perspectives. Implementing such systems is very expensive and relative investments tend to be irreversible. Further, it will have a long-term impact on the organisation's survival. Therefore, selecting an alternative manufacturing system as a means to improve and maintain the competitive advantage requires proper justification. One school of thought concerning justification of Advanced Manufacturing Systems (AMS) states that if manufacturing is to be considered as a competitive tool then justification has to become more of a policy decision rather than an accounting or financial procedure, while another school of thought states that advanced manufacturing systems can be 'sold' to the top-level management only if all relevant costs and benefits are quantified and presented in an easy-to-understand format (Kodali and Sangwan, 2004). For example, Boaden and Dale (1990) have expressed that the justification of the Computer Integrated Manufacturing (CIM) concept should be undertaken in order to demonstrate to an organisation's senior management team that CIM is a worthwhile venture. They also explained that in the case of concept justification, the development of a clear understanding of CIM itself and its implications for the organisation is a vital factor, which supports the former school of thought. On the other hand, the work of Chen *et al.* (1998) supports the latter school of thought, which explains that justification should be based on costs and benefits. They have commented that the modelling analysis of the economic view is very important for industrial people to accept the CIM system architecture for their system integration. However, they claimed that the estimation method for intangible factors would be the main obstacle for its success. Similarly, Kaplan (1986) too observed that the economic justification process has long been identified as the biggest hurdle in the adoption of advanced automated manufacturing systems.

Thus, the managers who are considering the introduction of Lean Manufacturing Systems (LMS) in their organisations not only have to identify its costs and benefits, but also have to understand and plan its implementation apart from ensuring that the use of LMS will be a viable alternative. The literature related to justification over the long run, has been inundated with a large number of methodologies and evaluation techniques, which look promising for the economic justification process for AMS (Bennett and Hendricks, 1987; Canada, 1986; Curtin, 1984a, 1984b; Meredith and Suresh, 1986; Michael and Millen, 1985; Moerman, 1988; Parsaei *et al.*, 1988; Parsaei and Wilhelm, 1989; Zahran *et al.*, 1992; Primrose, 1999). Several traditional financial techniques such as the Payback Period (PP), Average Rate of Return (ARR), Internal Rate of Return (IRR), Net Present Value (NPV), Break Even Point (BEP), etc. have been proposed that are exhaustive in nature and require hard-core quantitative data that may be difficult to retrieve or formulate. Today, most major organisations are struggling with their traditional investment justification procedures because they are either wrongly applied or the information included in the calculations is inadequate for the multifaceted problems being tackled (Kodali and Sangwan, 2004).

The use of Multi-Attribute Decision-Making (MADM) models for the selection or justification of manufacturing systems supports the former school of thinking i.e., justification has to become more of a policy decision rather than an accounting or financial procedure. It is very normal to make a decision of choosing an manufacturing system by analysing the cost aspects. But these decisions are part of a manufacturing strategy of an organisation. Due care should be taken to analyse such problems from various perspectives. Hence, apart from the cost, the problem should be analysed from the following perspectives:

- Capability of alternative manufacturing systems – in other words, based on the tools, techniques, practices, procedures and principles (i.e., components) of alternate manufacturing systems
- The impact of alternative manufacturing systems on the organisation as a whole - i.e., how each function within an operation's department is affected by the implementation of alternate manufacturing systems
- The impact on the stakeholders of the organisation – i.e., how these alternative manufacturing systems will affect the top management, employees, suppliers, customers and shareholders
- The perceived benefits for each of the alternate manufacturing systems
- The impact of implementing alternative manufacturing systems on the performance measures of the organisation

To demonstrate the analysis from the above-mentioned perspectives, a case study is presented in which the top management of the organisation wants to implement AMS such as LMS and CIMS.

5.2 An Overview about the Case Organisation

The organisation considered for case study is a medium-sized valve manufacturer located in the north-western part of India, which is one of the first tier suppliers to the pressure vessel manufacturers. It produces different types of valves (relief valves, flow control valves, etc.) and its associated components, which are predominantly used in pressure vessels. Table 5.1 presents a summary about the case organisation.

Table 5.1: A summary about the case organisation

Industry characteristics	Details about the case organisation
Industry type	Discrete type manufacturing
Industrial sector	Power sector
Product	Different types of valves and its associated components
Product type	Critical components
Production volume and variety	Low volume and high variety
Company vision	To be a star performer and market leader
Mission	Continuous improvement of products, processes and people

Following are some of the problems that are faced by the organisation:

- **High variety and low volume:** The design of valves is highly varying because it is customised for the type of pressure vessels built. Hence, the variety is high and naturally, the number of associated components and spares is also very high. On the other hand, the volume for each type of valve is low, which naturally increased the number of Stock Keeping Units (SKU) for the organisation. In addition to this problem, most of the valves and its associated parts differ in terms of dimensions, design (shape) and materials used, which makes the organisation to carry out a lot of setup and material handling activities.
- **Quality concerns**: Valve is considered to be one of the critical components in the pressure vessel assembly as it is concerned with the safety of the product as well as that of user. Hence its components have to be precisely machined and there is no room for even a slight deviation from the specifications. In the past, the company had faced few quality problems and some of their lots were returned back even for a slight deviation from the specifications resulting in significant losses. For instance, once a lot worth Rs. 12 Lakhs was rejected, as it was not conforming to the specifications.
- **Delivery**: Since the requirement of power is growing in India, the market for pressure vessels is also increasing. As a cascading effect, the demand for the valves and its associated components is also increasing. Hence, the company

was expecting more orders from the customers; however, the orders were not appreciably increasing as expected by the company. On analysing the problem, they found that the delivery performance of the company was not well appreciated by their clients. Even though they made earnest efforts to supply a fairly good quality product, they had problems in meeting the deadlines and target. They found that their on-time delivery record was just 75%.

- **High cost**: Adding fuel to their existing internal problems, the number of competitors in the valve market has started to increase resulting in increased cost pressure for the organisation. Further, in the last two years, the material cost, labour cost and energy costs were also spiralling upwards, but the clients were emphasising on continuous price reduction every year as per their long-term contract.

Analysing the production process, the manufacturing of valves and other components are currently manufactured with the help of semi-automatic, general purpose machines and few fully automatic turning and machining centres. The number of people on roll at present is around 80. Though the valve manufacturer is poised for growth, the management is worried about the above-mentioned problems. The managers in the top level would like to make changes and transform their existing or Traditional Manufacturing Systems (TMS). They are in the process of laying out strategies and policies to become a world-class valve manufacturer within the next 5 years. They were contemplating on the following alternatives to resolve the above-mentioned problems:

- A highly sophisticated and technically intensive CIMS and
- A highly practical and management oriented LMS

Though it is a medium-sized enterprise, the managers have identified CIMS as one of the alternatives based on the existing technology they possess and from the perspective of economy of scale, assuming an increase in demand in the future. The organisation is currently using the following computerised systems:

- **Computer Aided Design (CAD)**: They use software packages such as AutoCAD for the purpose of designing the tools, fixtures and other material handling systems apart from generating the drawings and documents for their products.
- **Computer Aided Manufacturing (CAM)**: They also use Computer Numerical Control (CNC) machines as they possess a couple of turning and machining centres apart from semi-automatic machines. In addition to this, they have also incorporated local automation for some machines as part of their productivity improvement activities carried out earlier.
- **Computer Aided Production Planning and Control (CAPPC)**: They perform the production planning and scheduling activities such as Material Requirements Planning (MRP) and order processing using standalone planning software developed indigenously, which utilises spreadsheet applications such as Microsoft Excel and Access. Being an industrial supplier, they did not require any high-end ERP or Supply Chain Management (SCM) software for order processing, tracking and monitoring and currently, they are also not indulging in any sort of e-business.

On the other hand, the top management was also open to implement management philosophies such as LMS. This is because, as a first tier supplier to pressure vessel manufacturers, they have obtained the ISO 9000 certification, which have shown them good results in the past as they could standardise various processes apart from reducing defects. Hence they were contemplating on implementing such effective manufacturing management practices and philosophies. But the issue here is ‘how to choose between LMS and CIMS?’ As described earlier, such decision problems require analysis from multiple perspectives. Apart from that, various factors and sub-factors should be considered in arriving at proper decisions. Hence, such problems can be solved using the application of MADM models.

5.3 Development of Multi-Attribute Decision Making Models for the Justification of Lean Manufacturing Systems

There are numerous MADM models available in the literature, which are used under different situations. Some examples are Elimination and Choice Translating Reality (ELECTRE), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Joint Probability Decision-making (JPDM), Equivalent Cost Analysis (ECA), Multi-Attribute Utility Theory (MAUT), Analytic Hierarchy Process (AHP), Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE), Performance Value Analysis (PVA), etc. Amongst these models, the most commonly used model is AHP, which was developed by T. L. Saaty. The AHP methodology as explained in Saaty's (1980) book has three main steps: structuring the hierarchy, performing paired comparisons between elements/decision alternatives and synthesizing the results. AHP would be appropriate whenever a goal is clearly stated and a set of relevant criteria and alternatives are available. When there are numerous criteria involved, AHP is one of the very few MADM approaches capable of handling so many criteria, even if some of the criteria are qualitative. Even for the current problems, AHP can be applied. But it was not utilised because of the following inherent limitations identified by Sarkis and Talluri (2002):

- Each element in the hierarchy is supposed to be independent, and a relative ratio scale of measurement is derived from pair-wise comparisons of the elements in a level of the hierarchy with respect to an element of the preceding level. However, in many cases, there is interdependence among criteria and alternatives.

- AHP employs a unidirectional hierarchical relationship among decision levels, which implies no influence of lower levels on the upper levels. But it may be possible for the components of the two levels to influence each other (feedback). These relationships cannot be evaluated using AHP.

To overcome these shortcomings, various other MADM models have been used in solving the decision problem of the case organisation. For the first two perspectives – namely ‘tools, techniques, practices, procedures and principles (i.e., components) of alternative manufacturing systems’ and ‘the impact of alternative manufacturing system on the organisation’, an ANP model is developed. For the next two perspectives – i.e., ‘the impact of alterative manufacturing systems on the stakeholders of the organisation’ and the ‘perceived benefits for each of the alternative manufacturing systems’, a PROMETHEE model, which work based on the outranking method is developed. AHP is not utilised because it is unable to handle decision problems that are subjected to constraints (Pandey and Kengpol, 1995). Apart from this, some of the authors such as Macharis *et al.*, (2004), Albadvi *et al.*, (2007) have compared PROMETHEE with AHP and found that:

- The PROMETHEE I does not aggregate good scores on some criteria and bad scores on other criteria as in AHP
- It has less pair-wise comparisons when compared to AHP and
- It does not have the artificial limitation of the use of the 9-point scale for evaluation as in AHP

Similarly, L’Eglise *et al.* (2001) explained that they chose the PROMETHEE for its ease of application, its efficiency and its interactivity as it has a transparent influence of each criterion and weight on the solution. According to them, another main advantage of this evaluation methodology is that it is based on the importance of a performance difference between two solutions, which is best describing whether a solution should be preferred to another one. Considering all these factors, PROMETHEE was chosen as the decision aid for these perspectives. Finally, for the last perspective – ‘impact of implementing alternative manufacturing systems on the performance measures of the organisation’, the - a simple model based on the PVA is developed, as it considers the performance and value of the alternative manufacturing systems.

5.3.1 Development of analytic network process for the justification of lean manufacturing systems

ANP developed by Saaty (1996) is a MADM model which allows for the consideration of the interdependencies among and between different levels of attributes and alternatives. It is a more general form of the AHP approach, incorporating feedback and interdependent relationships among decision attributes and alternatives. It is used for modelling more complex decision environments. ANP does involve representing relationships hierarchically but does not require a strict hierarchical structure as AHP. According to Meade and Sarkis (1999), it is also called as ‘model with feedback’. Table 5.2 shows the differences between AHP and ANP.

Table 5.2: Differences between AHP and ANP

AHP	ANP
It is conceptually easy to use; it is decisionally robust so that it can handle the complexities of real world problems (Saaty, 1980)	The ANP is built on the AHP and it is a more generalized approach for modelling more complex decision environments (Saaty, 1996)
A hierarchy is linear, with a goal in the top level, and the alternatives in the bottom level	The ANP is a nonlinear structure that deals with sources, cycles, and sinks
AHP assumes that the system’s elements are not correlated and are uni-directionally influenced by a hierarchical relation	ANP approach eliminates these limitations and allows a feedback relationship among the criteria at different levels and interdependence between the criteria at the same level through the development of a “*Super matrix*” (Saaty, 1996)
AHP assumes that the main elements and sub-elements within main elements are independent of each other	By allowing for dependence, the ANP goes beyond the AHP by accounting for independence among the elements and sub-elements. The ANP deals with dependence within a set of elements (inner dependence), and among different sets of elements (outer dependence) (Saaty, 1999)

AHP	ANP
AHP models a decision making framework that assumes a unidirectional hierarchical relationship among decision levels. The top element of the hierarchy (apex) is the overall goal for the decision model. The hierarchy decomposes from the general to a more specific attribute until a level of manageable decision criteria is met.	ANP does involve representing relationships, but a looser network structure makes possible the representation of any decision problem without concern for what comes first and what comes next as in a hierarchy (Saaty, 1999)
In the AHP approach there are one-way hierarchical arrows that show a dominance or control of one level of attributes over another set of sub-components or attributes.	In the ANP approach, with the allowance of interdependencies occurring among attributes and attribute levels, the graphical representation may include two way arrows (or arcs) among levels. A looped arc is used to show the interdependency relationships that occur within the same level of analysis. The directions of the arcs signify dependence, arcs emanate from an attribute to other attributes that may influence it.

ANP finds applications in various fields. It has been used by numerous authors for solving different types of problems. Meade and Sarkis (1999) used ANP as the decision making methodology for the evaluation of alternatives (e.g. projects) to help organisations become more agile with a specific objective of improving the manufacturing business processes. In order to evaluate alternatives that impact the business processes, a networked hierarchical analysis model based on the various characteristics of agility were proposed. Similarly, Cheng and Li (2004) applied ANP for contractor selection, while Agarwal, *et al.* (2006) used ANP based approach for modelling the metrics of lean, agile and leagile supply chain. They explored the relationship among lead-time, cost, quality, and service level and the leanness and agility of a supply chain in fast moving consumer goods business and concluded with the justification of the framework, which analysed the effect of market winning criteria and market qualifying criteria on the three types of supply chains (lean, agile and leagile). In the above described cases, the authors have used ANP as a standalone decision making tool. On the other hand, some researchers have used ANP in conjunction with another tool or technique. For example, Karsak, *et al.* (2002) combined goal programming approach with ANP for product planning in Quality Function Deployment (QFD). Table 5.3 provides a summary of the literature regarding the application of ANP in various fields. One of the reasons for using ANP for variety of applications can be due to the fact that it is capable of solving problems when complex interrelationships between the attributes are involved. But till now, there is no application of ANP in the field of LM and in particular it is not being used to make a decision of selecting a manufacturing system.

5.3.1.1 Algorithm

For the ANP study, the president of the organisation and the operations manager participated in addition to the academicians, in which one of them was assigned the job of recording the weight values during pair-wise comparison. The pair-wise comparison weight values for the study were gathered through real-time meeting and discussions. The participants deliberated about the weight values before agreeing upon the given values. Saaty (1999) discussed in detail about the steps to be followed in ANP. It consists of mainly six stages and each stage has different steps associated with it.

Stage 1: Model construction and problem structuring

Step 1. Identification of control criteria, clusters, elements and alternatives.

The first step in developing the ANP model is to structure the decision problem into goal, control criteria, clusters, elements and alternatives. In our case problem, the main goal or objective is to select the best manufacturing system which can improve the performance of the case organisation.

Table 5.3: A summary of the literature regarding the application of ANP in various fields

S. No.	Authors	Year	Area of Application	Remarks
1.	Meade and Sarkis	1999	Agile manufacturing	They used ANP for the evaluation of alternatives (e.g. projects) to help organisations become more agile, with a specific objective of improving the manufacturing business processes.
2.	Partovi	2001	Strategic services	This paper proposed an analytical method for quantifying "strategic service vision". This model starts with two matrices in series to relate market segments, service concepts and various processes. In addition, AHP, a decision making tool, is used to determine the intensity of the relationship between the row and column variables of each matrix, while ANP is used to determine the intensity of synergy effects among column variables. Finally, benchmarking is used to suggest potential breakthroughs in service delivery.
3.	Karsak *et al.*	2002	Product design	They proposed a 0-1 goal programming methodology that includes importance levels of Product Technical Requirements (PTRs) derived using the ANP, cost budget, extendibility level and manufacturability level goals to determine the PTRs to be considered in designing the product.
4.	Sarkis and Sunderraj	2002	Identifying location for an Electronic Company	This paper illustrates the decision of locating a repair-parts warehouse for Digital Equipment Corporation (DEC). The manager of DEC has to consider not only the long-term strategic and qualitative issues, typical of such problems, but they had to ensure that the facility that is to be located will be viable from a freight-cost (or quantitative) perspective. Hence the ANP was combined with an optimization model to conduct a comprehensive evaluation of various location to determine the hub location for DEC.
5.	Meade and Sarkis	2002	Reverse logistics – selecting a third-party reverse logistics providers	With the development of reverse logistics concepts and practice, the selection of partners for the specific function of reverse logistics support becomes more important. However, the factors that play an important role in selecting a third-party reverse logistics provider differ from the factors used for traditional supplier selection. Hence, this paper demonstrates how these new factors can be included for the selection of partner by modelling it using a ANP decision-making framework
6.	Meade and Presley	2002	R & D project selection	This paper used the ANP as a model to evaluate the value of competing R&D project proposals, which includes in its decision levels, the actors involved in the decision, the stages of research, categories of metrics, and individual metrics. The paper concluded with a case study, describing the implementation of this model at a small high-tech company.
7.	Yurdakul	2003	Long-term performance measurement	This paper provides a multi-criteria performance measurement model (i.e., ANP) to measure a manufacturing firm's performance in terms of the areas of success. The performance evaluation model developed here incorporates the competitive strategies and interdependence between the system attributes in its hierarchical structure and achieves a more realistic and accurate representation of the firm's long-term performance.

S. No.	Authors	Year	Area of Application	Remarks
8.	Shiau *et al.*	2003	Evaluation of sea-port marketing strategies	This study puts forward an integrated model of hierarchical structural analysis (HSA) and ANP, for evaluating the marketing strategy of seaport. The integration model of HSA and ANP has combined advantages as quantification, pair-wise comparison, hierarchical structure, and feedback, can make up for the deficiency of SWOT analysis, AHP, and even that of ANP.
9.	Agarwal and Shankar	2003	E-supply chain	In this paper, alternatives for trust development among buyer and supplier have been identified and evaluated to analyse the trust in an e-enabled supply chain using a framework of ANP.
10.	Cheng and Li	2004	Contractor selection in construction industry	Contractor selection is one of the main decisions in construction industry. In most studies of contractor selection, selection criteria are assumed to be independent of each other, but in reality, it involves interdependencies between elements of the same cluster or different clusters. Hence ANP has been used as a decision support system to help in making a decision of selecting a suitable contractor in the construction industry
11.	Tran *et al.*	2004	Environmental planning	This paper used ANP in integrating environmental indicators to rank eco systems and suggest cumulative impacts by combining ANP with Principal Component Analysis (PCA).
12.	Choudhury *et al.*	2004	Pharmaceutical supply chain	They utilised the ANP in a pharmaceutical company having 14 production locations and 22 branching/clearing and forwarding agents to optimize the total supply chain costs and also to suggest the measures realizing improvement in turnover and reduction of carrying costs.
13.	Raisinghani and Meade	2005	Knowledge management in an organization	In this paper, ANP was used to determine which construct of Knowledge Management is most important based on an organisation's performance criteria, dimensions of agility and supply-chain drivers.
14.	Hassan and Kikuo	2005	Flexible manufacturing systems	They described a model for the selection of an appropriate design method of a Computer Integrated Flexible Manufacturing Systems (CIFMS) utilizing the ANP within a Mixed Integer Goal Programming (MIGP) model. Since the selection process is multi-goal and has both integer and non-integer variables, ANP is combined with the use of a MIGP model for optimization.
15.	Bayazit	2006	Vendor selection	He noted that supplier selection problems are multi-objective problems which have many qualitative and quantitative concerns. Hence, in this study, he used an ANP model in evaluating the supplier selection process to help the managers.
16.	Agarwal *et al.*	2006	Supply chain performance	The paper explores the relationship among lead-time, cost, quality, and service level and the leanness and agility of a case supply chain in fast moving consumer goods business. It concluded with the justification of the framework, which analysed the effects of market winning criteria and market qualifying criteria on the three types of supply chains: lean, agile and leagile using ANP.

The alternatives considered are:

- Existing or Traditional Manufacturing Systems (TMS)
- Computer Integrated Manufacturing Systems (CIMS) and
- Lean Manufacturing Systems (LMS)

The selection of the best manufacturing system is based on the competitive priorities – i.e., the alternate manufacturing system should help the organisation in improving its competitive position by ensuring that it performs better in terms of every competitive priority. In ANP terminology, the following competitive priorities are referred as control criteria: Productivity (PRO), Quality (QUA), Cost (COS), Delivery (DEL), Morale (MOR), Flexibility (FLE) and Innovation (INN).

Next, to identify the clusters and elements, it is necessary to understand about the alternative manufacturing systems. Marri *et al.* (1998) discussed about the components of CIMS. He quoted that

> *"CIM is concerned with providing computer assistance, control and high-level integrated automation at all levels in manufacturing (and other) industries, by linking islands of automation into a distributed processing system. These isolated automated production islands include NC machines, distributed numerical control (DNC), CNC, CAD, CAM, MRP, manufacturing resource planning (MRP II), computer-aided process planning (CAPP), automated storage, computer controlled material handling equipment, and robotics".*

Similarly, in another study, Gunasekaran *et al.* (2001) analysed the implications of organisation and human behaviour due to implementation of CIM in SMEs and explained that implementing CIM requires cross-functional co-operation, and involvement of employees in product and process development. Apart from this, they highlighted that a successful CIM initiative in SMEs must have top management involvement and commitment and a CIM compatible organisational infrastructure which includes requisite skills, appropriate training and education, and adequate incentives and rewards. Similarly, a thorough understanding of LMS is carried out in Chapter 3. Thus, to establish these manufacturing systems in the case organisation, the corresponding components of these alternative manufacturing systems has to be implemented. A comparative analysis of the components/elements of both these manufacturing systems reveal that a separate set of elements for CIMS were not required as it was felt that most of the components of CIMS were also present in the LMS or TMS. Some of the elements of CIMS were already put into use (in the TMS) by the case organisation. For example, use of CAD, CAM, automation etc. were already present in the existing system and they were also part of the LMS. Similarly, the organisational and human related aspects for implementing CIMS and LMS are also the same as explained by Cheng and Podolsky (1993) and Gunasekaran *et al.* (2001). Finally, Table 5.4 shows the list of elements considered for the analysis. Implementing any of the alternative manufacturing systems considered above will affect the operations department of the case organisation and the decision areas associated with it.

Table 5.4: List of elements considered for the analysis

Function/Decision area	**Element**	**In short**
Product Design		**PRD**
	Design Simplification	DSN
	Use of Standardized Parts	USP
	Modular Design	MDN
	Concurrent Engineering	CEG
	Design for Manufacturing	DFM
	Platform Based Design	PBD
	CAD/CAM	CAD
	Use of Common Parts	UCP
Process Planning		**PRP**
	Cellular Manufacturing or Group technology	CEM
	New Process or Equipment	NPE
	Use of Multiple Small Machines	UMS
Facilities and Layout		**FAL**
	Workload Balancing	WLB
	U-Shaped Cell	USC
	One Piece Flow	OPF
	Standardization of Work Processes	SWP
Purchasing		**PUR**
	Sole Sourcing	SOS
	Frequent Multiple Small Lot Delivery	FMD
	Supplier Training and Development	STD
	Long term Supplier Relationship	LSR
	Information Sharing with Suppliers	ISS

Function/Decision area	Element	In short
Production Planning and Control		**PPC**
	Small Lot Production	SLP
	Use of MRP/ERP	ERP
	Use of EDI with suppliers	EDI
	Kanban System	KAN
	Pull Production	PUL
	Mixed Model Manufacturing	MMM
	Production Smoothing	PRS
Manufacturing		**MAN**
	Automation	AUN
	Visual Control	VIC
	Single Minute Exchange of Dies	SMD
	Andon and Jidoka	ANJ
	Standard Containers	STC
	Maintain Spare Capacity	MSC
	Focused Factory Production	FFP
Continuous Improvement		**COI**
	Housekeeping or 5S	HOK
	Use of Problem Solving Tools	PST
	Work-In-Process Inventory Reduction	WIP
	Value Stream Mapping	VSM
	Reduction of Safety Stock	RSS
	Cycle time and Lead time Reduction	CTR
Quality Control		**QCO**
	Statistical Process Control	SPC
	Defects at Source through successive check	DES
	Pokayoke or Defect Prevention	POK
	Customer Feedback	CUF
	Quality Circles	QUC
Maintenance		**MAI**
	Autonomous Maintenance	AUM
	Preventive Maintenance	PRM
	Maintenance Prevention	MAP
	Safety Improvement	SAI
Human Resource Management		**HRM**
	Multi Skilled Workforce	MSW
	Employee Empowerment and Participation	EEP
	Flat Organisation Structure	FOS
	Rewards and Recognition	RER
	Cross Functional Team working	CFT
	Suggestion Schemes	SUS
	Job Enlargement or Nagara System	JOE
	Communication Between Employees	COE
	Multi Functional Training	MFT
	Job Rotation or Flexible Job Responsibilities	JOR

Hence, it was felt that the evaluation of alternative manufacturing systems can be carried out from this perspective. Russell and Taylor III (2006) identified the different functions or activities (decision areas) carried out by an operations department, which include: operations strategy, product design, process planning, facilities and layout, purchasing, production planning and control, quality control, maintenance, human resources, logistics and supply chain management etc. Figure 5.1 shows the typical functions or activities (decision areas) carried out by an operations department.

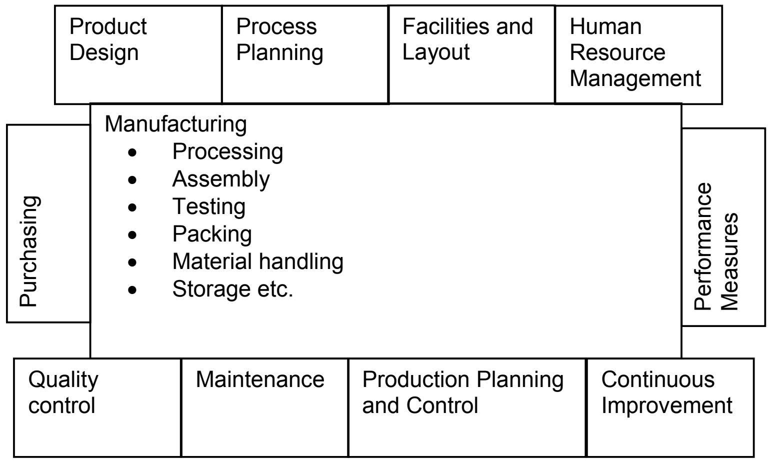


Figure 5.1: Typical functions or activities (decision areas) carried out by an operations department

Hence, the elements listed in Table 5.4 are categorized according to these decision areas. Some of the decision areas like capacity, information support systems, etc. are not considered for analysis separately, as the decisions or activities related to it are already considered in other decision areas. For example, decisions such as use of software packages related to CAD/CAM or ERP fall under the decision area of information systems. But, these decisions were considered to be a part of product design and production planning and control activities of operations department, which require the use of CAD/CAM/CAE and ERP respectively. According to the ANP terminology, the the decision areas as shown in Table 5.4 are considered to be the clusters - i.e., the entries that are highlighted in bold in Table 5.2 represent the cluster name, while the remaining attributes, which are grouped under each decision area represent the elements.

Step 2. Represent the relationships of control criteria, clusters, elements and alternatives in the form of a model.

The model can be structured as a network model as shown in Bayazit (2006) or as a hierarchical network model as shown in Agarwal *et al.* (2006) and Sarkis and Sunderraj (2002), with the goal at the top and the alternatives at the bottom, similar to the hierarchical structure of AHP. In the hierarchical structure, the influence of a higher level on a lower level is shown by a down arrow (↓), while the interdependencies within a component or within a level is shown with a looped arc. The control criteria, clusters and elements identified for the case problem are represented in the form of a hierarchical network. Figure 5.2 shows the main hierarchical network representation of the ANP model for the selection of best alternative manufacturing systems.

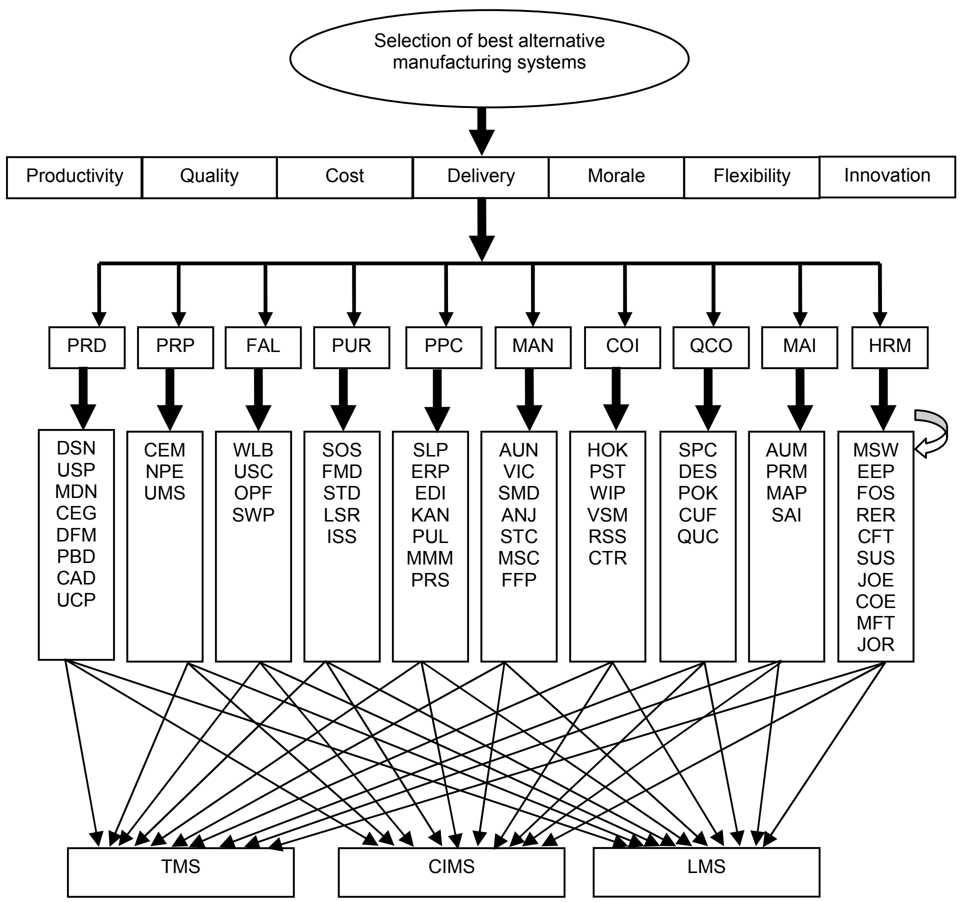


Figure 5.2: Main hierarchical network representation of the ANP model for the selection of best alternative manufacturing systems

In this case, the goal is to select the best alternative manufacturing system. The selection will be based on the competitive priorities of the organisation which are considered as the ‘control criteria’. In organisations, the top management gives priorities or importance ranking for the control criteria during the strategic decision process which will affect the decisions taken downstream. In other words, the control criteria have dominance over the different decision areas of the operations department. Each decision area work according to the competitive priorities set forth by the top management. The decision areas may adopt certain practices or procedures or use certain tools, techniques, to achieve the objectives of competitive priorities (control criteria). These tools, techniques, practices procedures etc. are called as ‘elements’. These elements are grouped according to the decision areas it affects. Hence, the decision areas are called as clusters. In addition to this, there exist some interdependencies between the elements within the clusters. Hence a looped arc is shown in the figure along with a clear dependence relationship between elements. For example, in the facilities and layout cluster, to obtain a ‘continuous one piece flow’, proper ‘workload balancing’ is required. ANP also uniquely captures the interdependencies at different levels of the control hierarchy as well as interdependencies that are inherited among different hierarchies. Based on this, it is possible to construct ‘seven’ sub-networks in the ANP model of our problem - one for each control criterion, namely, productivity, quality, cost, delivery, flexibility, morale and innovation. Figure 5.3 shows a sample sub-network representation of a control criterion - productivity.

Stage 2: Pair-wise comparisons between element and cluster levels

Pair-wise comparisons are carried out between the clusters as well as the elements to find out the importance of a cluster or element over the other cluster or element with respect to the corresponding control criteria. A scale having a range of 1 to 9, similar to the one used in AHP will be used for comparing where 9 indicates overwhelming dominance and 1 indicates equal importance. This stage consists of the following steps:

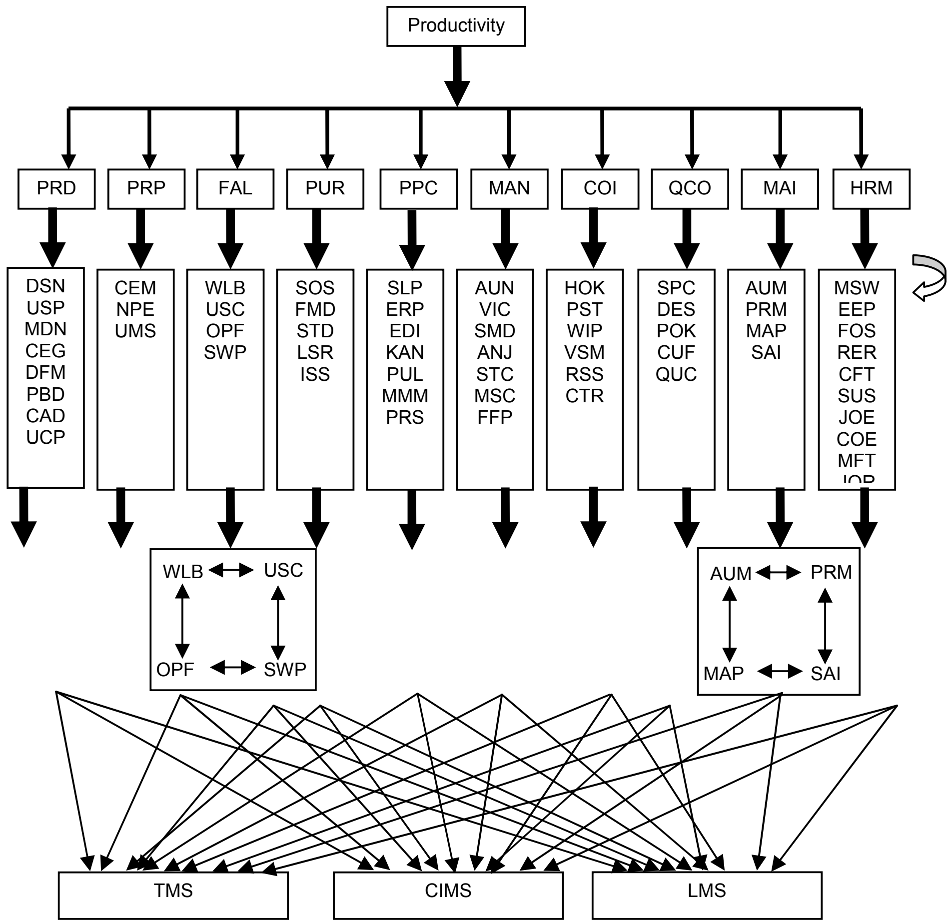


Figure 5.3: Sub network representation for the control criterion – 'productivity'

Pair-wise comparison at element level

Step 3. Pair-wise comparison is carried out between the elements with in a cluster with respect to one of the control criterion. A matrix will be formed and the relative weights of each cluster/element is obtained as the eigenvector (eVector) from the matrix, by using the formula

$$w_i = \frac{\sum_{i=1}^{I} \left(\frac{a_{ij}}{\sum_{j=1}^{J} a_{ij}} \right)}{J} \qquad \text{- (5.1)}$$

where, w_i = weight of the cluster/element ‘i’,

j = index number of columns, and

i = index number of rows.

For example, in this problem, a pair-wise comparison is carried out between the elements of one of the clusters – process planning (PRP) with respect to one of the control criteria – productivity (PRO). Table 5.5 shows a sample pair-wise comparison matrix of elements within the cluster PRP (process planning) with respect to the control criterion PRO (productivity). For obtaining the relative weights in Table 5.5, the pair-wise comparisons are presented in the form of simple questions. A sample question is as follows: “With respect to productivity, within the process planning cluster, what is the relative importance of cellular manufacturing (CEM) with respect to new process and equipment (NPE)?” The answer was 5 on a scale of 1–9 and this is entered in the second row (CEM), third column (NPE) in Table 5.5, while it’s reciprocal is entered in the second row second column. In a similar manner, the entire matrix is formed.

Table 5.5: A sample pair-wise comparison matrix of the elements within the cluster PRP (process planning) with respect to the control criterion PRO (productivity)
(Inconsistency index: 0.0824)

	CEM	NPE	UMS	eVector (A^D_{kja})
CEM	1.00	5.00	3.00	0.6267
NPE	0.20	1.00	0.25	0.0936
UMS	0.33	4.00	1.00	0.2797

Step 4. In a similar fashion, pair-wise comparisons were carried out between elements of other clusters, with respect to the same control criterion. At this

stage, for a given control criterion, the number of pair-wise comparison matrices will be equal to the number of clusters.

In this case, for the productivity cluster, nine more pair-wise comparison matrices will be formed for the remaining decision areas such as product design, facility and layout, quality control etc. apart from the one already formed for process planning. These matrices are not shown due to space restrictions. Thus in total, 10 matrices will be formed for the productivity cluster alone.

Step 5. Similar to the above steps (i.e., steps 3 and 4), the pair-wise comparisons are carried out between elements of clusters with respect to the remaining control criteria. At the end of this step, the number of pair-wise comparison matrices formed will be equal to the product of number of control criterion and number of clusters

For example, the pair-wise comparisons are again carried out between the elements of process planning, but with respect to the other control criteria say, quality. There are seven control criteria and under each control criteria 10 pair-wise comparison matrices are formed. Hence, there will be 70 pair-wise comparison matrices formed at the end of this stage. The eVectors obtained from these matrices will be used in Stage - 5 as 'A^{D}_{kja}', where 'k' represents the elements, 'j' – component and 'a' represents control criteria.

Pair-wise comparison at cluster level

Step 6. The pair-wise comparison matrix is developed to determine the importance of clusters with respect to each control criterion. Similar to step 3, using the equation 5.1, the eVectors are calculated.

For instance, the pair-wise comparison matrix is formed by comparing the clusters (i.e. decision areas) like product design, process planning, facility and layout, quality control, etc., with respect to the control criterion – productivity. Table 5.6 shows the pair-wise comparison for the relative importance of clusters (decision areas) with respect to the control criterion PRO (productivity).

Table 5.6: Pair-wise comparison for the relative importance of the clusters (decision areas) with respect to the control criterion PRO (productivity)
(Inconsistency index: 0.0907)

	COI	FAL	HRM	MAI	MAN	PPC	PRD	PRP	PUR	QCO	eVector (P_{ja})
COI	1.00	0.14	0.33	0.20	0.25	5.00	2.00	0.20	6.00	0.50	0.0499
FAL	7.00	1.00	5.00	3.00	4.00	6.00	9.00	0.33	5.00	2.00	0.2206
HRM	3.00	0.20	1.00	0.50	1.00	5.00	3.00	0.25	4.00	0.50	0.0742
MAI	5.00	0.33	2.00	1.00	0.33	4.00	3.00	0.50	6.00	0.50	0.0956
MAN	4.00	0.25	1.00	3.00	1.00	6.00	5.00	0.33	7.00	0.25	0.1108
PPC	0.20	0.17	0.20	0.25	0.17	1.00	2.00	0.25	3.00	0.25	0.0289
PRD	0.50	0.11	0.33	0.33	0.20	0.50	1.00	0.20	2.00	0.25	0.0250
PRP	5.00	3.00	4.00	2.00	3.00	4.00	5.00	1.00	7.00	3.00	0.2412
PUR	0.17	0.20	0.25	0.17	0.14	0.33	0.50	0.14	1.00	0.14	0.0172
QCO	2.00	0.50	2.00	2.00	4.00	4.00	4.00	0.33	7.00	1.00	0.1360

Step 7. Similarly the clusters are again compared with each other with respect to the other control criteria like quality, cost, flexibility, etc. The number of additional matrices formed in this stage will be equal to the number of control criteria and the corresponding eVectors of these matrices are used as 'P_{ja}' values in Stage - 5, where 'j' represents the component and 'a' representing control criteria.

In this problem, seven matrices are formed because we have considered 7 control criteria. Up to this stage, 77 (70+7) matrices in total have been formed.

Pair-wise comparison at control criteria level

Step 8. This step results in forming additional matrix to determine the importance of control criteria with respect to the goal. Again similar to step 3, pair-wise comparison matrix is formed for the control criteria and using equation 5.1, the eVectors are calculated. This eVector will be used in Stage 6 for the calculations of weighted index.

Table 5.7 shows the pair-wise comparison matrix for the relative importance of control criteria (competitive priorities) with respect to the goal. The obtained eVectors represents the relative importance of the control criteria with respect to the main goal of the problem. With this additional matrix the total number of matrices has increased to 78.

Table 5.7: Pair-wise comparison for the relative importance of control criteria (competitive priorities) with respect to the goal

(Inconsistency index: 0.0725)

	COS	DEL	FLE	INN	MOR	PRO	QUA	eVector
COS	1.00	4.00	5.00	6.00	3.00	0.33	0.50	0.1921
DEL	0.25	1.00	2.00	3.00	0.50	0.20	0.20	0.0643
FLE	0.20	0.50	1.00	3.00	0.33	0.25	0.33	0.0561
INN	0.17	0.33	0.33	1.00	0.33	0.20	0.25	0.0348
MOR	0.33	2.00	3.00	3.00	1.00	0.25	0.33	0.0953
PRO	3.00	5.00	4.00	5.00	4.00	1.00	0.50	0.2760
QUA	2.00	5.00	3.00	4.00	3.00	2.00	1.00	0.2811

Stage 3: Pair-wise comparisons for interdependencies

To find out the interdependencies between elements in the cluster, which occur in a sub-network of a control criterion, pair-wise comparisons are to be carried out between elements with respect to one of its elements in the clusters under each control criterion.

Step 9. By keeping one of the elements constant, pair-wise comparison is made between other elements in that cluster under the given control criterion. Again similar to step 3 and using equation 5.1, pair-wise comparison matrices are formed and the eVectors was calculated. These eVectors will be used to develop the un-weighted super matrix. The number of matrices formed in this step will be equal to the number of elements within the cluster.

In this problem, interdependencies occur between the elements of all of the clusters (shown by looped arc in the Figure 5.4). For example, in the process planning cluster, the elements Cellular Manufacturing (CEM) and Use of multiple small machines (UMS) are related as similar machines have to be grouped into a cell. Hence pair-wise comparison was carried out within the PRP cluster, between the remaining elements with respect to an element in the same cluster. For instance, Table 5.8 shows the pair-wise comparison of the elements within PRP (process planning) cluster with respect to UMS (use of multiple machines) and the control criterion – PRO (productivity).

Table 5.8: Pair-wise comparison of the elements under the cluster PRP (process planning) with respect to UMS (use of multiple small machines and the control criterion – PRO (productivity) (Inconsistency Index: 0.000)

	CEM	NPE	eVector
CEM	1.00	5.00	0.833
NPE	0.20	1.00	0.167

Similarly by keeping each element within process planning (PRP) cluster constant, pair-wise comparison matrices are formed between remaining elements with respect to the control criterion - productivity. Since three elements are present within the cluster PRP, three matrices will be formed for this cluster alone. The remaining two matrices are not shown here.

Step 10. Repeat step 9 for pair-wise comparison of elements within the remaining clusters with respect to one of the elements in that cluster and the same control criterion. The number of matrices formed in this stage will be equal to the total number of elements within each cluster with respect to a given control criterion.

For instance, under the control criterion productivity, there are 10 clusters (decision areas) and the elements in each cluster are varying. In total, there are 59 elements, which have been categorized into these 10 clusters. Hence an equal number of pair-wise comparison matrices for interdependencies are formed just for one control criterion.

Step 11. Similar to step 9 and 10, pair-wise comparisons for the interdependencies are again carried out among the elements of all clusters but with respect to the other control criteria. The number of matrices formed at the end of this stage will be equal to the product of number of control criteria and the total number of elements within all clusters. The eVectors from these matrices are used to form the un-weighted 'super matrix' for the corresponding control criteria.

In our case problem, at the end of this step, approximately 420 matrices would have formed.

Stage 4: Super matrix formation and analysis

Super matrix is used for the resolution of the interdependencies that exist between the components/elements. The super matrix will be used to find the relative stabilized weights of each of the elements/components.

Super matrix formation

The 'super matrix' is a matrix with same fields of components/elements (which have interdependencies) as rows and columns. There are 3 types of 'super matrices' that will be formed in this stage.

- The un-weighted super matrix, where the entries are taken directly from the eVectors obtained in stage 3

- The weighted super matrix, where each sub-matrix is multiplied by its weight to make the matrix column stochastic, i.e., the sum of values in each column is made equal to 1.
- The limiting super matrix obtained by raising the weighted super matrix to arbitrarily large powers.

Un-weighted super matrix formation

Step 12. The rows and columns of the super matrix are the elements of all the clusters. It is denoted by M. The eVectors obtained in Steps 9-11 are the entries for each column. It is formed for each control criterion. Hence the number of un-weighted super matrix will be equal to the number of control criteria.

For example, under the control criterion – productivity, the entries for the column UMS would be entered from the eVector obtained in step 9 (refer Table 5.9 for the values). Similarly other values from other clusters for the given control criterion are entered in the super matrix. In total, seven such un-weighted super matrices are formed one for each of the control criteria (competitive priorities). Since these matrices are very big, they cannot be represented in a single table and accommodated in a single page. Hence, these matrices are not shown considering the space limitations.

Weighted super matrix formation

Step 13. This step is used only when the un-weighted super matrix is not column stochastic. To check for column stochasticity, sum up the column entries. If the sum is equal to 1, then it is column stochastic. If the matrix is column stochastic, then proceed to step 15 else proceed to step 14.

In the case problem under consideration, the sum of the column entries of the un-weighted super matrix for the control criterion – PRO (productivity) is equal to 1 and hence it is already column stochastic. Hence step 14 was not carried out and directly, the limiting super matrix was calculated directly, which is shown in step 15. Similarly, the un-weighted super matrices of the remaining control criteria were also column stochastic. Hence, the weighted super matrices for these control criteria are not developed.

Step 14. If the sum of the column entries in the un-weighted matrix is not equal to 1, then it is not column stochastic. In such cases, each sub-matrix is multiplied by its weight of the cluster to make the matrix column stochastic, i.e., the sum of values in each column is made equal to 1. The obtained matrix is called weighted super matrix. The number of weighted super matrices will also be equal to the number of control criteria

Limiting Super Matrix

Since the 'un-weighted super matrix' in our case problem is already column stochastic, the 'limiting super matrix' is directly calculated.

Step 15. To obtain the limiting super matrix, the weighted super matrix has to be checked for cyclicity. If the weighted super matrix does not have cyclicity, it would be evaluated as $\lim_{x \to \infty} W^k$, where 'W' is the 'un-weighted' super matrix, whose power is raised arbitrarily to a large number, until the weights of each element have become stabilized, i.e., all the values in a row are same. In case of cyclicity, limiting matrix will be formed by using the following formula, $\lim_{x \to \infty} \left(\frac{1}{N}\right) \sum_{i=1}^{N} W_i^k$, where 'N' is the number of 'limiting super matrices'. The stabilized value in each row is the weight of that element of that component with respect to the corresponding control criteria. This value is used in Stage 5 as 'A^l_{kja}', where, 'k' representing the element of component 'j' under control criteria ‘a’. The number of limiting super matrices formed will be equal to the number of control criteria.

In this case problem, the un-weighted super matrix does not have cyclicity and hence the power of the matrix is raised to a large number for getting the limiting super matrix. In this matrix, the row values tend to be constant (which is the main objective of limiting super matrix) and it represents the weight of that element within the cluster with respect to the governing control criterion. Similarly six more limiting super matrices will be formed for the remaining control criteria. Again, due to the space limitations, all seven limiting super matrices are not shown. However, Table 5.9 shows the weight values obtained for each element from the limiting matrix of the control criterion – PRO (productivity).

Table 5.9: Weight values obtained for each element from the limiting matrix of the control criterion – PRO (productivity).

Elements	CTR	HOK	PST	RSS	VSM	WIP	OPF	SWP	USC	WLB	CFT	COE
Weight values	0.11	0.09	0.04	0.12	0.04	0.1	0.1	0.17	0.03	0.19	0.04	0.03
Elements	EEP	FOS	JOE	JOR	MFT	MSW	RER	SUS	AUM	MAP	PRM	SAI
Weight values	0.03	0.04	0.05	0.04	0.05	0.06	0.11	0.06	0.08	0.14	0.14	0.14
Elements	ANJ	AUN	FFP	MSC	SMD	STC	VIC	EDI	ERP	KAN	MMM	PRS
Weight values	0.1	0.09	0.07	0.03	0.08	0.04	0.08	0.05	0.07	0.08	0.03	0.11
Elements	PUL	SLP	CAD	CEG	DFM	DSN	MDN	PBD	UCP	USP	CEM	NPE
Weight values	0.07	0.09	0.04	0.03	0.03	0.05	0.07	0.08	0.09	0.11	0.23	0.07
Elements	UMS	FMD	ISS	LSR	SOS	STD	CUF	DES	POK	QUC	SPC	
Weight values	0.2	0.06	0.06	0.16	0.14	0.08	0.03	0.15	0.2	0.08	0.05	

Stage 5: Selection of the best alternative

Step 16. Till now the alternatives have not been analyzed. The eVector values related to alternatives are represented as ‘S_{ikja}’. The values for ‘S_{ikja}’ are obtained from the pair-wise comparison matrix, where the alternatives are compared with respect to an element ‘k’ of cluster ‘j’ for the control criteria ‘a’. Step 3 along with equation 1 will be used to calculate the eVector for the alternatives for each element of the cluster under each control criterion. The number of pair-wise comparison matrices obtained will be equal to the product of number of elements and number of control criteria.

In our case problem, the alternatives – TMS, CIMS and LMS are compared with each element within the clusters (decision areas) with respect to each control criterion (competitive priorities) to obtain the 'S_{ikja}' values. Table 5.10 shows a sample pair-wise comparison matrix of the alternatives under the element CEM (cellular manufacturing) within the cluster PRP (process planning) with respect to control criterion PRO (productivity). 60 pair-wise comparison matrices will be formed under the control criterion PRO (productivity) alone. If we consider all the seven control criteria, 420 (60 x 7) matrices will be formed.

Table 5.10: A sample pair-wise comparison matrix of the alternatives under the element CEM (cellular manufacturing) within the cluster PRP (process planning) with respect to control criterion PRO (productivity)

(Inconsistency index = 0.0053)

	CIMS	LMS	TMS	eVector (S_{ikja})
CIMS	1.00	0.50	5.00	0.3255
LMS	2.00	1.00	8.00	0.6044
TMS	0.20	0.12	1.00	0.0701

Step 17. In this step, desirability index for each of the alternatives will be calculated for each control criterion by using the following formula:

$$D_{ia} = \sum_{j=1}^{J} \sum_{k=1}^{K_{ja}} P_{ja} A^{D}{}_{kja} A^{I}{}_{kja} S_{ikja} \qquad - (5.2)$$

Where,

D_{ia} = Desirability index of alternative 'i' under the control criterion 'a'

Here

i = Alternatives

a = Control criterion

P_{ja} = Relative important weight of cluster 'j' on control criteria 'a' i.e., obtained from the pair-wise comparison matrix for the relative importance of the clusters under control criteria (Refer step 6)

A^D_{kja} = Relative important weight of element 'k' of cluster 'j' of control criteria 'a', i.e., obtained from pair-wise comparison matrix for elements with in the clusters under a given control criteria (Refer step 3)

A^I_{kja} = Stabilized weight of element 'k of cluster 'j' with respect to control criteria 'a', i.e. obtained from the row entries of limiting super matrix (Refer step 14)

S_{ikja} = Relative importance of alternative 'i' on the element 'k' of cluster 'j', with respect to the control criteria 'a'.

Similarly, desirability indices for the alternatives have to be calculated with respect to the other control criteria, which require the algorithm to be repeated again. For example, a sample desirability index calculation for the alternatives with respect to the control criteria PRO (productivity) is presented. Table 5.11 shows the desirability indices for the alternative manufacturing systems under the control criterion – PRO (productivity) along with the corresponding 'P_{ja}', 'A^D_{kja}', 'A^I_{kja}', and 'S_{ikja}' values.

Stage 6: Calculation of weighted index

Once all the desirability indices for the alternatives are calculated for all the control criteria, the weighted index for the alternative has to be calculated.

Step 18. The weighted index of an alternative 'i' is calculated by using the formula

$$AWI_i = \sum_{a=1}^{n} D_{ia} C_a \qquad - (5.3)$$

Where,

AWI_i = Weighted index of the alternative 'i',

D_{ia} = Desirability index of alternative 'i', for control criteria 'a', which are obtained from Step 17.

C_a = Relative important weights of control criteria 'a' on the overall objective, i.e. these values are obtained from pair-wise comparison matrix for the relative importance of the control criteria on the overall objective (step 8, see Table 5.7)

For example, in our case problem, the desirability indices of the alternatives obtained for control criteria PRO (productivity) are CIMS – 0.0307, LMS – 0.0871 and TMS – 0.0155. The relative importance of the control criterion PRO (productivity) is 0.2761. This is multiplied with each of the alternative values.

Table 5.11: Desirability indices for alternative manufacturing systems under the control criterion – PRO (productivity)

Decision Areas	P_{ja}	Elements	(A^D_{kja})	(A^L_{kja})	CIMS (S1)	LMS (S2)	TMS (S3)	CIMS	LMS	TMS
COI	0.0182	CTR	0.5649	0.11	0.1929	0.701	0.1061	0.0002	0.0008	0.0001
	0.0182	HOK	0.2255	0.09	0.1125	0.7089	0.1786	0.0000	0.0003	0.0001
	0.0182	PST	0.0821	0.04	0.1571	0.5936	0.2493	0.0000	0.0000	0.0000
	0.0182	RSS	0.0409	0.12	0.1564	0.745	0.0986	0.0000	0.0001	0.0000
	0.0182	VSM	0.0442	0.04	0.0986	0.745	0.1564	0.0000	0.0000	0.0000
	0.0182	WIP	0.0424	0.10	0.1564	0.745	0.0986	0.0000	0.0001	0.0000
FAL	0.1124	OPF	0.2509	0.1	0.1088	0.7286	0.1626	0.0003	0.0021	0.0005
	0.1124	SWP	0.0925	0.17	0.157	0.5936	0.2493	0.0003	0.0010	0.0004
	0.1124	USC	0.0544	0.03	0.1125	0.7089	0.1786	0.0000	0.0001	0.0000
	0.1124	WLB	0.6022	0.19	0.1169	0.6833	0.1998	0.0015	0.0088	0.0026
HRM	0.1792	CFT	0.1368	0.04	0.1998	0.6833	0.1169	0.0002	0.0007	0.0001
	0.1792	COE	0.0322	0.03	0.1125	0.7089	0.1786	0.0000	0.0001	0.0000
	0.1792	EEP	0.2494	0.03	0.1564	0.745	0.0986	0.0002	0.0010	0.0001
	0.1792	FOS	0.0168	0.04	0.1929	0.701	0.1061	0.0000	0.0001	0.0000
	0.1792	JOE	0.0198	0.05	0.229	0.6955	0.0755	0.0000	0.0001	0.0000
	0.1792	JOR	0.0302	0.04	0.1884	0.7306	0.081	0.0000	0.0002	0.0000
	0.1792	MFT	0.0968	0.05	0.5469	0.3445	0.1085	0.0005	0.0003	0.0001
	0.1792	MSW	0.0702	0.06	0.256	0.6708	0.0732	0.0002	0.0005	0.0001
	0.1792	RER	0.2934	0.11	0.1125	0.7089	0.1786	0.0007	0.0041	0.0010
	0.1792	SUS	0.0544	0.06	0.1088	0.7286	0.1626	0.0001	0.0004	0.0001
MAI	0.0892	AUM	0.234	0.08	0.0726	0.7612	0.1662	0.0001	0.0013	0.0003
	0.0892	MAP	0.5301	0.14	0.1662	0.7612	0.0726	0.0011	0.0050	0.0005
	0.0892	PRM	0.0716	0.14	0.1662	0.7612	0.0726	0.0001	0.0007	0.0001

Decision Areas	P_{ja}	Elements	(A^{D}_{kja})	(A^{L}_{kja})	CIMS (S1)	LMS (S2)	TMS (S3)	CIMS	LMS	TMS
	0.0892	SAI	0.1643	0.14	0.5736	0.3614	0.065	0.0012	0.0007	0.0001
MAN	0.0793	ANJ	0.062	0.1	0.2227	0.7071	0.0702	0.0001	0.0003	0.0000
	0.0793	AUN	0.3323	0.09	0.784	0.1349	0.0813	0.0019	0.0003	0.0002
	0.0793	FFP	0.1343	0.07	0.1488	0.7854	0.0658	0.0001	0.0006	0.0000
	0.0793	MSC	0.0259	0.03	0.0914	0.691	0.2176	0.0000	0.0000	0.0000
	0.0793	SMD	0.3187	0.08	0.1884	0.7306	0.081	0.0004	0.0015	0.0002
	0.0793	STC	0.0384	0.04	0.1125	0.7089	0.1786	0.0000	0.0001	0.0000
	0.0793	VIC	0.0884	0.08	0.1884	0.7306	0.081	0.0001	0.0004	0.0000
PPC	0.0217	EDI	0.0305	0.05	0.2706	0.6442	0.0852	0.0000	0.0000	0.0000
	0.0217	ERP	0.1139	0.07	0.7306	0.1884	0.081	0.0001	0.0000	0.0000
	0.0217	KAN	0.16	0.08	0.1721	0.7258	0.102	0.0000	0.0002	0.0000
	0.0217	MMM	0.0476	0.03	0.6442	0.2706	0.0852	0.0000	0.0000	0.0000
	0.0217	PRS	0.3886	0.11	0.1721	0.7258	0.102	0.0002	0.0007	0.0001
	0.0217	PUL	0.1811	0.07	0.1666	0.7396	0.0938	0.0000	0.0002	0.0000
	0.0217	SLP	0.0783	0.09	0.1125	0.7089	0.1786	0.0000	0.0001	0.0000
PRD	0.0545	CAD	0.288	0.04	0.7853	0.1488	0.0658	0.0005	0.0001	0.0000
	0.0545	CEG	0.0935	0.03	0.2227	0.7071	0.0701	0.0000	0.0001	0.0000
	0.0545	DFM	0.0476	0.03	0.1349	0.7838	0.0812	0.0000	0.0001	0.0000
	0.0545	DSN	0.045	0.05	0.081	0.731	0.188	0.0000	0.0001	0.0000
	0.0545	MDN	0.0237	0.07	0.2227	0.7071	0.0701	0.0000	0.0001	0.0000
	0.0545	PBD	0.0677	0.08	0.2176	0.691	0.0914	0.0001	0.0002	0.0000
	0.0545	UCP	0.1028	0.09	0.3531	0.5861	0.0608	0.0002	0.0003	0.0000
	0.0545	USP	0.3316	0.11	0.1571	0.5936	0.2493	0.0003	0.0012	0.0005
PRP	0.2792	CEM	0.6267	0.23	0.3255	0.6044	0.0701	0.0131	0.0243	0.0028
	0.2792	NPE	0.0936	0.07	0.7418	0.183	0.0752	0.0014	0.0003	0.0001
	0.2792	UMS	0.2797	0.2	0.0789	0.7957	0.1253	0.0012	0.0124	0.0020
PUR	0.017	FMD	0.0844	0.06	0.0986	0.745	0.1564	0.0000	0.0001	0.0000
	0.017	ISS	0.4252	0.06	0.2222	0.6667	0.1111	0.0001	0.0003	0.0000
	0.017	LSR	0.0504	0.16	0.1998	0.6833	0.1169	0.0000	0.0001	0.0000
	0.017	SOS	0.2648	0.14	0.2684	0.6144	0.1172	0.0002	0.0004	0.0001
	0.017	STD	0.1752	0.08	0.2857	0.5714	0.1429	0.0001	0.0001	0.0000
QCO	0.1493	CUF	0.0333	0.03	0.1571	0.5936	0.2493	0.0000	0.0001	0.0000
	0.1493	DES	0.1276	0.15	0.1311	0.6608	0.2081	0.0004	0.0019	0.0006
	0.1493	POK	0.4854	0.2	0.1929	0.701	0.1061	0.0028	0.0102	0.0015
	0.1493	QUC	0.0627	0.08	0.1998	0.6833	0.1168	0.0001	0.0005	0.0001
	0.1493	SPC	0.291	0.05	0.1571	0.5936	0.2493	0.0003	0.0013	0.0005
Desirability index								**0.0307**	**0.0871**	**0.0155**

Similarly, the desirability indices of the alternatives with respect to other control criteria and their corresponding relative importance values with respect to the goal are multiplied. Finally, all these values are summed up for each of the alternatives, which give the weighted index. In this case, the weighted index of the alternative – LMS was found to be 0.0664, while that of CIMS – 0.0233 and TMS – 0.0118. Table 5.12 shows the weighted indices for alternative manufacturing systems based on the control criteria (competitive priorities)

Table 5.12: Weighted indices for alternative manufacturing systems based on the control criteria (competitive priorities)

	Control criteria (competitive priorities) / weights for control criteria							Calculated weights for alternatives	
Alternatives	COS	DEL	FLE	INN	MOR	PRO	QUA	SPW1	NORM
	0.1921	*0.0643*	*0.0561*	*0.0348*	*0.0954*	*0.2761*	*0.2811*		
CIMS	0.0214	0.0071	0.0062	0.0039	0.0106	0.0307	0.0313	0.0233	0.2298
LMS	0.0610	0.0203	0.0177	0.0110	0.0301	0.0871	0.0892	**0.0664**	**0.6542**
TMS	0.0108	0.0036	0.0031	0.0020	0.0054	0.0155	0.0158	0.0118	0.1160
Sum								0.1015	1.0000

Step 19. From the weighted index, the normalized weighted index is calculated and the best alternative having the highest value is selected.

Table 5.12 also shows the calculation of normalized weighted index of alternative manufacturing systems. From the calculations shown, it can be seen that the normalized weighted index for alternative ‘LMS’ is the highest. Hence, it is considered as best among the alternatives chosen as it has a significant impact on the competitive priorities of the case organisation.

5.3.1.2 Results and discussion

Thus, an application of ANP methodology has been demonstrated for selecting LMS based on its impact on the functions or activities (decisions areas) of the operations department. Based on the weighted alternative index and normalized weighted alternative index in Table 5.12, it was found that LMS is superior in comparison with the available alternative manufacturing systems. Commenting about the problems faced by the case organisation, the application of ANP methodology as a Decision Support System (DSS) enabled the representatives of the organisation to make an informed decision of selecting LMS as the best manufacturing system from the available alternatives based on its capability and its impact on the decision areas of operations department. Indeed LMS has the ability to provide solutions for most of the problems faced by the organisation. For example the quality, which has been considered as one of the major problems in the valves, can be improved through the use of specific elements of LM such as pokayoke, defect at the source and successive check system, andon/jidoka, empowerment etc. Similarly, it can reduce cost through elements such as small lot production, continuous improvement activities. The above claimed benefits were also supported by Sohal and Egglestone (1994) and Jina *et al.* (1997).

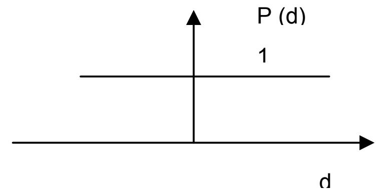
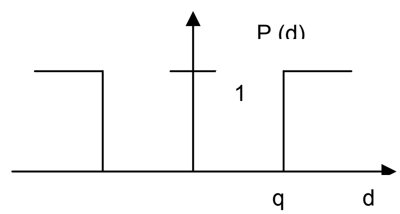
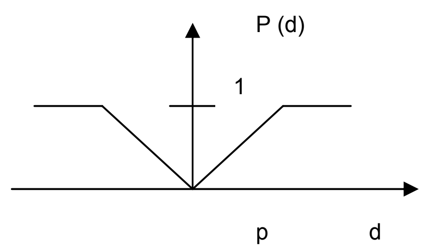
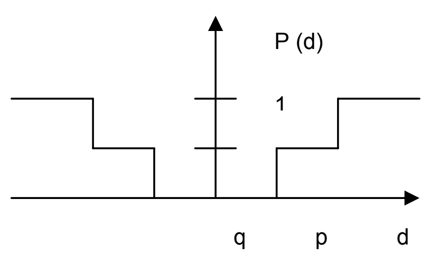
In the above problem, the interdependencies were assumed to be present between the elements within a cluster while constructing the ANP model for the problem. On the other hand, there are cases, where the elements within one cluster may also affect the elements in other clusters. For example, one of the elements in 'continuous improvement' cluster is 'cycle time and lead time reduction', which can be achieved through effective workload balancing and standardized work processes. But these elements have been categorised under facilities and layout cluster. Thus, there extends a relationship between an element in a cluster and an element in another cluster. For the sake of reducing the complexity, this issue was not considered while modelling the hierarchical structure and it was assumed that elements in one cluster do not influence the elements in other cluster. The same problem can be modelled and can also be solved without the above-mentioned assumptions but the number of pair-wise comparison matrices will tend to increase further. In addition to this, a sensitivity analysis can also be carried out to check the effectiveness and efficiency of the decisions, which was not carried out. Similarly, it should be remembered that the proposed solution from the ANP is applicable only for the case situation discussed. It cannot be generalised for the remaining industries or other industrial sectors.

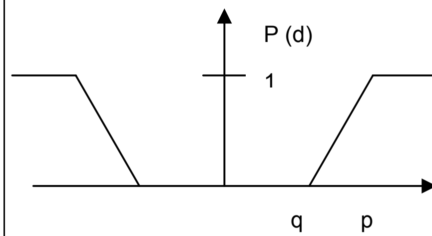
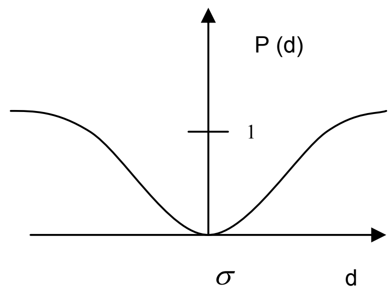
A minor issue regarding ANP is that it cannot be used for very complex problems, which involves more number of control criteria, clusters and elements as demonstrated here. This is because, the number of pair-wise matrices increases drastically and the time required to perform the ANP data entry to arrive at the solution will be very high. Hence, it may not be favoured by the practitioners. Though the ANP algorithm is cumbersome and time consuming, it has the benefits of providing a better solution than AHP and other MADM techniques as it takes into account interdependencies. In addition to this, since implementing or selecting a suitable manufacturing system is a strategic decision, the use of ANP in this case was justified as it requires such a complex analysis to make an effective decision.

5.3.2 Development of preference ranking organisation method for enrichment evaluations for justification of lean manufacturing systems

In the previous section, the case organisation determined that LMS is better than the alternate manufacturing systems from the perspective of capability of alternate manufacturing systems and its impact on the decision areas of operations department. Apart from cost, another important factor in the decision-making is to analyse 'how the alternative manufacturing system will impact the stakeholders of the organisation'. To accomplish this, MADM models which is based on the outranking techniques has been utilised. The ELECTRE and the PROMETHEE are the two most popular families of the outranking methods introduced by Roy (1973). PROMETHEE is a MADM method developed by Brans and Vincke (1985). It is still evolving and developing as evident from the works of Brans *et al.* (1986), Diakoulaki and Koumoutsos (1991), Brans and Mareschal (1994), Goumas and Lygerou (2000), etc. In this method, the intensity of the preference for alternative ‘a’ over alternative ‘b’ with regard to each criterion ‘j’ is measured in terms of a preference function P_j (a, b), which is evaluated based on the generalised criterion for each ‘j’. Brans *et al.* (1986) proposed the following six possible types of generalised criterion as shown in Table 5.13.

Table 5.13: Six possible types of generalised criterion (Source: Brans *et al.*, 1986)

Generalised criterion type	**Preference function** $P(d)$
Type I: Usual criterion $P(d) = \begin{cases} 0 & d = 0 \\ 1 & \lvert d \rvert = 1 \end{cases}$	
Type II: U-shape criterion $P(d) = \begin{cases} 0 & \lvert d \rvert \le q \\ 1 & \lvert d \rvert > q \end{cases}$	
Type III: V-shape criterion $P(d) = \begin{cases} \frac{\lvert d \rvert}{p} & \lvert d \rvert \le p \\ 1 & \lvert d \rvert > p \end{cases}$	
Type IV: Level criterion $P(d) = \begin{cases} 0 & \lvert d \rvert \le q \\ \frac{1}{2} & q < \lvert d \rvert \le p \\ 1 & \lvert d \rvert > p \end{cases}$	

Generalised criterion type	Preference function $P(d)$
Type V: V-shape criterion with indifference criterion $P(d) = \begin{cases} 0 & \lvert d\rvert \le q \\ \dfrac{\lvert d\rvert - q}{p-q} & q < \lvert d\rvert \le p \\ 1 & \lvert d\rvert > p \end{cases}$	
Type VI: Gaussian criterion $P(d) = 1 - e^{\left(-d^2/2\sigma^2\right)}$	

In order to define these criterions and evaluate the preference functions, one or two of the following thresholds have to be fixed:

- Indifference threshold (q): It is the lowest value of d_j (a, b) below which the decision maker considers there is indifference between ‘a’ and ‘b’.
- Strict preference threshold (p): It is the lowest value of d_j (a, b) below which the decision maker considers there is a strict preference of ‘a’ over ‘b’.
- Standard deviation (σ): It is a well known parameter directly connected with standard deviation of a normal distribution.

A weighted average of the preference functions is calculated to obtain a rank ordering of the alternatives. ‘PROMETHEE I’ provides a partial pre-ordering of the alternatives through a pair-wise dominance comparison of positive and negative outranking flows, while, ‘PROMETHEE II’ provides a complete pre-ordering through a comparison of net outranking flows.

A review of literature on PROMETHEE revealed that it has received wide attention and has been applied in diverse areas. Raju and Pillai (1999) utilized PROMETHEE II to select the best reservoir configuration for the case study of Chaliyar river basin, Kerala, India. They compared the PROMETHEE II with four other MADM methods, namely, ELECTRE-2, AHP, Compromise Programming (CP) and EXPROM-2 and commented that though these methods follow different approaches the analysis has shown that the same preference strategy is reached by all the methods. Further, they concluded that CP was best suited for their case problem. Cavallaro (2005) utilised PROMETHEE II for selecting renewable energy installations from a number of alternatives that are operating in the area of Messina in Sicily. They explained the algorithm using a case study approach in which Wind was suited as the best among the alternatives for various scenarios like economic-oriented, environment-oriented, etc. Table 5.14 shows the summary of PROMETHEE applications in various fields. However, no such application of PROMETHEE was found in the field of LMS.

5.3.2.1 Algorithm

The algorithm of PROMETHEE II for the problem under study is discussed below in a step-by-step manner:

Step 1. Define the problem and determine the objectives.

The problem for the case organisation is ‘how to select a suitable manufacturing system from the available alternatives?’

Step 2. Identify the alternatives ‘a_i’ available.

The alternatives considered in this case are:

- Existing or Traditional Manufacturing Systems (TMS),
- Computer Integrated Manufacturing Systems (CIMS) and
- Lean Manufacturing Systems (LMS)

Table 5.14: Summary of PROMETHEE applications in various fields

S. No.	Authors	Area of Application	Remarks
1.	Briggs *et al.*, 1990	Nuclear waste management	This paper discusses about the application of the PROMETHEE methods and the geometrical representation GAIA for a real life case study of nuclear waste management in Belgium. The decision-making deals with the choice of a financing method adapted to several possible time scenarios for the waste disposal and to identify several possible sites for the construction of a geological repository involving several points of view of different actors such as electricity companies, consumers, public bodies, etc.
2.	Pavic and Babic, 1991	Location selection	This paper considers the problem of location choice for such production systems where the basic and additional location factors can be identified. The basic location factors are transportation costs, production costs and duration of transport. The additional factors are bottleneck time, building costs, infrastructure cost, weather conditions, expansion possibility and transportation possibilities. The importance of the basic location factors are solved by the use of a parametric approach to identify a list of efficient locations and after that the location choice among these efficient solutions are found by the use of the PROMETHEE method.
3.	Mladineo *et al.*, 1992	Public policy decision	This paper demonstrates a case study to make a public policy decision, in which the Government was involved in the application of the PROMETHEE method and the GAIA to select a suitable route for the future Adriatic highway along the Adriatic coast, from the two alternative routes, i.e. the coastal and the continental one.
4.	Kolli and Parsaei, 1992	Advanced manufacturing technology	The paper deals with use of PROMETHEE for demonstrating the justification of advanced manufacturing technology before its implementation, using a hypothetical case situation. They considered six criteria, namely, product quality, manufacturing flexibility, market response, costs, inventory and lead time to rank six alternatives.
5.	Abu-Taleb and Mareschal, 1995	Water resources planning	The paper describes the application of the PROMETHEE V to evaluate and select from a variety of potentially feasible water resources development options, to allocate the limited funds to alternative development projects and programs. Important policy issues such as environmental protection, water demand and supply management, and regional cooperation were explicitly considered during the analysis using a real-life case study of Ministry of Planning at Jordan
6.	Le Teno and Mareschal, 1998	Life cycle analysis in the construction field	They utilised the PROMETHEE in the field of Life Cycle Assessment (LCA), which is predominantly used to calculate the total input and output flows of materials and energy from and to the environment during every step of a product life. In the construction field, LCA flows cannot be known with precision without loss of realism. Hence intervals have been introduced to model them. They made necessary changes to devise an interval version, called “PROMETHEE I'” for obtaining the product Environment Quotient (EQ).

S. No.	Authors	Area of Application	Remarks
7.	Babic and Plazibat, 1998	Ranking of enterprises	This paper deals with the ranking of enterprises according to the achieved level of business efficiency using the PROMETHEE method and AHP. The PROMETHEE method was used for final ranking and AHP was used to determine the importance of criteria. Such problems are often encountered in banks, where it is necessary to make a great number of business decisions, e.g. in case of investment decisions, loan granting, etc., which are made based on business efficiency.
8.	Al-Rashdan *et al.*, 1999	Environmental assessment	In this paper, the authors combined the Nominal Group Technique (NGT) and PROMETHEE to develop a reliable methodology to prioritise environmental projects in Jordan and evaluate their environmental impacts. It was implemented on a sample of wastewater projects in Jordan.
9.	Goumas and Lygerou, 2000	Energy exploitation	In this paper, the PROMETHEE was extended to deal with fuzzy input data and they call it as F-PROMETHEE. They applied this method for the evaluation and ranking of alternative energy exploitation schemes of a low temperature geothermal field. They identified the possible uses of geothermal energy as alternatives: greenhouse heating (flowers), subsoil heating (asparagus), drying of agricultural products and water heating, for fish farming (eel). To evaluate these alternatives, they used the following four criteria: the net present value of the investment, the creation of new jobs, the energy consumed and a risk index.
10.	Costa and De Almeida, 2001	Information system planning	This paper presents the information system planning methodology and the priorities assignment of information systems. It utilised PROMETHEE to select modules of an information system, utilising the criteria like impact on strategic factors and operational aspects. They discussed a case study to demonstrate the same.
11.	Pastijn *et al.*, 2003	Selection of simulation model	In this paper, the authors have applied the variant of the original PROMETHEE method, in order to select the best simulation model configuration among a finite set of alternatives. For each alternative configuration a number of replications of terminating simulation runs are performed. At the end of each replication, and for each configuration, the results of various performance measures are obtained. In the selection problem, these performance measures are typically considered as conflicting criteria for which the alternative configurations have been assessed by a number of computer simulation replications, which was further fed into an interval version of the PROMETHEE, in order to select the best model configuration. They discussed their approach by means of a case study of an incident management model for a call centre.
12.	Waeyenbergh *et al.*, 2004	Maintenance	In this paper, the PROMETHEE II was used to select the appropriate measurement intervals for carrying out measurement regarding the cleanliness of the paint shop in an automotive company.
13.	Albadvi, 2004	Information Technology (IT) as a national strategy	The authors used the PROMETHEE to define a model for IT national strategy to build an advanced information infrastructure society in Iran. The objective is to propose a national strategy with specific policy programs for each field in which IT should be promoted. In the process, they selected a set of IT application flagships in different budgeting levels, using the PROMCALC and GAIA decision support system.

S. No.	Authors	Area of Application	Remarks
14.	Nowak, 2005	Investment project selection	In this paper, simulation, stochastic dominance rules and PROMETHEE II was employed for solving an investment projects selection problem. The simulation approach was used for obtaining financial evaluation of projects, while expert judgements are used in order to evaluate project with respect to other criteria. They have demonstrated their hybrid approach using a hypothetical case situation.
15.	Mavrotas *et al.*, 2006	Selection of firms for financial support	This paper presents a multiple criteria approach for the selection of firms applying for financial support from public funds. Besides the budget constraint, the consideration of additional policy constraints, which prevent from directly exploiting rankings provided by a multiple criteria method. In such a case the problem solution is to find a set of alternatives satisfying the constraints and at the same time maximizing a measure of global performance. Their proposed procedure relied on the PROMETHEE V method which is combined with an integer programming formulation capable to effectively deal with the problem's combinatorial character.
16.	Routroy and Kodali, 2007	Carrier selection in SCM	This paper enumerates the application of PROMETHEE II while selecting the carrier in the supply chain for any logistics function. They considered both the qualitative and quantitative factors (around 30 in total), apart from considering 4 alternatives. They demonstrated the decision-making proces using a hypothetical case situation.
17.	Albadvi *et al.*, 2007	Stock trading	In this paper, the authors have applied PROMETHEE for the selection of the right stock at the right time. They structured the problem around two pillars: Industry evaluation and Company evaluation and applied the model at Tehran Stock Exchange (TSE) as a real case. They conducted a survey from the experts in order to determine the effective criteria for both types of evaluation. In industry evaluation they prioritised the different industrial sectors utilizing 13 criteria, while for company evaluation, they prioritised the stock of companies in a particular industrial sector using 28 criteria.
18.	Araz and Ozkarahan, 2007	Supplier evaluation and management	This paper proposes a methodology for effective strategic sourcing and evaluating supplier involvement during product development. They used PROMETHEE to evaluate the performance of alternative suppliers by simultaneously considering supplier capabilities and performance metrics to provide a preference relation between suppliers. Further, they proposed a new MCS method based on the PROMETHEE to sort the suppliers based on their preference relations. They claimed that it can assist concurrent design teams in classifying suppliers into four categories: strategic partners, the promising suppliers which are possible candidates for supplier development programs, competitive suppliers and the suppliers to be pruned. It also identified the differences in performances across supplier classes and helps concurrent design teams in monitoring the suppliers' performances and making decisions about necessary development programs.

Step 3. Determine the attributes/criteria/performance indicators 'g_j' (where j = 1, 2, 3 ….J) that govern the problem.

As discussed earlier, the selection of alternative manufacturing systems will be based on various perspectives, namely, the costs, impact on the stakeholders of organisation and the perceived benefits. Table 5.15 shows the list of elements that need to be considered for making a decision based on the cost, impact on stakeholders of the organisation, benefits, etc.

Table 5.15: List of elements that need to be considered for making a decision based on the cost, impact on stakeholders of the organisation, benefits, etc.

S. No.	Taxonomy	Elements	In short	Unit	Brief explanation
	Financial / Cost				
1.		Operational cost	OPC	Rs. in Lakhs	Includes cost expended in implementing changes as required by new systems. It may include tooling costs, utility cost and other costs incurred for the operations of these alternative systems
2.		Training cost	TRC	Rs. in Lakhs	Cost incurred in training employees, suppliers etc.
3.		Middleware cost	MWC	Rs. in Lakhs	Cost involved in purchasing the hardware like machines, computers, software etc.
4.		Consultant cost	COC	Rs. in Lakhs	Cost spent on hiring an consultant to provide guidance
5.		Overhead cost	OVC	Rs. in Lakhs	Cost incurred in terms of increased employee salaries, rewards, hiring and firing charges etc.
	Organisational				
6.		Time required (in months)	TIR	In months	Refers to the time required for implementing the changes
7.		Readiness	REA		Implies the readiness of the organisation to accept the changes
8.		Ease of implementation	EOI		Refers to the degree of simplicity in implementing such changes
9.		Changes in organisation size structure	OSS		Refers to the degree of changes effected in the organisation size and structure
10.		Feasibility	FEA		Deals with whether the identified alternatives are suitable for implementation in the organisation
	Role of top management				
11.		Top management's initiative and commitment	TMI		Requires a high level of commitment and involvement from top management in implementing changes

S. No.	Taxonomy	Elements	In short	Unit	Brief explanation
12.		Availability of resources	AVA		Deals with providing the resources (4Ms) that are required to incorporate the changes
13.		Risk of failure	ROF		Deals with the amount of risk the organisation can withstand in case of failure during the implementation process
	Impact on employees				
14.		Increase in roles and responsibilities	IRR		Deals with changes in roles and responsibilities for the employees due to hiring and firing, job enlargement, empowerment etc.
15.		Multi-skilling	MUS		The alternative manufacturing systems require the employees to be multi-skilled, so that they can monitor multiple workstations or work in number of assembly stages etc.
16.		Stress and fatigue	STF		Refers to the increase in stress, strain and fatigue for the employee due to the alternative manufacturing systems
17.		Team working	TEW		Alternative manufacturing systems require employees to work in team
18.		Job security	JSU		Alternative manufacturing systems may result in removal of employees
19.		Other union issues	UNI		Implementation of alternative manufacturing systems is dependent on employee's union and their consensus
	Impact on suppliers				
20.		Changes in supplier requirements	CSR		Alternative manufacturing systems may require the supplier to be certified, supplier to be involved in design etc.
21.		Changes in supply practices	CSP		Suppliers are required to delivery frequently in small lot sizes at the point of use using standard containers. They may be even required to follow vendor managed inventory concepts
22.		Reduction in number of suppliers	RSU	in %	Refers to reduction in suppliers because of sole sourcing
23.		Changes in supplier infrastructure	CSI		Alternative manufacturing systems require the suppliers to adopt Electronic Data Interchange (EDI), acquire sophisticated machines and improve other infrastructure
	Impact on customers				
24.		Value addition	VAA		Provides a better value for the money in terms of the products and features
25.		Reduction in price	REP	in %	Deals with reduction in price of products due to cost cutting measures

S. No.	Taxonomy	Elements	In short	Unit	Brief explanation
26.		High variety and flexibility	HVF		Deals with availability of multiple types of products
27.		Increase in availability	INA		Refers to easy availability of products as and when required by the customers
		Impact on shareholders			
28.		Brand image	BRI		Implementing alternative systems may improve the brand value of the company
29.		Increase in sales	SAL	in %	Refers to increase in sales due to improved quality, reduced price etc.
30.		Profits and turnover	PRO	in %	Deals with increase in profit and turnover due to increase in sales
31.		Rate of returns	ROR	in %	Since alternative manufacturing systems require heavy investment, the rate of return should be high and payback period should be low for the same
	Perceived benefits				
32.		Reduction in delivery time	IDL	in %	Results in faster delivery time due to the reduction in lead time, cycle time, setup time etc.
33.		Reduction in inventory	INV	in %	Results in reduced inventory in the form of raw materials, work in progress and finished goods
34.		Reduction in manpower	MAP	in %	Results in reduction of both direct and indirect manpower
35.		Reduction in defects	DEF	in PPM	Results in reduction in defects (both scrap and rework)
36.		Improved manufacturing performance	MPE		Increases the production rate, productivity, utilisation and efficiency as more units are produced from the same output (includes man, machine, materials etc.) at a faster rate
37.		Increase in market share	MAS	in %	Results in improvement in market share due to improved quality, value, etc.
38.		Overall cost reduction	OCO	in %	Results in overall cost savings and reduction in investment

Step 4. Classify the attributes/criteria/performance indicators into direct (performance grows while measure increases) and indirect categories (performance grows while measure decreases). In other words, identify those elements, which have to be maximised and minimised.

For instance, if sales are considered, it should always be maximised with the implementation of new systems. Hence, it will falls under the direct category. On the other hand, if the cost factors (say implementation cost) are considered, it should always be minimised, in which case it fall under indirect category. In this manner, the identified elements were classified into direct or indirect case.

Step 5. Choose the preference function for each attribute/criterion/performance indicators. A guideline to choose the preference function was provided by Routroy and Kodali (2007), which are as follows:

- Type I (Usual criterion): It is a basic type without any threshold and seldom used.
- Type II (U-shape criterion): It uses a single indifference threshold, which is generally used with qualitative criteria.
- Type III (V-shape criterion): It uses a single preference threshold and often used with quantitative criteria.
- Type IV (Level criterion): It is similar to U-shape but with an additional preference threshold and it is mostly used with qualitative criteria.
- Type V (V-shape criterion with indifference threshold criterion): It is similar to V-Shape but with an additional indifference threshold and often used with quantitative criteria.
- Type VI (Gaussian criterion): It is seldom used.

Utilising the above guidelines, the preference function was assigned to each element.

Step 6. Form the threshold matrix using the strong preference threshold value ‘p_j’ and indifference threshold value ‘q_j’ for each attribute/criterion/ performance indicator if required depending upon the preference function.

Step 7. Assign absolute weight value 'w_j' on a suitable scale (say 1 to 10) for each attribute/criterion/performance indicator reflecting the normative judgment of the decision maker.

In this case, the participants were asked to rate the importance of each attribute/criterion/performance indicator with respect to the problem. For instance, the participants were asked verbally – 'how do you rate the importance of 'implementation cost' with respect to the objective?' In a similar manner, the importance rating for all elements was collected from the participants. Steps 4 to 7 are shown in Table 5.16, which illustrates the classification and assignment of preference function for each element.

Table 5.16: Classification and assignment of preference function for each element

S. No.	In short	Max or Min	Units	Type	Name of the preference function	Type of preference function	w_j	q_j	p_j
1.	OPC	Minimize	Rs. in Lakhs	Quantitative	Linear	Type V	9	2	8
2.	TRC	Minimize	Rs. in Lakhs	Quantitative	Linear	Type V	7	0.5	2.5
3.	MWC	Minimize	Rs. in Lakhs	Quantitative	Linear	Type V	8	3	7
4.	COC	Minimize	Rs. in Lakhs	Quantitative	Linear	Type V	7	0.5	1
5.	OVC	Minimize	Rs. in Lakhs	Quantitative	Linear	Type V	9	2	6
6.	TIR	Minimize	in months	Quantitative	Level	Type IV	8	3	12
7.	REA	Maximize		Qualitative	U-shape	Type II	7	2	0
8.	EOI	Maximize		Qualitative	U-shape	Type II	8	2	0
9.	OSS	Minimize		Qualitative	U-shape	Type II	7	2	0
10.	FEA	Maximize		Qualitative	U-shape	Type II	7	2	0
11.	TMC	Maximize		Qualitative	U-shape	Type II	8	2	0
12.	AOR	Maximize		Qualitative	U-shape	Type II	7	2	0
13.	ROF	Minimize		Qualitative	U-shape	Type II	8	2	0
14.	IRR	Minimize		Qualitative	U-shape	Type II	6	2	0
15.	MUS	Maximize		Qualitative	U-shape	Type II	7	2	0
16.	STF	Minimize		Qualitative	U-shape	Type II	8	1	0
17.	TEW	Maximize		Qualitative	U-shape	Type II	7	2	0
18.	JOS	Maximize		Qualitative	U-shape	Type II	8	1	0
19.	UNI	Minimize		Qualitative	U-shape	Type II	7	2	0
20.	CSR	Minimize		Qualitative	Level	Type IV	6	1	3
21.	CSP	Minimize		Qualitative	Level	Type IV	6	1	3
22.	NOS	Minimize	in %	Quantitative	V-Shape	Type III	7	0	7
23.	CSI	Minimize		Qualitative	Level	Type IV	6	1	3
24.	VAA	Maximize		Qualitative	Level	Type IV	8	1	3

S. No.	In short	Max or Min	Units	Type	Name of the preference function	Type of preference function	w_j	q_j	p_j
25.	PRI	Maximize	in %	Quantitative	V-Shape	Type III	7	0	10
26.	HVF	Maximize		Qualitative	U-shape	Type II	6	2	0
27.	AVA	Maximize		Qualitative	U-shape	Type II	7	2	0
28.	BRI	Maximize		Qualitative	U-shape	Type II	6	2	0
29.	SAL	Maximize	in %	Quantitative	V-Shape	Type III	7	0	3
30.	PRO	Maximize	in %	Quantitative	Linear	Type V	8	2	10
31.	ROR	Maximize	in %	Quantitative	V-Shape	Type III	7	0	2
32.	DET	Minimize	in %	Quantitative	V-Shape	Type III	8	0	8
33.	INV	Minimize	in %	Quantitative	V-Shape	Type III	7	0	10
34.	MAN	Minimize	in %	Quantitative	V-Shape	Type III	6	0	5
35.	DEF	Minimize	in PPM	Quantitative	Linear	Type V	8	10	50
36.	MPE	Maximize		Qualitative	U-shape	Type II	7	2	0
37.	MAS	Maximize	in %	Quantitative	V-Shape	Type III	8	0	5
38.	OCO	Maximize	in %	Quantitative	V-Shape	Type III	9	0	5

Step 8. Obtain the relative weight value ‘W_j’ for each attribute/criterion/performance indicator ‘g_j’ from absolute weight value ‘w_j’ using the following equation:

$$W_j = \frac{w_j}{\sum w_j} \qquad \text{such that} \quad \sum W_j = 1 \tag{5.4}$$

Step 9. Form the performance matrix, by filling up the co-efficient ‘g_{ij}’ related to the attribute/criterion/performance indicator ‘g_j’ (j = 1, 2, 3 ….J) for the alternative ‘a_i’ (i = 1, 2, 3………I).

For most of the quantitative elements, data were obtained from the case organisation. For instance, the training cost (TRC) under the existing system was Rs. 3 lakhs and the participants estimated that the training cost for alternative manufacturing systems will be around Rs. 10 and 8 lakhs for CIMS and LMS respectively.

Step 10. Quantify the qualitative attributes using the scale of 1 to 10, where 1 refers to very low, 3 means low, 5 means medium, 7 means high, and 9 means very high.

Similarly, for the qualitative attributes, the participants were asked to compare the alternatives with respect to each of the attributes. They were asked to rate each element/attribute with respect to the alternatives. After a thorough discussion and deliberations, they provided the rating values. For example, the participants provided the rating of 4 for TMS, 7 for CIMS and 6 for LMS for the criterion ‘union issues’. This is due to the reason that CIMS will result in complete automation of the existing manufacturing system resulting in lesser amount of work, thereby lesser labour, which may result in the reduction of manpower. Similarly, implementing LMS will result in the reduction of Non-Value Added (NVA) activities, which may also result in reduction of labour. Hence, considering these issues, the participants felt that there will be more union intervention and problems, while implementing CIMS and LMS. In particular, they felt that CIMS will have more impact than LMS on such union issues. In a similar manner, the data were obtained and the performance matrix was constructed. Table 5.17 shows the performance matrix. Steps 8 to 10 are shown in Table 5.17.

Table 5.17: Performance matrix

Criteria (g_j **)**	**Alternatives (** a_i **)**		
	TMS	**CIMS**	**LMS**
OPC	38	32	26
TRC	3	10	8
MWC	15	74	30
COC	4	7	6
OVC	22	40	34
TIR	6	30	24
REA	3	5	6
EOI	3	5	6
OSS	2	4	6
FEA	3	6	6
TMC	3	5	5
AOR	4	5	5
ROF	3	7	5
IRR	2	6	7
MUS	3	6	7
STF	4	2	6
TEW	3	5	7
JOS	6	3	4
UNI	4	7	6
CSR	3	4	7
CSP	3	4	7
NOS	3	5	8
CSI	3	5	7
VAA	4	7	8
PRI	4	5	3
HVF	3	7	6

Criteria (g_j)	Alternatives (a_i)		
	TMS	**CIMS**	**LMS**
AVA	3	6	6
BRI	3	6	6
SAL	4	7	7
PRO	5	4	6
ROR	4	3	5
DET	8	6	6
INV	8	6	5
MAN	7	5	6
DEF	600	200	300
MPE	3	7	6
MAS	3	5	6
OCO	3	4	6

Step 11. Calculate the preference index for each alternative over all criteria. The preference index is defined as:

$$\pi(a_1, a_2) = \sum_{j=1}^{J} W_j \times P_j\,(a_1, a_2) \tag{5.5}$$

where,

'W_j' refers to the weight assigned to the criterion 'j' and

$P_j(a_1, a_2)$ is represented as $P_j\left[d_j(a_1, a_2)\right]$

where,

$P_j(a_1, a_2)$ refers to the value of the preference function according to the difference between the evaluations of the alternatives a_1 and a_2 on the criterion 'j' , where $\left(d_j(a_1, a_2) = g_j(a_1) - g_j(a_2)\right)$.

$\pi(a_1, a_2)$ represents the intensity of preference of the decision maker of alternative 'a_1' over action 'a_2', when considering simultaneously all the criteria. It is a figure between '0' and '1' and:

$\pi(a_1, a_2)$ = 0 denotes a weak preference of 'a_1' over 'a_2' for all the criteria

$\pi(a_1, a_2) = 1$ denotes a strong preference of 'a_1' over 'a_2' for all the criteria.

Step 12. Compute positive (where alternative is dominating) and negative (where alternative is dominated) outranking flows for each alternative as shown in equation 5.6 and 5.7:

$$\phi^{+}(a_1) = \sum_{i=1}^{I} \pi(a_1, a_i) \tag{5.6}$$

$$\phi^{-}(a_1) = \sum_{i=1}^{I} \pi(a_1, a_i) \tag{5.7}$$

Step 13. Compute the net flow as shown in equation 5.8.

$$\phi(a_1) = \phi^{+}(a_1) - \phi^{-}(a_1) \tag{5.8}$$

The higher the leaving flow and the lower the entering flow, the better the action. Table 5.18 shows the positive, negative and net flow for each alternative with varying weights. Steps 11 to 13 are shown in Table 5.18.

Table 5.18: Positive, negative and net flow for each alternative with varying weights

Alternatives (a_i)	**Positive outranking flow (P_i^+)**	**Negative outranking flow (P_i^-)**	**Net flow (P_i)**
TMS	0.6072	0.703	-0.1058
CIMS	0.4155	0.4644	-0.0489
LMS	0.5962	0.4415	0.1547

Step 14. Compute the pre-orders of the alternatives using the following conditions:

$$\begin{cases} a_1 P^{+} a_2 \text{ iff } & \phi^{+}(a_1) > \phi^{+}(a_2) \\ a_1 I^{+} a_2 \text{ iff } & \phi^{+}(a_1) = \phi^{+}(a_2) \end{cases}$$
$$\begin{cases} a_1 P^{-} a_2 \text{ iff } & \phi^{-}(a_1) > \phi^{-}(a_2) \\ a_1 I^{-} a_2 \text{ iff } & \phi^{-}(a_1) = \phi^{-}(a_2) \end{cases} \tag{5.9}$$

Step 15. Compile the partial pre-order (PROMETHEE I) of the alternatives by considering the intersection of the above pre-orders.

$$\begin{cases} a_1 P_1 a_2 \quad (a_1 \text{ outranks } a_2) & \text{if } a_1 P^+ a_2 \text{ and } a_1 P^- a_2 \\ & \text{or } a_1 P^+ a_2 \text{ and } a_1 I^- a_2 \\ & \text{or } a_1 I^+ a_2 \text{ and } a_1 P^- a_2 \\ a_1 I_1 a_2 \quad (a_1 \text{ is indifferent to } a_2) & \text{iff } a_1 I^+ a_2 \text{ and } a_1 I^- a_2 \\ a_1 R a_2 \quad (a_1 \text{ and } a_2 \text{ are incomparable}) & \text{otherwise.} \end{cases} \tag{5.10}$$

By using the PROMETHEE I method, some actions still remain incomparable, because only confirmed outrankings are given by the partial pre-order. Table 5.19 shows the partial pre-orders for the alternatives.

Table 5.19: Partial pre-orders for the alternatives

Partial pre-orders
TMS incomparable to CIMS
TMS incomparable to LMS
LMS outranks CIMS

Step 16. To derive the complete pre-order of the alternatives, use the following conditions of the net flow (PROMETHEE II) and rank the alternatives by their net flow.

$$\begin{cases} a_1 P_{11} a_2 \ (a_1 \text{ outranks } a_2) & \text{iff } \phi(a_1) > \phi(a_2) \\ a_1 I_{11} a_2 \ (a_1 \text{ is indifferent to } a_2) & \text{iff } \phi(a_1) = \phi(a_2) \end{cases} \tag{11}$$

Table 5.20 shows the complete pre-orders in the form of net flow for the alternatives along with their rank.

Table 5.20: Complete pre-orders in the form of net flow for the alternatives along with its rank

Alternatives	Net flow (P_i)	Rank
TMS	-0.1058	3
CIMS	-0.0489	2
LMS	0.1547	1

5.3.2.2 Results and discussion

Highly user-friendly software for PROMETHEE II is developed in VC++ to aid the user for performing the comparison of the elements with respect to the alternatives and carrying out the analysis utilising the user inputs. The indigenously developed software is capable of generating graphical outputs and also supports the data retrieval in the form of a spreadsheet. For instance, Figure 5.4, Figure 5.5 and Figure 5.6 represent the graphs depicting the positive, negative and net outflow of alternatives for the criterion – 'training cost (TRC)' respectively, which were generated from indigenously developed software. From these graphs, it can be inferred that under the criterion – 'training cost (TRC)', TMS is found to be better as per positive outflow (refer Figure 5.4) as the training cost was least. Similarly, referring to Figure 5.5, since CIMS and LMS incur more training cost, naturally, the negative outflow for these alternatives were very high. Considering the net outflow (refer Figure 5.6), it can be concluded that TMS performed better than the other alternatives. On the other hand, if you consider the overall positive, negative and net outflow of the alternatives as shown in Figure 5.7, it can be found that LMS has outscored both CIMS and TMS, as it has ranked well in other criteria. The only disadvantage of the indigenously developed software is that, it does not have the graphical functionality of Geometrical Analysis for Interactive Assistance (GAIA).

To check for the sensitivity of the decision made, the PROMETHEE analysis was repeated with same data values, but the weight values for individual elements were kept equal. In other words, the managers of the case organisation want to give equal importance to all the elements and hence, equal weight values (say 1) was assigned for each criterion.

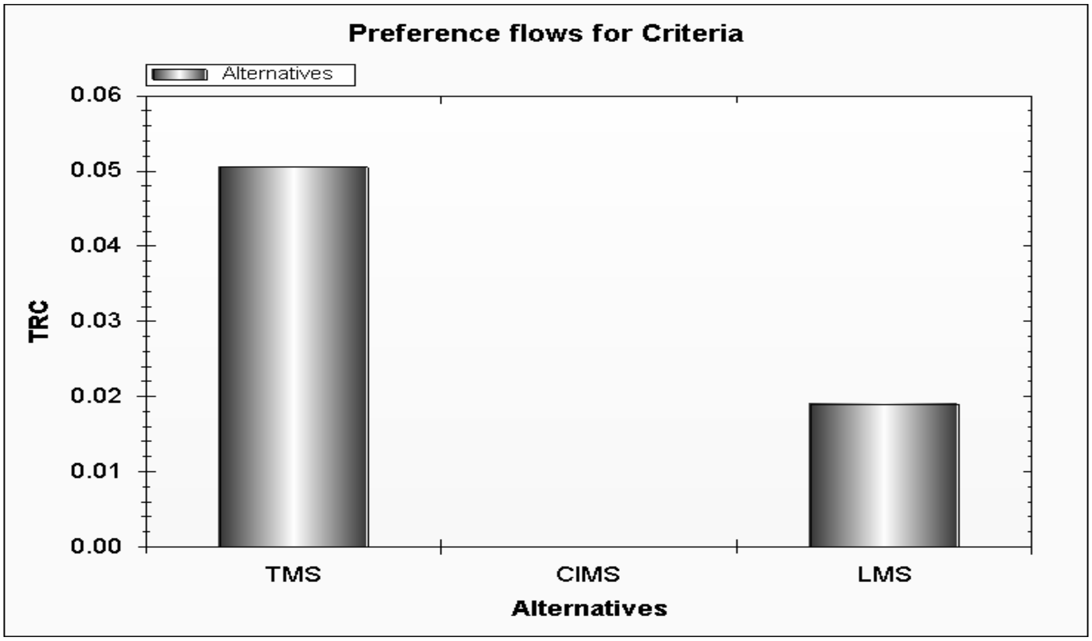


Figure 5.4: Positive outflow of the alternatives for the criterion – Training cost (TRC)

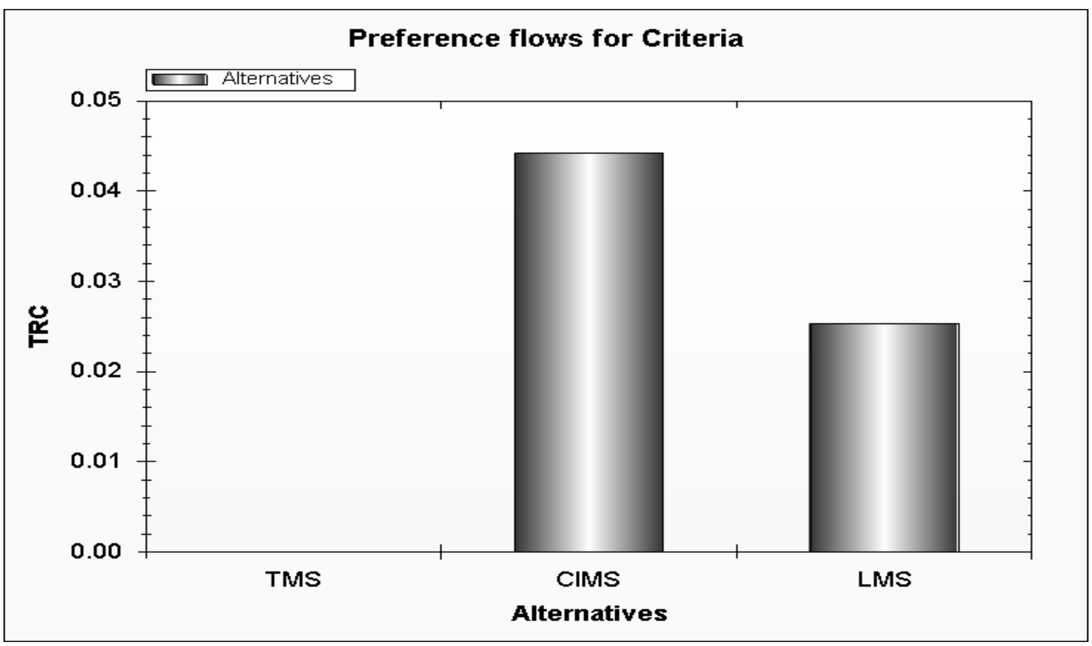


Figure 5.5: Negative outflow of the alternatives for the criterion – Training cost (TRC)

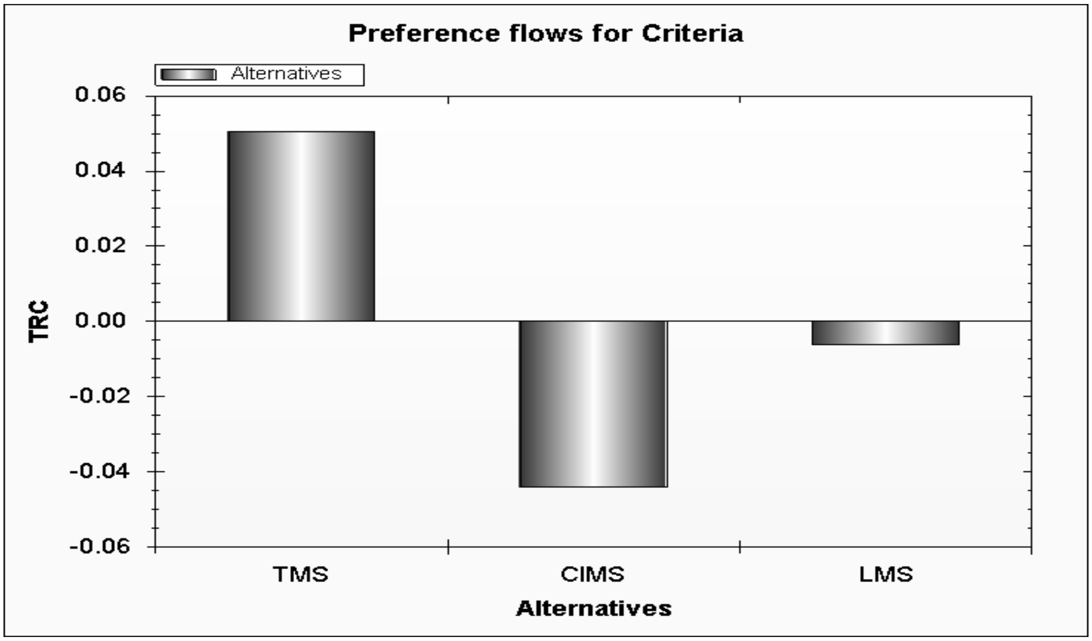


Figure 5.6: Net outflow of the alternatives for the criterion – Training cost (TRC)

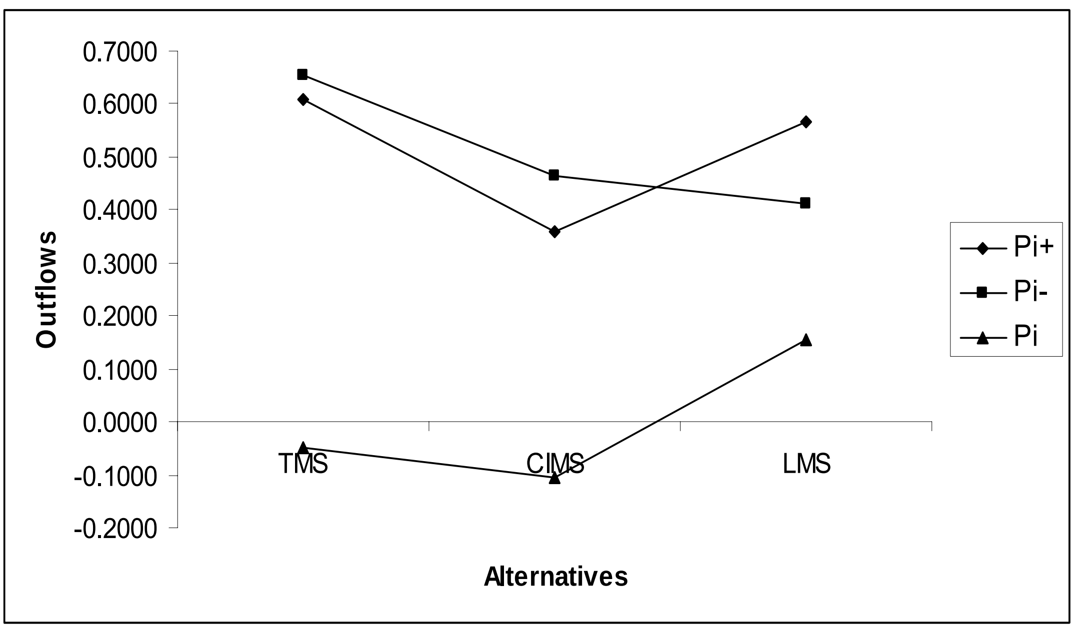


Figure 5.7: Overall positive, negative and net outflow of the alternatives
(Pi+: Positive outflow, Pi-: Negative outflow, Pi: Net outflow)

Table 5.21 shows the positive, negative and net flow for each alternative with equal weights. In this case also, it was found that LMS has outranked the other two alternatives. Thus, it can be said that the decision is highly reliable.

Table 5.21: Positive, negative and net flow for each alternative with equal weights

Alternatives (a_i)	**Positive outranking flow (P_i^+)**	**Negative outranking flow (P_i^-)**	**Net flow (P_i)**	**Rank**
TMS	0.5816	0.6886	-0.1070	3
CIMS	0.3880	0.4527	-0.0647	2
LMS	0.5886	0.4169	0.1717	1

The above-described problem can also be extended by incorporating the constraints (such as financial, technical, social etc.) of the organisation along with the factors/elements considered. Furthermore, it can be modelled by using an extended version of PROMETHEE called the PROMETHEE V. Since a single case study approach has been utilised, the findings cannot be generalised for any other industry.

5.3.3 Development of performance value analysis for justification of lean manufacturing systems

In this section, the problem is analysed based on the performance measures, which will be affected by the implementation of such alternative manufacturing systems. A detailed literature review regarding the performance measures for LMS were carried out in Chapter 4. The obtained performance measures were discussed with the experts from the case organisation to identify relevant performance measures for their organisation. Table 5.22 shows the list of performance measures identified for the selection of suitable manufacturing systems and the classification scheme (i.e. taxonomy) which is established from the perspective of competitive priorities in Chapter 4 was utilised. Thus, the identified performance measures have been classified into eight significant categories.

Table 5.22: List of performance measures identified for the selection of suitable manufacturing systems

Significant category	Performance Measures	In Short
Cost (COS)	Scrap and rework cost (in Lakhs of Rs.)	SRC
	Manufacturing cost per unit (in Lakhs of Rs.)	MAC
	Overall plant investment (in Lakhs of Rs.)	OPI
	Inventory investment (in Lakhs of Rs.)	INI
	Warranty cost (in Lakhs of Rs.)	WAC
	Other cost of poor quality (in Lakhs of Rs.)	CPQ
	Purchase cost (in Lakhs of Rs.)	PUC
	Maintenance cost (in Lakhs of Rs.)	MTC
	Transportation cost (in Lakhs of Rs.)	TRC
	Tooling cost (in Lakhs of Rs.)	TOC
	Design and establishment cost (in Lakhs of Rs.)	DEC
	Personnel cost (in Lakhs of Rs.)	PEC
	Operating cost (in Lakhs of Rs.)	OPC
	Product development cost (in Lakhs of Rs.)	PDC
Quality (QUA)	First pass yield (in %)	FPY
	Rate of customer returns (in %)	RCR
	Customer complaints	NCC
	Defective products shipped to customer (in PPM)	DPC
	Standardisation of procedures and processes (through documentation)	SPP
	Percentage of manufacturing process under statistical control (in %)	MPC
	Rate of preventive maintenance over total maintenance	PRM
	Number of suppliers (in Nos.)	NOS
	Number of certified suppliers (in Nos.)	NCS
	Percentage of products accepted as good without inspection from suppliers (in %)	PAG
	Percentage of defective products adjusted by production line workers (in %)	DPW
	Sole sourcing suppliers	NSS
	Number of suggestions made to suppliers in a year (in Nos.)	NSU
Delivery (DEL)	Customer lead time (in days)	CLT
	Number of kanbans (in Nos.)	KAN
	Purchasing lot size	PLS
	Throughput time or manufacturing lead time (in days)	MLT
	Percentage of parts delivered directly to the point of use from supplier without incoming inspection or storage (in %)	PDU
	Percentage of parts delivered just in time between sections in the production line (in %)	PDL
	Average distance or travel time between the supplier and manufacturer (in Kms.)	TRT

Significant category	Performance Measures	In Short
	Supplier or delivery lead time (in days)	DLT
	Percentage on time delivery (in %)	OTD
	Frequency of the deliveries	FOD
	Penalties due to short quantity or late delivery	RIP
	Adherence to schedule	ATS
	Level of integration between suppliers delivery and the company's production information systems	LII
	Average number of years a supplier is associated with the manufacturer	INS
	Use of standardised container size	USC
Flexibility (FLE)	Work in process inventory (in days)	WIP
	Setup time (in hours)	SET
	Finished goods inventory (in days)	FGI
	Availability of reserve capacity	ARC
	Batch size	BAS
	Percentage of flexible employees cross trained to perform three or more jobs (in %)	FEM
	Percentage of production equipment that is computer integrated or automated (in %)	AUT
	Length of product runs	LPR
	Overall flexibility	OFX
	Number of mixed models in a line (in Nos.)	NMM
	Raw material inventory (in days)	RMI
	Frequency of die changes	FDC
Productivity (PRO)	Manufacturing cycle time (in hours)	MCT
	Labour productivity (in %)	LAP
	Number of inventory or stock rotations (in Nos.)	SRO
	Production capacity (in number of units per year)	PRC
	Total floor space (in m^2)	TFS
	Overall Equipment Efficiency (OEE) (in %)	OEE
	Equipment utilisation (in %)	EQU
	Overall productivity	OPR
	Labour utilisation (in %)	LAU
	Utilisation of capacity	UTC
	Production rate	PRR
	Production volume	PRV
	Number of stages in the overall material flow (in Nos.)	RNS
	Number of bottleneck stages (in Nos.)	NOB
	Material productivity (in %)	MAP
	Machine productivity (in %)	MCP

Significant category	Performance Measures	In Short
	Maintenance time (in hours per week)	RMT
	Value added time (in hours)	VAT
	Non value added time (in days)	NVA
	Average operation time per week (in days)	AVT
	Reliability of machines (%)	REL
	Percentage of unscheduled downtime or equipment breakdown time (in %)	USD
	Takt time (in hours)	TAK
Morale (MOR)	Direct labour (in Nos.)	DIL
	Indirect labour (in Nos.)	IDL
	Number of awards and rewards provided for workers (in Nos.)	REC
	Percentage of inspection carried out by autonomous defect control (in %)	ICA
	Number of teams (in Nos.)	TEA
	Percentage of employees working in team (in %)	EWT
	Number of workers/employees (in Nos.)	NOW
	Reduction in number of workers	RNW
	Employee turnover rate	ETR
	Amount of training (in number of days/year)	TRH
	Use of visual management or aids	VMA
	Level of housekeeping	HOK
	Condition of work environment	WOE
	Worker morale and satisfaction	WMS
	Number of shifts or working hours (in Nos.)	RWH
	Communication between employees and management	COM
	Percentage of people involving in stopping the line due to problems (in %)	PSL
	Hierarchy in the organisation structure (in Nos.)	HIE
	Absenteeism rate	ABM
	Number of accidents (in Nos.)	NOA
	Overtime per week (in days)	OVE
Innovation (INN)	Number of suggestions per employee per year (in Nos.)	SUG
	Time to market for new products (in years)	TTM
	Time spent on engineering changes (in days)	TEC
	Percentage of parts co-designed with suppliers (in %)	PCS
	Number of new products introduced (in Nos.)	NNP
	Total parts in Bill of Materials (BOM)	NOP
	R&D expenditure as a percentage of turnover (in %)	RDE
	Percentage of common or standardised parts (in %)	COP
Competitive advantages (COA)	Gross annual profit (in lakhs of Rs.)	GRP

Significant category	Performance Measures	In Short
	Total sales (in lakhs of Rs.)	TOS
	Revenue (in lakhs of Rs.)	REV
	Customer good will	CGW
	Market share (in %)	MAS
	Loss of customers	LOC
	Brand image	BRI
	Dividends paid to shareholders (in %)	DTS
	Return on assets	ROA
	Price of the product (in lakhs of Rs.)	PRI
	Customer satisfaction	CUS
	Lost sales	LOS
	Time-based competitiveness	TBC

Since there are many main elements (significant category) and sub-elements (performance measures) to be analysed during decision-making, the use of Performance Value Analysis (PVA) was suggested. The PVA model is well received in literature (D'angelo *et al.*, 1996a-b). Various researchers such as Kodali *et al.* (2004), Kodali and Sangwan (2004), Kodali and Routroy (2006) have used the same for various applications. It is a revised version of utility value analysis, which considers the direct/indirect and quantitative/qualitative elements/criteria/attributes/performance indicators and aggregates the weight values of such multiple criteria to arrive at a decision. To demonstrate the PVA, the input from the decision making team of the case organisation were utilised, who were asked to compare the alternatives in light of the above-listed performance measures. The data obtained from them were fed into the PVA.

5.3.3.1 Algorithm

The steps to follow in using the PVA are as follows:

Step 1. Define the problem and determine the objective.

In this case, the problem is to select a suitable manufacturing system, which can help the case organisation to achieve a significant competitive advantage over other firms, while the objective is to justify the same based on its impact on the performance measures.

Step 2. Identify the alternatives 'a_i' available.

The alternatives are:

- Existing/Traditional Manufacturing Systems (TMS),
- Computer Integrated Manufacturing Systems (CIMS) and
- Lean Manufacturing Systems (LMS).

Step 3. Determine the attributes/criteria/performance indicators 'c_j' that govern the problem.

They are obtained from the list of performance measures identified in Table 5.22.

Step 4. Classify the attributes/criteria/performance indicators into significant categories.

The performance measures were already classified into the following significant categories of cost [COS], quality [QUA], delivery [DEL], flexibility [FLE], innovation [INN], morale [MOR], productivity [PRO] and competitive advantages [COA] as shown in Table 5.22.

Step 5. Classify the attributes/criteria/performance indicators into direct (performance grows while measure increases) and indirect categories (performance grows while measure decreases).

Table 5.23 shows the classification of performance measures into direct and indirect categories for the significant category – Cost. It can be found that the up arrow (↑) is used for direct category while a down arrow (↓) is used for indirect category.

Table 5.23: Classification of performance measures into direct and indirect categories for the significant category – Cost

Significant category	Performance Measures	In Short	Max or Min
Cost	Scrap and rework cost (in Lakhs of Rs.)	SRC	↓
	Manufacturing cost per unit (in Lakhs of Rs.)	MAC	↓
	Overall plant investment (in Lakhs of Rs.)	OPI	↓
	Inventory investment (in Lakhs of Rs.)	INI	↓
	Warranty cost (in Lakhs of Rs.)	WAC	↓
	Other cost of poor quality (in Lakhs of Rs.)	CPQ	↓
	Purchase cost (in Lakhs of Rs.)	PUC	↓
	Maintenance cost (in Lakhs of Rs.)	MTC	↓
	Transportation cost (in Lakhs of Rs.)	TRC	↓
	Tooling cost (in Lakhs of Rs.)	TOC	↓
	Design and establishment cost (in Lakhs of Rs.)	DEC	↓
	Personnel cost (in Lakhs of Rs.)	PEC	↓
	Operating cost (in Lakhs of Rs.)	OPC	↓
	Product development cost (in Lakhs of Rs.)	PDC	↓

Step 6. Group the attributes/criteria/performance indicators as quantitative and qualitative measures

Table 5.24, shows the classification of quantitative and qualitative measures for the significant category – Flexibility. For steps 5 and 6, the performance measures were categorised based on the discussions with experts.

Table 5.24: Classification of performance measures into qualitative and quantitative categories for the significant category – Flexibility

Significant category	Performance Measures	In Short	Qual or Quan
Flexibility	Work in process inventory (in days)	WIP	Quan
	Setup time (in hours)	SET	Quan

Significant category	Performance Measures	In Short	Qual or Quan
	Finished goods inventory (in days)	FGI	Quan
	Availability of reserve capacity	ARC	Qual
	Batch size	BAS	Qual
	Percentage of flexible employees cross trained to perform three or more jobs (in %)	FEM	Quan
	Percentage of production equipment that is computer integrated or automated (in %)	AUT	Quan
	Length of product runs	LPR	Qual
	Overall flexibility	OFX	Qual
	Number of mixed models in a line (in Nos.)	NMM	Quan
	Raw material inventory (in days)	RMI	Quan
	Frequency of die changes	FDC	Qual

Step 7. Absolute weight values 'w_j' on a suitable scale (say 1 to 10) is assigned for each attribute/criterion/performance indicator reflecting the normative judgment of the decision maker.

The experts assigned the weight values individually. For most of the performance measures, the weight values were same and only for few performance measures, significant differences were found between them. In such cases, the same was thoroughly discussed and the weight values were revised. Table 5.25 shows the assignment of weight values for the significant category – Innovation.

Table 5.25: Assignment of weight values for the significant category – Innovation

Significant category	Performance Measures	In Short	Weight values for criterion
Innovation	Number of suggestions per employee per year (in Nos.)	SUG	8
	Time to market for new products (in years)	TTM	7
	Time spent on engineering changes (in days)	TEC	5
	Percentage of parts co-designed with suppliers (in %)	PCS	7
	Number of new products introduced (in Nos.)	NNP	8
	Total parts in Bill of Materials (BOM)	NOP	6
	R&D Expenditure as a percentage of turnover (in %)	RDE	8
	Percentage of common or standardized parts (in %)	COP	7

Step 8. Form the performance matrix, i.e., co-efficient 'e_{ij}' related to the attribute/criterion/performance indicator 'c_j' (j = 1, 2, …J) and the alternative 'a_i' (i = 1, 2, …I). If it is a qualitative measure, quantify the same using the scale of 1 to 10. In the case of a direct category, 1 refers to low, 5 means medium, and 9 means high, while it is the vice versa in the case of indirect category (i.e., 9 for low, 5 for medium and 1 for high).

Table 5.26 shows the formation of performance matrix for the significant category – Competitive advantages.

Table 5.26: Formation of performance matrix for the significant category – Competitive advantages

Significant category	**Performance Measures**	**In Short**	**Performance matrix (e_{ij})**		
			TMS	**CIMS**	**LMS**
Competitive advantages	Gross annual profit (in lakhs of Rs.)	GRP	240	300	305
	Total sales (in lakhs of Rs.)	TOS	550	650	675
	Revenue (in lakhs of Rs.)	REV	600	675	700
	Customer good will	CGW	Low	Medium	High
	Market share (in %)	MAS	22	25	28
	Loss of customers	LOC	Low	Medium	High
	Brand image	BRI	Medium	High	High
	Dividends paid to shareholders (in %)	DTS	8	10	11
	Return on assets	ROA	Low	Medium	High
	Price of the product (in lakhs of Rs.)	PRI	0.6	0.35	0.3
	Customer satisfaction	CUS	Low	Medium	High
	Lost sales	LOS	High	Medium	Low
	Time-based competitiveness	TBC	Low	High	High

Step 9. Obtain the relative weight values for each attribute/criterion/performance indicator 'c_j' from absolute weight values 'w_j' as shown in Equation 5.12.

$$\overline{W_j} = \frac{w_j}{\sum w_j}\text{, such that } \sum \overline{W_j} = 1 \qquad (5.12)$$

Table 5.27 shows the relative weight values for the performance measures under the significant category – Quality

Table 5.27: Relative weight values for the performance measures under the significant category – Quality

Significant category	Performance Measures	In Short	Weight values for criterion	Relative weight values
Quality	First pass yield (in %)	FPY	8	0.009
	Rate of customer returns (in %)	RCR	10	0.011
	Customer complaints	NCC	10	0.011
	Defective products shipped to customer (in PPM)	DPC	9	0.010
	Standardization of procedures and processes (through documentation)	SPP	8	0.009
	Percentage of manufacturing process under statistical control (in %)	MPC	7	0.008
	Rate of preventive maintenance over total maintenance	PRM	7	0.008
	Number of suppliers (in Nos.)	NOS	6	0.007
	Number of certified suppliers (in Nos.)	NCS	7	0.008
	Percentage of products accepted as good without inspection from suppliers (in %)	PAG	8	0.009
	Percentage of defective products adjusted by production line workers (in %)	DPW	7	0.008
	Sole sourcing suppliers	NSS	6	0.007
	Number of suggestions made to suppliers in a year (in Nos.)	NSU	5	0.006

Step 10. Form the normalised performance matrix. The values for each attribute/criterion/performance indicator 'c_j' are obtained based on the following conditions:

- Direct category (when performance increases while measure increases)

$$p_{ij} = \frac{e_{ij}}{\max(e_j)} \qquad (5.13)$$

for each alternative 'a_i' related to attribute 'c_j'

- Indirect category (when performance grows while measure decreases)

$$p_{ij} = \frac{\min(e_j)}{e_{ij}} \quad (5.14)$$

for each alternative 'a_i' related to attribute 'c_j'. Table 5.28 shows the normalised performance matrix for performance measures under the significant category – Productivity.

Table 5.28: Normalised performance matrix for performance measures under the significant category – Productivity

Significant category	In Short	Max or Min	Performance matrix (e_{ij})			Normalised performance matrix (P_{ij})		
			TMS	CIMS	LMS	TMS	CIMS	LMS
Productivity	MCT	↓	0.6	0.35	0.4	0.583	1.000	0.875
	LAP	↑	78	90	85	0.867	1.000	0.944
	SRO	↑	6	10	12	0.500	0.833	1.000
	PRC	↑	10000	14000	11000	0.714	1.000	0.786
	TFS	↓	1200	1000	950	0.792	0.950	1.000
	OEE	↑	42	65	75	0.560	0.867	1.000
	EQU	↑	73	80	85	0.859	0.941	1.000
	OPR	↑	Low	Medium	High	0.111	0.556	1.000
	LAU	↑	86	80	90	0.956	0.889	1.000
	UTC	↑	83	85	80	0.976	1.000	0.941
	PRR	↑	Low	High	Medium	0.111	1.000	0.556
	PRV	↑	Low	High	Medium	0.111	1.000	0.556
	RNS	↓	14	12	11	0.786	0.917	1.000
	NOB	↓	4	2	2	0.500	1.000	1.000
	MAP	↑	82	85	90	0.911	0.944	1.000
	MCP	↑	78	85	90	0.867	0.944	1.000
	RMT	↓	26	28	20	0.769	0.714	1.000
	VAT	↑	4.5	6	6.5	0.692	0.923	1.000
	NVA	↓	3	2	1	0.333	0.500	1.000
	AVT	↑	4.1	5	5.5	0.745	0.909	1.000
	REL	↑	74	85	80	0.871	1.000	0.941
	USD	↓	33	25	20	0.606	0.800	1.000
	TAK	↓	0.5	0.35	0.3	0.600	0.857	1.000

Step 11. Obtain partial performance measure 'Z_{ij}' by multiplying relative weight values of attribute/criterion/performance indicator with each of its row members (alternatives), i.e., Partial performance of j^{th} attribute is given as:

$$Z_{ij} = p_{ij} \times \overline{W_j} \tag{5.15}$$

where (i = 1, 2, . . . I).

Table 5.29 shows the partial performance measure for performance indicators under the significant category – Morale.

Step 12. Aggregate the partial performance measures for each alternative into an overall measure. Overall measure 'N_i' of alternative 'a_i' is the sum of 'Z_{ij}'

$$N_i = \sum_{j=1}^{J} Z_{ij} \tag{5.16}$$

Step 13. Rank the alternatives 'a_i' in accordance with decreasing value of 'N_i'. Steps 12 and 13 are shown in Table 5.30. Table 5.30 shows the overall performance measures and ranking of alternatives

Step 14. Perform the significant category analysis.

To obtain the results of this analysis, set the weights of each attribute/criterion/performance indicator to zero, which are different from the significant category being considered and repeat step 7 to step 13. Table 5.31 shows the significant category analysis for the category - Competitive advantages.

Table 5.29: Partial performance measure for performance indicators under the significant category – Morale

Significant category	In Short	Max or Min	Qual or Quan	Weight values for criterion	Performance matrix (e_{ij})			Relative weight values	Normalised performance matrix (P_{ij})			Partial performance measures (Z_{ij})		
					TMS	CIMS	LMS		TMS	CIMS	LMS	TMS	CIMS	LMS
Morale	DIL	↓	Quan	8	42	35	35	0.009	0.833	1.000	1.000	0.008	0.009	0.009
	IDL	↓	Quan	8	38	30	35	0.009	0.789	1.000	0.857	0.007	0.009	0.008
	REC	↑	Quan	7	6	8	12	0.008	0.500	0.667	1.000	0.004	0.005	0.008
	ICA	↑	Quan	7	24	90	95	0.008	0.253	0.947	1.000	0.002	0.008	0.008
	TEA	↑	Quan	7	4	6	9	0.008	0.444	0.667	1.000	0.004	0.005	0.008
	EWT	↑	Quan	6	20	50	70	0.007	0.286	0.714	1.000	0.002	0.005	0.007
	NOW	↓	Quan	8	80	75	70	0.009	0.875	0.933	1.000	0.008	0.009	0.009
	RNW	↑	Qual	7	Low	High	Medium	0.008	0.111	1.000	0.556	0.001	0.008	0.004
	ETR	↓	Qual	6	High	Medium	Low	0.007	0.111	0.556	1.000	0.001	0.004	0.007
	TRH	↑	Quan	7	14	24	30	0.008	0.467	0.800	1.000	0.004	0.006	0.008
	VMA	↑	Qual	7	Low	Medium	High	0.008	0.111	0.556	1.000	0.001	0.004	0.008
	HOK	↑	Qual	7	Low	Medium	High	0.008	0.111	0.556	1.000	0.001	0.004	0.008
	WOE	↑	Qual	6	Poor	Fair	Good	0.007	0.111	0.556	1.000	0.001	0.004	0.007
	WMS	↑	Qual	7	Low	Medium	High	0.008	0.111	0.556	1.000	0.001	0.004	0.008
	RWH	↓	Quan	6	3	2	2	0.007	0.667	1.000	1.000	0.005	0.007	0.007
	COM	↑	Qual	7	Low	Medium	High	0.008	0.111	0.556	1.000	0.001	0.004	0.008
	PSL	↑	Quan	7	12	15	25	0.008	0.480	0.600	1.000	0.004	0.005	0.008
	HIE	↓	Quan	5	6	5	4	0.006	0.667	0.800	1.000	0.004	0.005	0.006
	ABM	↓	Qual	6	High	Medium	Low	0.007	0.111	0.556	1.000	0.001	0.004	0.007
	NOA	↓	Qual	6	High	Low	Low	0.007	0.111	1.000	1.000	0.001	0.007	0.007
	OVE	↓	Quan	7	2	1	0.5	0.008	0.250	0.500	1.000	0.002	0.004	0.008

Table 5.30: Overall performance measures and ranking of alternatives

	Alternatives		
	TMS	**CIMS**	**LMS**
Overall performance measure (N_{ij})	0.490	0.773	0.961
Rank	3	2	1

Table 5.31: Significant category analysis for the category - Competitive advantages

Significant category	**In Short**	**Max or Min**	**Weight values for criterion**	**Performance matrix (e_{ij})**			**Relative weight values**	**Normalized performance matrix (P_{ij})**			**Partial performance measures (Z_{ij})**		
				TMS	**CIMS**	**LMS**		**TMS**	**CIMS**	**LMS**	**TMS**	**CIMS**	**LMS**
Competitive advantages	GRP	↑	10	240	300	305	0.100	0.787	0.984	1.000	0.079	0.098	0.100
	TOS	↑	9	550	650	675	0.090	0.815	0.963	1.000	0.073	0.087	0.090
	REV	↑	9	600	675	700	0.090	0.857	0.964	1.000	0.077	0.087	0.090
	CGW	↑	7	Low	Medium	High	0.070	0.111	0.556	1.000	0.008	0.039	0.070
	MAS	↑	8	22	25	28	0.080	0.786	0.893	1.000	0.063	0.071	0.080
	LOC	↓	6	Low	Medium	High	0.060	1.000	0.556	0.111	0.060	0.033	0.007
	BRI	↑	8	Medium	High	High	0.080	0.556	1.000	1.000	0.044	0.080	0.080
	DTS	↑	7	8	10	11	0.070	0.727	0.909	1.000	0.051	0.064	0.070
	ROA	↑	6	Low	Medium	High	0.060	0.111	0.556	1.000	0.007	0.033	0.060
	PRI	↓	8	0.6	0.35	0.3	0.080	0.500	0.857	1.000	0.040	0.069	0.080
	CUS	↑	8	Low	Medium	High	0.080	0.111	0.556	1.000	0.009	0.044	0.080
	LOS	↓	7	High	Medium	Low	0.070	0.111	0.556	1.000	0.008	0.039	0.070
	TBC	↑	7	Low	High	High	0.070	0.111	1.000	1.000	0.008	0.070	0.070
				Aggregated partial performance measures for alternatives							**0.526**	**0.814**	**0.947**

Step 15. Repeat step 14 for all significant categories.

Table 5.32 shows the aggregated partial performance measures for alternatives under each significant category. Take the decision based on the overall performance measure calculated above in Table 5.31 and the aggregated performance measures of significant categories.

Table 5.32: Aggregated partial performance measures for alternatives under each significant category

Significant category	**Aggregated partial performance measures for alternatives**		
	TMS	**CIMS**	**LMS**
COS	0.735	0.754	0.915
QUA	0.364	0.728	0.991
DEL	0.418	0.703	1.000
FLE	0.327	0.726	0.944
PRO	0.643	0.893	0.941
MOR	0.369	0.743	0.970
INN	0.464	0.743	1.000
COA	0.526	0.814	0.947

5.3.3.2 Results and discussions

Based on the results obtained, graphs for partial performance measures for the alternatives are drawn as shown in Figures 5.8 - 5.10. Analysing Figures 5.9 and 5.10, reveals that for some of the performance indicators such as level of automation (AUT), indirect labour (IDL), CIMS have scored better than LMS. In the case of measures such as first pass yield (FPY), utilisation of capacity (UTC), both have equal values. But considering all the indicators as a whole, LMS have outscored CIMS. Similarly, analysing Table 5.32, it can be found that performance of CIMS is more or less equivalent to that LMS in terms of productivity (PRO) and competitive advantages (COA). However, in terms of cost (COS), CIMS is more or less equal to that of TMS, because it involves substantial investment in hardware and software, which is lesser than that of LMS. But as a whole, in all the significant categories, LMS has clearly outperformed both CIMS and TMS. Thus, it can be concluded that for the given case situation, LMS seems to be a best alternative. Hence, based on the above analysis, it can be concluded that the selection of LMS is justified for the case organisation. However, the obtained results cannot be generalised for other industries in the same sector or industries across different sectors, as these firms may be different from the case organisation considered in terms of its size, products, manufacturing process, financial position, culture etc.

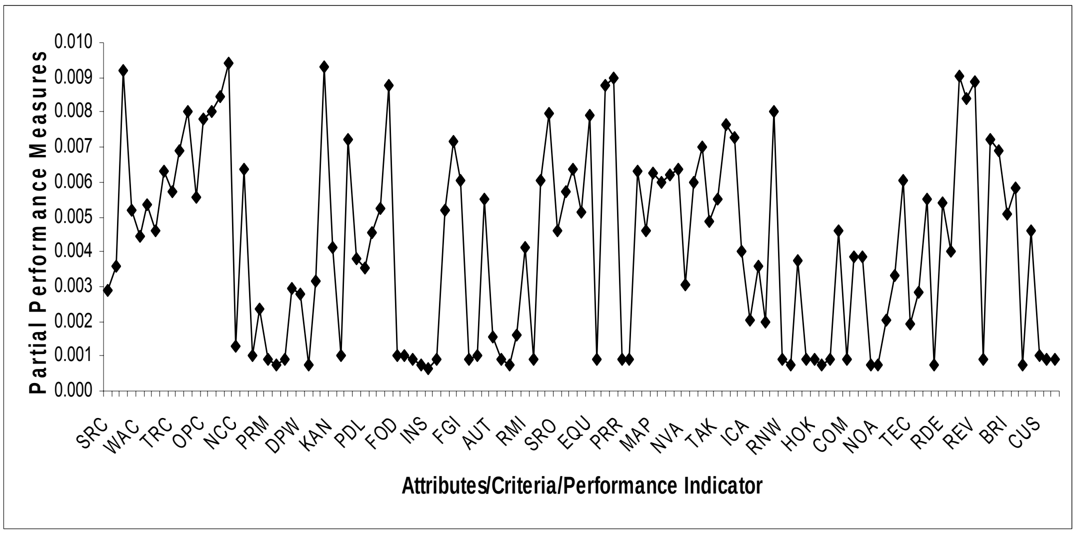


Figure 5.8: Partial performance measures for the alternative – TMS

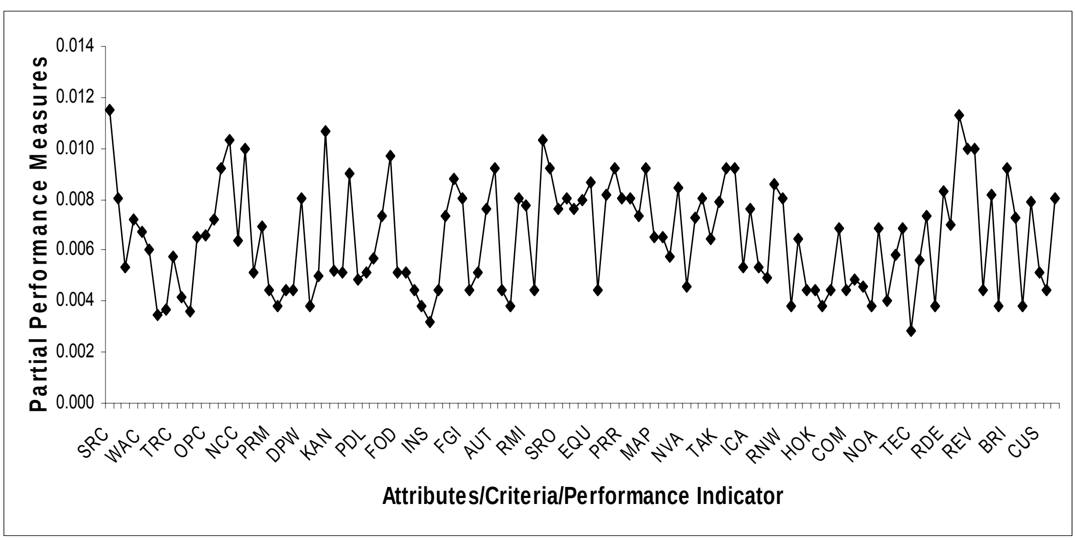


Figure 5.9: Partial performance measures for the alternative – CIMS

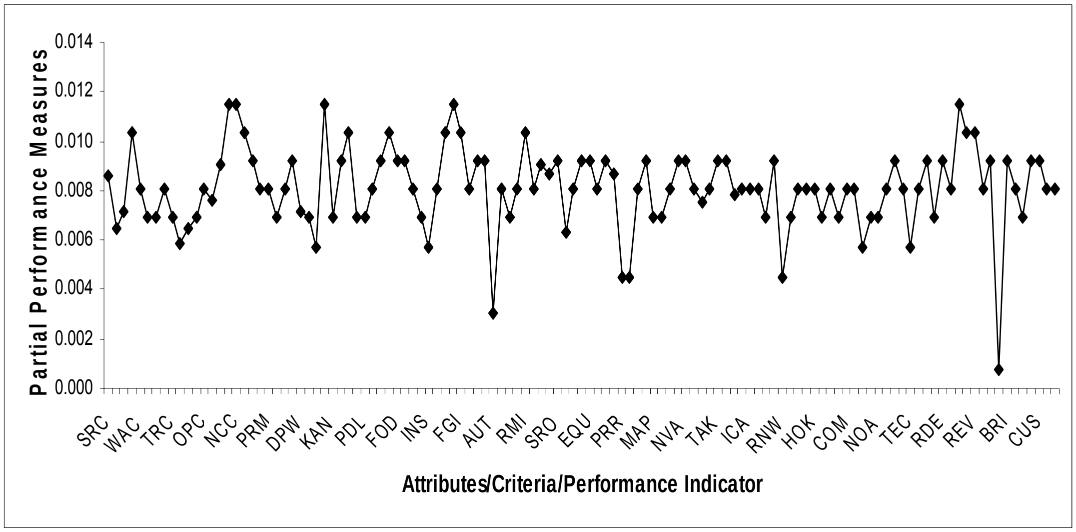


Figure 5.10: Partial performance measures for the alternative – LMS

5.4 Conclusions

This chapter started with an introduction regarding the justification of AMS. It was found that the traditional justification procedures such as NPV, IRR are difficult to apply in the current scenario, as implementing AMS require an analysis from multiple perspectives. Hence, an attempt was made to provide fill in this gap by presenting a case of a valve manufacturing company, in which the management has to decide whether to implement CIMS or LMS. Since such decisions are strategic in nature, it requires an in-depth analysis for which multiple factors and attributes have to be considered. Hence, MADM models were used for analysis. For the first two perspectives – namely ‘tools, techniques, practices, procedures and principles (i.e., capability) of alternative manufacturing systems’ and ‘the impact of alternative manufacturing system on the organisation’, an ANP model is developed. For the next two perspectives – i.e., ‘the impact of alterative manufacturing systems on the stakeholders of the organisation’ and the ‘perceived benefits for each of the alternative manufacturing systems’, a PROMETHEE model, which work based on the outranking method is developed. Finally, for the last perspective – ‘impact of implementing alternative manufacturing systems on the performance measures of the organisation', a simple model based on the PVA is developed, as it considers the performance and value of the alternative manufacturing systems. A brief overview about these MADM models was provided and the basis for selecting the same was discussed. In addition to this, a review on the applications of these models was presented apart from demonstrating the algorithms of all the models in a step-by-step manner. The results of these models indicated that the LMS is superior, when compared to the other alternatives. Hence, the case organisation should proceed with the implementation of LMS.

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Chapter 6

Development of Simulation Models for the Design of Lean Manufacturing Systems

6.1 Introduction

In recent years, many organisations both in India and other countries are implementing the principles and concepts of 'Lean Manufacturing (LM)' with the objective of achieving a superior competitive advantage over other organisations. Few companies have attained their objective, while many of them did not. For instance, Dunstan *et al.* (2006) examined the application of LM in a mining environment. They described about the implementation of certain LM elements that are applicable in these industries and noted that health and safety related incidents were reduced from 154 to 67; absenteeism was reduced by 3.4% to 1.8%, while about $2 million (Australian) were saved during the year 2006. On the other hand, Bamber and Dale (2000) discussed about the application of Lean Production (LP) methods to a traditional aerospace manufacturing organisation and found that there are two main stumbling blocks to the LM application - the redundancy programme and a lack of employee education in the concept and principles of lean production. Apart from these, other reasons include: the managers of these organisations may not have clearly understood about the following:

- How to implement LM?
- What changes will happen in an organisation, when it gets transformed through LM? and
- How LM will affect the performance measures of an organisation?

Mohanty *et al.* (2007) too supported this statement and noted that

> *“many of the companies that report initial gains from lean implementation often find that improvements remain localized, and the companies are unable to have continuous improvements going on. One of the reasons, we believe, is that many companies or individual managers who adopted lean approach have incomplete understanding and, as a result, could not be able to gain all the benefits as Toyota enjoys”.*

To overcome the first issue (i.e. how to implement LM), researchers have proposed different methodologies and steps. For example, Åhlström and Karlsson (2000) developed a framework for LM from the perspective of process of adoption. They discussed briefly about the content of the framework apart from depicting the major actions taken by a case company. Womack and Jones (1996) enumerated the five tenets of LM and emphasised that VSM has to be carried out as the first step towards LM implementation. Dhandapani *et al.* (2004) presented a case study of a steel company to demonstrate the construction of current state and future state VSMs and explained that per annum production costs can be reduced by 8% of turnover, while capital equivalent to 3.5% of turnover can be released through the removal of inventory. It is evident from the above case study that VSM can provide answers to both the second and third questions too, as it provides an estimation of improvement of performance measures apart from depicting ‘how an organisation will look in the future through future state maps’.

6.1.1 Advantages and shortcomings of value stream mapping

A literature review in Chapter 2 also revealed that VSM has been applied widely. Any LM implementation starts with the development of VSM. The main reason for using VSM is that it has the following advantages (Rother and Shook, 1999):

- It helps to visualise and clearly see the entire flow

- It helps in identifying the waste in the value stream
- It shows the linkage between the information flow and the material flow
- It provides an understanding of how the organisation will be in the future, if all improvement activities are implemented properly and if the identified wastes were eliminated or removed

Although the VSM has the above-mentioned advantages, it suffers from the following shortcomings:

- The VSM is static in nature and it can capture only a snapshot view of the shop floor on any particular day. For instance, on a given day, the production might be running smoothly without any problems, while on the other day, the entire shop floor might suffer due to breakdowns of machines, quality problems, unavailability of raw materials, etc. Hence, in these circumstances, the VSM tend to vary as per the situation that prevails in the organisation
- It identifies only the areas for improvement and provides only a tentative solution in the future state map. These solutions may not get implemented during the actual implementation due to infeasibility
- The values in the future state map is obtained based on the assumption that all the issues in the problematic areas will be completely resolved. However, in practice, the entire problem may not be completely resolved due to the reasons of infeasibility
- Similarly, the reduction in NVA, the increase in process ratio and the benefits that are assumed to be obtained after carrying out possible improvements are based on estimates. But, in practice, similar benefits may not be achieved
- Drawing VSM's by hand, displaying them, and making changes to them is a cumbersome process and it takes a lot of time

Similarly other researchers also have identified the shortcomings of VSM. Lian and Van Landeghem (2002) listed out the following:

- VSM is composed by physically ‘walking’ along the flow and recording what happens on the floor. Hence, it may limit both the level of detail and the number of different versions that can be handled
- In real world situations, many companies are of a high variety, low volume type. Hence, it may require value streams to be composed for many tens or hundreds or industrial parts and products. This adds a level of complication (and variability) that cannot be addressed by normal methods
- Revealing as a VSM map may hamper, many people from failing to ‘see’ how it translates into reality. So, the VSM risks ending up as a nice poster, without much further use

McDonald *et al.* (2002) too noted that VSM may not serve the purpose, when it is used to map a production line which produces different types of product families that are having different processing times and set-up times for each processing step apart from different number of shifts.

To overcome such issues, researchers have suggested that simulation can be used in conjunction with VSM to simulate both the current and future state of the case organisation. For instance, Detty and Yingling (2000) demonstrated the simulation study to quantify the benefits of LM in an assembly process for a high volume (500 000 units/year) consumer electronic product. McDonald *et al.* (2002) described the integration of VSM and simulation in a dedicated product line in an engineer-to-order motion control products manufacturing plant. Huang and Liu (2005) used the simulation model to represent a low volume manufacturer of oval-gear flow-meters having a demand of about 1000 units/year. Comm and Mathaisel (2005) developed a simulation model in Arena to demonstrate the production system of Orient Handbag Limited, a high variety batch manufacturer. Lian and Landeghem (2007) discussed about the application of VSM-based simulation generator in a manufacturer of poultry and pig raising equipments for feeding, drinking, feed storage and feed transportation systems. A detailed review was already presented in Chapter 2. However, the literature related to simulation and LM suffers from the following research gaps:

- Many simulation studies that are undertaken from the early 1990s to present are addressing the areas of kanban, pull/push, mixed model assembly/production, inventory control (small lot production) etc. But adequate importance is not given to other JIT/LM elements such as layout change, visual management, process improvements, multi-machine activity (job enlargement), floor space reduction and other LM elements.
- Similarly, most of the studies were focused on analysing one or few issues such as finding the optimal size of kanbans or developing a schedule for mixed model assembly or analysing the performance of push/pull systems. Very few studies have been undertaken considering a combined implementation of JIT/LM elements. Philipoom *et al.* (1996) too noted that previous research has looked at these issues independently and claimed that their paper is the first paper to provide an integrated approach which addressed the multiple-level, capacitated resource problem of determining container sizes, number of kanbans, and product sequence simultaneously in a just-in-time (JIT) shop with kanbans. However, they do not carry out simulation.
- Apart from this, there is no study available, which discusses about application of simulation and VSM in case industries that deal with a high volume medium variety batch production system, high and a low volume, high variety job shop production system

In this chapter, an attempt has been made to resolve the above gaps by developing the simulation models for designing the Lean Manufacturing Systems (LMS) in

- a shop floor that manufactures brake linings using a batch production system
- a cell that produces spiral and crown wheels (gears) using a mass production system and
- a factory that fabricates doors and windows using a job shop production system

In all the above cases, the organisations have just started with the design of LMS. Therefore, the purpose of these simulation models is to help the managers understand how the performance measures of these organisations will be affected by the implementation of various LM elements. It should be remembered here that these simulation studies are not meant for optimisation purposes; rather it will provide an idea to the managers of the case organisations about 'how the organisation will be after getting transformed through the principles and practices of LM' and 'how the implementation of these LM elements will affect the performance measures of the organisation', before the actual implementation.

All the simulation models were developed using a software package called QUeuing Event Simulation Tool (QUEST), which can emulate a complete three-dimensional digital factory environment. It provides a single collaborative environment for industrial engineers, manufacturing engineers and management to develop and prove out best manufacturing flow practices throughout the production design process. Using QUEST, it is possible to experiment with parameters such as facility layout, resource allocation, kaizen practices, and alternate scheduling scenarios, which can help in quantifying the impact of the decisions on production throughput and cost. It has the capability to quickly build a simulation model to the level of detail required, adding more detail as necessary to improve accuracy throughout the design process. The most commonly needed behaviour logic can be selected from comprehensive logic menus that are parameter driven. On the other hand, for unique problems, it has robust and flexible simulation language which provides distributed processing with access to all system variables. This high-level, structured language allows users to define custom behaviours and gain unlimited control over the simulation*.

6.2 Development of Simulation Model for the Design of Lean Manufacturing Systems for a Shop Floor that Manufactures Brake Linings using a Batch Production System

The company considered for this study is named as XYZ Limited (XYZL) to preserve the confidentiality. XYZL is a fully Indian owned company manufacturing automotive, non-automotive and industrial friction materials, which are extensively used in commercial vehicles, passenger cars, tractors (agricultural) and motor cycles. It manufactures a variety of products, which include: asbestos-free woven clutch facings, disc pads, flexible rolls, etc. The products are exported to more than 69 countries catering to the after-market needs of international customers such as Mercedes Benz, Volvo, etc. Furthermore, XYZL is also the preferred supplier to some of the well-known automobile manufacturers in India. It has four manufacturing plants and the combined production capacity of all plants exceeds 1.2 million brake blocks per month. It has obtained ISO/TS 16949 and ISO 14001 certification and their products have been tested to meet international requirements besides the Indian IS 11852. XYZL also practices TPM and recently, they have started implementing LMS in one of their plant located in the southern part of India to achieve world-class standards (Vijayaraghavan, 2006).

6.2.1 Manufacturing process of brake linings

The plant considered for LM implementation has four manufacturing shops and each shop manufacture a wide variety for brake linings. However, as a pilot project, the top

* http://www.delmia.com

management was planning to implement these concepts first in one of the shop that manufactures brake linings for heavy commercial vehicles. Currently, this shop manufactures 5 different varieties of products. Even though a wide variety of brake linings are manufactured by the case organisation, it should be remembered that the manufacturing process involved for making the brake linings is same. Figure 6.1 shows the flow chart depicting the sequence of manufacturing process for brake linings.

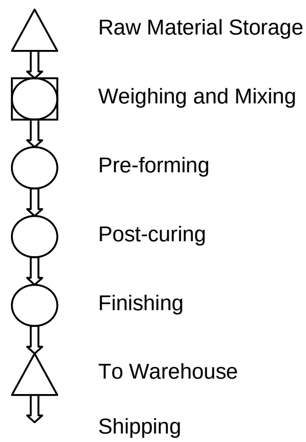


Figure 6.1: Flow chart depicting the sequence of manufacturing processes for brake linings (Source: Vijayaraghavan, 2006)

Vijayaraghavan (2006) has discussed in detail about each stage of the manufacturing process. A cursory analysis of the manufacturing process reveals that brake linings are manufactured in batches. Each stage in the process such as pre-curing, post-curing, etc. require the products to be maintained at certain temperature for definite period of time. If the required temperature and time is not maintained, the desired output of the brake linings will not be obtained. Hence, these processes are considered to be time and temperature dependent batch production system.

6.2.2 Value stream mapping of the shop floor that manufactures brake linings using a batch production system

To start with the LM implementation, the managers and engineers of the case organisation as a team, performed the VSM. It is done in two steps. The first step is to draw the current state VSM, which provides a snapshot of how things are being done currently, and the second step is to draw the future state map, which shows how things are supposed to be done. Figure 6.2 shows the current state VSM of the shop that manufactures heavy duty brake linings using a batch production system. From figure 6.2, it can be found that the Value Added Time (VAT) is just 0.45 days, while the Production Lead Time (PLT) is about 4.65 days. This clearly reveals that the manufacturing process of brake linings involves lot of Non-Value Added (NVA) activities. In addition to this, other data such as material flow, information flow, number of workers, cycle time, inventory, etc. are also captured by the current state VSM. Figure 6.2 also reveals that inventory has piled up before all the workstations. Since, inventory in an organisation hides all other problems (Nicholas, 1998), the engineers in XYZL would like to reduce inventory through various improvement activities.

They also attempted to visualise how their organisation will be after reducing the inventory by implementing the LM principles using a future state VSM. Figure 6.3 shows the future state VSM of the shop that manufactures heavy duty brake linings using a batch production system. From this figure, it can be found that the inventory level at the compounding area and in other processing stages can be reduced to a great extent, thereby resulting in improvement in process ratio. To eliminate these wastes and achieve significant improvement, various tools, techniques, practices, procedures and principles (in short, it will be called as ‘elements’) of LM have to be implemented. Hence, before the actual implementation of the tools, the current state and future state were simulated to understand the feasibility of implementing these tools and techniques apart from providing the managers an idea of how it will affect the performance of the current manufacturing system apart from demonstrating a real-time picture of the transformation of shop floor.

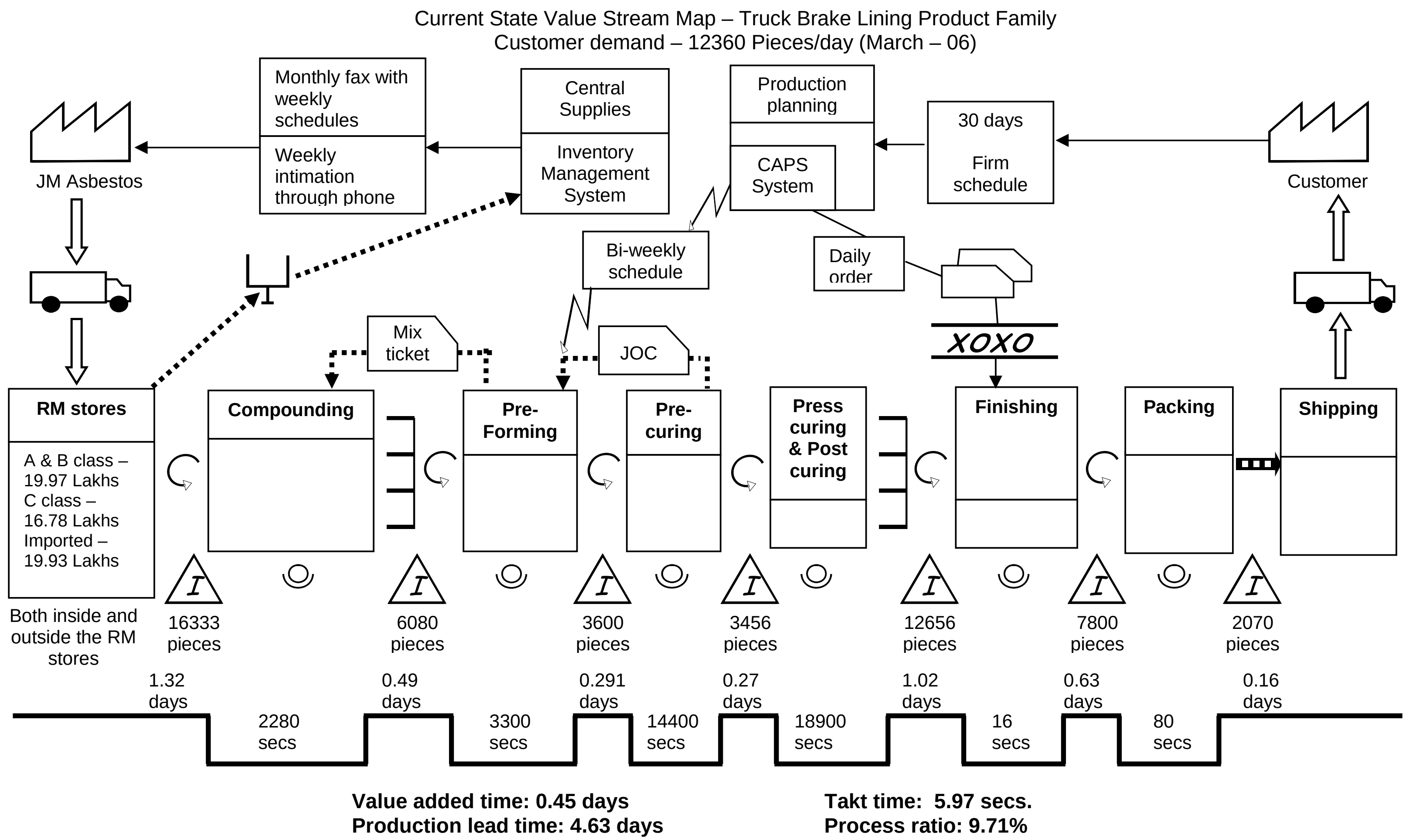


Figure 6.2: Current state VSM of the shop that manufactures heavy duty brake linings using a batch production system (Source: Vijayaraghavan, 2006)

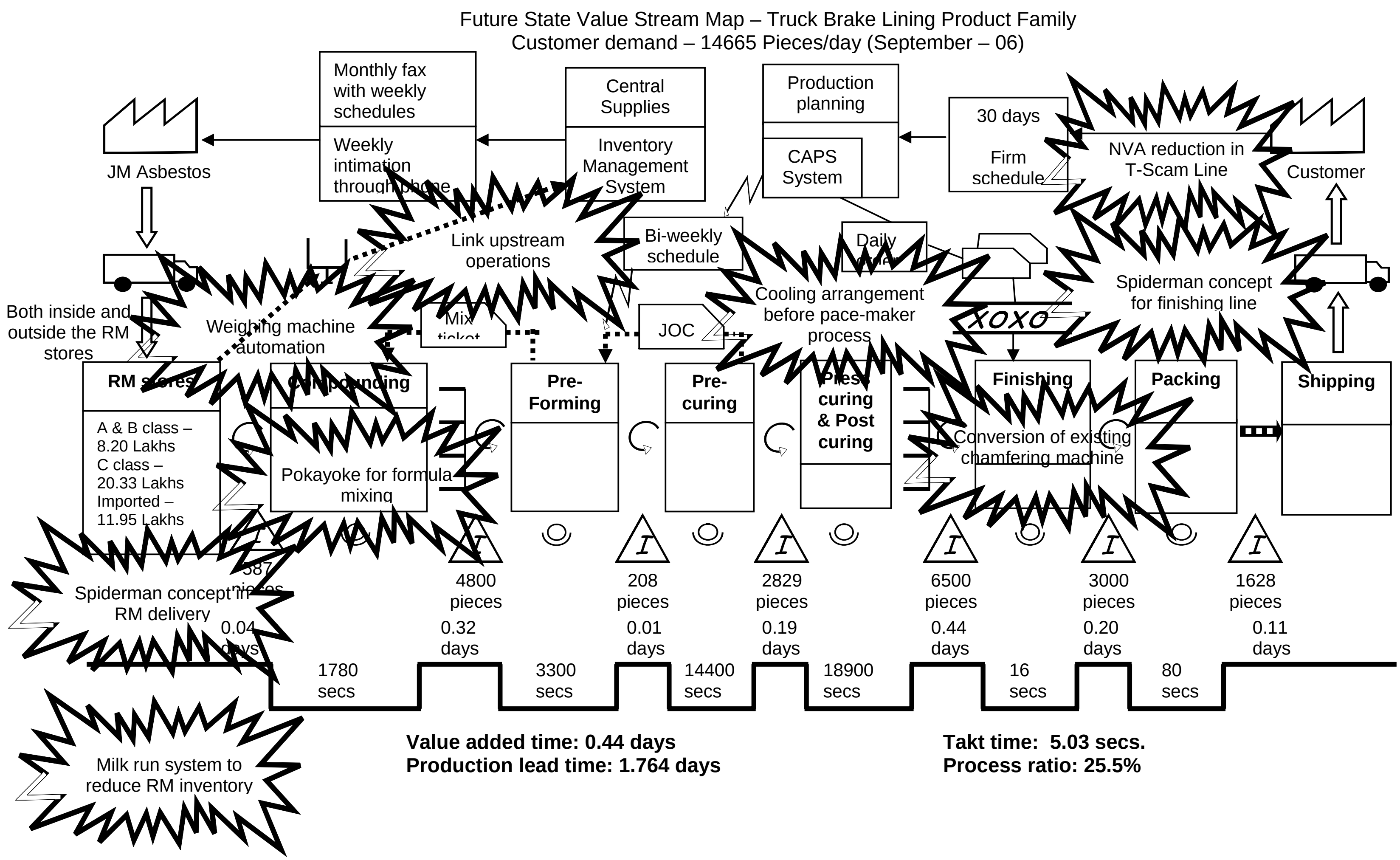


Figure 6.3: Future state VSM of the shop that manufactures heavy duty brake linings using a batch production system (Source: Vijayaraghavan, 2006)

6.2.3 Simulation model for the current state map

The data which were collected during the development of current state VSM has been used for developing the simulation model. From Figure 6.2, it can be found that initial inventory at the various stages of the process are as follows:

- Compounding: contains RM equivalent to 16333 pieces,
- Pre-forming: holds semi-processed mix equivalent to 6080 pieces,
- Pre-curing: stores semi-processed mix equivalent to 3600 pieces,
- Press curing & post curing: stocks semi-process mix equivalent to 3456 pieces,
- Finishing = 12656 pieces,
- Packing = 7800 pieces and
- Shipping = 2070 pieces.

In addition to this, other details such as setup time, number of operators, uptime of the machines etc. were also collected. However, they are not shown in the figure. Among the different process, compounding area holds the maximum inventory and hence it is identified as a major problem area. Hence more details regarding the same were collected, which are given below:

- Raw Material (RM) is issued only during the day shift and quantity required for 3 shifts is kept in the shop floor, with an inventory of about 24,000 kgs.
- RM is moved to the shop floor only with the help of a forklift, since a huge inventory is to be handled.
- Daily RM usage is not based on the actual consumption but it is purely based on the average of last three-month consumption.
- In the manufacturing cell of heavy duty (commercial vehicle) brake linings, around 5 varieties of products are made. Each type of brake linings requires

different chemical compounds to be mixed. Hence, a large inventory is required to be maintained for different chemicals and compounds.

Similarly, the assumptions made for developing the current state VSM are as follows:

- The inventory is taken entirely to be initial inventory. Before the start of the simulation, this inventory will be built up before the workstations. This is due to the fact that a VSM captures the snap shot picture of the shop floor at any given point of time. Hence, the simulation too starts with the current situation as obtained from the current state VSM. However, the inventory values are scaled down by a factor of 100 for the ease of simulation. Since the inventory values of the manufacturing process during the current state is very high, it will result in huge stack of coloured bars before each work station during the simulation. Furthermore, it presents a poor visual representation of the simulation model as the user will not be able to judge whether the material is flowing between different manufacturing stages or not. For instance, if we give an initial inventory of 4000 units, then the computer has to generate a representation of about 4000 units before the actual simulation, which consumes significant time. If the same has been scaled down by 100, the computer has to generate a representation of only 40 units, which would drastically reduce the simulation time.
- The setup time is assumed to be zero for all the machines, as every product goes through the same processes without any change of machines and only the cycle time slightly changes for each process depending upon the type of brake linings.
- Every machine has one operator.
- Inter request time of the sink is made equal to the takt time, as they already have a pull system

- Each day works with 3 shifts with each shift having two 10 minute tea breaks and a 50 minute lunch break in each shift. Each shift is for 8 hours.
- The source is made passive.
- The sink pulls 5 different product types with same proportions.

Based on these data and assumptions, a simulation model for the current state VSM was developed. Figure 6.4 shows the simulation model for the current state VSM of the shop that manufactures heavy duty brake linings using a batch production system. On the other hand, Figure 6.5 shows the simulation model for the current state VSM of the shop that manufactures heavy duty brake linings using a batch production system with initial inventory before each stage of production process. In Figure 6.5, different coloured towers in the RM store and the compounding area represents the initial RM inventory, while the five towers having different colours that are present before other stages such as pre-curing, post curing, etc, represents the WIP of five different brake linings that are being processed in the cell. Furthermore, all the machines and sequence of operations has been laid out according to the data collected from the organisation and the layout.

6.2.4 Simulation model for the future state map

Since inventory is the major problem, efforts were directed to reduce the same. Furthermore, the future demand is also expected to increase by 14665 pieces per day. Hence, to reduce the inventory and meet the increase in demand, several LM elements were considered to obtain necessary process improvements especially in the compounding area. The team identified the following improvement activities to overcome the problems (Vijayaraghavan, 2006):

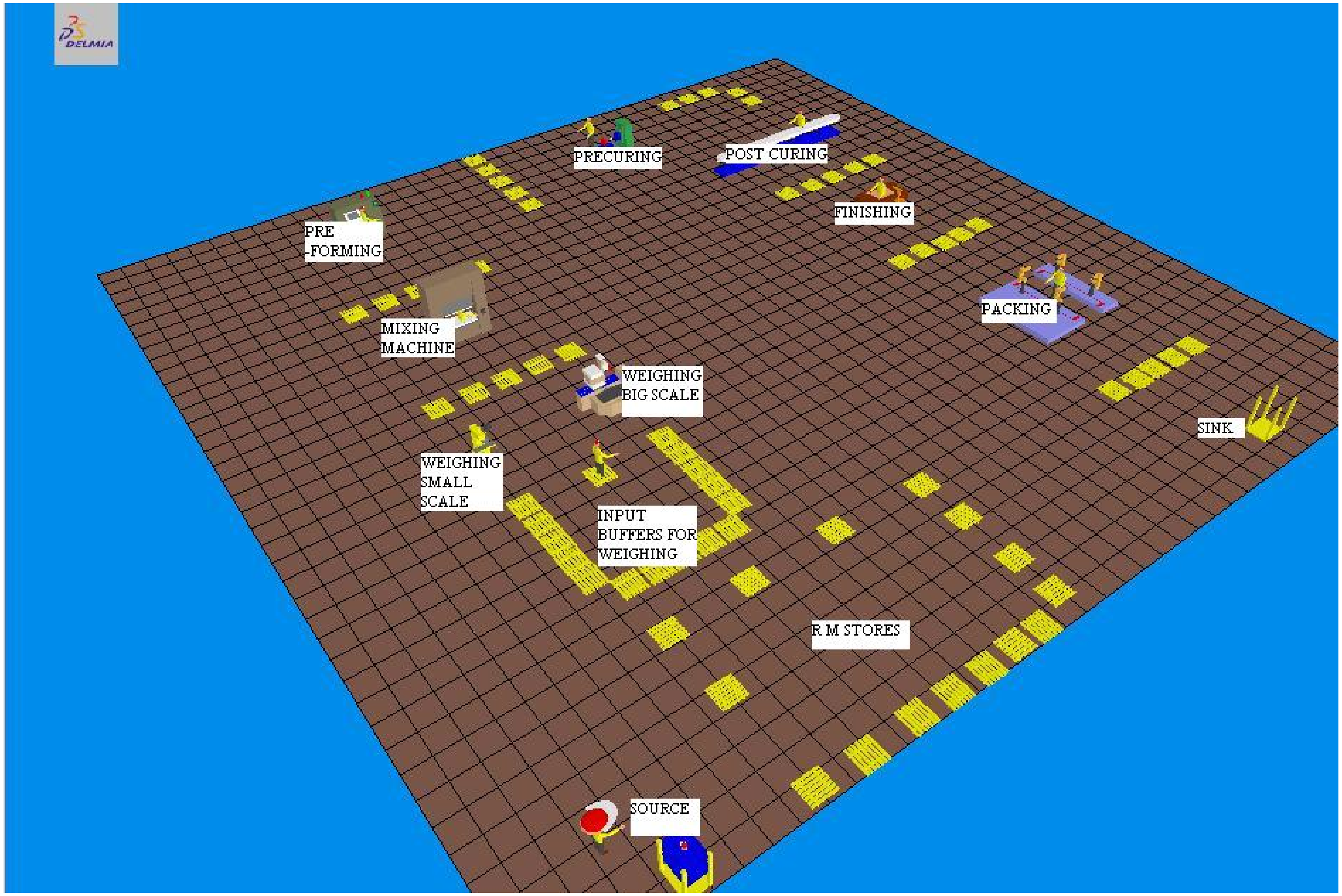


Figure 6.4: Simulation model for the current state VSM of the shop that manufactures heavy duty brake linings using a batch production system

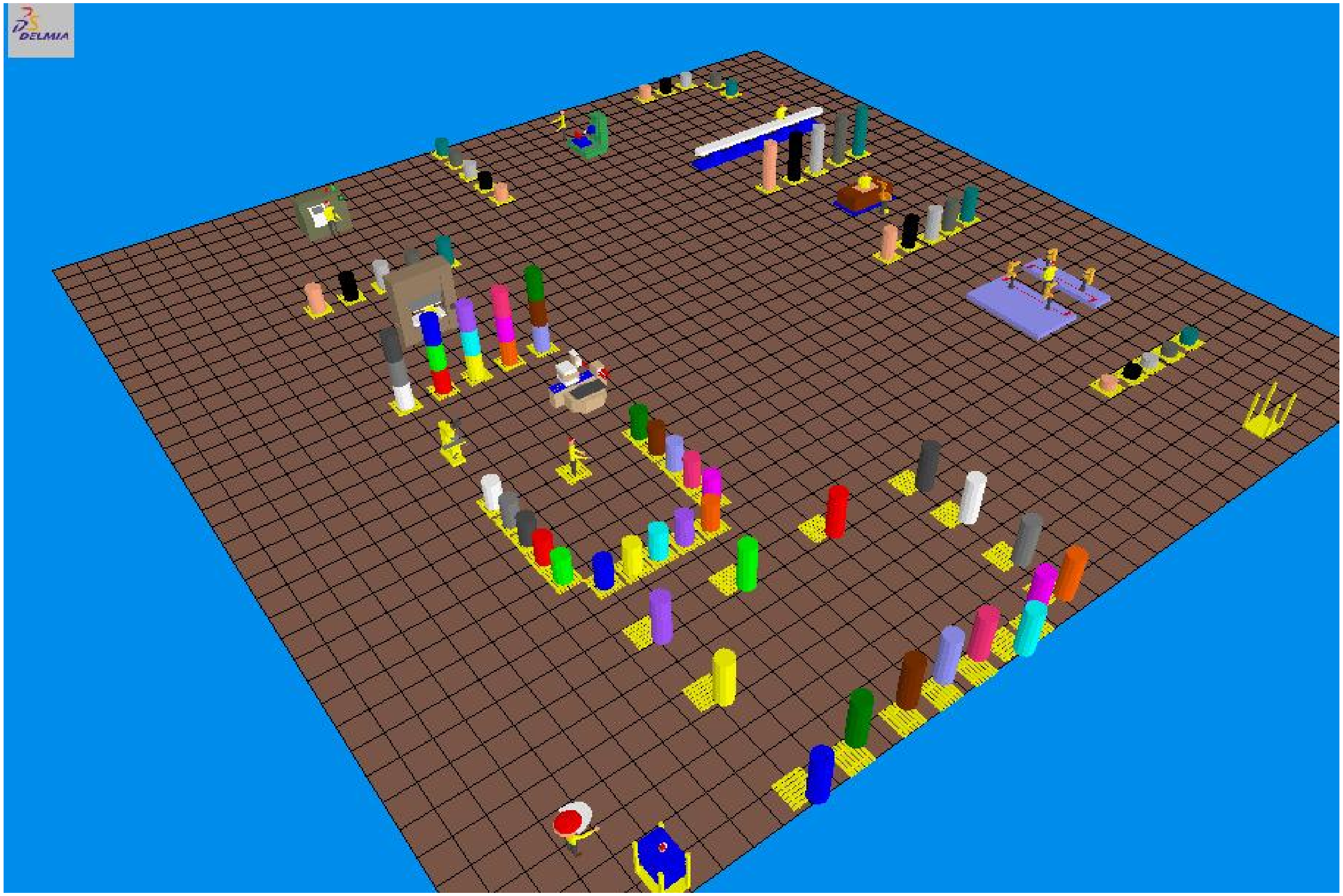


Figure 6.5: Simulation model for the current state VSM of the shop that manufactures heavy duty brake linings using a batch production system with initial inventory

- **Introduction of a dedicated material handler:** According to the terminology of Toyota Production System (TPS), the dedicated material handler is called a 'spiderman'. His job is to move intermediate products/materials between processes and finished goods to the packing line in a continuous cycle. The main purpose of implementing this methodology is to eliminate the unnecessary movement of operators.

- **Layout change:** The engineers of XYZL were planning to change the layout to ensure that the workers stay in their places. Apart from this, they were also interested in reducing the movement of spiderman, which require a change in the layout. Vijayaraghavan (2006) has discussed in detail about the same.

- **Re-design of RM trolley**: When a mix of particular brake lining has to be produced, the operator has to pull the individual RM trolley from the assigned location for weighing. After weighing the individual RM, the trolley has to be placed back in its position. Hence, the engineers found that lot of wastes in the form of transportation and motion of workers. The engineers constructed a string diagram to identify the total distance that has been covered by the operator and found that the total walking distance for one mix (i.e., one product) was approximately 94.5 metres. To reduce this NVA, the engineers utilised the suggestions provided by a team of workers. They suggested that a rotating trolleys with bearings for each bin of the RM (2 bins) can be provided to minimise the operator movement. Apart from this, they also suggested that the small and large weighing scales can be placed together instead of keeping it apart, which will further reduce the operator movement.

- **Formula automation in the weighing operation before the mixing machines**: During the weighing operation, all the RMs are brought together and are weighed together manually to achieve the required type of brake linings. A formula comprises of about as many as five cards. Each individual card comprises of around five to six RMs that are to be weighed in the required proportion, which require the operator to weigh 20 to 25 different chemicals and compounds to create a particular mix of brake lining. Furthermore, they need to use different weighing scales for different compounds. For RMs having weight greater than 3 kgs, a weighing machine having 600 kg capacity scale, with an accuracy of about 100 gms is used, while for materials having weight lesser than 3 kgs, a smaller weighing scale having a 10 kg capacity scale having an accuracy of about 1 gm is used. Finally, the operator has to fill the mix ticket after weighing each and every RM. During this process, various problems such as wrong RM selection, over/under weighing, wrong sequence of weighing, etc., were encountered Hence, the engineers were more interested in developing a pokayoke system to prevent such errors. They utilised an external consultant to automate the weighing operation, who suggested a system comprising of automated weighing machines and a PC with a RS232 interface. The team members were convinced that the new automated system will result in faster mixing by the operators apart from ensuring that the operating procedure of RM mixing is strictly followed. Hence, they were predicting a reduction in cycle time and increase in yield of the process.

Based on the improvements activities identified, a simulation model for the future state is developed by incorporating necessary changes in the current state simulation model. All the assumptions that were made for the simulation current state map holds good for future state map, except the following: the inventory is scaled down by a factor of 50 for the ease of simulation. The reason for the same is that inventory is assumed to be reduced significantly when compared to the current state map. Hence, the factor was also reduced by half. Figure 6.6 shows the simulation model for the future state VSM of the shop that manufactures heavy duty brake linings using a batch production system.

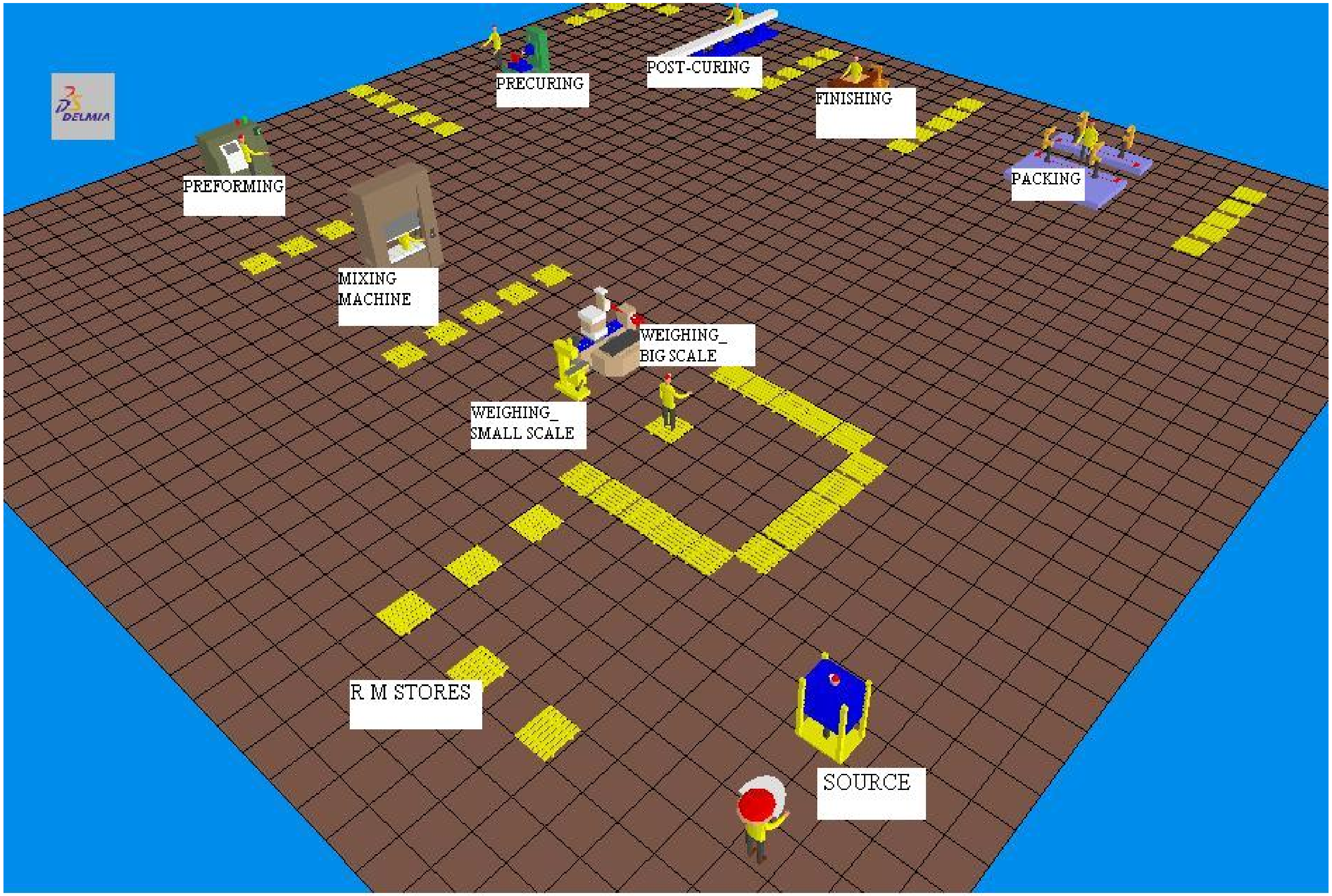


Figure 6.6: Simulation model for the future state VSM of the shop that manufactures heavy duty brake linings using a batch production system

Since a future state map can be obtained only after all the improvement activities are carried out, the following changes were made in Figure 6.4 to get Figure 6.6:

- **Formula automation in the weighing operation**: Since manual weighing is eliminated, and electronic weighing system is introduced, the process will be completely automated except the activities of loading and unloading of the raw materials. To depict the automation of weighing process of the RM, a small change has been incorporated in the simulation model shown in Figure 6.4, where the cycle time for weighing machine 1 and weighing machine 2 has been reduced by 10 minutes.
- **Spiderman concept and layout change**: To incorporate the effect of layout change, spiderman concept and rotating trolleys, following changes were incorporated in the simulation model:
    - Unnecessary inventory of raw materials were removed and they were moved closer to the weighing operation
    - Similarly, the large weighing scale and smaller weighing scale which were placed farther apart in Figure 6.4 was brought together
    - Apart from this, the changes in the layout which occurred due to the redesign of individual trolley to rotating trolleys, has been incorporated by reducing the distance between the trolleys and the machines the individual trolleys.

6.2.5 Results and discussions

The models for both the current state and future state are simulated for 30 days to represent a month’s production. To compare these two models, various performance measures identified in Chapter 4 are used to quantify the degree of improvements.

Table 6.1 shows the comparison of performance measures for the current state and future state VSM of the heavy duty brake lining manufacturing shop floor.

Table 6.1: Comparison of performance measures for the current state and future state VSM of the heavy duty brake lining manufacturing shop floor

S. No.	Performance measures	Current state	Future state
1.	Demand per day (in no. of pieces)	12360	14665
2.	Initial inventory at the beginning of simulation (in days)		
	• Compounding	1.32	0.04
	• Pre-forming	0.49	0.327
	• Pre-curing	0.29	0.014
	• Press curing & Post curing	0.27	0.193
	• Finishing	1.02	0.44
	• Packing	0.63	0.21
3.	Value added time (in days)	0.45	0.44
4.	Production lead time (in days)	4.63	1.76
5.	Process ratio	9.71%	24.94%
6.	Takt time (in sec)	5.97	5.03
7.	Cycle time (in sec)		
	• Compounding	2280	1780
	• Pre-forming	3300	3300
	• Pre-curing	14400	14400
	• Press curing & Post curing	18900	18900
	• Finishing	16	16
	• Packing	18	18
8.	Work In Process (WIP) inventory after 30 day simulation (in nos.)		
	• Part A	7000	3750
	• Part B	7000	3750
	• Part C	7100	3800
	• Part D	7200	3850
	• Part E	7500	3900
9.	Parts produced after 30 day simulation (in nos.)		
	• Part A	80600	94100
	• Part B	74600	88650
	• Part C	81700	88800
	• Part D	80400	89950
	• Part E	87600	95400
10.	Parts shipped after 30 days of simulation (in nos.)		
	• Part A	73600	90350
	• Part B	67600	84900
	• Part C	74600	85000
	• Part D	73200	86100
	• Part E	80100	91500
11.	Walking distance		
	• by operator for weighing one mix	94.5 m	0.5 m
	• by operator in a shift for weighing	1024.72 m	6.12 m
12.	Average utilisation of the cell	61.2%	72.6%
13.	Floor space used	96 sq. m.	11 sq. m.

In Table 6.1, all inventories are represented in the form of days. This is due to the fact that to calculate the total PLT in a VSM, the inventory is considered as ‘the number of days, a part wait before it gets processed’. Hence based on the daily demand, the inventory is converted into number of days by dividing the available inventory by per day requirement. For instance, in the current state VSM (Figure 6.2), compounding area has an inventory of about 16333 pieces, while the other processes has 6080, 3600, 3456, 12656, 7800 and 2070 pieces respectively. The demand per day is 12360 pieces. Therefore, the inventory at various stages is divided by the per day demand – i.e., 16333/12360 = 1.32 days. In other ways, compounding area holds about 1.32 days of stock, which are yet to be processed. In a similar manner, the stock details for other stages were calculated. Another important aspect in VSM is the calculation of process ratio. The process ratio is defined as the ratio of VAT and total PLT. For instance, from the future state VSM (Figure 6.3), the sum of VAT of all stages is found to be 0.44 days, while the total PLT, which includes the waiting time of the parts before the machines in the form of inventory, is found to be 1.764 days. Hence, the process ratio of future state VSM is (0.44/1.764)*100 = 24.94%. Similarly, the ‘takt time’ was calculated. It is defined as the rate at which the customer pulls the product. In a mathematical form, it is represented as the ratio of available time in seconds and daily requirement. In this case, the organisation works for 3 shifts of 8 hours each. Further each shift has breaks of about 70 minutes (two 10 minute tea break and 50 minutes lunch break). Hence available time in seconds is 73800. The demand per day for the current state map is 12360 pieces. Hence, the takt time for current state VSM = 73800/12360 = 5.97 sec, while for the future state VSM, it is found to be 5.03 seconds.

From the obtained results of the simulation models, it can be found that the case organisation can achieve the following benefits:

- Inventory level at various stages can be reduced drastically by 53% on an average, while the number of units produced will increase, due to the reduction in value added and NVA time through process improvements. For instance, from Table 6.1, it was found that total WIP was found to be reduced from 7000 nos. to just 3800 nos.
- The automation of weighing operation has resulted in a time savings of about 10 minutes, where the initial cycle time of weighing operation alone is 35 minutes. Since, compounding area is the bottleneck process; any improvement in this area would affect the rest of the manufacturing processes. Hence, the number of units produced by each process can increase by 16.75%, 18.84%, 8.69%, 11.88% and 8.90% respectively. Similarly, it can be found that the number of units shipped will also be increased. However, it should be remembered that the cycle time of other processes such as pre-curing, post curing etc. remains unchanged. If necessary process improvements are undertaken for these processes, the cell can become more productive and it can produce more brake linings with the existing capacity itself.
- Since more units are produced and the idle time and walking time has been reduced, the average utilisation of the machines will also increase from 61.2% to about 72%.
- The walking distance of the labourer (i.e. the spiderman) from source to the RM stores can be reduced substantially. It was found from the model that the labour walking distance is drastically reduced from 1042.74m to 6.12m. Thus, the walking distance can be reduced by 98%,
- Due to the changed layout, the area covered by the RM stores has reduced from 96 sq. m. to 11 sq. m. Thus a floor space savings of about 85 sq. m. is expected, which will result in a floor space reduction of about 88%.

On the other hand, it can be observed from the simulation results that the case organisation has not obtained the desired improvements that are predicted in the future state map. For instance, according to the future state VSM shown in Figure 6.5, the inventory before

- Compounding stage should be 575 units,
- Pre-forming stage should be 4796 units,
- Pre-curing stage should be 206 units,
- Press curing and post curing stage should be 2830 units,
- Finishing stage should be 6452 units and
- Packing stage should be 3079 units.

But, the inventory as per the future state simulation model is found to be higher, as each stage holds approximately a constant inventory of around 3750 units. However, considering the current state VSM, it can be found from the simulation results that a significant amount of wastes can be reduced or eliminated.

To obtain these improvements, the team members have implemented the following LM elements: VSM, process simplification, automation, layout change, pokayoke, Andon system, inventory reduction, work standardisation, storage space reduction, standardised containers, WIP reduction, cycle time and lead time reduction. A cursory analysis of the framework proposed in Chapter 3 reveals that the proposed frameworks of LMS include all these elements, which further validates our frameworks. However, it should be understood that it is not possible to implement all the elements of LM in the case organisation. For instance, it is very difficult to implement single piece flow, load levelling, line balancing, etc. The processes such as compounding, pre-curing, post curing, etc. follow a time and temperature dependent batch production system and under such circumstances it is not possible to have a single piece flow. Similarly, it is very difficult to implement line balancing, load levelling etc. as the cycle time for some of the processes such as pre-curing and press-curing (i.e., the heating time and cooling time) cannot be reduced as it directly affects the quality of the brake linings. Also, it should be remembered that the case organisation has just started with the LM implementation. Hence, other LM elements such as kanban system, pull system, supplier related elements etc. are not implemented and this may be taken up in the future.

6.2.6 Validation

It should be understood here that the simulation results are obtained with necessary assumptions. In the case of actual situation, the shop floor is quite dynamic and uncertain. It may suffer from interruptions that occur due to various reasons. Hence, the actual result may not be exactly matching with the simulation results. However, verifying the simulation results with the company personnel revealed the following:

- RM inventory was reduced from 24,000 kg to 6,000 kg in shop floor due to redesigned rotating trolley. About 32 skids of RMs were removed from shop floor, which accounts for more than 53% reduction in the raw material storage stage alone. On the other hand, the simulation results revealed that overall inventory level can be reduced by an average of only 53%.
- Removing the unnecessary inventory storage from the shop floor also resulted in savings of about 90 sq. m of floor space in the RM storage area as compared to 85 sq. m which was obtained from the simulation results.
- Earlier, the engineers found that the total walking for one mix is 94.5 m. With the redesigned trolley arrangements, the operator has to walk only just 0.5 m,

thereby the unnecessary walking and its associated time has been eliminated. However, according to the simulation results, the walking distance has been reduced from 1042. 6 m to 6.12 m. The reduction in walking distance also reduced the operator fatigue, which again had a direct impact on the productivity of the labour.

- The formula automation in the weighing area also helped in calculating the bulk density of the mixture and the yield without any manual intervention. These parameters are internally checked and it is displayed in the terminal, thereby providing feedback such as OK and NOT OK. Thus manual calculation of bulk density and yield are avoided and the acceptance card for the mixture is also printed automatically. Thus, a pokayoke (i.e. mistake proofing) system was also established, which can prevent errors. Thus, in addition to the improvements in performance measures, such benefits were also obtained in the compounding area.

6.3 Development of Simulation Model for the Design of Lean Manufacturing Systems for a Cell that Produces Spiral and Crown Wheels (Gears) using a Mass Production System

To preserve the confidentiality, the company is named as PQR Limited (PQRL). PQRL is a manufacturer of three wheelers, multi-utility and cross country vehicles, Light Commercial Vehicles (LCVs), tractors and Heavy Commercial Vehicles (HCVs). It was founded in the late 1950s with the production of the 3-Wheelers in collaboration with a Germany company and went on to establish a presence in the LCVs through the 1980s and 1990s. Especially in the last five years with a major product development effort, PQRL has introduced new LCVs, a new family of utility vehicles, new state-of-the-art tractors, and a new range of three-wheelers, which are manufactured at the three plants located in western and central parts of India. All these plants have received the ISO

9001:2000 certification. Recently, in 2004, the engine plant obtained the TS 16949: 2002 certification. Since, these certifications helped the organisation to streamline and systemize their operations; the top managers were interested in implementing LM in the Western plant. Hence, they started with the LM implementation in the crown wheel and pinion manufacturing shop. They chose this shop floor as a 'model shop' because of the following reasons:

- The unit price of crown wheel and pinion pair is high
- It involves a complex manufacturing process and hence the throughput time is high

Apart from this, the demand forecast for the next two years reveal that the production volume has to be doubled. Table 6.2 shows the production plan and daily requirements (including spares requirement) for the next two years.

Table 6.2 Production plan and daily requirements (including spares) for the next two years (Source: Hariharan, 2007)

Type of gears	Product type	Yearly requirements			Daily requirements		
		2007	2008	2009	2007	2008	2009
Hypoid pairs	A	6500	8750	13000	22	30	44
	B	19100	25200	25200	64	84	84
	C	6600	8750	11000	22	30	37
	Total	32200	42700	49200	**108**	**144**	**165**
Spiral pairs	D	27600	41400	45000	92	138	150
	E	6600	8900	13000	22	30	44
	Total	34200	50300	58000	**114**	**168**	**194**

The management of PQRL would like to equip their company to meet the future demand needs with minimum increase in resources. So, they zeroed in on LM principles and philosophy.

6.3.1 Manufacturing process of crown wheel and pinion

Crown wheel and pinion forms the heart of transmission system of vehicle and is accommodated in the differential assembly of the vehicle. These gear pairs are made from seven steel forgings, which weighs around 5 kg each and are machined as two separate parts and they are paired before the assembly. In PQRL, the crown wheel and pinion pairs are divided into two categories, namely, hypoid and spiral. Spiral pairs are co-axial pairs where as hypoid are off-set pairs. The manufacturing of both the spiral and hypoid pairs follow a strict process sequence. Figure 6.7 shows the flow chart depicting the sequence of manufacturing process for hypoid and spiral pairs. It depicts only the important stages of the production process and each stage of the process will have many sub-operations with in them, which are carried out on different machines scattered across the layout. Hariharan (2007) has discussed in detail regarding the production process of these gears. Thus analysing the production processes, it can be inferred that the gears are mass produced with a limited number of mixed model manufacturing.

6.3.2 Value stream mapping of the cell that produces spiral and crown wheels (gears) using a mass production system

To start with the design of LMS, the VSM has to be developed. Both the hypoid and spiral pairs are manufactured in separate lines. These production lines operate independently and send a batch of gears to the assembly section. Figure 6.8 shows the current state VSM of the cell that produces spiral and crown wheels (gears) using a mass production system. But, Figure 6.8 did not show the process sequence or the value stream for crown wheel because of the space limitations.

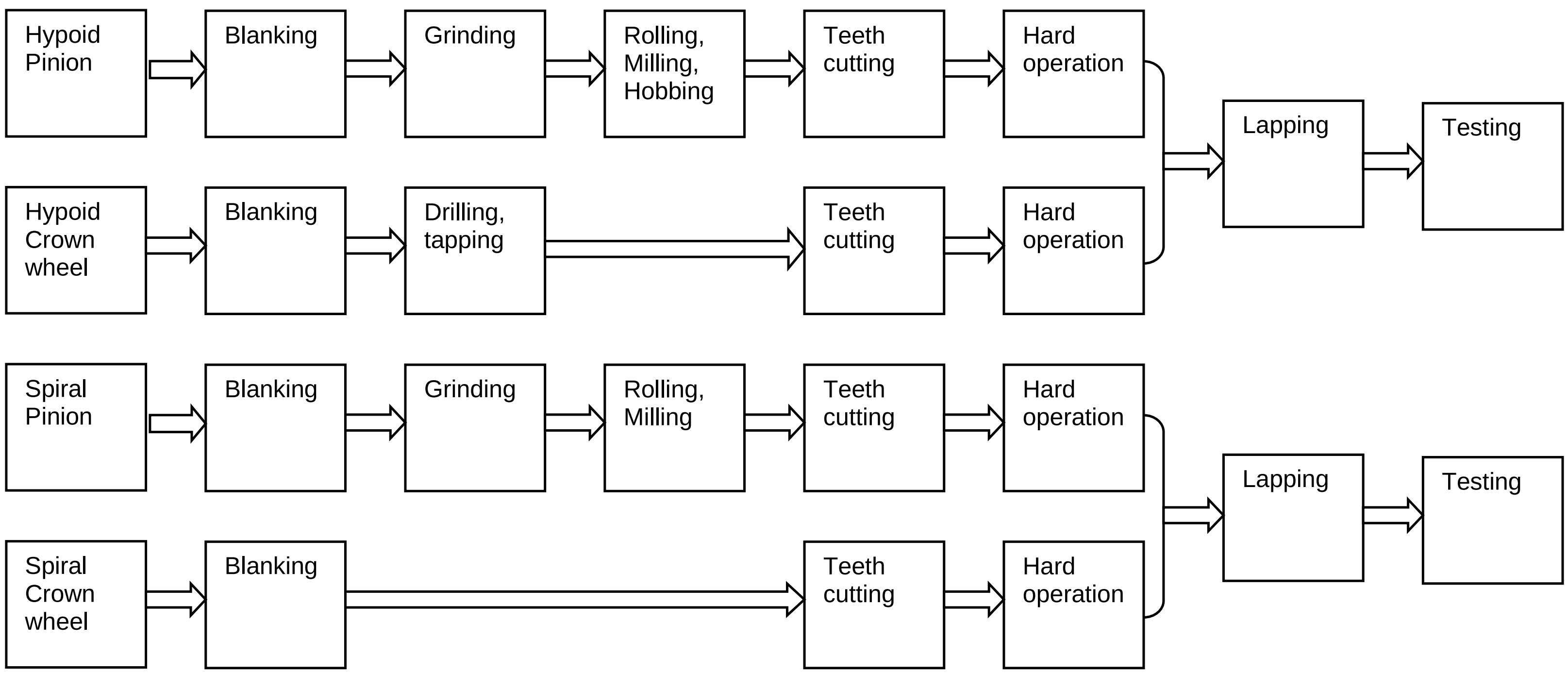


Figure 6.7: Flow chart depicting the sequence of manufacturing process for hypoid and spiral pairs (Source: Hariharan, 2007)

However, the cycle time of the various manufacturing processes of crown wheel are much lesser than that of hypoid pinion. Hence, it will not affect the overall production lead time. From Figure 6.8, it can be found that the VAT for making a hypoid pinion is just 62.53 minutes, while the PLT is about 37.85 days. The Value Stream Index (VSI) is found to be just 0.0017, which clearly reveals that the manufacturing process of these gears involves lot of NVA activities resulting from the seven wastes identified by Ohno (1988). In particular, the inventory has piled up before all the workstations. In addition to inventory reduction, the engineers in PQRL were interested in improving the process ratio by focusing on various process improvements and line balancing techniques. Hence, based on the improvements identified, a future state VSM is developed. Figure 6.9 shows the future state VSM for the cell that produces spiral and crown wheels (gears) using a mass production system. From Figure 6.9, it can be found that the total inventory has to be reduced to just 1500 pairs apart from achieving a reduction in the processing times in other stages. Thus it was estimated that the process ratio can be doubled to 0.39%.

6.3.3 Simulation model for the current state map

In addition to the data from the current state VSM, additional information such as setup time, number of operators, uptime of the machine etc. were collected. The summary of the same is given below (Hariharan, 2007):

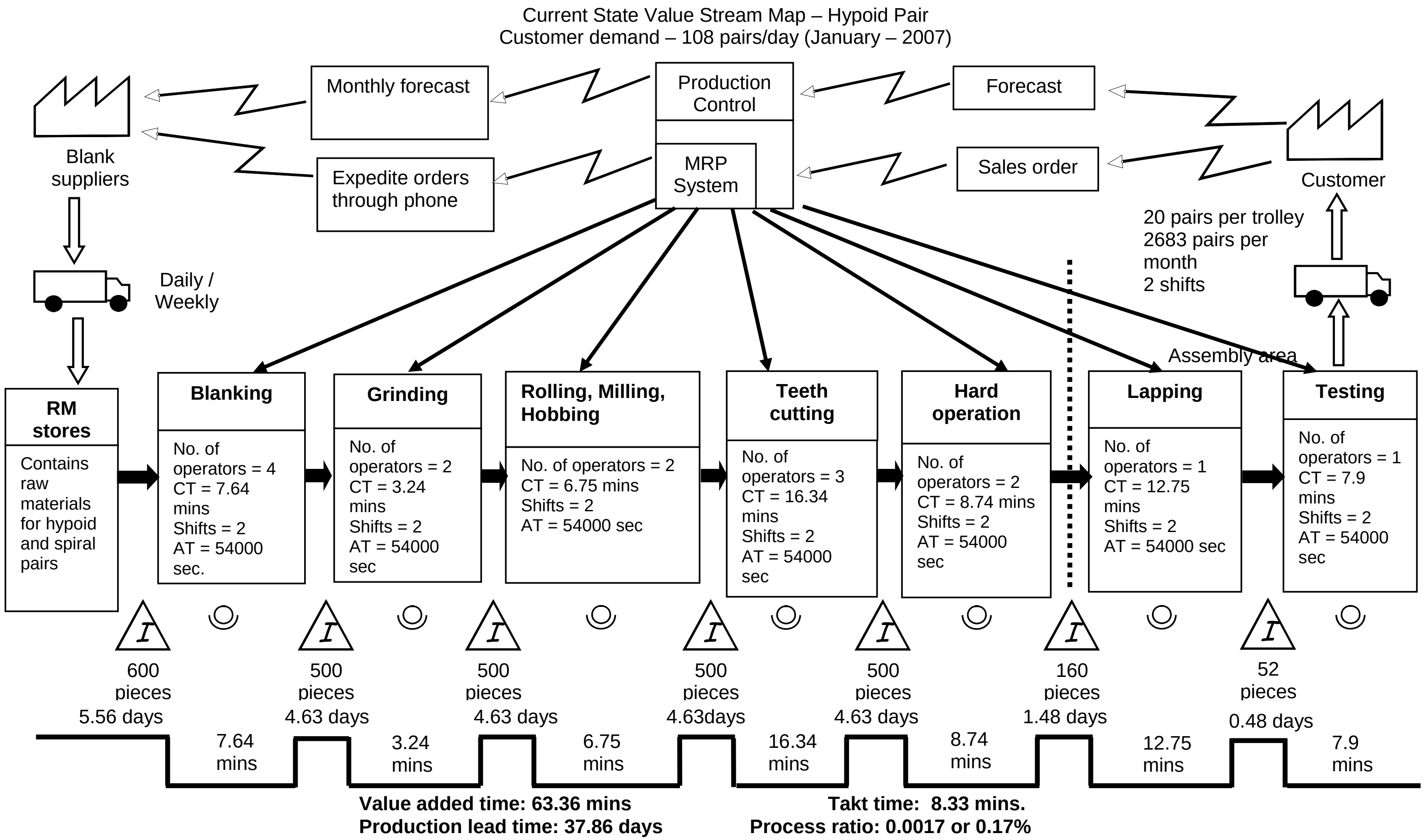


Figure 6.8: Current state VSM for the cell that produces spiral and crown wheels (gears) using a mass production system

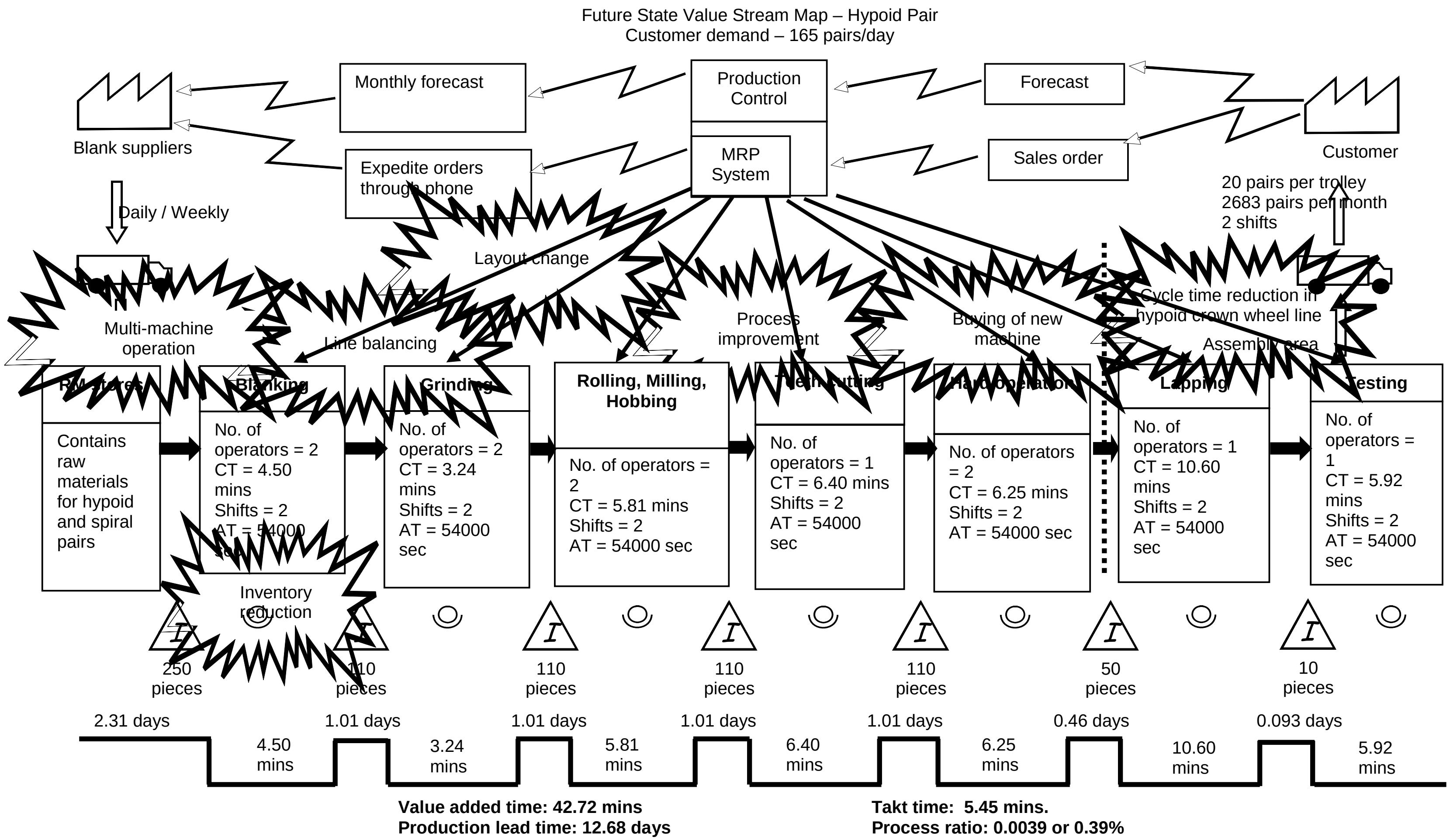


Figure 6.9: Future state VSM for the cell that produces spiral and crown wheels (gears) using a mass production system

- **Inventory**: The inventory of crown wheels is found to be 5924 nos., while that of pinions are found to be 4424 nos. Out of which, the inventory of spiral pairs are considered to be more than that of hypoid pairs, because the production requirement per day for spiral pairs are more than that of hypoid pairs. The daily requirement is calculated based on the fact that the company works for 2 shift a day with 7.5 hours per shift (excluding the lunch and break time). They operate for 25 days a month. Table 6.2 also shows the daily requirement for the next three years.
- **Floor space**: Stocks of crown wheel and pinion occupy about 58 sq. m. with in the layout of 794 sq. m.
- **Operators**: 42 operators were involved in meeting the daily demand of 108 pairs per day.
- **Number of shifts**: Each day consists of 2 shifts with each shift having two 15 minute tea breaks and a 30 minute lunch break in each shift. Each shift is for 7.5 hours.

Apart from this, the following assumptions were made to construct the simulation model for the current state VSM:

- The inventory is taken entirely to be initial inventory. Before the start of the simulation, this inventory will be built up before the workstations. This is due to the fact that a VSM captures the snap shot picture of the shop floor at any given point of time. Hence, the simulation too starts with the current situation as obtained from the current state VSM.
- The setup time is assumed to be zero for all the machines, as every product goes through the same processes without any change of machines and only the cycle time slightly changes for each process depending upon the type of pinions

or crown wheels. Apart from this, PQRL has different dedicated machines for performing some of the operations of hypoid and spiral pairs.

- Every machine has one labour (i.e. operator)
- The source is an active source and the inter arrival time of each source is made equal to the cycle time of the first machine in each line. This is due to the fact that the organisation follows a push system of operation in the shop floor.
- The part fractions for the various sources are in proportion to the number of products of each part type required.
- If an operation has two similar machines performing the same operation then the machining time of all such similar machines is assumed to be a constant.

With these actual data and the list of assumptions, the current state VSM is simulated to ensure that the model replicates exactly the actual production happening in their organisation. Figure 6.10 shows the simulation model for the current state VSM of the cell that produces spiral and crown wheels (gears) using a mass production system, which is developed based on the existing layout of the shop floor. Hariharan (2007) has discussed in detail about the existing layout. It can be found that the movement of materials between various machines is not uniform and involves a lot of repetitive and zigzag movements.

6.3.4 Simulation model for the future state map

As said earlier, the current state VSM revealed lot of wastes. Hence, to reduce these wastes and meet the increase in demand, the engineers of the case organisation were interested in establishing a Single Piece Flow (SPF).

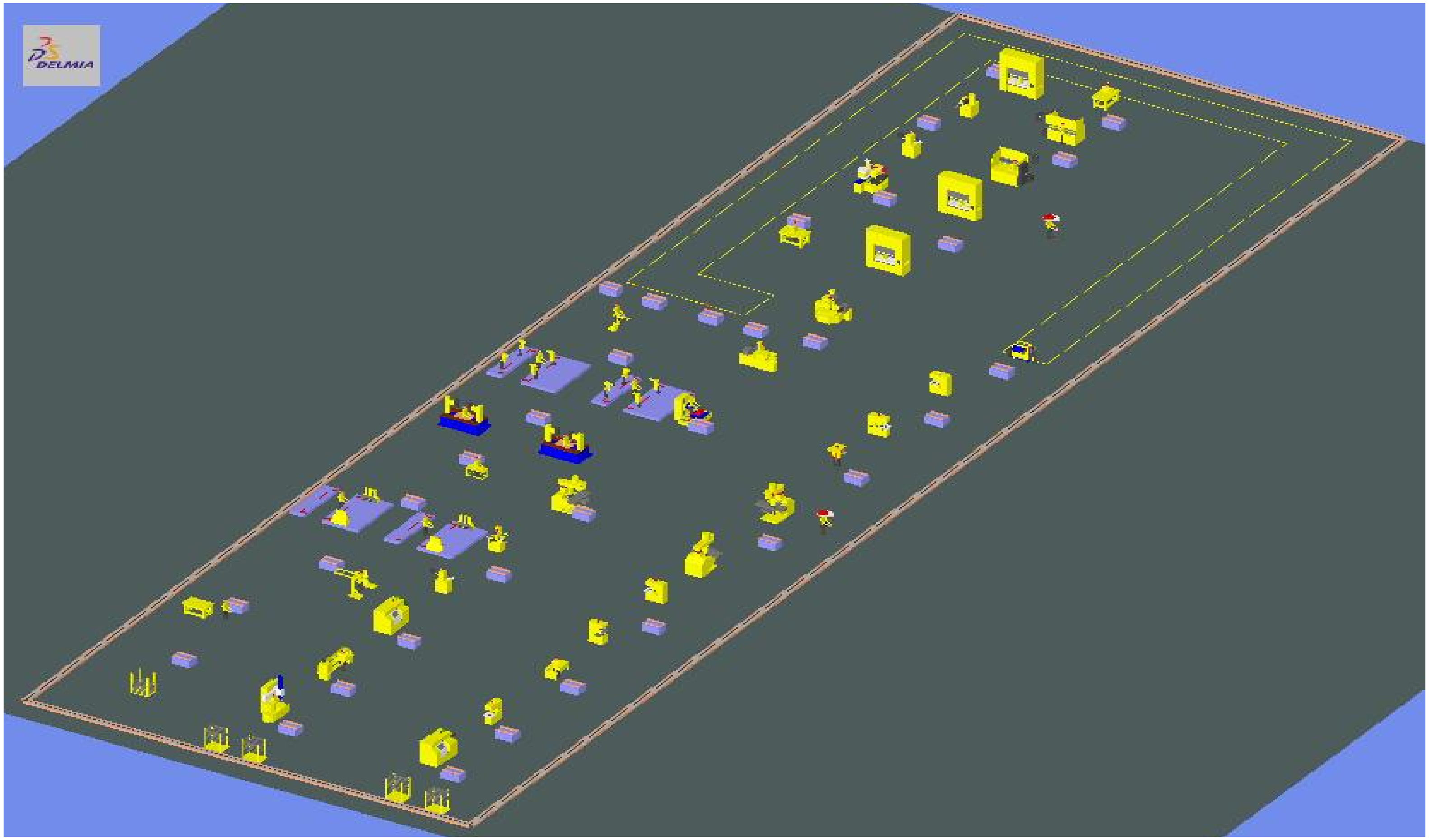


Figure 6.10: Simulation model for the current state VSM of the cell that produces spiral and crown wheels (gears) using a mass production system

SPF is defined as the system where all process approach the condition such that each process can produce only one piece, convey it one at a time and in addition has only one piece in stock both between equipment and process. To achieve this state, several other LM elements have to be implemented and the team identified the following improvement activities:

- **Line balancing**: As evident from the current state VSM shown in Figure 6.8, the time taken between each processing stages are highly varying and they are not balanced. To balance the line, the operation sequence for making hypoid pairs and spiral pairs (which include the processing steps of pinion, crown wheel and its assembly) were studied. Table 6.3 shows the operation sequence for hypoid pinion, crown wheel and assembly while Table 6.4 shows the operation sequence for spiral pinion, crown wheel and assembly along with the standard time. From these tables, the standard time taken to produce a hypoid pair is found to be 89.62 minutes, while that of a spiral pair is about 69.18 minutes. But, it was found that the average time for producing a hypoid pair is 2.57 hours (considering the longest of production time between hypoid and spiral pair). This clearly revealed that the manufacturing system is suffering from wastes due to "unnecessary processing". Furthermore, it can be found that the line is not balanced properly. Hence, the engineers were interested in conducting the time study to balance the line.
- **Layout improvement:** Improper layout leads to wastes in the form of unnecessary handling of materials, movement of workers. To support the activities such as machine grouping, multi-machine activities and line balancing, layout improvement in crown wheel & pinion line has been planned. Hariharan (2007) has discussed in detail about the proposed layout.

Table 6.3: Operation sequence for hypoid pinion, crown wheel and assembly (Source: Hariharan, 2007)

	Operation Description	Machine	Standard Operation Time (mins)		Remarks
			Before LM	After LM	
Hypoid pinion	Facing and centering	Lathe	1.91	3.2	Multi-machine activity
	Turn holding diameter	Centre Lathe	1.23		
	Turning 1st side	CNC turning	3.2		
	Turning 2nd side	CNC turning	1.3	1.3	
	Grind Outer Diameter (OD) 41.55h5 and face	Cylindrical grinding	1.22	1.22	
	Grind OD 38h5	Cylindrical grinding	1.02	1.02	
	Grind OD 30.5h5	Cylindrical grinding	1.0	1.0	
	Thread rolling	Rolling machine	0.75	0.75	
	Mill locking slot	Horizontal milling machine	1.2	1.2	
	Spline hobbing	Hobbing machine	4.75	4.75	
	Generate 9 teeth – Rough	Gleason 16 Generator	6.28	6.28	Multi-machine activity
	Generate 9 teeth – Finish (Concave)	Gleason 118 Generator	5.02		
	Generate 9 teeth – Finish (Convex)	Gleason 118 Generator	5.02		
	Washing and cleaning the job	Washing	0.12	0.12	
	Straightening	Hydraulic press	2.0	2.0	
	Grind 41.275p6	Cylindrical grinding	1.06	2.5	Machine can be changed to Angular Head Grinding machine
	Grind 31.8h11 and face	Cylindrical grinding	1.52		
	Grind 30.16h5	Cylindrical grinding	0.98		
	Grind pinion teeth face	Cylindrical grinding	1.18		
	Grind face total length	Cylindrical grinding	1.0	1	
	Washing and cleaning the job	Washing	0.12	0.12	
	Total		**41.88**	**26.46**	
Hypoid crown wheel	Turning	CNC twin spindle	4.19	4.19	
	Drilling and tapping	Vertical Machining Centre	8.17	8.29	Multi-machine activity
	Washing and clean the job	Washing	0.12		

	Operation Description	Machine	Standard Operation Time (mins)		Remarks
			Before LM	After LM	
	Generate 44 teeth – Rough	Gleason 606 Generator	5.23	5.23	Multi-machine activity
	Generate 44 teeth – Finish	Gleason 605 Generator	4.4		
	Washing and clean the job	Washing	0.12		
	Bore Grinding	Internal Grinding	4.86	4.86	
	Total		**27.09**	**22.565**	
Assembly of Hypoid Pinion and Crown wheel	Top land chamfering	Manual	4.5		
	Checking of pairs	Lapping machine	2.25	6.1	Operation combined
	Lapping of the pairs	Lapping machine	5.0		
	Wash the job in kerosene	Manual	1.0		
	Testing of the pairs	Testing machine	6.4	6.4	
	Etch the information	Manual	1.1	1.1	
	Wash the job in kerosene	Manual	0.4	0.4	
	Total		**20.65**	**18.5**	
	Total time taken (mins)		**89.615**	**67.525**	

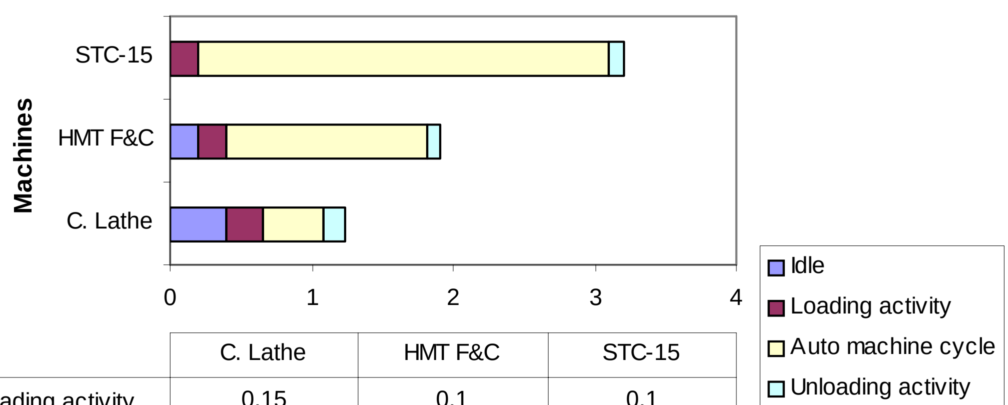
Table 6.4: Operation sequence for spiral pinion, crown wheel and assembly (Source: Hariharan, 2007)

	Operation Description	Machine	Standard Operation Time (mins)		Remarks
			Before LM	After LM	
Spiral Pinion	Facing and Centering	Lathe	1.68	2.39	Multi machine activity
	Copy turn 1st side	Copying machine	2.39		
	Turn groove	Centre Lathe	2.44	2.44	
	Copy turn 2nd side	Copying machine	2.94	2.94	
	Grind thread side	Angular grind	1.27	1.27	
	Grind taper side	Angular grind	1.27	1.27	
	Washing and clean the job	Washing	0.12	0.12	
	Thread rolling	Rolling machine	0.77	0.77	
	Roll serration 50 teeth	Rolling machine	0.72	0.72	

	Operation Description	Machine	Standard Operation Time (mins)		Remarks
			Before LM	After LM	
	Mill locking slot	Horizontal milling machine	1.43	1.43	
	Generate 6 teeth – Rough	Gleason 16 generator	4.37	4.37	Multi machine activity
	Generate 6 teeth – Finish (Concave)	Gleason 118 generator	3.41		
	Generate 6 teeth – Finish (Convex)	Gleason 118 generator	3.41		
	Washing and clean the job	Washing	0.12		
	Straightening	Hydraulic press	2	2	
	Grind thread side	Angular grind	1.81	1.81	
	Grind taper side	Angular grind	1.81	1.81	
	Grind taper	Cylindrical grind	1.13	1.13	
	Washing and clean the job	Washing	0.12	0.12	
	Total		**33.21**	**24.59**	
Spiral crown wheel	Turning	CNC twin spindle machine	3.64	3.75	2 new Monfort FARL 1042 machine can be added for multi machine activity
	Washing and cleaning the job	Washing	0.12		
	Generate 39 teeth – Rough	Gleason 606 generator	4.73	4.73	Multi machine activity
	Generate 39 teeth – Finish	Gleason 605 generator	4		
	Washing and cleaning the job	Washing	0.12		
	Bore grinding	Internal grinding	4.86	4.86	
	Total		**17.47**	**13.34**	
Spiral pinion and crown wheel assembly	Mark 'O' for identification	Manual	0.5	0.5	
	Top land chamfering	Manual	4.08	4.08	
	Checking of pairs	Lapping machine	2.25	6.1	Operation combined
	Lapping of the pairs	Lapping machine	5		
	Wash the job in kerosene	Manual	0.75		
	Testing of the pairs	Testing machine	4.13	4.13	
	Etch the information	Manual	1.39	1.39	
	Wash the job in kerosene	Manual	0.4	0.4	
	Total		**18.5**	**16.6**	
	Total time taken (mins)		**69.18**	**54.53**	

- **Multi-Machine Activity (MMA):** It is a concept wherein one operator operates more than one machine at a time. It can be used only when the following conditions are satisfied:
    - o Machine auto-cycle is high and idle time of a labour is higher than that of idle time of machine
    - o The operation on the machine to be combined can be easily performed during the auto-cycle of the other machine
    - o The machines are arranged side-by-side and there is no interference between them

After the time study, the production engineers found that MMA can be implemented in some of the areas of crown wheel & pinion manufacturing line. For instance, Figure 6.11 shows the man-machine activity chart for the blanking stage of hypoid pinion.



	C. Lathe	HMT F&C	STC-15
Unloading activity	0.15	0.1	0.1
Auto machine cycle	0.43	1.41	2.9
Loading activity	0.25	0.2	0.2
Idle	0.4	0.2	0

Time in Minutes

Figure 6.11: Man-machine activity chart for the blanking stage of hypoid pinion
(Source: Hariharan, 2007)

Since, in this stage, the turning process in CNC lathe is taking about 3.23 minutes (inclusive of loading, automatic machining and unloading activities), while the other operations such as facing and centring, turning etc. requires only lesser operation time, these operations can be clubbed together and the cycle time for these operations will be equal to the operation consuming the longest time. After combining these three operations, the cycle time will be only 3.23 minutes and a single operator will be performing all these operations, as he moves from one machine to another in a sequence. This can result in elimination of idle time for the operator apart from reducing the operators from 3 to 1. In this manner, the MMAs were introduced in various processing stages of the pinion and crown wheel manufacturing line. Table 6.2 and 6.3 also shows the improved operation sequence for hypoid pinion, crown wheel and assembly as well as the spiral pinion, crown wheel and assembly.

- **Machine Grouping:** It has to be carried out for establishing the multi-machine activity. It helps in reducing the material movement and thereby reduces the waste due to "transportation". In this case, machine grouping is done to enable multi-machine activity by forming a "manufacturing cell" according to products and operation sequence. The engineers and managers felt that it requires some additional machines to easily form the machine cells within the crown and pinion line. Based on the daily production target, time taken for each operation and the machine requirement for 2 shifts, they calculated the number of machines required. Hence, they introduced new machines apart from duplicating some of the existing machines to increase the rate of production and eliminate unnecessary movements. Table 6.5 shows the details of machines/equipments requirement for the pinion and crown manufacturing line.

Table 6.5: Details of machines/equipments requirement for the pinion and crown manufacturing line (Source: Hariharan, 2007)

Machine description	Component Name	Initial Method			Improved Method				Total Number of Machines
		Standard time per piece (mins)	Machine requirement based on 2 shift	Number of machines available	Standard time per piece (mins)	Machine requirement based on 2 shift	Number of machines available	Additional machines	
Facing and Centering machine	Hypoid Pinion	1.91	0.29		1.91	0.29			
	Spiral Pinion	1.68	0.26		1.68	0.26			
	Total	3.59	0.55	1	3.59	0.55	1	1	2
Centre Lathe	Hypoid Pinion	1.23	0.18		1.23	0.18			
	Spiral Pinion	2.44	0.38		2.44	0.38			
	Total	3.67	0.56	1	3.67	0.56	1	1	2
CNC Turning	Hypoid Pinion	4.5	0.67	1	4.5	0.67	1	0	1
Cylindrical grinding	Hypoid Pinion	9.16	1.37		5.48	0.82			
	Spiral Pinion	1.13	0.18		1.13	0.18			
	Total	10.29	1.55	2	6.61	1	2		2
Thread rolling	Hypoid Pinion	0.75	0.11		0.75	0.11			
	Spiral Pinion	1.49	0.23		1.49	0.23			
	Total	2.24	0.34	1	2.24	0.34	1		1
Horizontal Milling machine	Hypoid Pinion	1.2	0.18		1.2	0.18			
	Spiral Pinion	1.43	0.23		1.43	0.23			
	Total	2.63	0.41	1	2.63	0.41	1		1
Hobbing	Hypoid Pinion	4.75	0.71	1	4.75	0.71	1		1
Geason Generator 16 (Rough)	Hypoid Pinion	6.28	0.94		6.28	0.94			
	Spiral Pinion	4.37	0.69		4.37	0.69			
	Total	10.65	1.63	2	10.65	1.63	2		2
Geason Generator 118 (Finish concave)	Hypoid Pinion	5.02	0.75		5.02	0.75			
	Spiral Pinion	3.41	0.54		3.41	0.54			
	Total	8.43	1.29	2	8.43	1.29	2		2
Geason Generator 118 (Finish convex)	Hypoid Pinion	5.02	0.75		5.02	0.75			
	Spiral Pinion	3.41	0.54		3.41	0.54			
	Total	8.43	1.29	2	8.43	1.29	2		2

Machine description	Component Name	Initial Method			Improved Method				Total Number of Machines
		Standard time per piece (mins)	Machine requirement based on 2 shift	Number of machines available	Standard time per piece (mins)	Machine requirement based on 2 shift	Number of machines available	Additional machines	
Hydraulic Press	Hypoid Pinion	2	0.3		2	0.3			
	Spiral Pinion	2	0.32		2	0.32			
	Total	4	0.62	1	4	0.62	1		1
CNC Twin Spindle	Hypoid Crown Wheel	4.19	0.63		4.19	0.63			
	Spiral Crown Wheel	3.64	0.57						
	Total	7.83	1.2	1	4.19	0.63	1		1
Monforts	Spiral Crown Wheel				7.5	1.18	2		2
Vertical Machining Centre	Hypoid Crown Wheel	8.17	1.22	1	4.67	0.7	1		1
Tapping	Hypoid Crown Wheel				4.67	0.7	1		1
Gleason Generator 606	Hypoid Crown Wheel	5.23	0.78		5.23	0.78			
	Spiral Crown Wheel	4.73	0.75		4.73	0.75			
	Total	9.96	1.53	2	9.96	1.53	2		2
Gleason Generator 605	Hypoid Crown Wheel	4.4	0.66		4.4	0.66			
	Spiral Crown Wheel	4	0.63		4	0.63			
	Total	8.4	1.29	2	8.4	1.29	2		2
Internal Grinding	Hypoid Crown Wheel	4.9	0.73		4.9	0.73			
	Spiral Crown Wheel	4.86	0.77		4.86	0.77			
	Total	9.76	1.5	2	9.76	1.5	2		2
Lapping Machine	Hypoid Pairing	7.25	1.08		6.1	0.91			
	Spiral Pairing	7.25	1.14		6.1	0.96			
	Total	14.5	2.22	2	12.2	1.87	2		2
Testing	Hypoid Pairing	6.4	0.96		4.13	0.96			
	Spiral Pairing	4.13	0.65		4.13	0.65			
	Total	10.53	1.61	2	8.26	1.61	2		2

These improvements activities were simulated by incorporating necessary changes in the current state simulation model. The following assumptions were made to construct the simulation model for the future state map:

- The inventory for the future state is assumed to 1500, as it was set as the target by the top management of the case organisation. Since two models, namely hypoid and spiral pairs are manufactured; the target is divided equally as 750 of hypoid pairs and 750 of spiral pairs, which are distributed among the different stages of the production processes.
- Each labor works on more than one machine as per the data given in Table 6.3 and 6.4 as multi-machine activity is introduced in the future layout.
- Inter arrival time at the source is made equal to the takt time as products has to be made according to the demand of the customers.
- Apart from the above-mentioned changes, other assumptions are same as the simulation model for the current state VSM.

Figure 6.12 shows the simulation model for the current state VSM of the cell that produces spiral and crown wheels (gears) using a mass production system. Since a future state map can be obtained only after all the improvement activities are carried out, the following changes were incorporated in the future state simulation model when compared to current state model:

- **Layout change and multi-machine activity:** Since, multi-machine activities were introduced at various stages of the crown wheel and pinion manufacturing line, the position of various machines in the current state VSM shown in Figure 6.10 has been changed. Different cells were formed. Similarly, changes in layout were carried out for implementing the MMAs in various parts of the crown wheel and pinion manufacturing line.

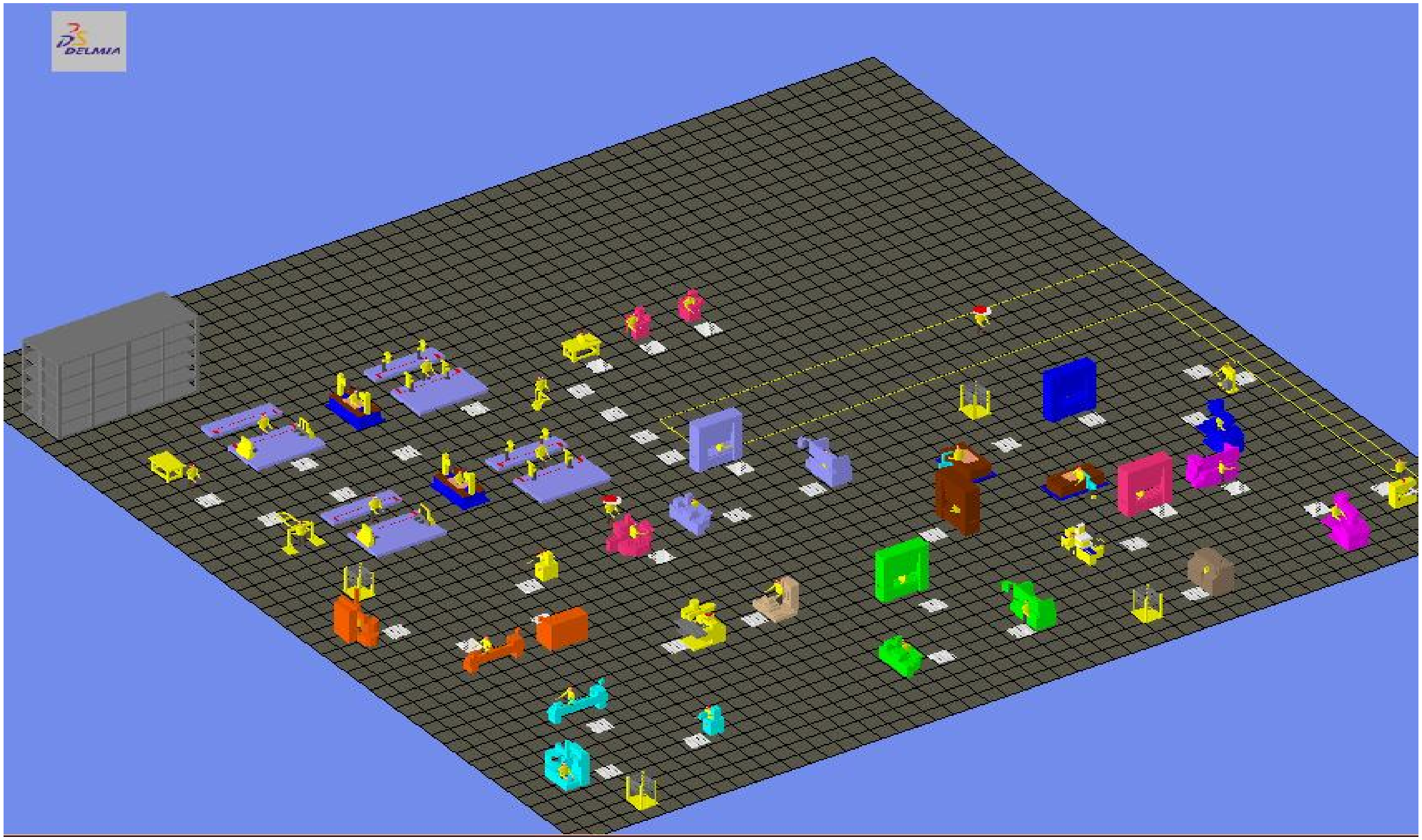


Figure 6.12: Simulation model for the future state VSM of the cell that produces spiral and crown wheels (gears) using a mass production system

- **Introduction of new machines**: Due to increase in demand, the engineers have planned to introduce the following new machines:
  - o Monofronts in the spiral crown wheel line (with a cycle time of 3.75 minutes and operated by 2 persons),
  - o Tapping machine in the hypoid crown wheel line (with cycle time of 0.70 minutes and handled by 1 operator),
  - o Copying machine in the spiral pinion line (with cycle time of 5.33 minutes and operated by a single person)
- **Manpower:** Due to the introduction of multi machine activity the engineers calculated that numbers of workers required will reduce to 31 instead of 42.

Thus all such changes in the layout, manpower, number of machines, sequence of operations etc. were incorporated in the simulation model of the future state VSM.

6.3.5 Results and discussions

The models for both the current state and future state are simulated for 30 days to represent a month's production. Table 6.6 shows the comparison of performance measures for the current state and future state VSMs of cell that produces spiral and crown wheels (gears) using a mass production system. Similar to the previous case, the VAT, PLT, VSI, takt time etc. were computed.

Table 6.6: Comparison of performance measures for the current state and future state VSMs of the cell that produces spiral and crown wheels (gears) using a mass production system

S. No.	Performance measures	Current state	Future state
1.	Demand per day (in number of pieces)		
2.	○ Hypoid pairs	108	165
3.	○ Spiral pairs	114	194
4.	Initial inventory at the beginning of simulation (in days)		
5.	○ Blanking	5.56	2.31
6.	○ Grinding	4.63	1.01
7.	○ Rolling, milling and hobbing	4.63	1.01

S. No.	Performance measures	Current state	Future state
8.	○ Teeth cutting	4.63	1.01
9.	○ Hard operation	4.63	1.01
10.	○ Lapping	1.48	0.46
11.	○ Testing	0.48	0.093
12.	Value added time (in minutes)	63.36	42.72
13.	Production lead time (in days)	37.87	12.68
14.	Process ratio	0.17%	0.39%
15.	Takt time (in minutes)	8.33	5.45
16.	Cycle time (in minutes)		
17.	○ Blanking	7.64	4.50
18.	○ Grinding	3.24	3.24
19.	○ Rolling, milling and hobbing	6.75	5.81
20.	○ Teeth cutting	16.34	6.40
21.	○ Hard operation	8.74	6.25
22.	○ Lapping	12.75	10.60
23.	○ Testing	7.9	5.92
24.	Total Work In Process (WIP) inventory after 30 day simulation (in numbers)	19331	3656
25.	○ Hypoid pinion	3893	680
26.	○ Spiral pinion	5098	1148
27.	○ Hypoid crown wheel	4914	680
28.	○ Spiral crown wheel	5426	1148
29.	Parts produced after 30 day simulation (in numbers)	3392	5085
30.	○ Hypoid pairs	1966	2309
31.	○ Spiral pairs	1426	2776
32.	Walking distance by the operators (in m)	81202.6	62414.2
33.	Manpower used (in numbers)	42	31
34.	Floor space used (in square metres)	794	675
35.	No. of machines involved in multi-machine activity	-	19

From the obtained results of the simulation models, it can be found that the case organisation can achieve the following benefits:

- Inventory level at various stages can be reduced drastically by 78% on an average. For instance, the WIP of hypoid pinion after 30 days of simulation was found to be 3893 numbers, which can be reduced to mere 680 numbers in the future state.
- The introduction of MMAs and line balancing has resulted in a reduction in cycle time at various stages of the crown wheel and pinion manufacturing line. Hence, the total number of pairs that can be produced may increase by 33%. In particular, the hypoid pair production can be increased by 16%, while spiral pair production can be increased by 49%. If further process improvements are

undertaken then the entire shop can become more productive and it can meet the future demands of the gear pairs with the existing capacity itself.

- The walking distance of the labourer within the crown wheel and pinion line can also be reduced substantially in the new layout. It was found from the model that the labour walking distance for entire month is drastically reduced from 81202.64 m to 62412.2 m.
- Due to the improved layout, the floor space can also be reduced from 794 sq. m. to 675 sq. m., which accounts for 15% space reduction approximately.

To obtain these improvements, the engineers have used the following elements: VSM, process simplification, line balancing, layout change, job enlargement (MMA), cellular manufacturing, inventory reduction and floor space reduction. A cursory analysis of the framework proposed in Chapter 3 reveals that the proposed frameworks of LMS include all these elements, which further validates our frameworks. However, it should be remembered that the case organisation has just started with the design of LMS. Hence, LM elements such as kanban system, pull system, mixed model manufacturing/scheduling, load levelling and other supplier related elements etc. are not implemented and this may be taken up in the future.

6.3.6 Validation

The simulated values were verified by checking the same with the company data. It was found that most of the simulated values are matching. Thus, in addition to the improvements in performance measures, other benefits were also obtained by the case organisation:

- Due to re-arrangement of layout by machine grouping, transportation distance reduced by 74%. The engineers have found that the spiral pinion travels a maximum distance of 340 m, while the hypoid crown wheel travels 120 m to get processed. Thus, on an average, the parts travel about 230 m with in the assembly line. Due to rearrangement of machines, the distance travelled by parts has been reduced to an average of 60.5 m.

- Apart from this, they have introduced visual management system such as “identification of location for storing raw materials”. Previously, the boxes containing hundreds of raw materials were placed in non-identified location. Now, they were placed in identified location as per the part to be assembled. Thus, they reduced the mix-up of raw materials that enters the production area.
- The engineers actually eliminated the trolley system, which has been used to move the parts from one operation to another. Sometimes, the workers also used these trolleys as a buffer. Since, the machines were re-grouped, the distance between different machines was reduced and hence the trolleys were eliminated and manual delivery is being followed.
- These trolleys, which were removed from the assembly area was used to move the material to other processing stages such as heat treatment, washing machine etc. Further, the number of parts (i.e. quantity) which can be transported, has been established and hence these trolleys act as a “standard containers”.
- Additional machines were introduced, which resulted in reduction of the cycle time to match the production rate apart from creating dedicated cells. Thus, to some extent it facilitated small lot production, but still the ideal state of single piece flow has not been obtained.

6.4 Development of Simulation Model for the Design of Lean Manufacturing Systems for a Factory that Fabricates Doors and Windows using a Job Shop Production System

The company considered for case is named as ABC Limited (ABCL) to maintain the confidentiality. ABCL is a unit of "LMN Limited", which has an annual turnover of about Rs. 2500 crores and has 30 years of experience in managing large-scale process industries. The company had launched the business of Poly Vinyl Chloride (PVC) window systems in India from 2003 in technical collaboration with a UK plastics company and established a state-of-the-art PVC profile extrusion plant at Rajasthan, while the furniture fabrication units are located in Bhiwadi apart from other metros such as Hyderabad, Bangalore, Mumbai and Chennai. The total production capacity is about 100,000 windows per annum. The LM implementation is currently carried out in the fabrication unit located in Hyderabad, which has strength of about 80 people. Since, the windows are 'custom designed', this industry falls under the 'job shop' production process. Since the growth of construction industry in India is booming in recent times, the demand for furniture is also increasing. For instance, the production target based on demand for the Hyderabad plant is expected to increase from 40 windows per day to 60 windows per day. As the market is increasing, naturally the case organisation has to compete not only with similar industries, but also with local furniture manufacturers, who make wooden doors and windows. However, the production rate of the cell is just 160 squares per shift of 8 hours, which is sufficient enough to meet only the existing demand. The current Work-In-Progress (WIP) for the entire fabrication unit is found to be 1000 squares per day, with an average of 125 squares before each work station (Sridhar, 2007). Because of the lower productivity and higher inventory, the top management of the ABCL is interested in implementing the principles and concepts of LM to remain competitive and meet the increasing demand without much increase in the resources.

6.4.1 *Manufacturing process of doors and windows*

As a starting point, they arranged the training for their managers, officers and technicians in the following tools and techniques: a) 5S, b) Kaizens (continuous improvement), c) Value Stream Mapping (VSM), d) Muda (wastes), etc. (Sridhar, 2007). After their initial training in LM, the team started to collect the details regarding the existing situation of the shop floor. The production process is analysed and the different stages involved in making a window/door is identified. Figure 6.13 shows the flow chart depicting the sequence of manufacturing process for of making the window. Each stage is equipped with both semi-automatic and automatic machines. Sridhar (2007) has discussed in detail about the manufacturing process and operation sequence.

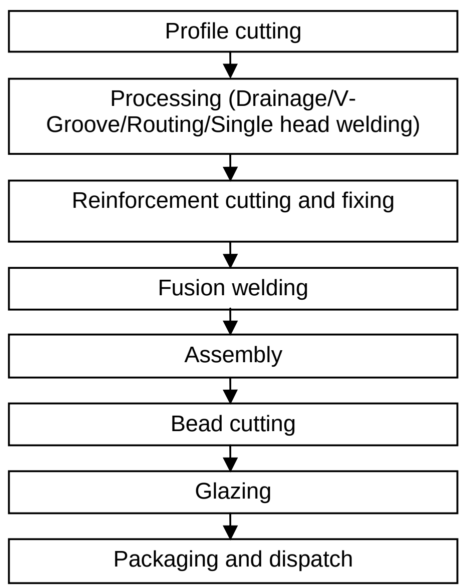


Figure 6.13: Flow chart depicting the sequence of manufacturing process for making the window (Source: Sridhar, 2007)

6.4.2 *Value stream mapping of the factory that fabricates doors and windows using a job shop production system*

The next step is to draw the VSM, for which an understanding regarding the process sequence described above is a pre-requisite. Figure 6.14 shows the current state VSM of the factory that fabricates doors and windows using a job shop production system. It can be found that the VAT for the line is just 1476 seconds, while the PLT is about 12.53 days or 360864 seconds. The process ratio or VSI is found to be just 0.0041, which clearly reveals that the manufacturing process of windows involves lot of NVA activities resulting from the following seven wastes identified by Ohno (1988). The next step is to compute the takt time. Currently, the demand is only 40 windows or 160 squares. The plant works for a single shift of 8 hours, which does not include the lunch breaks of 30 minutes and tea breaks of 15 minutes. Therefore, the available time is found to be 8 * 60 * 60 = 28800 seconds. Hence, the takt time for the current state is found to be 8 x 60 x 60 / 160 = 180 seconds. However, a cursory analysis of the current state VSM reveals that the stages such as profile cutting, processing (i.e. drainage, V-groove etc.), reinforcement assembly and fusion welding have cycle times less than the takt time, while the time taken for the remaining stages are greater than the takt time. This is the reason why an excess amount of inventory is stored in the shop floor.

On the other hand, if we consider the future target for production, which is about 60 windows per day or 240 squares, the mismatch between the cycle times of different processing stages and takt time is very high. The takt time according to the future demand is found to be 8 * 60 * 60 / 240 = 120 seconds. It can be found that only the first stage can meet the future customer demand, as it has the lowest cycle time of 85 seconds. The cycle time for all other stages is greater than the future takt time. To improve the cycle time at each stage, other details such as the operations that are carried out in each stage, number of people, shop floor layout was collected. From Figure 6.14, it can be found that inventory has piled up before all the workstations and there is a huge mismatch between the cycle time and takt time. The engineers in ABCL were interested in carrying out various process improvement activities apart from inventory reduction. Hence, they were contemplating on implementing the following elements of LM:

- Line balancing towards continuous flow processing with single piece production.
- Layout change to reduce the people movement and unnecessary transportation of materials.
- Kaizens to simplify the process by combining/eliminating/simplifying the operations and thereby reduce Muda or NVA activities.
- Establish supermarket at various places of the manufacturing line to reduce inventory
- Work towards continuous production by reducing the batch quantities and thereby reduce over production.
- Work towards mixed production at the pacemaker assembly.

By considering all these improvement activities, a future state VSM was developed. Figure 6.15 shows the future state VSM of the factory that fabricates doors and windows using a job shop production system. From this figure, it can be found that the engineers are attempting to reduce the total inventory to just 1.45 days of stock. In other words, it has to be reduced to 350 squares from 1000 squares earlier. Similarly, the processing time is expected to reduce through process improvement techniques, which will result in increasing the process ratio to 0.018 from 0.004.

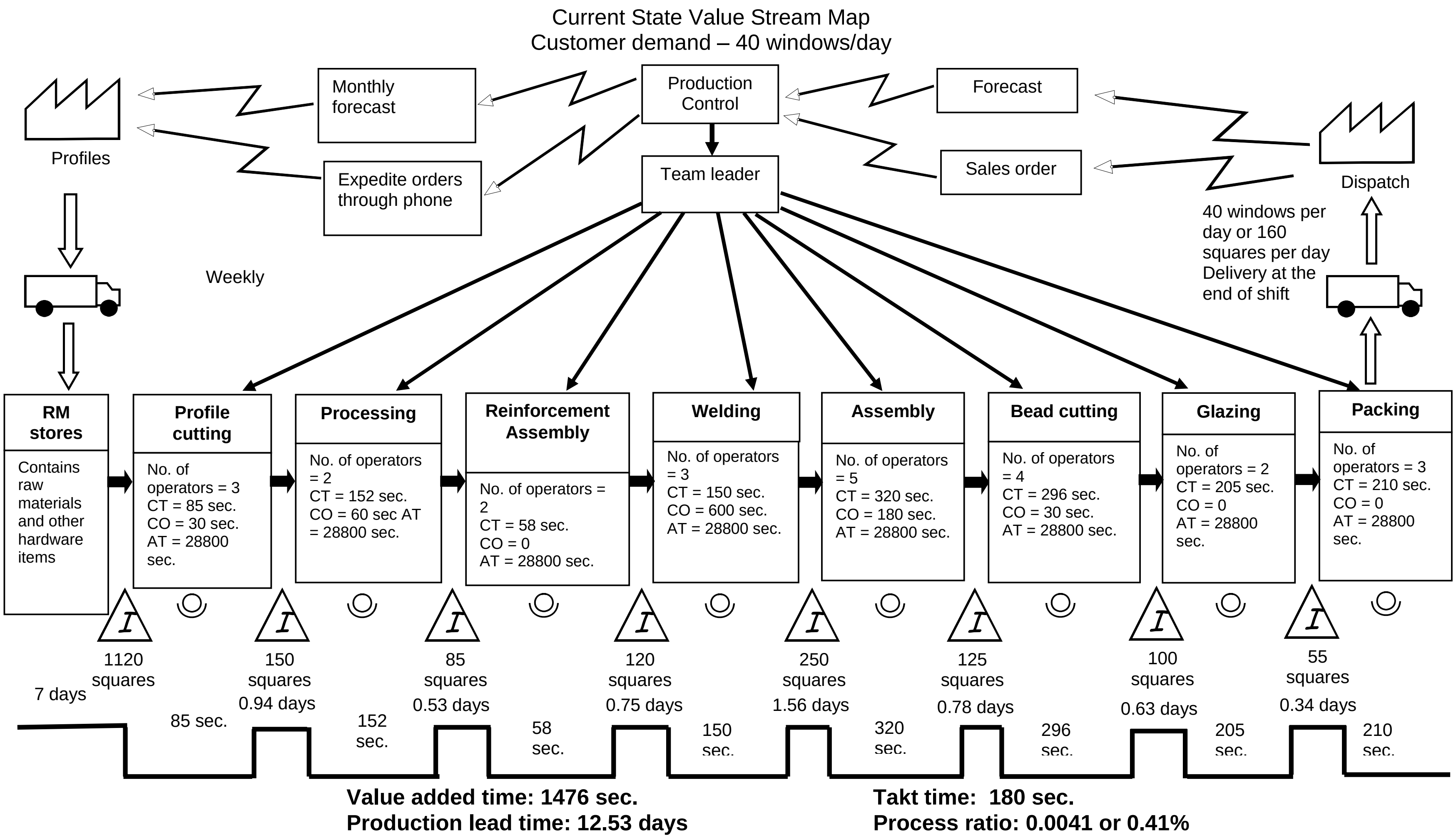


Figure 6.14: Current state VSM of the factory that fabricates doors and windows using a job shop production system (Source: Sridhar, 2007)

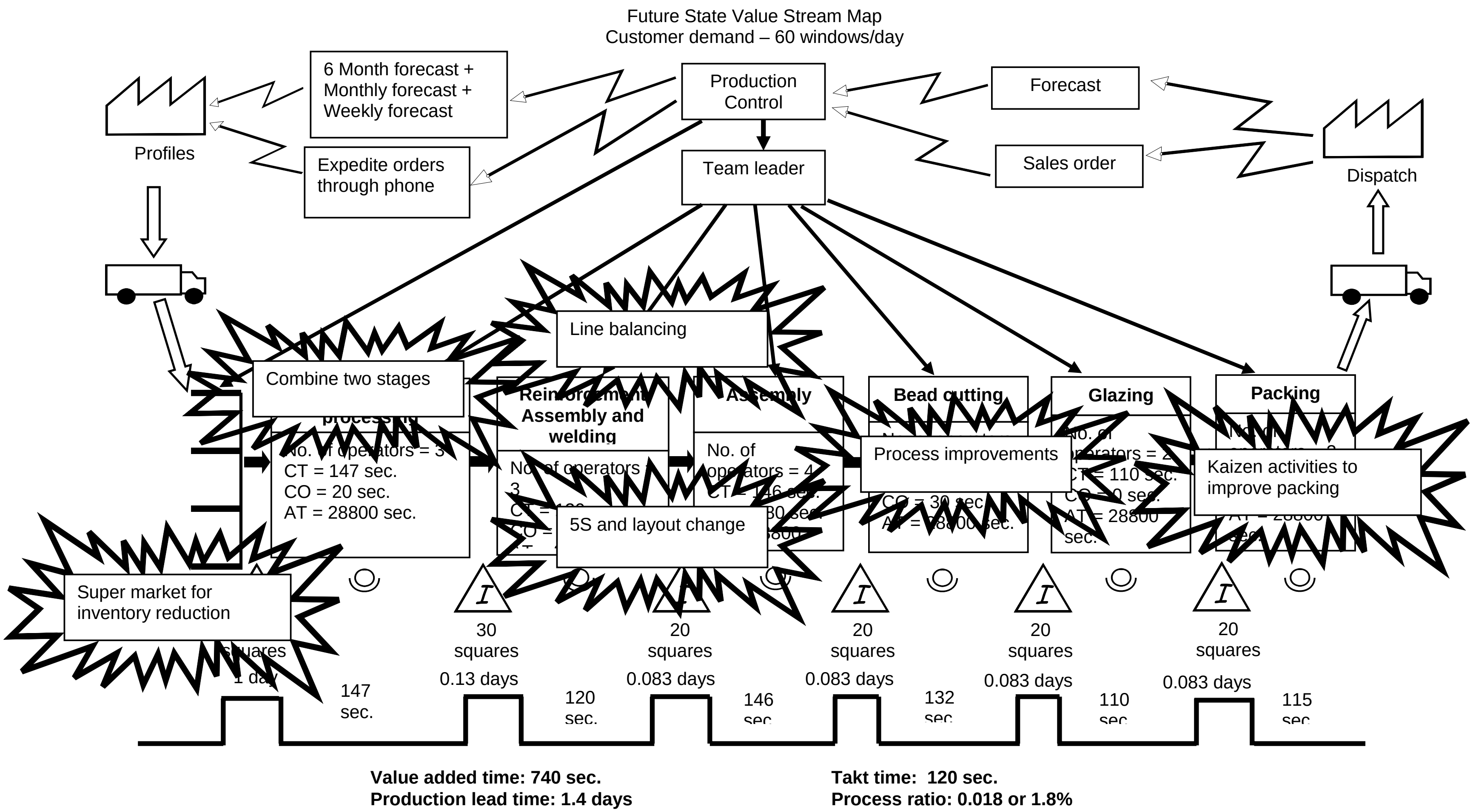


Figure 6.15: Future state VSM of the factory that fabricates doors and windows using a job shop production system (Source: Sridhar, 2007)

6.4.3 Simulation model for the current state map

Apart from the data obtained from current state VSM, additional data such as setup time, number of operators, uptime of the machine etc. were collected. Table 6.7 shows the details of manpower requirement and operations carried out in each stage.

Table 6.7: Details of manpower requirement and operations carried out in each stage (Source: Sridhar, 2007)

S. No.	Operation	Manpower required		Operations involved
		T	C	
1	Profile cutting	1	2	• Study the drawing and select the profile as per drawing. • Collect the profiles from the rack. • Set the machine and cut as per the length. • Write the location code on all profile cut pieces.
2	Processing	2		• Study the drawing, Collect the profiles from trolley and make necessary holes to fit the hardware elements
3	Reinforcement. assembly	1	1	• Insert the cut Galvanised Iron (GI) reinforcement in to the PVC profile as per drawing and fix the screws. • Drill the fisher holes in the outer frame pieces.
4	Welding	2	1	• Collect the profiles, clean at the corners and weld as per drawing.
5	Assembly	3	2	• Clean all welding flashes and assemble the weather seal gasket. • Select the hardware such as handle, lock, etc. as per the specifications and drawing. • Assemble as per the drawing.
6	Bead cutting	1	3	• Drill fisher holes which are not possible in reinforcement assembly stage. • Assemble the fire tree gasket, measures the bead length and cut in the machine.
7	Glazing	1	1	• Collects the window panels and glasses as per the location codes available on windows and glasses. • Cut to sizes of glasses is available from the vendor readily. • Then assemble the bead to the window.
8	Inspection & packing	1	2	• Inspect the windows for sizes and visual defects in couplers, hardware, etc. • Paste all 6 varieties of stickers on the windows. • Pack the window by keeping the window on bubble roll sheet on floor.
	Total	12	12	

Note: 'T' stands for technicians, while 'C' stands for casual labourers.

From Table 6.7, it is found that 24 people (12 technicians and 12 casuals) are required to meet the demand of 40 windows per day. The total available shop floor area of the Hyderabad plant is about 1791 sq. m., out of which 1400 sq. m. is used by the manufacturing line. Apart from this data, the following assumptions were made to construct the simulation model:

- The inventory is taken entirely to be the initial inventory. Before the start of the simulation, this inventory will be built up before the workstations. This is due to the fact that a VSM captures the snap shot picture of the shop floor at any given point of time. Hence, the simulation too starts with the current situation as obtained from the current state VSM.
- The labour for each stage is allocated as per the Table 6.7.
- The setup time in 'seconds' is included as per the current state VSM and it has been assumed that setups are performed during the starting of production. The setup involves fixing the tool, cleaning and ensuring that materials required are ready for production. However, there is no setup in between production as every product goes through the same processes without any change of machines.
- Each day consists of 1 shift with each shift having two 15 minute tea breaks and a 30 minute lunch break, which is separate and does not interfere with the production hours of 8 hours in each shift.
- The source is an active source and the inter arrival time of each part is made equal to the cycle time of the first machine in each line. This is due to the fact that the organisation follows a push system of operation in the shop floor.
- If an operation has two similar machines performing the same operation then the machining time of all such similar machines is assumed to be a constant.

With these actual data, the current state VSM is simulated to ensure that the simulation model replicates exactly the actual production happening in their organisation. Figure

6.16 shows the simulation model for the current state VSM of the factory that fabricates doors and windows using a job shop production system, while Figure 6.17 shows the snap shot of the current state of VSM during the simulation run. In Figure 6.16, all the processing stages of the window manufacturing are represented as per the layout, which was discussed in detail by Sridhar (2007). In the case of Figure 6.17, the simulation run of the model clearly shows the build up of initial inventory before each stages of processing.

6.4.4 Simulation model for the future state map

As mentioned earlier, to reduce the wastes identified in the current state VSM and meet the increase in demand, the engineers were interested in establishing the following LM elements:

- **Layout change**: To reduce wastes such as unnecessary transportation and motion, the engineers proposed an improved layout for the shop floor. Details regarding the improved layout are available in Sridhar (2007). They proposed that the total shop floor area utilisation can be reduced to 12 x 60 = 720 sq. m. from 1400 sq. m.
- **Line balancing**: From Figures 6.14 and 6.15, it can be found that the operations are not at all balanced. For instance, the profile cutting operation takes only 85 seconds but the fusion welding process takes 150 seconds, while bead cutting consumes 296 seconds. Hence, the focus is to balance the line by ensuring that the processing time in each stage is equally distributed and it is more or less equal to the takt time. To accomplish this, the production engineers proposed combining the different stages of manufacturing.

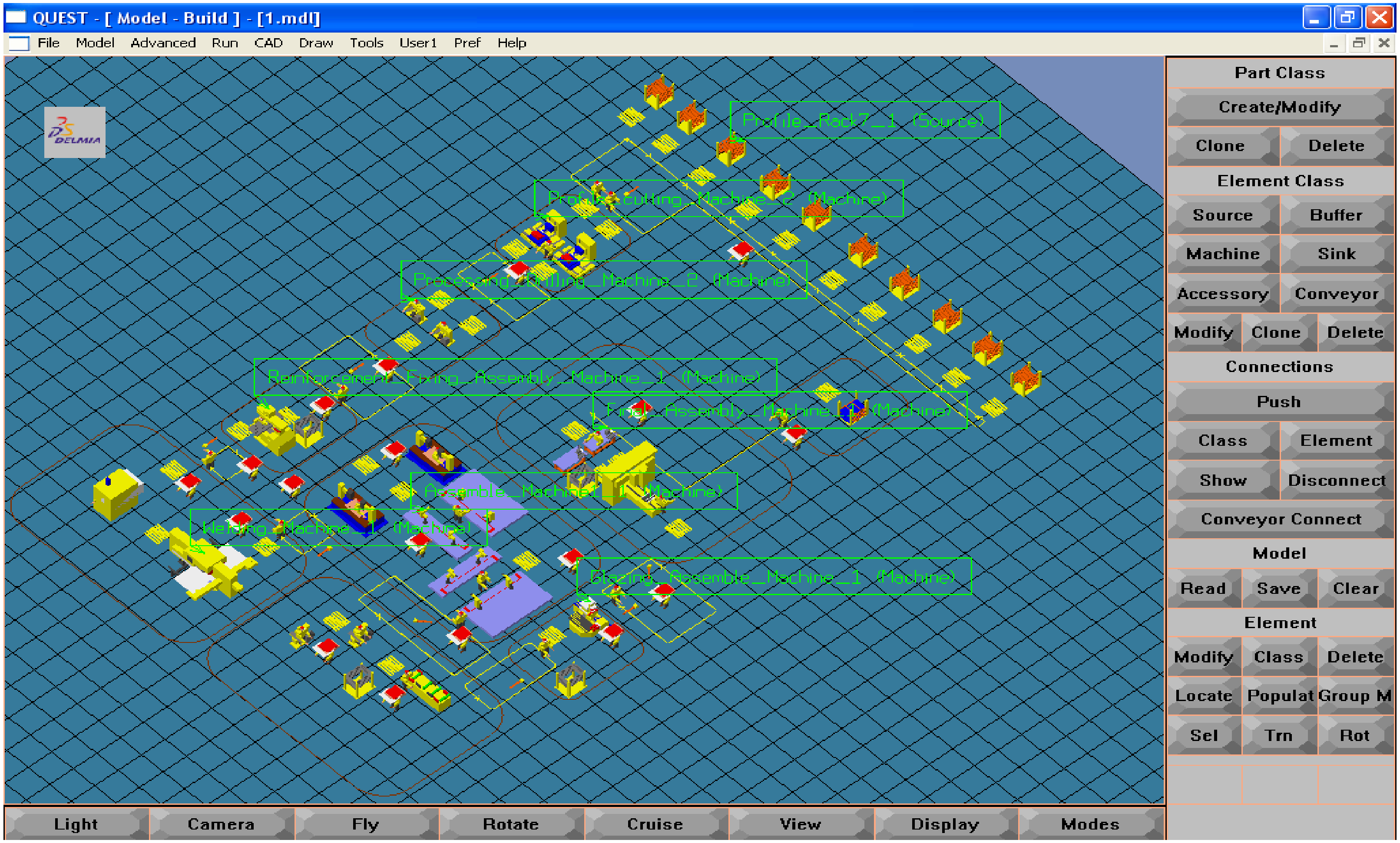


Figure 6.16: Simulation model for the current state VSM of the factory that fabricates doors and windows using a job shop production system

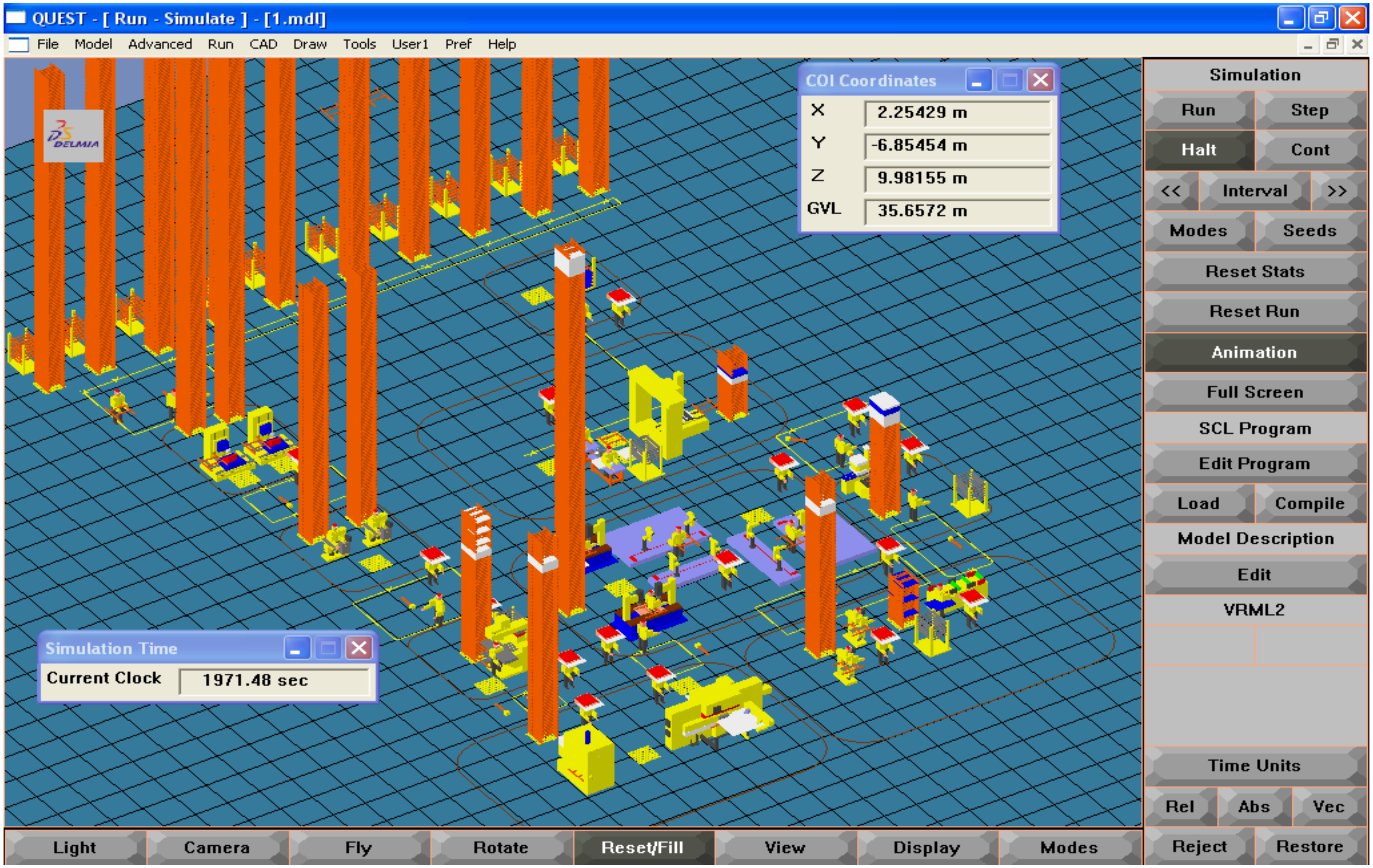


Figure 6.17: Snap shot of the current state VSM during the simulation run

For instance, they proposed combining the operations of profile cutting machine having 1 technician and 2 casuals with processing machines of 2 technicians (i.e., in total, 3 technicians and 2 casuals). They identified that manpower of 2 technicians and 2 casuals is sufficient for the merged stages, as both the profile cutting machine and processing is doing over production. To integrate these two stages, the layout has to be changed, which will naturally eliminate the inventory held between these work stations previously. In a similar manner, they proposed combining the reinforcement assembly and welding machine operations. Initially they had 1 technician and 1 casual in reinforcement assembly and 2 technicians and 1 casual in welding work station (total of 3 technician and 2 casuals). Again by proposing a layout change to place these two stages nearer and fine-tuning the process through some kaizens, they estimated that 1 technician and 2 casuals are sufficient to work in both the stations. Naturally, the inventory between these two stages will become zero. Similarly, various process improvements to balance the line and reduce the cycle time were performed. Table 6.8 shows the revised manpower requirement for the improved layout.

- **Kaizens**: Similarly, the team identified kaizen activities for other stages such as assembly, bead cutting and glazing operations to eliminate NVA activities, which will result in reduction in process time apart from improving the safety. A sample of proposed kaizen activities are as follows:
    - **Use of double bead block in bead cutting machine**: Earlier, they were using a mono-block (work holding device) to hold the PVC and perform the bead cutting operation. They planned to redesign the work holding device in such a way that it can hold two PVCs of same size at the same time and the bead cutting can happen simultaneously in both the PVCs, which can lead to productivity improvement.

Table 6.8: Revised manpower requirement for the improved layout (Source: Sridhar, 2007)

S. No.	Operation	Manpower required		Operations involved	Modifications
		T	C		
1	Profile cutting	1	1	• Study the drawing and select the profile as per drawing. • Collect the profiles from the rack. • Set the machine and cut as per the length. • Write the location code on all profile cut pieces.	Combined the operational responsibility for both technicians, which will also reduce the inventory held between these stages
2	Processing	1		• Study the drawing, Collect the profiles from trolley and make necessary holes to fit the hardware elements	
3	Reinforcement assembly		1	• Insert the cut Galvanised Iron (GI) reinforcement in to the PVC profile as per drawing and fix the screws. • Drill the fisher holes in the outer frame pieces	Combined the operations of reinforcement fixing and welding with one technician and 2 casuals, which will also reduce the inventory held between these stages
4	Welding	1	1	• Collect the profiles, clean at the corners and weld as per drawing.	
5	Assembly	2	2	• Clean all welding flashes and assemble the weather seal gasket. • Select the hardware such as handle, lock, etc. as per the specifications and drawing. • Assemble as per the drawing.	Can assemble 60 windows/shift on an average with additional operations of stickers pasting and couplers attachments.
6	Bead cutting	1	2	• Drill fisher holes which are not possible in reinforcement assembly stage. • Assemble the fire tree gasket, measures the bead length and cut in the machine.	Takes the responsibility of glazing operation also and support the members as and when it is required.
7	Glazing	1	1	• Collects the window panels and glasses as per the location codes available on windows and glasses. • Cut to sizes of glasses is available from the vendor readily. • Then assemble the bead to the window.	
8	Inspection & packing		2	• Inspect the windows for sizes and visual defects in couplers, hardware, etc. • Paste all 6 varieties of stickers on the windows. • Pack the window by keeping the window on bubble roll sheet on the packing fixture	
	Total	7	10		

- **Packing area improvement**: From the current state map, it can be found that packing and dispatching were taking more time. Hence, they studied the process in detail and came out with lot of process improvements. In the earlier method, the bubble sheet is un-rolled on the floor and cut by the operator manually according to the size of the window. The operator has to sit and bend to perform the cutting, which was unproductive due to increased strain and fatigue for the worker. The production engineers have designed a trolley, in which the bubble sheet roll can be mounted at the top on a roll and it can be easily unrolled by pulling it and can be cut without bending. The next step is to pack the windows using these cut bubble sheets. Previously, the packing is performed by placing the window on the floor and covering it with bubble sheet. Since, it is taking too much time, the engineers were interested in developing a rotary packing table, in which the windows can be placed and can be rotated according to the orientation required for packing. The bubble sheet is rolled around it and an adhesive tape is affixed over it. In this stage, the bending of operator is completely avoided and hence the productivity loss due to fatigue can be eliminated.

These improvements can lead to drastic reduction in the cycle time and the engineers have attempted to reduce to half the existing cycle time for those stages, which had significant cycle time (such as packing, bead cutting, assembly etc.). Considering all the changes and improvements discussed above, a simulation model for the future state map is developed. Figure 6.18 shows the simulation model for the future state VSM of the factory that fabricates doors and windows using a job shop production system.

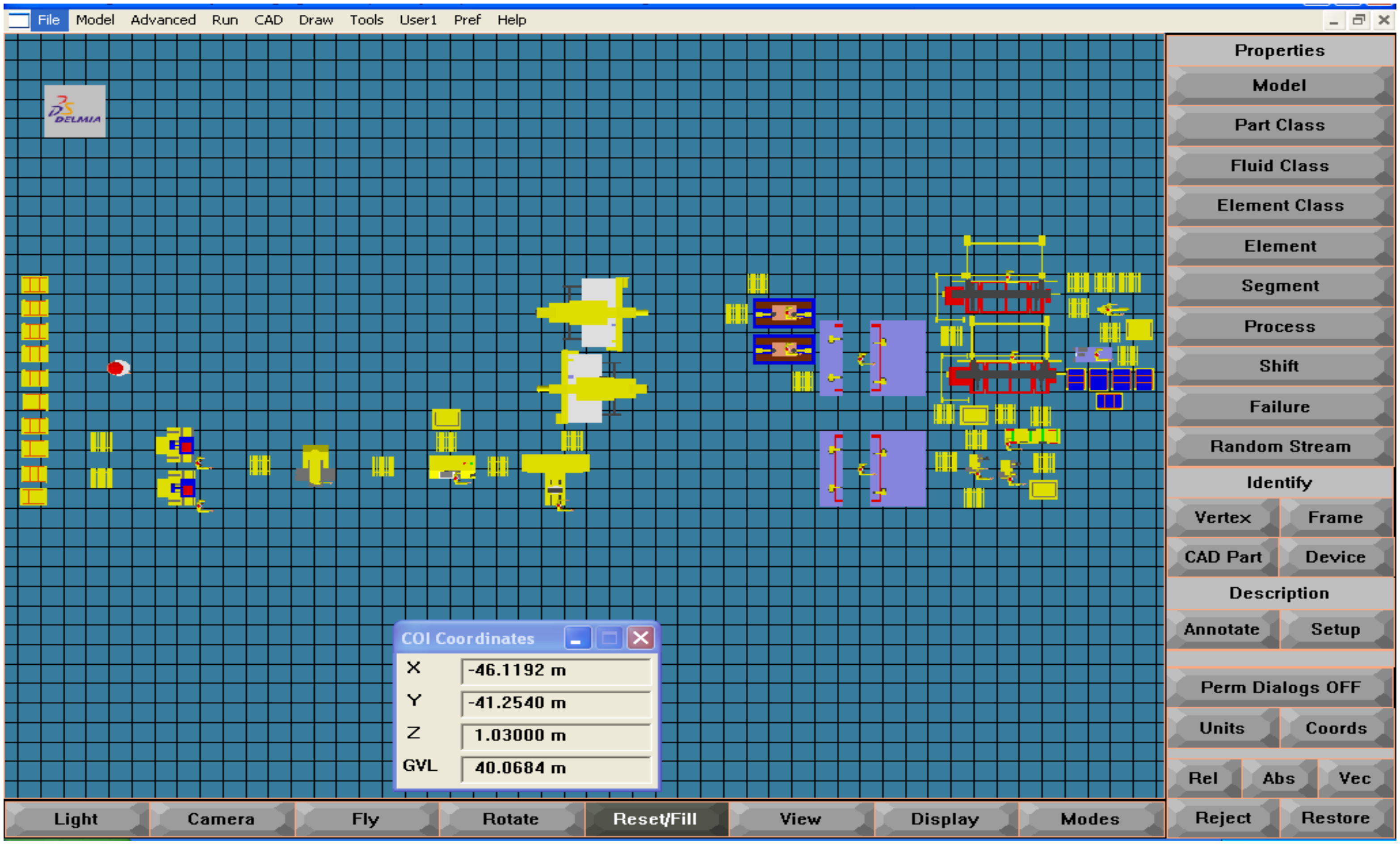


Figure 6.18: Simulation model for the future state VSM of the factory that fabricates doors and windows using a job shop production system

A cursory look at Figure 6.18 will reveal that the layout has been changed and the parameters associated with simulation such as initial inventory, cycle time etc. has been modified. However, the assumptions for the future state simulation model are same as that of current state simulation model.

6.4.5 Results and discussions

The models for both the current state and future state are simulated for 30 days to represent a month's production. Table 6.9 shows the comparison of performance measures for the current state and future state VSMs of the factory that fabricates the doors and windows using a job shop production system. It can be found that the number of units produced is measured in 'number of squares'. Generally, the industry practice is to measure the production rate based on units/hour. Thus, the production rate should be measured as number of windows/doors produced per hour. However, in this case, the size of window/doors differs considerably and hence this unit of measurement many not adequately reflect the daily production. For instance, if the size of window is more, then the complexity associated with it will affect the manufacturing and handling, naturally leading to lesser number of windows/doors on a particular day.

Table 6.9: Comparison of performance measures for the current state and future state VSMs of the factory that fabricates the doors and windows using a job shop production system

S. No.	Performance measures	Current state	Future state
1.	Demand per day		
	• In number of windows	40	60
	• In number of squares	160	240
2.	Initial inventory of squares at the beginning of simulation (in number of days)		
	• Profile cutting	1120 (7)	240 (1)
	• Drainage, V grooving and other profile machining operations	150 (0.94)	
	• Reinforcement assembly	85 (0.53)	30 (0.125)
	• Fusion welding	120 (0.75)	
	• Assembly	250 (1.56)	20 (0.083)
	• Bead cutting	125 (0.78)	20 (0.083)
	• Glazing	100 (0.63)	20 (0.083)
	• Packing and dispatch	55 (0.34)	20 (0.083)

S. No.	Performance measures	Current state	Future state
3.	Value added time (in minutes)	63.36	42.72
4.	Production lead time (in days)	37.87	12.68
5.	Process ratio	0.17%	0.39%
6.	Takt time (in seconds)	180	120
7.	Cycle time (in seconds)		
	• Profile cutting	85	147
	• Drainage, V grooving and other profile machining operations	152	
	• Reinforcement assembly	58	120
	• Fusion welding	150	
	• Assembly	320	146
	• Bead cutting	296	132
	• Glazing	205	110
	• Packing and dispatch	210	115
8.	Total Work In Process (WIP) inventory after 30 day simulation (in numbers)		
	• In number of squares	4992	1196
	• In number of windows	1248	299
9.	Parts produced after 30 day simulation (in numbers)		
	• In number of squares	7956	10535
	• In number of windows	1989	2561
10.	Distance travelled by a single window (in m)	62.5	54
11.	Manpower used (in numbers)	24 (12 technicians + 12 casuals)	17 (10 technicians + 7 casuals)
12.	Floor space used (in square metres)	1587	720

Hence, to overcome this shortcoming and establish the uniformity in computing the total production, the case organisation has a practice of counting the total production based on ‘number of squares’ in that window/door. If the window/door size exceeds more that 1.5 metres in size, then it is counted as 2 squares. In addition to this, other parameters such as inventory, VAT, PLT, VSI or process ratio are calculated as per the previous cases. Apart from this, the results obtained from the simulation models revealed that the case organisation can achieve the following benefits:

- The distance a part travelled from raw material to finished products such as windows/doors got reduced. As per the existing layout, the total distance travelled by the part is found to be 62 m. After the revised layout, the travel distance from profile storage to dispatch is found to be 54 m. resulting in a reduction of about 8 m. per window.

- Inventory level at various stages can be reduced by 76% on an average. For instance, the WIP of windows after 30 days of simulation was found to be 1248 numbers, which can be reduced to just 299 windows in the future state.
- The introduction of kaizen and line balancing has resulted in a reduction in cycle time at various stages of the manufacturing line. Hence, the total number of windows that can be produced may increase by 28.5%. If further process improvements are undertaken then the entire shop can become more productive and it can meet the future demands of 85 windows per day with the existing capacity itself.

To obtain these improvements, the engineers have implemented the following LM elements: VSM, process simplification, line balancing, layout change, job enlargement and floor space reduction. However, it should be remembered that the case organisation has just started with the design of LMS. Hence, other LM elements such as kanban system, pull system, mixed model manufacturing/scheduling, load levelling and other supplier related elements etc. are not implemented and this may be taken up in the future.

6.4.6 Validation

The simulated values were verified by checking the same in the company after LM implementation. It was found that most of the simulated values are matching. In addition, the following actual results are obtained from the case organisation (Sridhar, 2007):

- Due to the changed layout, the distance a part travelled from raw material to finished products such as windows/doors got reduced. According to the simulation model, the total distance travelled by the part from profile storage to dispatch is found to be 62 metres in the current state layout. However, in reality, it was around 66 metres on an average, while the travel distance after revising the layout is found to be 51 metres, a reduction of about 15 meters per window.

- Although, various LM elements were implemented, the case organisation could not drastically reduce the inventory as shown in the future state map. They could reduce only by half of the current state map, as the employees were hesitant in reducing it to such a low level. Since, the process variability and supplier variability are not yet improved; the operation manager and supervisor still preferred keeping some WIP. Nonetheless, it is a significant achievement and the LM team is continuously directing their efforts to slowly reduce the inventory by implementing various LM tools.

6.5 Conclusions

This chapter started with the claim that one of the reasons for an organisation's failure in their LM implementation is due to the fact that the managers do not fully understand how an organisation will be after it gets transformed by the principles of LM. Even though VSM can resolve the above issue to some extent, it suffers from various shortcomings. Hence, researchers suggested the use of simulation in conjunction with the VSM. A review of literature related to simulation and LM/JIT too revealed that most of the simulation studies focused on studying about the LM elements such as kanbans (finding the optimal number of kanbans), push and pull systems (comparison), mixed model assembly (sequencing and scheduling) etc. Other LM elements such as multi-machine activity (job enlargement), machine grouping (cell manufacturing), pokayoke, process improvements, cycle time reduction, layout changes, automation etc. has not been given adequate importance in the simulation studies. Hence, to overcome all these issues, simulation is used in conjunction with VSM to model the current state and future state VSM of:

- a shop floor that manufactures brake linings using a batch production system
- a cell that produces spiral and crown wheels (gears) using a mass production system and
- a factory that fabricates doors and windows using a job shop production system

The impact of implementing some of the LM tools on the performance of these organisations was analysed by comparing the performance measures for current and future state VSM and it was found that there was significant improvement in the productivity and quality, while there was significant reduction in inventory, cycle time, floor space and other wastes. Finally, the results of the simulation model were found identical with the results obtained after the implementation of improvement activities in the shop floor. It should be noted here that the case organisations has just started off with their LM implementation efforts and hence only a few LM elements such as line balancing, multi machine activity, layout change, machine grouping (cell manufacturing), pokayoke, Andon, layout change, work standardisation, inventory reduction etc. has been implemented and advanced LM elements such as kanban, pull system, load levelling, etc. are not implemented. However, it can be concluded that the case organisations are in the right track of LM implementation and if the managers and engineers of the organisation implements the remaining LM elements properly, then the case organisations are bound to achieve a superior competitive advantage over its competitors in the near future.

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Chapter 7

Assessment of Lean Manufacturing Systems

7.1 Introduction

The success of implementing change management programmes such as Lean Manufacturing (LM), Total Quality Management (TQM), Total Productive Maintenance (TPM), etc. is dependent on many factors and one such factor is the process of obtaining the feedback regarding whether the implementation has been carried out properly or not. Povey (1996) noted that all goal setting and strategic planning activities of organizations should be aimed at answering three fundamental questions:

- What is the current state of the organization?
- Where does an organization want to reach?
- How to reach the target?

He also noted that when trying to answer these questions, the organization must create a picture of its strengths and areas where improvements can be made by performing a process called 'assessment'. Since, implementing LM in an organisation is also a strategic planning activity; these questions are also equally applicable. Hence, in this chapter, an attempt has been made to assess the following:

- How much the Human Resources (HR) of an organization has contributed in implementing LMS?
- Which elements of LM have been implemented and which other elements can be implemented by HR? and
- Where does the organisation that have implemented LM stands in comparison with the 'best-in-class' organisation and an organisation that is a leader in that particular product segment?

7.2 Development of a Graph Theoretic Model for the Assessment of Roles and Responsibilities of Human Resources in Implementation of Lean Manufacturing System

Chang and Lee (1996) identified the specific factors needed for the successful implementation of JIT techniques, which includes: top management support; bottom-up management style; participation of all employees; education and training; good relationship with vendors; good relationship with customers; communication between production department and marketing department; union support; Total Quality Control (TQC); Quality Circles (QC), Statistical Process Control (SPC) and integration of Material Requirement Planning (MRP) or Manufacturing Resources Planning (MRP II) and Just-In-Time (JIT). A closer analysis of these factors reveals that almost six out of the 12 factors are related to the people – i.e., the HR of the organisation. It was also supported by Pil and MacDuffie (1996), who argued that the successful operation of Japanese production systems depends on HR policies which deliver "willing co-operation" rather than mere compliance on the part of the workforce. Generally, within any organisation, apart from the workforce (i.e., the shop-floor associates), other stakeholders such as engineers, managers and executives of the top management also play an important role in any organisational transformation programme. In addition to these people, the success of such transformations is also dependent on external people such as consultants, shareholders, suppliers, customers, etc. with whom the organisations interact on a regular basis. Among these external people, the roles of suppliers and customers are very important (Grover *et a*l., 2005). Hence, the term HR has been expanded to include not only the different categories of employees (such as shop-floor associates, engineers/supervisors, managers and executives of top management) within an organisation, but also the suppliers and customers. Based on this updated terminology of HR, an attempt has been made to understand:

- What will be the roles and responsibilities of shop-floor associates, engineers/supervisors, managers, and executives of top management apart from suppliers and customers during the implementation of LMS in an organisation or in an organisation that have already implemented LMS? To be precise, implementing LM requires the implementation of certain LM elements by various categories of HR stated above. Hence, it is necessary to understand what tools, techniques, practices and procedures (in short, we call it as 'elements') of LM will be implemented by each category of HR?
- How to assess whether each category of HR has implemented the assigned elements of LM properly or not? In other words, what is the contribution of each category of HR in implementing the elements of LM?

7.2.1 Taxonomy for lean manufacturing elements from the perspective of human resources

Many researchers have provided a classification scheme for the LM elements, which was discussed in Chapter 3. For example, researchers such as Spencer and Guide (1995), Feld (2001), Shah and Ward (2003), Treville and Antonakis (2006) to name a few have suggested different taxonomies for LM elements. In a similar manner, a classification scheme for the identified LM elements has been proposed from the perspective of the roles and responsibilities of HR. The logic behind this taxonomy is that HR is considered to be a major source of strength and an asset to any organisation (Grover *et al*. 2005) and the success of an organisation having LM is dependent on the proper implementation of LM elements by the HR. Snape *et al*. (1995) too noted that HR plays a central role in the implementation of organisational change programmes such as TQM.

Earlier in the introduction, the term HR has been defined to include the shop floor associates, engineers, managers and executives of top management (internal stakeholders) apart from suppliers and customers (external stakeholders). Therefore, it is necessary for each of these stakeholders to know 'what will be their roles and responsibilities in a LM environment?' In other words, 'which elements of LM should they follow or practice during LM implementation or in a LM environment? To answer these questions, the structure proposed by Grover *et al*. (2005) has been adapted to propose the taxonomy of LM elements. The structure includes employers, employees, customers and suppliers and the same has been extended to include the role of managers and engineers apart from the shop floor associates by sub-dividing the category of employees, apart from renaming employers as top management. Figure 7.1 shows the framework for classifying the LM elements. Based on this framework, the taxonomy for LM elements is developed by classifying the identified LM elements under the broad categories of internal and external stakeholders.

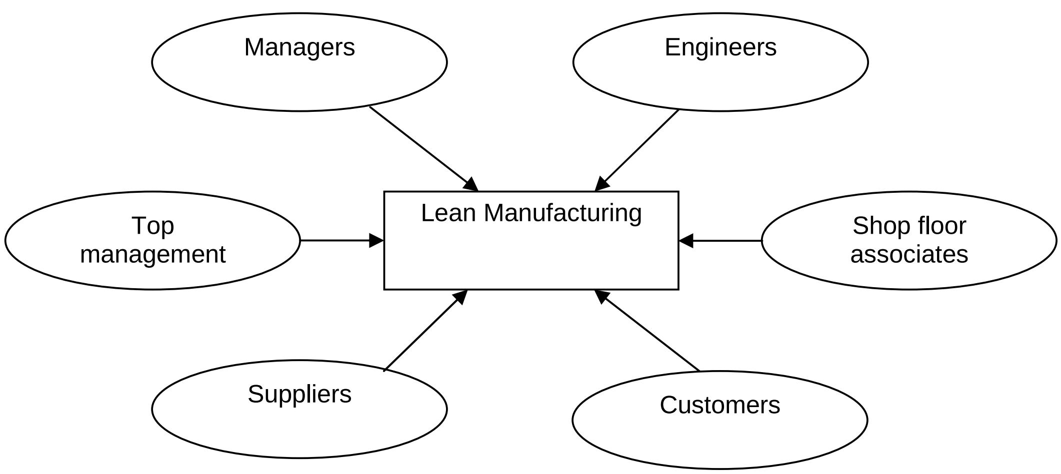

Figure 7.1: A framework for classifying the LM elements (adapted from Grover *et al*., 2005)

For example, shop floor associates are responsible for elements such as Successive Check (SUC), Autonomous Maintenance (AUM), etc., while the engineers will carry out Work-load Balancing (WLB), Setup time reduction (SMD), etc. On the other hand, the managers (middle-level) are responsible for implementing Kanban (KAN), Pull system (PUL), etc., while the executives in the top management will be involved in establishing policies such as Long Term Employment (LTE), Rewards and Recognition (RRE), use of New Process or Technology or Equipment (NPE), etc. In addition to these internal stakeholders, the roles and responsibilities of suppliers as well as customers is also considered, which is inline with the Deming's concept of 'extended enterprise' (Mitra, 1998). They are considered as the external stakeholders. For example, the elements such as Quality Certification (QUC), Just-In-time Delivery (JID), use of standardised containers, etc. are the responsibilities of suppliers, while the role of customers is to derive the value out of the product produced by the organisation and provide necessary feedback to the organisation, in case they are not getting adequate value for the price they pay for the product. Table 7.1 shows the taxonomy for LM elements from the perspective of HR.

Table 7.1: Taxonomy for LM elements from the perspective of HR

Taxonomy	**LM element**	**In short**
Shop floor associates	Autonomous Maintenance	AUM
	Housekeeping or 5S	HOK
	Employee Empowerment	EEM
	Employee Participation	EEP
	Andon	AND
	Jidoka	JID
	Defects at Source or Self Inspection	DAS
	Successive Check	SUC
	Work Standardisation	WST
	Process Sharing	PRS
	Visual Control	VIC
	Suggestion Schemes	SUS
	Job Rotation or Flexible Job Responsibilities	JOR
	Job Enlargement or Nagara System	JOE
	Use of Problem Solving Tools	PST
	Multi Skilled Workforce	MSW
	Multi Functional Training	MFT
	Cross Functional Team working	CFT
Engineers	Quality Circles	QUC

Taxonomy	LM element	In short
	Storage Space Reduction	SSR
	Work-In-Progress Inventory Reduction	WIP
	Pokayoke or Defect Prevention	POK
	Elimination of buffers	ELB
	Cycle time and Lead time Reduction	CTR
	Safety Improvement Programmes	SIP
	Product and Process Simplification	PPS
	Layout change or U-Shaped Cell	LAY
	Workload Balancing	WLB
	Statistical Process Control	SPC
	Single Minute Exchange of Dies	SMD
Manager	Group technology	GRT
	Automation	AUN
	One Piece Flow	OPF
	Pull Production	PUL
	Small Lot Production	SLP
	Kanban System	KAN
	Mixed Model Manufacturing	MMM
	Production Smoothing	PSM
	Use of Flexible Multiple Small Machines	UFM
	Commonisation and Standardized Parts	CSP
	Design for Manufacturing	DFM
	Modular Design	MDN
Top Management	Value Stream Mapping	VSM
	Focused Factory Production	FFP
	Communication Between Employees	COE
	Flat Organisation Structure	FOS
	Long Term Employment	LTE
	Rewards and Recognition	RER
	Long term Supplier Relationship	LSR
	New Process or Equipment	NPE
	Maintain Spare Capacity	MSC
	Total Productive Maintenance	TPM
	Cellular Manufacturing	CEM
	Computer Integrated Manufacturing (Use of CAD/CAM/CAE)	CIM
	Total Quality Management	TQM
	Concurrent Engineering	CEG
Suppliers	Frequent Multiple Just-in-Time-Small Lot Delivery	JTD
	Supplier Training and Development	STD
	Information Sharing with Suppliers	ISS
	Standard Containers	STC
	Use of EDI with suppliers	EDI
	Quality Certification	QUC
	Sole Sourcing	SOS
	Supplier Proximity	SPR
	Supplier Involvement in Design	SID
Customers	Value addition or Value for Money	VFM
	Customer Feedback or Feedback Mechanism	FBM
	After Sales Service	ASS

Achanga *et al*. (2006) have identified the critical success factors for lean implementation in Small and Medium-scale Enterprises (SMEs). They classified these factors into the following: leadership, organisation culture, finance and skills and expertise. They explained that the leadership factor includes vision and strategic initiatives, good level of education and the willingness to support initiatives such as LM. The organisational culture criterion includes; management ability to operate in diverse environments, easy acceptance of change and long-term focus on their roles. Financial criterion includes the availability of funds to enable capital investment and strong financial management. Skills and expertise criterion includes the recruitment and enhancement of capable workforce and provision of training and innovation, etc. But it is assumed that these success factors or elements are the pre-requisites for any change management programme. Similar elements were also identified in our proposed framework, which are considered to be the fundamental requirements for LM and these basic elements should be in place before any change management programme can be initiated. Since, the focus is to develop a mathematical model for assessing the roles and responsibilities of HR in implementing LM elements by analysing 'which LM elements will be implemented by which category of HR?, only those elements, which are unique to the LM were considered, while the rest of the elements were eliminated. Table 7.2 shows the consolidated list of LM elements considered for graph theoretic (GT) modelling.

Table 7.2: Consolidated list of LM elements considered for GT modelling

Taxonomy	Element	In short	Notation
Top Management (B^1)	Rewards and Recognition and Long Term Employment (Human Resource Policies)	HRP	B_1^1
	Total Productive Maintenance/Total Quality Management (Modern Manufacturing Philosophies)	MMP	B_2^1
	Flat Organisation Structure and Communication Between Employees	ORC	B_3^1
	Cellular Manufacturing and Maintain Spare Capacity (Manufacturing Modes and Methodology)	CSC	B_4^1
	Focused Factory Production and Concurrent Engineering	FCE	B_5^1
	Computer Integrated Manufacturing (Use of CAD/CAM/CAE) and New Process or Equipment	CIM	B_6^1
Managers (B^2)	Group technology and Commonisation and Standardized Parts	GRT	B_1^2
	Mixed Model Manufacturing and Production Smoothing	MMM	B_2^2
	Automation and Use of Flexible Multiple Small Machines	AFM	B_3^2
	Pull Production and Kanban System	PUL	B_4^2

Taxonomy	Element	In short	Notation
	One Piece Flow and Small Lot Production	SLP	B_5^2
	Design for Manufacturing and Modular Design	DFM	B_6^2
Engineers (B^3)	Workload Balancing and Layout Change	WLC	B_1^3
	Single Minute Exchange of Dies and Work in Progress Reduction	SMD	B_2^3
	Cycle time and Lead time Reduction	CTR	B_3^3
	Product and Process Simplification	PPS	B_4^3
	Storage Space Reduction and Elimination of Buffers	SSE	B_5^3
	Pokayoke and Statistical Process Control	QIC	B_6^3
Shop floor associates (B^4)	Job Enlargement and Job Rotation	JER	B_1^4
	Andon and Jidoka	ANJ	B_2^4
	Autonomous Maintenance and Housekeeping	AMH	B_3^4
	Defects at Source and Successive Check	DSC	B_4^4
	Suggestion Schemes and Quality Circles	SUS	B_5^4
	Visual Control and Use of Problem Solving Tools	VPS	B_6^4
Customers (B^5)	Value for Money	VFM	B_1^5
	Customer Feedback or Feedback Mechanism	FBM	B_2^5
	After Sales Service	ASS	B_3^5
Suppliers (B^6)	Supplier Involvement in Design and Long term Supplier Relationship (Supplier Partnership)	SUP	B_1^6
	Information Sharing with Suppliers and Use of EDI with suppliers (Supplier Communication)	SCO	B_2^6
	Sole Sourcing and Supplier Proximity	SSP	B_3^6
	Quality Certification	QUC	B_4^6
	Frequent Multiple Just-in-Time-Small Lot Delivery and Standard Containers (Supplier Delivery)	SDE	B_5^6
	Supplier Training and Development	SPR	B_6^6

Note: In this table, each LM element has been represented as B_i^l, where the subscript 'i' represents the LM elements that are grouped under a particular taxonomy (i.e., stakeholder) represented by 'l'.

The basic difference between Table 7.1 and Table 7.2 is that some of the pre-requisite elements such as Employee Participation (EEP), Employee Empowerment (EEM), Cross Functional Teams (CFT), etc. were removed as they are common for any change management programme. For instance, the above-said elements are also required for the TQM environment (Grover *et al.*, 2004). Similarly, in Table 7.2, most of the LM elements listed in Table 7.1 were combined into one. For instance, Andon (AND) and Jidoka (JID), Defect at Source (DAS) and Successive Check (SUC), etc. are combined into one. It should be noted here that such consolidation and combination of elements were carried out for the sake of simplicity and to increase the clarity of understanding of the modelling approach. If all the elements listed in Table 7.1 were considered individually for the analysis, the modelling would become more complex.

7.2.2 An overview of graph theoretic model

The GT model has been well received in the literature as it has been used by various researchers in diverse fields. For example, Sethi and Agrawal (1993) used the multi-graph approach to provide a hierarchical classification of kinematic chains. Venkataswamy and Agrawal (1997) used it to evaluate the quality of an automotive vehicle, while Mohan *et al*. (2003) used it for system modelling of a coal-based steam power plant. On the other hand, Grover *et al*. (2004) made an attempt to evaluate the factors responsible for TQM environment using the GT model and represented the TQM environment uniquely by a single number/index. Similarly, Kulkarni (2005) used the GT model to compute TQM performance index for evaluating the various industries practicing TQM for a given period of time.

The reason for such a wide variety of applications is its versatility. It is highly suitable for visual analysis, when it is necessary to analyse and understand the system as a whole with clear cut identification of system, sub-system and components. GT representation also has an edge over the conventional representations such as block diagrams, cause and effect diagrams and flow charts. Although these tools provide visual analysis of relationships, they do not depict interactions among factors and they cannot be processed or expressed in a mathematical form. Further, the GT model considers both the contribution of factor itself (i.e., the inheritance of factor) and the extent of dependence among other factors (i.e., their interactions). Considering the nature of the problem to be modelled and the advantages GT model provides, it is concluded that it is best suitable for evaluating the roles and responsibilities of HR in implementation of LMS.

The GT modelling consists of the following phases: a directed graph (digraph) representation, matrix representation and permanent representation. Digraph representation is used for modelling and visual analysis and it is the starting point for further analysis. Matrix representation is used for analysing the digraph model mathematically and for computer processing. Permanent multinomial function characterises the system under study uniquely and the permanent value of the multinomial function represents the system by a single number, which can be used for comparison, ranking and optimum selection. The mathematical aspects of the GT model and the development of required matrices can be found in the papers of Grover *et al*. (2004, 2006).

7.2.3 A hypothetical case study

To demonstrate the application of GT model in the field of LM, an example of a hypothetical organisation which is implementing LMS for the last one year is considered. Since it takes at least 3 to 4 years to completely implement LMS, it is not valid to assume that the organisation have implemented all the LM elements completely. Hence, it is assumed that the case organisation has implemented some of the elements identified in Table 7.2 partially, while some of them are completely implemented by the respective stakeholders. For instance, elements such as autonomous maintenance, housekeeping, defect at source, successive check, pokayoke, etc. are implemented thoroughly; but elements such as kanban, pull production, cellular manufacturing are being in the process of implementation. Since the initial implementation of LM elements would have definitely improved the performance of the company, the top management would like to understand how much their HR team has contributed in the implementation of LMS. They would like to understand 'which category of people has a key role to play in the implementation of LMS'. This assessment can be accomplished by measuring the following parameters:

- **Degree of implementation of LM elements:** As shown in Table 7.2, specific categories of HR are connected to different LM elements – i.e., each stakeholder has been assigned the duty of implementing a set of LM elements. In other words, implementing such elements of LM represent their 'inherent duty/characteristics', which can be measured by quantifying the 'degree of implementation' of each LM elements. This measurement is called as 'measurement of inheritances' in the parlance of GT modelling. Since, the success of LM depends on the proper implementation of these LM elements by the respective stakeholders; the term 'degree of implementation of LM elements' attempts to quantify how effectively the stakeholders have implemented the LM elements identified under their category.

- **Degree of relationships between the stakeholders:** Implementing a new programme such as LM in an organisation is not a responsibility of one person or a team of members from one particular department. Rather, it requires the support of each and every employee right from shop-floor associates to executives of top management apart from the support of suppliers and customers. Among the LM elements identified under a particular stakeholder, some can be implemented individually, while for some of the LM elements, the stakeholder might be dependent on another stakeholder thereby requiring some interaction between them. Therefore, a relationship is established in the form of a digraph between different stakeholders during the LM implementation apart from their traditional hierarchical relationships. Utilising this digraph, the degree of relationship between various stakeholders can be measured.

- **Degree of relationship between LM elements under a particular stakeholder**: Under each category of the stakeholder, some of the LM elements can be implemented alone as they are independent and may not affect other LM elements. However, most of the LM elements are related – i.e., implementation of one will affect another. The purpose of this measurement is to quantify the degree of relationship that exists between different LM elements identified under a particular stakeholder. In other words, if one LM element is implemented properly, then it will be easy to implement other element also. For instance, if 5S is implemented properly, then it will be very easy to implement the element called 'setup time reduction', as 5S helps in reducing the time in locating the tools, dies, etc. Hence, this parameter measures whether the related LM elements are implemented effectively. Again these relationships are captured by digraphs, which are drawn at the sub-system level. In the parlance of GT modelling, such relationships between various categories of HR and various elements of LM are called as 'interdependencies'. To perform the assessment of these parameters, a hypothetical team comprising of four members is formed by drawing people from each category of the internal stakeholders. If necessary, a six member team can also be formed, if there is a representation from the supplier and customer ends. These members can physically verify the implementation of LM elements or may interview the personnel responsible for implementing such LM elements. In addition to this, if the team members are well-versed in LM concepts, some of the parameters can be assessed based on their domain experience and expertise. They may use an assessment template describing the list of LM elements, its relationship and the relationship between each stakeholder, in which suitable scale can be used to mark the degree of inheritances and degree of interactions.

7.2.4 Algorithm

The application of GT model for the purpose of assessing the roles and responsibilities of HR in an organisation involve different phases and each of these phases involves various steps. The detailed step-by-step procedure of GT modelling is simultaneously explained as the case study unfolds.

Phase 1: Development of Digraphs

Step 1. Determine the problem to which the GT modelling can be applied.

In this case, the problem is to assess the roles and responsibilities of HR in an organisation that has been implementing LM in the last one year.

Step 2. Identify the various factors affecting the problem under study and represent them as B^i's.

Since, the successful implementation of LMS is highly dependent on the HR; the factors represent the various stakeholders (i.e., different categories of HR involved in the LM implementation). It include the top management (representing Chairman, Chief Executive Officers (CEOs), President, Vice President, Director, etc.), managers (i.e., the departmental heads such as the Operation Manager, Purchase Manager, etc.), engineers (who acts as the interface between managers and shop-floor associates/workers), shop-floor associates, suppliers and customers. These stakeholders are represented using the following notation – top management (B^1), managers (B^2), engineers (B^3), shop floor associates/workers (B^4), customers (B^5) and suppliers (B^6). They will be responsible for implementing different LM elements, which are grouped under the respective category as shown in Table 7.2.

Step 3. Develop the relationships between the factors logically using a digraph, depending on their interdependencies.

A digraph is used to represent the relationships between the factors (B^i) and their interdependencies (b_{ij}) in terms of nodes and edges. It facilitates a better visualisation of the problem under study and helps in understanding the interactions between the various factors or sub-systems associated with it. 'b_{ij}' indicates the degree of dependence of the 'j'th factor on the 'i'th factor. But, in the digraph (b_{ij}) is represented as a directed edge from node i to node j. The purpose of this digraph is to capture these inheritances and interdependencies graphically among the various stakeholders involved in LM implementation. Figure 7.2 shows the digraph capturing the inheritances and interdependencies between various stakeholders (B^i's) of the organisation involved in LM implementation. To develop such relationships, the evaluation team can use their own expertise or they can rely on external consultants and academicians to assist them in developing the digraphs.

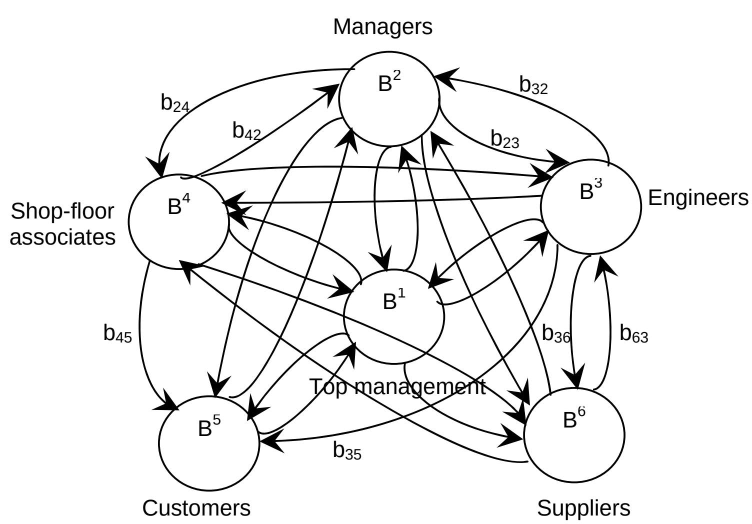

Figure 7.2: Digraph capturing the inheritance and interdependencies between various stakeholders (B^i's) involved in LM implementation

The logic behind the digraph construction is explained as follows:

- A directed edge from B^1 to B^2, B^3, B^4, B^5 and B^6 indicates the interaction of top management with other stakeholders. Generally the top management develops the vision, mission, strategies, policies, etc., which act as the guiding torch for the entire organisation and affect the remaining categories of HR. For example, it is the executives of top management who make the decision of implementing LM in an organisation. The managers, engineers, shop floor associates have to work towards achieving the policies, strategies and targets set forth by the top management. Similarly, a relationship between top management and customers exists, because the organisation can survive only when it can sell its product to the customers and the organisation has to develop the products that are required by the customers, which possess necessary value for the money they spend. In addition to this, the top management is expected to provide customer care by setting up necessary after-sales facilities, which includes service and availability of spares among others. Similarly, if the organisation is a supplier to another organisation, then the customer may force the supplying organisation to adopt LM. This makes it necessary to have directed arrows from both B^1 to B^5 and B^5 to B^1. The top management's interaction with the supplier can be explained based on the fact that the product will be of good quality, if the incoming raw materials provided by suppliers are of good quality. To get a good supply of quality products, it requires a better relationship with suppliers, which should be long term and strategic in nature. Activities such as strategic supplier selection or establishing long term supplier relationship and partnership are dependent on the top management.
- A directed edge from factor B^2 to B^1, B^3, B^4, B^5, B^6 represents that the managers' decision and the way of working will also affect the remaining stakeholders. For example, the managers need to provide necessary feedback and information to

the top management to make strategies and policies. Similarly, they need to guide the engineers and shop floor associates in achieving the desired departmental target, which should be consistent with the organisation's strategy. In other words, the engineers and shop-floor associates work according to the decisions of the managers. For instance, the manager may decide to implement kanban system or an automation system to improve the performance of shop floor. In such cases, the engineers and shop floor associates have to fulfil his/her decision. The managers will be interacting more with the suppliers and customers in comparison with the top management. For example, they will be involved in monitoring the customer complaints and also in managing the design and development of product, process and other supporting activities. They will also be involved in selecting the suppliers, auditing the suppliers and ensure that the suppliers provide good quality products.

- The directed arrows from B^3 to B^1, B^2, B^4, B^5 and B^6 represents that the engineers will provide feedback and update about the execution of decision taken by managers and top management. Even though, the engineers are not directly involved with the top management activities, they are related indirectly. If the top management wishes to improve its competitiveness in the market, it may opt for job cuts, which will affect the entire employees including the managers, engineers and shop-floor associates. On the other hand, the top management's decision can be effectively implemented only by the support of engineers and shop-floor associates. In the case of shop-floor associates, the engineers will act as team leaders or foremen or supervisors and guide the shop-floor associates in meeting the desired targets. The engineers will be directly interacting with suppliers in coordinating with them and ensuring that they supply the right parts in right quantity at right time. Similarly, engineers will have a direct interaction with customers in case the organisation is a supplier to another organisation and they will also be involved during selling, after sales service, etc.

- In the case of shop-floor associates, their involvement, skills, motivation and interaction guides the engineer, managers and top management to undertake new ventures, initiate change management programmes and set new production targets. Hence there is a directed edge from B^4 to B^1, B^2 and B^3. Similarly, the concept of unionization among the shop-floor associates/workers also affects the decisions of the top management, managers and engineers. Further the output of the shop-floor associates is heavily dependent on the quality of input (materials) provided by the supplier. In such cases, the associates may also give feedback to suppliers directly or indirectly through the engineers. In case of the customers, there is only a one-way relationship. It depends on the quality of the output of shop-floor associates in the form of defect-free products, which affects customer's satisfaction. On the other hand, the suppliers can directly interact only with the shop-floor associates, engineers and managers in case of any problems. The suppliers may not have significant relationship with the top management, while the suppliers and customers of an organisation will not be having any relationship.

This digraph representation is highly general and can be applied to any type of organisation. If an organisation wants to evaluate only their internal stakeholders, then those nodes and its associated arcs dealing with external stakeholders can be removed from the digraph.

Phase 2: Matrix representation - Derivation of Variable Permanent Matrix (VPM)

Step 4. Represent the digraph in the form of VPM.

The step by step procedure to develop VPM has been discussed in detail by Grover *et al*. (2004, 2006). The VPM at system level is also represented as matrix B or VPM-B. The actual VPM-B for our problem, derived based on the digraph (refer Figure 7.2) is shown below:

$$B = VPM - B = \begin{pmatrix} B^1 & b_{12} & b_{13} & b_{14} & b_{15} & b_{16} \\ b_{21} & B^2 & b_{23} & b_{24} & b_{25} & b_{26} \\ b_{31} & b_{32} & B^3 & b_{34} & b_{35} & b_{36} \\ b_{41} & b_{42} & b_{43} & B^4 & b_{45} & b_{46} \\ b_{51} & b_{52} & 0 & 0 & B^5 & 0 \\ 0 & b_{62} & b_{63} & b_{64} & 0 & B^6 \end{pmatrix} \qquad (1)$$

The nodes in the digraph represented as B^1 to B^6 occupy the diagonal position in the matrix B, while the remaining off-diagonal positions are filled up based on the relationship between the stakeholders, which is represented by a direct arrow in Figure 7.2. If an arrow is not present between the stakeholders, then the value corresponding to it in the matrix B will be '0'. The purpose of this VPM is to capture the roles and responsibilities of HR during the implementation of LMS by capturing the degree of interdependencies (i.e. relationship or interactions represented by b_{ij}'s) between different categories of HR and the degree of inheritances represented by B^i's (i.e., each stakeholder contribution) in a mathematical form.

Step 5. The next step is to evaluate the matrix, which involves the calculation of 'permanent' of the matrix.

The permanent equation of matrix (1) or permanent of B is multinomial and is called Variable Permanent Function (VPF-B). It is also represented as per (B) or per B. This permanent function is a standard matrix function which is commonly used and defined in combinatorial mathematics. It is evaluated by standard procedures and is same as the determinant of VPM-B but with all signs positive. The permanent equation for VPM-B or per B (i.e. matrix 1) can be solved using the equation given in Figure 7.3, which represents the general form of a permanent equation for any 6x6 matrix. The value obtained from this equation represents 'Comprehensive Assessment Index (CAI)' - the overall assessment of roles and responsibilities of HR in LM implementation, as it has captured both the degree of relationships between various stakeholders and their contribution to LM implementation by calculating the degree of implementation of LM elements and the degree of relationship between the LM elements identified under their category. But to solve this equation, the values for the entities in the matrix are needed. The next phase provides details about how to obtain the values for matrix 1.

$$
\begin{aligned}
VPF-B = per\,B = & \prod_{i=1}^{6} B_i + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{ji})B_kB_lB_mB_n \\
& + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{jk}b_{ki} + b_{ik}b_{kj}b_{ji})B_lB_mB_n \\
& + \left[\left(\begin{array}{l} \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{ji})(b_{kl}b_{lk})B_mB_n \\ + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{jk}b_{kl}b_{li} + b_{il}b_{lk}b_{kj}b_{ji})B_mB_n \end{array}\right)\right] \\
& + \left[\begin{array}{l} \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{ji})(b_{kl}b_{lm}b_{mk} + b_{km}b_{ml}b_{lk})B_n \\ + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{jk}b_{kl}b_{lm}b_{mi} + b_{im}b_{ml}b_{lk}b_{kj}b_{ji})B_n \end{array}\right] \\
& + \left[\begin{array}{l} \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{ji})(b_{kl}b_{lm}b_{mn}b_{nk} + b_{kn}b_{nm}b_{ml}b_{lk}) \\ + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{jk}b_{ki})(b_{lm}b_{mn}b_{nl}) \\ + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{ji})(b_{kl}b_{lk})(b_{mn}b_{nm}) \\ + \sum_i\sum_j\sum_k\sum_l\sum_m\sum_n (b_{ij}b_{jk}b_{kl}b_{lm}b_{mn}b_{ni} + b_{in}b_{nm}b_{ml}b_{lk}b_{kj}b_{ji}) \end{array}\right]
\end{aligned}
$$

Figure 7.3: The general form of permanent equation for any 6x6 matrix

Phase 3: Quantification of B^i's and b_{ij}'s of the matrix for the given problem

Step 6. Quantify the B_i's at sub-system level

Each factor B^i in matrix 1 can be considered as a sub-system with as many sub-factors affecting them. In this case, every stakeholder of the organisation (B^i's) is considered as a sub-system, as they have a significant role to play in the LM implementation. They are responsible for implementing different LM elements that are identified under respective category (refer Table 7.2 for details). Hence, for the sake of clarity, the following notation is used: each LM elements has been represented as B_i^I, where the subscript 'i' represents the LM elements that are grouped under a particular stakeholder, while the superscript 'I' represents the stakeholder. The same notation is used in Table 7.2. To find out the values of B_i^I's and the interdependency values b_{ij}'s in the VPM-B matrix (matrix 1), the following steps have to be followed:

- The digraph for each sub-system should be drawn as explained in Phase 1. The purpose of the digraph at sub-system level is to capture the degree of implementation of LM elements (i.e. inheritances) and the degree of relationship between various LM elements (i.e. interdependencies) identified under a particular stakeholder in a graphical form. For instance, if the top management takes the decision of having a long-term employment for the employees (B_1^1), it may affect the establishment of a flat organisation structure (B_3^1). Similarly, in the case of shop-floor associates, defect at source and successive check system (B_4^4) may require the use of Andon and Jidoka (B_2^4), while quality circle (B_5^4) requires the associates to use problem-solving tools and visual control tools (B_6^4). Thus, these relationships between LM elements are represented in the form of diagraphs for each stakeholder. Figures 7.4 - 7.9 shows the digraphs representing the relationship and interdependencies between elements of LM under each stakeholder of the organisation. Similarly, the team members can draw suitable diagraphs based on the LM elements implemented in their organisation. As said earlier, these digraphs are drawn based on the domain knowledge and experience in the field of LM.

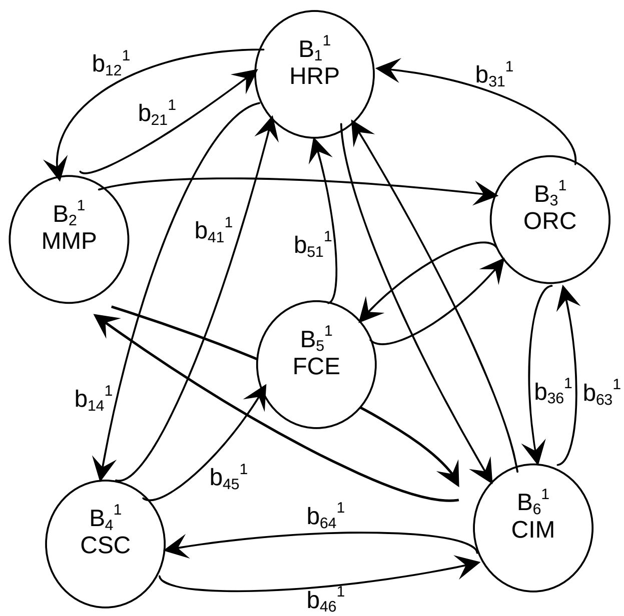

Figure 7.4: Digraph representing the inheritance and interdependencies between elements of LM under top management (B_{SS1})

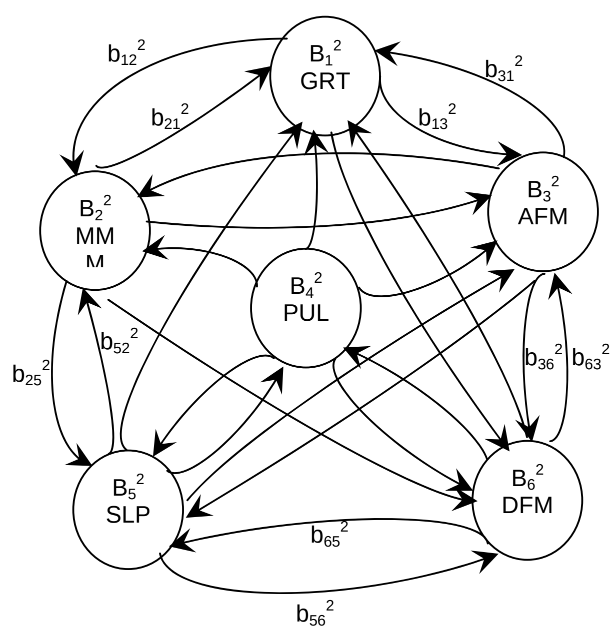

Figure 7.5: Digraph representing the inheritance and interdependencies between elements of LM under managers (B_{SS2})

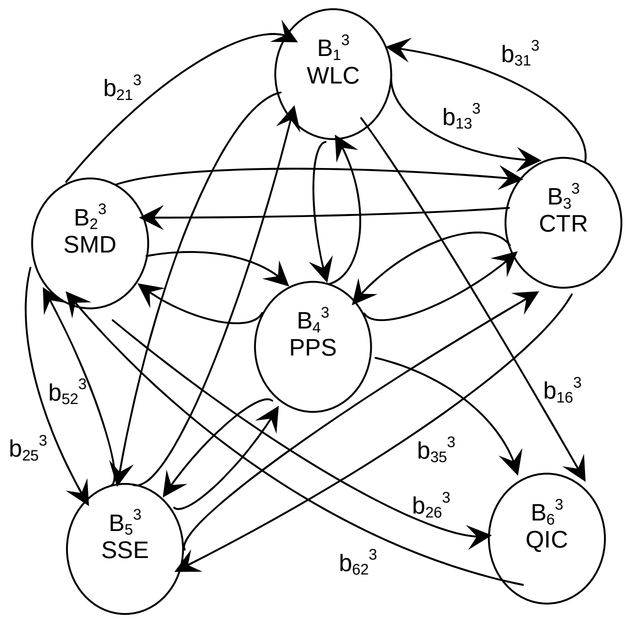

Figure 7.6: Digraph representing the inheritance and interdependencies between elements of LM under engineers (B_{SS3})

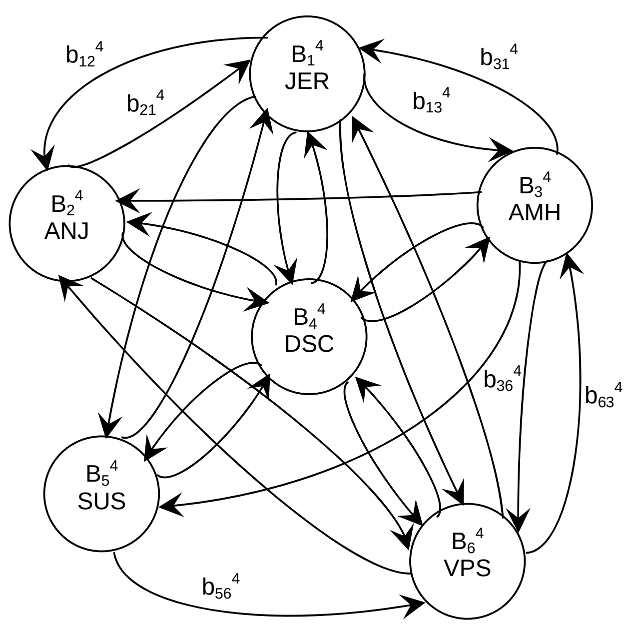

Figure 7.7: Digraph representing the inheritance and interdependencies between elements of LM under shop floor associates (B_{SS4})

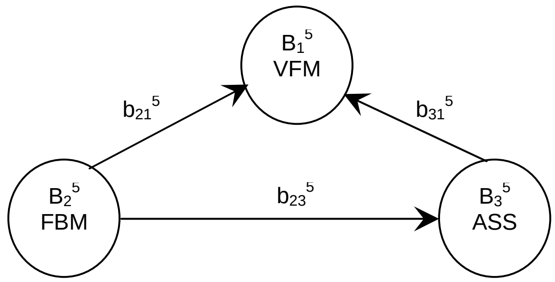

Figure 7.8: Digraph representing the inheritance and interdependencies between elements of LM under customers (B_{SS5}) (Source: Grover *et al*., 2005)

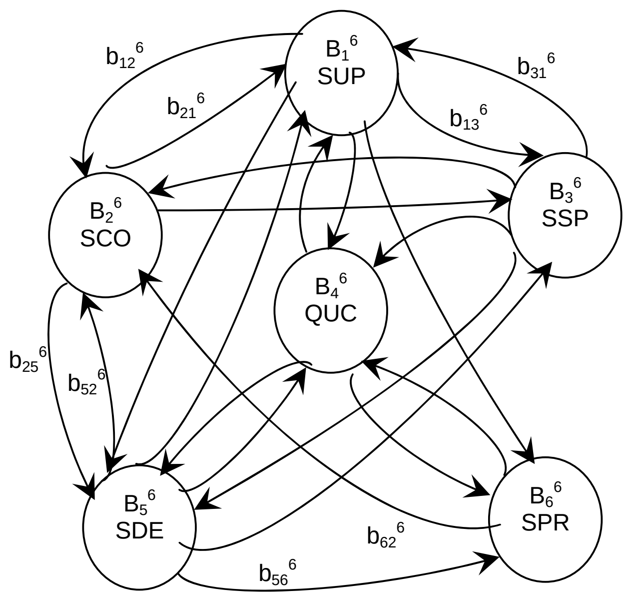

Figure 7.9: Digraph representing the inheritance and interdependencies between elements of LM under suppliers (B_{SS6})

- Using the steps in phase 2, the VPM for sub-systems (i.e., stakeholders) represented as VPM-B_{SS1}, VPM-B_{SS2}, ……, VPM-B_{SS6} can be derived. These matrices can also be represented as B_{SS1}, B_{SS2} …..B_{SS6}. The purpose of these matrices at sub-system level is to capture the degree of implementation of LM elements (i.e. inheritances) and the degree of relationship between different LM elements (i.e. interdependencies) under a particular stakeholder in a mathematical form. The value of $B_i^{l'}$s within the sub-system matrix represents the inheritances, while b_{ij}^{l}'s represent the interdependencies. For instance, a sample VPM-B_{SS1} or B_{SS1} for the stakeholder – 'top management' sub-system derived from its corresponding digraph (refer Figure 7.4) is shown below:

$$B_{SS1} \; or \; VPM - B_{SS1} = \begin{pmatrix} B_1^1 & b_{12}^1 & 0 & b_{14}^1 & 0 & b_{16}^1 \\ b_{21}^1 & B_2^1 & b_{23}^1 & 0 & 0 & b_{26}^1 \\ b_{31}^1 & 0 & B_3^1 & 0 & b_{35}^1 & b_{36}^1 \\ b_{41}^1 & 0 & 0 & B_4^1 & b_{45}^1 & b_{46}^1 \\ b_{51}^1 & 0 & b_{53}^1 & 0 & B_5^1 & 0 \\ b_{61}^1 & b_{62}^1 & b_{63}^1 & b_{64}^1 & 0 & B_6^1 \end{pmatrix} \qquad (2)$$

Similar to matrix (2), VPMs for others sub-systems can be developed. From these matrices, the permanent for each of the sub-systems can be calculated using the equation shown in Figure 7.3 after obtaining the values for B_i^{l}'s and b_{ij}^{l}'s.

- As mentioned earlier, the B_i^l values within VPM of sub-systems represent the degree of implementation of the LM elements by the stakeholders, which can be evaluated using a suitable scale. Table 7.3 suggests a scale to capture the degree of implementation of each LM element (B_i^{l}'s) under the sub-systems.

Table 7.3: A scale to capture the degree of implementation of each LM element (B_i's) under the sub-systems (adapted from Saaty, 1980)

S. No.	Quantitative measure of factors	Explanation
1	Extremely low	When the stakeholders do not know about the LM element, and it has not been implemented
3	Low	When the stakeholders know about the LM element, but it has not been implemented
5	Average	When the stakeholders know about the LM element, but it has been implemented only to certain extent
7	High	When the stakeholders know about the LM element and it has been implemented properly and well documented
9	Extremely high	When the stakeholders know about the LM element and it has been implemented properly as a result of which excellent results have been achieved
2, 4, 6, 8	Represent the intermediate values	Used, when compromise is needed between two scales.

This scale is adapted from the Saaty's (1980) relative scale of importance used in the Analytic Hierarchy Process (AHP). The team of evaluators themselves can perform this assessment or they can perform this assessment along with the external consultants (such as the authors) by making a site visit and observing the degree of implementation of LM elements directly. Apart from this, they can also interview the key personnel from each category to understand 'what is their understanding regarding different LM elements classified under their respective category?, how effectively they have implemented it?, how much they have contributed in implementing it?, etc.' They can discuss themselves and arrive at a consensus before assigning a suitable value or they can assess them individually and an average of the team score after rounding off to the nearest integer can be assigned to each of the elements to rate the degree of implementation. For instance, the team would have felt that the element 'GRT' has been implemented properly, if a documented procedure exists to group different parts. Then, a value of '7' can be entered for B_1^1. Similarly, all the LM elements in the particular category are assessed. A checklist as shown in Table 7.4 can be used for evaluating the degree of implementation of LM elements. A sample VPM-B_{SS2} (i.e.B_{SS2}) is shown in matrix 3 with the values filled in for the diagonal element depicting the level of implementation of each LM element under the category – 'managers'.

$$B_{SS2} = VPM - B_{SS2} = \begin{pmatrix} 7 & b_{12} & b_{13} & 0 & 0 & b_{16} \\ b_{21} & 8 & b_{23} & 0 & b_{25} & b_{26} \\ b_{31} & b_{32} & 6 & 0 & b_{35} & b_{36} \\ b_{41} & b_{42} & b_{43} & 9 & b_{45} & b_{46} \\ b_{51} & b_{52} & b_{53} & b_{54} & 8 & b_{56} \\ b_{61} & 0 & b_{63} & b_{64} & b_{65} & 7 \end{pmatrix} \quad (3)$$

Table 7.4: Checklist for evaluating the degree of implementation of LM elements

S. No.	Taxonomy	Element	In short	Notation	Rate the level of implementation by placing a tick mark against the following numbers								
					1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1.	**Top Management (B^1)**	Rewards and Recognition and Long Term Employment (Human Resource Policies)	HRP	B_1^1									
2.		Total Productive Maintenance/Total Quality Management (Modern Manufacturing Philosophies)	MMP	B_2^1									
3.		Flat Organisation Structure and Communication Between Employees	ORC	B_3^1									
4.		Cellular Manufacturing and Maintain Spare Capacity (Manufacturing Modes and Methodology)	CSC	B_4^1									
5.		Focused Factory Production and Concurrent Engineering	FCE	B_5^1									
6.		Computer Integrated Manufacturing (Use of CAD/CAM/CAE) and New Process or Equipment	CIM	B_6^1									
7.	**Managers (B^2)**	Group technology and Commonisation and Standardized Parts	GRT	B_1^2									
8.		Mixed Model Manufacturing and Production Smoothing	MMM	B_2^2									
9.		Automation and Use of Flexible Multiple Small Machines	AFM	B_3^2									
10.		Pull Production and Kanban System	PUL	B_4^2									
11.		One Piece Flow and Small Lot Production	SLP	B_5^2									
12.		Design for Manufacturing and Modular Design	DFM	B_6^2									
13.	**Engineers (B^3)**	Workload Balancing and Layout Change	WLC	B_1^3									
14.		Single Minute Exchange of Dies and Work in Progress Reduction	SMD	B_2^3									
15.		Cycle time and Lead time Reduction	CTR	B_3^3									

S. No.	Taxonomy	Element	In short	Notation	Rate the level of implementation by placing a tick mark against the following numbers								
					1	2	3	4	5	6	7	8	9
16.		Product and Process Simplification	PPS	B_4^3									
17.		Storage Space Reduction and Elimination of Buffers	SSE	B_5^3									
18.		Pokayoke and Statistical Process Control	QIC	B_6^3									
19.	**Shop floor associates (B^4)**	Job Enlargement and Job Rotation	JER	B_1^4									
20.		Andon and Jidoka	ANJ	B_2^4									
21.		Autonomous Maintenance and Housekeeping	AMH	B_3^4									
22.		Defects at Source and Successive Check	DSC	B_4^4									
23.		Suggestion Schemes and Quality Circles	SUS	B_5^4									
24.		Visual Control and Use of Problem Solving Tools	VPS	B_6^4									
25.	**Customers (B^5)**	Value for Money	VFM	B_1^5									
26.		Customer Feedback or Feedback Mechanism	FBM	B_2^5									
27.		After Sales Service	ASS	B_3^5									
28.	**Suppliers (B^6)**	Supplier Involvement in Design and Long term Supplier Relationship (Supplier Partnership)	SUP	B_1^6									
29.		Information Sharing with Suppliers and Use of EDI with suppliers (Supplier Communication)	SCO	B_2^6									
30.		Sole Sourcing and Supplier Proximity	SSP	B_3^6									
31.		Quality Certification	QUC	B_4^6									
32.		Frequent Multiple Just-in-Time-Small Lot Delivery and Standard Containers (Supplier Delivery)	SDE	B_5^6									
33.		Supplier Training and Development	SPR	B_6^6									

Step 7. Quantification of b_{ij}^{l}'s at the sub-system level

The value of b_{ij}^{l}'s represents the degree of relationships between two LM elements, which is assessed using another scale as shown in Table 7.5. Table 7.5 represents the scale to obtain the values of interdependencies (b_{ij}'s) between factors (B^{i}'s).

Table 7.5: A scale to obtain the values of interdependencies (b_{ij}'s) between factors (B^{i}'s)

S. No.	Quantitative measure of interdependency	Assigned value of factor
1	Very strong	5
2	Strong	4
3	Medium	3
4	Weak	2
5	Very weak	1

As explained in the previous step, to assess the relationship between different LM elements, direct observation has to be carried out by the evaluators and in some cases, it may require interviewing the employees, supervisors, etc. to arrive at a particular scale value. For instance, under the engineer's category, the product and process simplification (B_4^3) are related to cycle time and lead time reduction (B_3^3) in both ways. Assuming that the organisation has attained significant reduction in cycle time and lead time through necessary product and process improvements, a value of '5' is given by the team of evaluators. The same is filled in the b_{43}^{4} position of the matrix 4 to represent a very high degree of interdependency between them. On the other hand, a value of '4' is assigned by the evaluators for the inverse relationship between these elements, which clearly explains that, the degree of inverse relationship between these elements is less. For instance, the cycle time and lead time reduction (B_3^3) can also be obtained by workload balancing and layout change (B_1^3) in addition to product and process simplification (B_4^3). In a similar manner, the values for remaining b_{ij}^{l}'s are obtained based on the degree of relationship for all other related LM elements under a particular category. In case there is no relationship, i.e. there is no directed arrow from one node to another in the digraph and a value of '0' is assigned. A sample VPM- B_{SS3} (i.e. B_{SS3}) for the stakeholder – 'engineer' is shown with all the values filled in for both the diagonal and off-diagonal elements depicting the inheritance and the interdependencies between the sub-factors.

$$B_{SS3} = VPM - B_{SS3} = \begin{pmatrix} 8 & 0 & 5 & 4 & 3 & 2 \\ 4 & 9 & 5 & 4 & 3 & 2 \\ 5 & 5 & 6 & 4 & 3 & 0 \\ 3 & 3 & 5 & 7 & 3 & 2 \\ 4 & 5 & 3 & 3 & 6 & 0 \\ 0 & 3 & 0 & 0 & 0 & 5 \end{pmatrix} \qquad (4)$$

These values indicate that the degree of implementation of certain elements is not good, while that of other elements are well-implemented. For instance, in the above matrix (i.e., matrix 4), the element B_2^3 is assumed to be implemented properly and hence a value of '9' is assigned, while in the case of B_6^3, only a value of 5 is assigned, which means that it is not implemented properly. Same is the case with the relationships (i.e., b_{ij}^3). Some relationships are very weak – i.e., implementing one LM element do not have significant effect on another. For example, let us assume that the organisation has implemented the defect at source properly through necessary work standardisation procedures; but still the defects are obtained at the end of the assembly line reveals that the successive check system is not proper. In other words, the relationship between work standardisation and successive check system are not proper. Hence a low value has to be assigned. In a similar manner, the matrices can be filled with values from both the tables.

Step 8. From the derived variable permanent matrices VPM-B_{SS1}….. VPM-B_{SS6}, the permanent of the matrices for the sub-systems are calculated using the equation shown in Figure 7.3.

They are represented as Per (B_{SS1}), Per (B_{SS2})….. Per (B_{SS6}). The purpose of this permanent equation is to quantify the roles and responsibilities of every stakeholder by integrating the inheritances and interdependencies. It should be noted here that if more number of factors were considered, the permanent equation tends to become so large and it will result in computational complexity. A sample permanent value for VPM-B_{SS4} (i.e., B_{SS4}) representing the quantification of roles and responsibilities of the stakeholder – 'shop-floor associates' is shown below:

$$Per\ (B_{SS4}) = 801688$$

The obtained value can also be expressed in logarithmic term as $\log_{10}$ (801688), which will be equal to 5.9. In a similar manner, the permanent values for the remaining sub-system matrices are obtained, which are required to fill in the diagonal elements of matrix 1. To calculate the permanent, the evaluators needs not perform the complex calculation as shown in Figure 3. Instead, the values for the matrices can be fed into a small C program, which will directly give the permanent value.

Phase 4: Evaluating the VPM-B matrix

Step 9. To evaluate the value of VPM-B at system level (i.e. matrix 1), the off-diagonal values are obtained from the permanent of the sub systems, while the values for the diagonal values are obtained from a suitable table.

As said earlier, the values of diagonal elements for matrix 1 are obtained from the 'permanent' calculated for each sub-system, which after representing them in logarithmic terms (log(base 10)) are shown below:

- Per (B_{SS1}) = 405066 or 5.6
- Per (B_{SS2}) = 1285733 or 6.1
- Per (B_{SS3}) = 1223550 or 6.1
- Per (B_{SS4}) = 801688 or 5.9
- Per (B_{SS5}) = 504 or 2.7
- Per (B_{SS6}) = 1112450 or 6.0

However, in the diagonal of the matrix, the original permanent values such as 405066, 1285733 etc. are used instead of logarithmic values. The values of off-diagonal elements (b_{ij}'s) for matrix 1 can be obtained from Table 7.5 based on the degree of interdependencies (relationships) among the stakeholders (B_i's). Generally, the relationship between various stakeholders can be captured based on experience and by identifying the level of coordination, co-operation, teamwork, etc. in the organisation. For instance, if the number of cross functional teams, quality circle teams or supplier training and partnership are high, then one can assume that there is a good relationship between various stakeholders. If more number of quality circle teams are present, then the degree of relationship between engineers and shop floor executives are high. Similarly, if the cross functional teams are higher, then the degree of relationship between engineers, managers and even suppliers or customers may be high. Based on this logic, the values for these off diagonal matrices can be entered after adequate discussion by the team of evaluators. The complete VPM-B matrix for quantifying the roles and responsibilities of HR in a LM environment is shown below:

$$B = VPM - B = \begin{pmatrix} 405066 & 5 & 4 & 4 & 4 & 4 \\ 5 & 1285733 & 5 & 4 & 4 & 4 \\ 3 & 5 & 1223550 & 5 & 4 & 4 \\ 3 & 4 & 5 & 801688 & 3 & 4 \\ 4 & 4 & 0 & 0 & 504 & 0 \\ 0 & 5 & 4 & 3 & 0 & 1112450 \end{pmatrix} \quad (5)$$

Step 10. Again, the value of permanent function for the system level matrix (i.e. matrix 5) is calculated using the equation shown in Figure 7.3.

The obtained value (i.e., Per (B)) represents a quantified value for the total contribution of various stakeholders in implementing the LM elements by integrating the degree of implementation of LM elements, the degree of relationships between the stakeholders and the degree of relationship between various LM elements under each stakeholder. It can also be termed as a Comprehensive Assessment Index (CAI) of the roles and responsibilities of top management, managers, engineers, shop-floor associates, customers and suppliers of an LM organisation. In our problem, the permanent of the matrix 5 is found to be Per (B) = 2.86 x 10^{32}, which when converted into logarithmic values for the sake of simplicity is found to be 32.4. The above CAI value represents the single numerical index, which quantified the roles and responsibilities of various stakeholders of the hypothetical organisation. Since the organisation has not completely implemented all the LM elements with in the last one year, they have got the above value as CAI. However, if we compare this value with other organisation which is known for its LM implementation (say Toyota) or organisation which have not implemented LM at all, it is possible to compare and analyse where does the organisation stand. The next phase will discuss about the best-case situation and worst-case situation.

Phase 5: Calculation of best-case and worst-case CAI

Step 11. To calculate the range within which the values of CAI can vary, calculate the permanent of VPM-B (i.e., matrix 1) for different case situations.

A similar approach was utilised by Grover *et al*. (2006) in which they calculated the CAI for the hypothetical best and worst value of human index. In a similar manner, the CAI is computed for four different case situations, which are discussed below:

- **Practical best-case situation:** This situation can occur only if the organisation under assessment has implemented all the LM elements properly and successfully. For instance, it can be assumed that such a scenario can be found in Toyota. Since, the concept of LM was developed by studying the TPS it is valid to assume that every LM element identified in Table 7.3 would have been implemented completely and successfully in Toyota. Hence, the degree of implementation of LM elements in TPS will have a maximum value of 9, i.e., the diagonal elements in each sub-system would be 9. In other words, the CAI will be at its best, when the inheritance of all its factors is at its best. In this case, the VPM for B_{SS4} will be re-written as:

$$B_{SS4} = VPM - B_{SS4} = \begin{pmatrix} 9 & 2 & 3 & 3 & 1 & 2 \\ 4 & 9 & 0 & 3 & 0 & 3 \\ 4 & 2 & 9 & 3 & 2 & 2 \\ 4 & 5 & 3 & 9 & 2 & 3 \\ 3 & 0 & 0 & 2 & 9 & 1 \\ 3 & 4 & 3 & 3 & 0 & 9 \end{pmatrix} \quad (6)$$

In a similar manner, the VPM for other sub-systems are also re-written in such a way that the diagonal elements have the value of '9'. The permanent value for the matrix 6 (Per B_{SS4}) is found to be 2049987. Similarly, the permanent values for other matrices are calculated for the practical best-case situation and are shown in Table 7.6. Based on these permanent values of B_{SS1} to B_{SS6}, the CAI is obtained by calculating the permanent of the matrix 5 (i.e., VPM-B). In this case, the diagonal elements of matrix 5 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS6}) obtained for the best-case situation and the Per (B) for the VPM-B is found to be 3.73×10^{34}, which when expressed as log (base 10) (i.e., it is written as $\log_{10} (3.73 \times 10^{34})$), is equal to 34.6.

- **Theoretical best-case situation:** On the other hand, a hypothetical best-case or theoretical best-case situation can be derived by having the maximum values for both inheritances and interdependencies in sub-systems. In other words, as described earlier, a maximum value of 9 can be assigned to the diagonal elements (B_i^{l}'s) of sub-systems to represent a very high degree of LM implementation and a maximum value of 5 can be assigned to b_{ij}^{l}'s, representing the highest degree of relationship between different LM elements. Based on this, the matrix 6 can be re-written as follows:

$$B_{SS4} = VPM - B_{SS4} = \begin{pmatrix} 9 & 5 & 5 & 5 & 5 & 5 \\ 5 & 9 & 0 & 5 & 0 & 5 \\ 5 & 5 & 9 & 5 & 5 & 5 \\ 5 & 5 & 5 & 9 & 5 & 5 \\ 5 & 0 & 0 & 5 & 9 & 5 \\ 5 & 5 & 5 & 5 & 0 & 9 \end{pmatrix} \qquad (7)$$

The permanent value for the matrix 7 (Per B_{SS4}) is found to be 11406466. Similarly, the permanent values for other matrices are calculated and are shown in Table 7.6. Based on these permanent values of B_{SS1} to B_{SS6}, the CAI is obtained by calculating the permanent of the matrix 5 (i.e., VPM-B). The diagonal elements of matrix 5 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS6}) obtained for the theoretical best-case situation and the Per(B) for the VPM-B is found to be 2.33 x 10^{37}, which can be expressed for the sake of simplicity as $\log_{10}(2.33 \times 10^{37})$, which is equal to 37.3. The obtained value represents the theoretical best-case situation for quantification of roles and responsibilities of HR in a LM environment, when the degree of implementation of LM elements and degree of relationship between LM elements are at its maximum. But achieving such a state is considered to be ideal situation as the degree of relationship between various stakeholders and elements of LM cannot be at the maximum.

- **Worst-case situation**: This situation can occur if an organisation has not implemented any of the LM elements properly and successfully, i.e. each category of HR did not implement any of the LM elements properly that are grouped under their category. For instance, such situation can be found in an organisation that has just started the process of implementing LM. Hence, the degree of implementation of LM elements in such an organisation will have a minimum value of 1, i.e., the diagonal elements in each sub-system matrices will be 1. In such an organisation, the degree of relationship between stakeholders can be at the highest, but it may not have implemented LM or it has just started with the LM implementation. In other words, the CAI will be at its worst, when the inheritance of all its factors is at its worst. In this case, the VPM for B_{SS6} will be re-written as follows:

$$B_{SS6} = VPM - B_{SS6} = \begin{pmatrix} 1 & 4 & 5 & 3 & 4 & 3 \\ 4 & 1 & 2 & 0 & 4 & 0 \\ 4 & 3 & 1 & 2 & 4 & 0 \\ 3 & 0 & 0 & 1 & 4 & 3 \\ 4 & 4 & 4 & 3 & 1 & 2 \\ 0 & 2 & 0 & 4 & 0 & 1 \end{pmatrix} \quad (8)$$

In a similar manner, the VPM for other sub-systems are also re-written in such a way that the diagonal elements have the value of '1'. The permanent value for the matrix 8 (Per B_{SS6}) is found to be 77476. Similarly, the permanent values for other matrices are calculated for worst-case situation and are shown in Table 7.6. Based on these permanent values of B_{SS1} to B_{SS6}, the CAI for worst-case situation is obtained by calculating the permanent of the matrix 5 (i.e., VPM-B). In this case, the diagonal elements of matrix 5 is replaced with the permanent values of the sub-systems (Per B_{SS1} to Per B_{SS6}) obtained for the worst-case situation and the Per(B) for the VPM-B is found to be 1.69×10^{23}. The permanent value can be expressed as $\log_{10} (1.69 \times 10^{23})$, which is equal to 23.2.

- **Ideal worst-case situation:** But in some situation, if an organisation has not implemented any of the LM elements then the relationship between LM elements will also be poor. Such a situation may exist in organisation, which still function in a traditional manner. Under such circumstances, minimum values for both the degree of implementation of LM elements and degree of relationship between LM elements can be considered. In other words, the values of b_{ij}'s of all the sub-system matrices should have a value of '1', in addition to the diagonal values. For instance, in this case, the matrix 8 will be rewritten as

$$B_{SS6} = VPM - B_{SS6} = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{pmatrix} \qquad (9)$$

The permanent value of B_{SS6} (i.e., matrix 9) will be 154. In a similar way, the matrices for remaining sub-systems are rewritten and the permanent values for B_{SS1} to B_{SS6} are calculated. These values are shown in Table 7.6. These permanent values of sub-system matrices can be substituted in VPM-B (i.e, matrix 5) and the permanent for VPM-B can be calculated, representing the CAI for ideal worst-case situation. The CAI for ideal worst case situation is found to be 1.33 x 10^{11}, which can be expressed as $\log_{10}$ (1.33 x 10^{11}), which is equal to 11.1.

The purpose of calculating the CAI for different case situations is that evaluators can use these values to understand where the organisation stand from the perspective of the roles and responsibilities of their HR during LM implementation by comparing the CAIs with a similar organisation. For example, we have obtained a CAI value of 2.86 x 10^{32} or 32.4 for the hypothetical case organisation. Similarly, from Table 7.6, the CAI value for best-case situation is found to be 3.73 x 10^{34} or 34.6. As explained earlier, hypothetically, this value can be assumed to be quantification of roles and responsibilities of HR in Toyota in implementing LMS.

Table 7.6: Permanent values for best-case and worst-case situations

System / Sub-system	Current value (Normal situation)	$\log_{10}$ (Current value) (Normal situation)	Maximum value (Theoretical best-case situation)	$\log_{10}$ (Maximum value) (Theoretical best-case situation)	Maximum value (Practical best-case situation)	$\log_{10}$ (Maximum value) (Practical best-case situation)	Minimum value (Worst-case situation)	$\log_{10}$ (Minimum value) (Worst-case situation)	Minimum value (Ideal worst-case situation)	$\log_{10}$ (Minimum value) (Ideal worst-case situation)
Per B_{SS1}	405066	5.6	4058616	6.6	1271547	6.1	12723	4.1	64	1.8
Per B_{SS2}	1285733	6.1	10690316	7.0	2284935	6.4	61023	4.8	252	2.4
Per B_{SS3}	1223550	6.1	8476816	6.9	3380544	6.5	80764	4.9	168	2.2
Per B_{SS4}	801688	5.9	11406466	7.0	2049987	6.3	34879	4.5	312	2.5
Per B_{SS5}	504	2.7	729	2.8	729	2.9	1	0.0	1	0.0
Per B_{SS6}	1112450	6.0	7608166	6.8	2542820	6.4	77476	4.9	154	2.2
Per B	**2.86E+32**	**32.4**	**2.33E+37**	**37.3**	**3.73E+34**	**34.5**	**1.69E+23**	**23.2**	**1.33.E+11**	**11.1**

Thus, it can be found that there exist a significant difference between the hypothetical case organisation and Toyota and it can be found from Table 7.6 that degree of contribution by individual stakeholders (i.e., permanent of sub-systems) for Toyota is much higher. On the other hand, the hypothetical case organisation has performed better than the worst-case organisation that has not implemented LM or those organisations that have just started with LM implementation. This is because the hypothetical case organisation has been implementing LM for one year and hence the stakeholders had adequate contribution when compared to worst-case organisations. Thus, it can be found that the obtained CAI value can be used to benchmark other organisations while assessing their degree of responsibility of the stakeholders. Apart from this, the worst case and best case analysis acts as a substitute to sensitivity analysis to analyse the impact of change in values given by the evaluators. Though there is a drastic change in the results of the permanent equation due to change in the matrix values, the impact on the conclusion is insignificant, as the objective of this approach is not to perform any decision-making.

7.2.5 Results and discussion

Thus, an application of the GT approach has been successfully demonstrated to assess the roles and responsibilities of HR in LM environment using a hypothetical case situation. One of the most commonly asked question in this approach is “how to assign values to the elements of the various matrices”. The values are obtained from the well-defined scale, which are shown in Table 7.3 and 7.5. Secondly, it has been clearly mentioned that the values for the degree of implementation, degree of relationship between stakeholders and the degree of relationship between LM elements are given by a team of evaluators or by an auditor, who is an expert in LM. If the organization uses this approach on a self-assessment basis, then the values can be given by the team of internal evaluators, while if the organization uses it for award or benchmarking purpose, the evaluator can be an external auditor or an expert.

From the results of the GT approach, it is possible to infer the following for the hypothetical case organisation under study:

- The quantified value for the roles of responsibilities of each category of stakeholders can be found by analysing the B^{i}'s in VPM-B. These values, which are obtained from the permanent equation of the sub-systems (B_{SS1}…. B_{SS6}), can also be called as 'top management contribution index', 'managers contribution index', 'engineers contribution index', shop floor associates contribution index', 'supplier commitment index' and 'customer satisfaction index' respectively. Comparing these B^{i}'s, it is possible to identify which stakeholders' contribution is the highest in LM implementation. Many researchers have expressed that implementing LM actually increases the responsibility of workers or shop-floor associates. For instance, researchers such as Klein (1989), Landsbergis (1999), Spithoven (2001), Conti *et al*. (2006), etc. have studied these issues and noted that LM increases the work intensity and stress level. But this analysis revealed the other side too. It can be found that the roles and responsibilities of other stakeholders such as engineers and managers are also high in comparison with that of shop floor associates. i.e., the roles and responsibilities of shop floor associates/workers was found to be 801688 or 5.9 (i.e., Per B_{SS4}), while that of managers (i.e., Per B_{SS2}) and engineers (i.e., Per B_{SS3}) were found to be 1285733 (6.1) and 1223550 (6.1) respectively. The reason is that the work content of engineers and managers also increases as they have to make many tactical decisions while implementing LM. Apart from this, it was found that the level of interaction of managers and engineers with other stakeholders is also higher as they have to maintain direct relationship with the remaining stakeholders.

- Similarly, it is also possible to conclude that the top management and suppliers also have significant responsibility in the LM environment. But, on the other hand, the role of customers is the least. It is true to a certain extent because the customers will not be directly participating in the lean implementation of any organisation. In the case of industrial suppliers, the customers may ask them to implement LM and to some extent provide assistance during the implementation process, but they will not directly take any responsibility during implementation. The requirement of a general customer is to get the right product with right value for their money at right price in right quantity at right time. They will not bother whether a company has implemented LM, TQM, TPM or Six-Sigma (SS) etc. to achieve this objective. On the other hand, the success of lean implementation is dependent on suppliers. If suppliers are not supporting, then LM cannot be implemented successfully and hence their roles and responsibilities are significant as evident from the permanent value (i.e., Per B_{SS5}).

- The CAI, which represents the cumulative quantification of the roles and responsibilities of every stakeholder of an organisation in a LM environment is a single index without any unit and hence can be used for comparing different organisations having LM in place to assess the degree of contribution of the HR members. A similar approach was used by Kulkarni (2005) to compute the TQM performance index using GT approach for different organisations that have implemented TQM and this index was used to compare and rank the organisations with respect to their TQM performances. Further, it helps in analyzing which category of HR has contributed more and which category has contributed less. Thus, it helps in identifying the improvement areas. Apart from this, it also helps the organization to follow a continuous improvement philosophy by enabling them to set newer achievable targets.

Some of the major advantages of this model over the other methodologies are listed as follows:

- At the outset, the method may look a bit complex due to the graphs, matrices and mathematical equations. But, it is highly reliable. It involves identifying the factors (different category of stakeholders), sub-factors (LM elements to be implemented by various stakeholders) and the digraphs to depict the relationships (i.e., relationship between the stakeholders and the relationship between LM elements under each stakeholder) between them. Based on the digraphs, the VPM is derived and its corresponding VPF is developed using the permanent of the matrix. To obtain the values of VPM matrix which captures both the inheritances and interdependencies, suitable scales as shown in Table 7.3 and 7.5 are used. Once the values are obtained in the VPM matrix, the permanent of the matrix can be easily calculated. But it should be remembered here that the computational complexity may increase, when the number of factors and sub-factors considered for a given problem increases. Even for the problem under study, the calculation of permanent for a 6x6 matrix manually is a bit cumbersome for which a small C- program is written to evaluate the same.
- It takes into account the interactions among various factors/sub-factors (in other words, the interactions between different categories of HR and various elements of LM grouped under a particular stakeholder), thus attempting to mimic the actual working conditions during the assessment, thereby supporting the contention of Biazzo and Panizzolo (2000).

- The individual contribution (roles and responsibilities) of each stakeholder (or each category of HR) and the total contribution of HR were quantified using the output of the permanent equation, which can be used by the HR department for assessing the performance of HR in terms of department/organisation apart from using it effectively for self-assessment, improvement, ranking and comparison of HR in an organisation (Grover, *et al*., 2005).

7.3 Development of a Benchmarking Process for the Assessment of Lean Manufacturing Systems

In recent times, many organisations are attempting to implement or have already implemented LM. Some companies have implemented only a few tools/techniques/practices/procedures (i.e., 'elements' in short), while others have implemented a whole spectrum of LM elements. For instance, Dunstan *et al.* (2006) examined the application of LM in a mining environment. They described about the implementation of only certain LM elements that are applicable in these industries and noted that health and safety related incidents were reduced from 154 to 67; absenteeism was reduced by 3.4% to 1.8%, while about $2 million (Australian) were saved during the year 2006. On the other hand, Lee and Jo (2007) noted that over the past 40 years, Hyundai developed its own production model, namely the Hyundai Production System (HPS), initially by emulating the Toyota Production System (TPS), followed by re-interpreting and modifying TPS to adapt to the company's unique circumstances. These cases present us with the following intriguing questions, which have not been addressed properly till now:

- What is the degree of leanness of the above organisations? and
- Where does an organisation that is implementing or have already implemented LM stand in comparison with other organisations that are considered as 'best-in-class' in LM implementation?

To answer these questions, Benchmarking (BM) can be an effective tool, as it can be used for both self-assessment and comparison. A literature review regarding the papers relating BM and LM in Chapter 2 revealed that there is no paper in the literature relating BM and LM which discussed about the application of a standard BM process to perform both the assessment and comparison. Hence, an attempt has been made to fill up this research gap. Apart from this, an attempt is also made to find answers for the following questions:

- What is the current status of BM in the field of LM?
- How can BM be used as an assessment tool to evaluate how much an organization has implemented LM? and
- What details are required to perform BM in a LM environment?

7.3.1 Development of the benchmarking process

Benchmarking is a tool generally used for continuous improvement. It utilizes a systematic process for improving the performance of product/service, process or an organisation as a whole by continuously identifying, understanding, and adapting best practices that are found either inside or outside the organization. However, the definitions of BM vary. Key themes include measurement, comparison, identification of best practices, implementation and improvement. One of the most commonly quoted definitions is “BM is the search for the best industry practices which will lead to exceptional performance through the implementation of these best practices” (Camp, 1989). There are plenty of definitions available in the literature and according to Nandi and Banwet (2000), Spendolini has found out 49 definitions for BM. Some of noted definitions were given by Bemowski (1991), Vaziri (1992), International Benchmarking Clearing House Design Committee (Lema and Price, 1995), Epper (1999), American

Productivity & Quality Centre (1993), Dervitsiotis (2000), Freytag and Hollensen (2001), Sarkis (2001), Maire (2002), etc. to name a few. A latest definition of benchmarking states that:

> *It is the process of identifying, understanding, and adapting outstanding practices from organizations anywhere in the world to help an organization improve its performance. It is an activity that looks outward to find best practice and high performance and then measures actual business operations against those goals (Kumar et al., 2006).*

Analysing various definitions, BM can be described as: 'a continuous analysis of strategies, functions, processes, products or services, performances, etc. compared within or between best-in-class organisations by obtaining information through appropriate data collection method, with the intention of assessing an organisation's current standards and thereby carry out self-improvement by implementing changes to scale or exceed those standards'. Maire *et al.* (2005) commented that the multiple definitions which were proposed express various stages in the evolution of BM and concluded that BM has passed four important stages of evolution. As suggested by Maire *et al.* (2005), BM is still evolving and in recent times, the focus of BM literature has shifted and addresses issues on improving the BM process, i.e. it focuses on in-depth study of BM to identify the missing links. Dattakumar and Jagadeesh (2003) noted that, "the BM technique has seen a steady growth and appears to be heading towards maturity level, considering the gamut of publications". For example, Dervitsiotis (2000) has discussed about how BM has serious limitations if it has to be applied in an organization under a paradigm shift (transition of an established organization from the present to the future competitive environment). Similarly, Ungan (2004) said that although many companies are involved in BM, adoption of best practices is not as high as might be expected. Hence, he studied about the factors that have an impact on the adoption decision of manufacturing best practices. Anderson and McAdam (2004) discussed that traditionally, BM has occurred at the output stage of an organization, which is more downstream, based on the measurement of lag benchmarks of organizational performance. They commented that BM should be increasingly occurring at the input, process stage, which is otherwise known as the upstream elements of the organization whereby lead benchmarks of performance are to be identified. Therefore, it is clearly evident that BM must evolve from being backward looking static measures to more forward looking dynamic ratios for which a new concept called "Lead Benchmarking" has been proposed. Similarly, Collins *et al.* (2006) have identified that the data analysis aspect of the BM process is an area in need of further refinement. They have raised the following questions: how can it be proven that the best practices realized are actually the best? How can the relevance of best practices be assessed by an organization? And finally, what is the best method for determining the best practices? As a solution to the above-mentioned problems, they have utilized and validated the decision-based analysis tool of multi-attribute utility theory for the BM gap analysis process.

Though the BM is heading towards changes and improvements, it is felt that some of the fundamental questions related to BM are yet to be addressed completely. Hence, the following issues are taken up for further analysis:

- **Classification scheme for benchmarking:** A cursory review of different BM process models revealed that the most common steps are: "identify the benchmarking subject" and "identify benchmarking partners". In this case, if an organization identifies a subject, it can generally fall under product, process, function, performance, strategy, etc. Similarly, if an organization needs to identify a partner to carry out BM, it can be an internal organization (another plant or a function or a subsidiary) or an external organization, which can be a direct competitor or best-in-class industry leader or a non-competitive organization. If this is true, then why shall there be a separate classification scheme such as product BM, process BM, performance BM, etc.? If benchmarking warrants such classifications, are there any differences in the steps/processes to carry out BM? Does it involve any special methodology which is unique to each classification scheme?

- **Wide array of benchmarking models:** A plethora of models have been proposed by different authors, depicting how BM process has to be carried out. Some of the models have been developed uniquely for a particular type of BM. If the basic classification scheme itself is in question, then how is it possible to have unique models for each type of BM? If these models are different and propose different steps to carry out BM, are there any “best practices” in these BM models? If available, should it not be included to have a better BM model?

Hence, an attempt has been made to provide answers for these questions by:

- Questioning the existing classification scheme of benchmarking;
- Describing the existing benchmarking models;
- Discussing the benchmarking methodology for benchmarking the existing models

7.3.1.1 Existing classification scheme of benchmarking

Watson (1993) has studied the classification scheme and has traced the evolution of BM as shown in Figure 7.10. But a review of literature reveals that there are many kinds of classification scheme for BM. Fong *et al.* (1998) has established a classification scheme of BM as shown in Table 7.7. In addition, there are different definitions that exist for each type of BM, which makes it clear that there is still a lack of consensus about the classification of BM. To support this fact, a brief overview of different classification schemes and types of BM has been provided in Table 7.8.

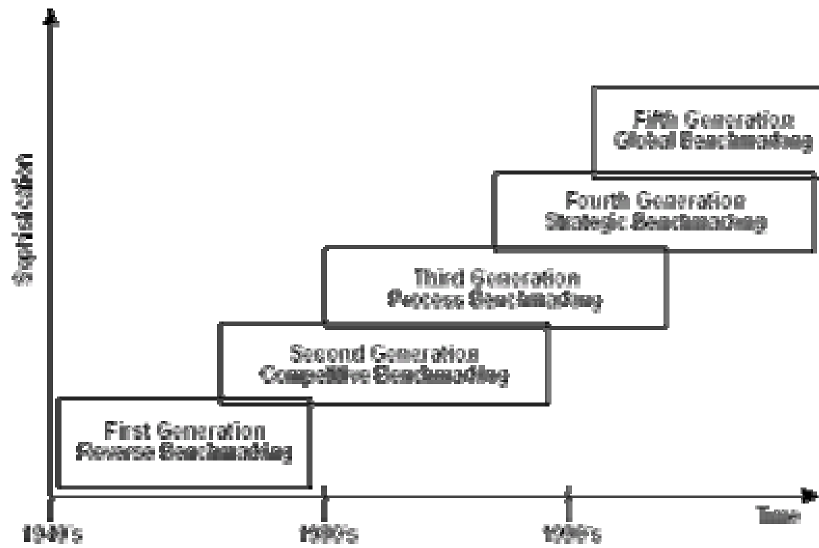

Figure 7.10: Evolution of BM as a developing science (Source: Watson, 1993)

Table 7.7: Classification scheme of BM (Source: Fong *et al.*, 1998)

Classification	Type	Meaning
Nature of referent other	Internal	Comparing within one organization about the performance of similar business units or processes
	Competitor	Comparing with direct competitors, catch up or even surpass their overall performance
	Industry	Comparing with company in the same industry, including non-competitors
	Generic	Comparing with an organization which extends beyond industry boundaries
	Global	Comparing with an organization where its geographical location extends beyond country boundaries
Content of benchmarking	Process	Pertaining to discrete work processes and operating systems
	Functional	Application of the process benchmarking that compares particular business functions at two or more organizations
	Performance	Concerning outcome characteristics, quantifiable in terms of price, speed, reliability, etc.
	Strategic	Involving assessment of strategic rather than operational matters
Purpose for the relationship	Competitive	Comparison for gaining superiority over others
	Collaborative	Comparison for developing a learning atmosphere and sharing of knowledge

Table 7.8: Overview of different classification schemes and types of BM

Author(s)	No. of classifications	Name of each classification and types	Remarks
Spendolini (1992)	3	• Internal benchmarking • Competitive benchmarking • Functional benchmarking	More concerned about the products, services and processes and do not consider other benchmarking subjects like strategies, performance, practices, etc.
Codling (1992)	3	• Internal benchmarking • External benchmarking • Best practice benchmarking	Best practice benchmarking is same as that of functional benchmarking defined by Spendolini. The definition of external benchmarking seems to be interrelated with internal benchmarking as evident from the following part of the definition: "comparison with partners from differing business units of the same organization"
Partovi (1994)	2 + 4	• Two types o Product benchmarking o Process benchmarking • Four ways based on benchmarking partners o Benchmarking internal operations o Benchmarking your competitor o Benchmarking against best-in-class o Strategic benchmarking	Strategic benchmarking integrates strategic competitive analysis with best-in-class-benchmarking
Malec (1994)	3	• Strategic benchmarking • Business benchmarking • Product benchmarking	This scheme seems to be different. For example, strategic benchmarking seems to be similar to competitive benchmarking, while business benchmarking relates to functional benchmarking. Again this classification falls short with respect to application of benchmarking for process, performance, internal benchmarking, etc.
Lema and Price (1995), Jackson *et al.* (1994)	4	• Internal benchmarking • Functional benchmarking • Competitive benchmarking • Generic benchmarking	According to them, number of authors seem to agree on four types of benchmarking, but on comparing the definition for each benchmarking classification they found that there is no consensus among the authors on the meaning of each type

Author(s)	No. of classifications	Name of each classification and types	Remarks
Karlof and Ostblom (1993)	3	• Internal benchmarking • Functional benchmarking • External benchmarking	• Opposes a separate classification called competitive benchmarking. • Definition for functional benchmarking combines the functional and generic benchmarking concepts • External benchmarking overlaps with the definitions of competitive and functional benchmarking and contradicts with the definition of Codling (1992)
Shetty (1993)	3	• Strategic benchmarking • Operational benchmarking • Business-management benchmarking	
Singh and Evans (1993)	5	• Internal benchmarking • Functional benchmarking • Competitive benchmarking • Generic benchmarking • Consultant study benchmarking	Consultant study benchmarking is not inline with the common classification scheme, but can be considered as one method of doing benchmarking
Lema and Price (1995)	2 + 4	• Internal benchmarking • External benchmarking o Reverse engineering, o Competitive benchmarking o Functional benchmarking o Generic benchmarking	This sub-classification under external benchmarking seems to be redundant as one of the steps in benchmarking process is – 'identifying the benchmarking partner'. In this case, the organization can choose an internal plant or a competitor or a best-in-class company, which may not be a direct competitor.
Le Vie Jr. (1998)	6	• Internal benchmarking • External competitive benchmarking • External industry (compatible) benchmarking • External internal (cross-industry) benchmarking • Combined internal and external benchmarking	He has proposed these types based on the following factors – cooperation, relevance of information and degree of breakthrough. In this case, the names of the classification seem to be different, but the core definitions are not altered

Author(s)	No. of classifications	Name of each classification and types	Remarks
Nandi (1995)	2 +5 + 5	• Based on the organization chosen for benchmarking o Internal benchmarking, o Competitive benchmarking o Industry benchmarking o Best-in-class benchmarking o Relationship benchmarking • Based on the goals of the benchmarking o Performance/ result benchmarking o Product / customer satisfaction benchmarking o Strategic benchmarking o Process benchmarking Diagnostic benchmarking	In this scheme, the definitions of internal and competitive benchmarking are similar to the definitions given by other authors. Similarly, industry benchmarking is similar to functional benchmarking and the best-in-class benchmarking resembles the generic benchmarking. But the relationship benchmarking has not been addressed by any other authors This scheme can be considered as sub-classification for the above-mentioned types. Data for each type listed here can be obtained from internal plants or competitor or best-in-class industries or from joint-venture partners. The definitions of product benchmarking, process benchmarking and strategic benchmarking are similar to the definitions given by other authors. Similarly some unique classifications have been proposed – performance benchmarking and diagnostic benchmarking which were not addressed by other authors.
Fong *et al*. (1998)	11	Refer Table 7.7	• They have classified based on the nature of the referent other, the content of what was to be benchmarked and the purpose of the formation of the inter-organizational relationships associated with benchmarking. • Their classification scheme revealed two unique benchmarking types – "global benchmarking" and "collaborative benchmarking", but they have missed a basic benchmarking type – namely the product benchmarking/reverse engineering
Maas and Flake (2001)	2	• Hooded benchmarking • Open benchmarking	• Hooded benchmarking is defined as the benchmarking process in which a Clearing house takes care of sensible data and releases them anonymously, which helps in limiting the anxiousness of copying and misuse of data. • An open benchmarking is defined as the benchmarking process in which all partners agree in the benchmarking code of conduct, by which the handling of data and information is determined

Fong *et al.* (1998) emphasized that while selecting a particular BM type,

> *"organizations should adopt a contingency approach for the selection of BM types. They should consider some major factors or conditions, such as the extent of interdependence, number of benchmarking partners, degree of mutual trust, and strategic activities that guide the choice. For example, BM is likely to be either extremely competitive or extremely collaborative when BM partners are highly interdependent. BM is likely to be competitive when it is initiated by an individual "benchmarker"; it is likely to be collaborative when it is initiated by a respected third-party agent".*

These statements are the evidences to show that the current classification scheme makes it tougher for the users to identify and select a correct benchmarking type. Summarizing the classification schemes, irrespective of attribute chosen for classification, the following types of benchmarking are available in the literature: internal benchmarking, competitive benchmarking, functional benchmarking, best-in-class/generic benchmarking, external benchmarking, strategic benchmarking, operational benchmarking, business-management benchmarking, consultant study benchmarking, reverse engineering/product benchmarking, process benchmarking, relationship benchmarking, performance benchmarking/result benchmarking, diagnostic benchmarking, hooded benchmarking, open benchmarking, etc. However, an explanation for each classification type seems to overlap with one another and thus seems to be inconsistent. Hence, it creates confusion in the minds of practitioner. Based on the domain knowledge and experience, it is hypothesised that, BM should be classified as internal and external benchmarking. All other cases such as strategic, product, process, functional, etc. can be listed under these two categories. This is because, when benchmarking has to be carried out, it becomes imperative to decide on the benchmarking subject and the subject can be a product, process, function, strategy, performance or even a standard for an award such as European Foundation for Quality Management (EFQM) excellence award, etc. Whatever may be the subject, a suitable benchmarking partner has to be found. The partner may be from internal sources such as another plant or branch of an organization or an external organization such as the direct competitor or an organization from completely different industry. Such a classification scheme for BM may be simple and can reduce the confusion among the practitioners.

7.3.1.2 Existing models of benchmarking

The process of benchmarking has passed from a "continuous and systematic process of evaluation of the products, services" to a "continuous process of identification, learning and implementation of best practices in order to obtain competitive advantages, whether internal, external or generic". Elmuti and Kathawala (1997) have recommended that the BM process should provide the basic framework for action, with flexibility for modification to meet individual needs. The model chosen by the organisation should be clear and basic, emphasising logical planning and organisation and establishing a protocol of behaviour and outcomes. The purpose of the BM process models is to describe the steps that should be carried out while performing benchmarking. Although the core of different benchmarking approaches is similar, most of the authors have tailored their methodology or models based on their own experience and practices (Partovi, 1994). According to Bhutta and Huq (1999), BM can be carried out in many steps; some companies have used up to 33 steps while others have used only four. Thus, in addition to the Xerox pioneering ten-step benchmarking process (Camp, 1989), there is Filer *et al*. (1988) seven-step process, Spendolini's (1992) five-step process, IBM five phase/14-step process (Eyrich, 1991), Alcoa's six-step benchmarking, AT&T's 12-step BM process (Bemowski, 1991). Many academicians too have proposed their own models, which were even later modified and adapted for different benchmarking situations. For example, Boxwell (1994) has suggested an eight-step BM process, which has been used by Nath and Mrinalini (1995) to benchmark R&D organizations. Sole and Bist (1995) has modified the Spendolini's five-step process by adding one more step. This model was used to benchmark the technical-writing departments producing sets of manuals for a product that runs on a variety of operating systems. Similarly, a literature review revealed about 35 models. Deros *et al.* (2006) have reviewed some of the benchmarking models and classified the same into the following – academic/research-based models and consultant/expert-based models. The same categorization scheme has been extended further by including one more type called organisation/industry based models. A brief definition for each categorization scheme is described in Chapter 3. Utilising the same, the reviewed models were classified as shown in Table 7.9.

Table 7.9: Taxonomy for BM models

Taxonomy	**Benchmarking models**
Consultant / Expert based models	Camp, 1989 Codling, 1992 Vaziri, 1992 Boxwell, 1994 Spendolini, 1992 Watson, 1993 Sole and Bist, 1995 Balm, 1992 Harrington and Harrington, 1996 MacDonald and Tanner, 1996 Matters and Evans, 1997 Pulat, 1994 Tutcher, 1994 Leibfried and McNair, 1992 Mass and Flake, 2001 Keehley and MacBride, 1997 Finnigan, 1996
Academic/Research based models	Andersen and Moen, 1999 Andersen and Pettersen, 1996 Fong *et al.*, 1998 Yasin and Zimmerer, 1995 Bateman’s model (Elmuti and Kathuwala, 1997) Freytag and Hollensen, 2001 Drew’s model (Carpinetti and de Melo, 2002) Longbottom, 2000 Shetty’s Model (Lema and Price, 1995)
Organization based models	Xerox, (Finnigan, 1996) NPC India, (Nandi, 1995) AT&T (Bemowski, 1991) ALCOA (Bemowski, 1991) Society of Manufacturing Engineers [SME], (Fridley *et al.*, 1997) Corning Company, (Sweeney, 1994) Yellow Pages (Simpson and Kondouli, 2000) The Employment Service (Simpson and Kondouli, 2000) Avon Product’s Benchmarking (Leibfried and McNair, 1992)

In addition to the above-discussed variations, a cursory review of the BM models revealed that they are highly dissimilar in terms of number of steps, number of phases and application. This has resulted in another problem for the practitioners – when it becomes necessary to choose a particular model for BM. Since each model has been customized for a particular application or for particular classification scheme of BM, practitioners may also have a dilemma of whether the model chosen by them are appropriate and whether will it satisfy their requirements. To overcome this, an attempt has been made to propose a comprehensive BM model, by carrying out a benchmarking of the reviewed models to identify the best practices. Since our classification scheme comprises only of internal and external benchmarking, the proposed model can be applied universally to both the classification scheme. The next section deals about benchmarking the benchmarking models.

7.3.1.3 Benchmarking the benchmarking models

Zairi and Leonard (1994) have carried out a similar study. But their study was limited to only 14 BM process models. Furthermore, their objective and intention of study was completely different. In this study, more number of models has been considered which is about 2.5 times greater than the earlier study. About 35 published models have been examined and benchmarked. In addition to this, the objective of this work is to improve upon the traditional, most widely used Xerox model by incorporating the best practices in BM, which has evolved over time. The reasons for choosing the Xerox model for BM are as follows:

- In the earlier study, Zairi and Leonard (1994) highly rated Camp's model (which they identified as the "Xerox" methodology). They stated that all of the processes they examined contain planning or preparation, analytical, integration and action phases and concluded that "most, if not all, of the methodological approaches (i.e. models) are preaching the same basic rules of BM, but using different languages", and that "most methodological approaches are based on the Xerox approach, which is considered to be an effective and generic way of conducting benchmarking projects".

- The literature review also revealed that the Xerox benchmarking process model has been highly cited and quoted in the literature. Hence, it is assumed that it is the most commonly used models by the practitioners.
- Furthermore, the Xerox model has been used for quite a long time without any modifications. Hence, it was felt that it should be improved and evolving best practices should be incorporated within this model.

Considering these facts, the Xerox's benchmarking model, shown in Figure 7.11 has been chosen for BM and in the process the same will also get benchmarked with other models.

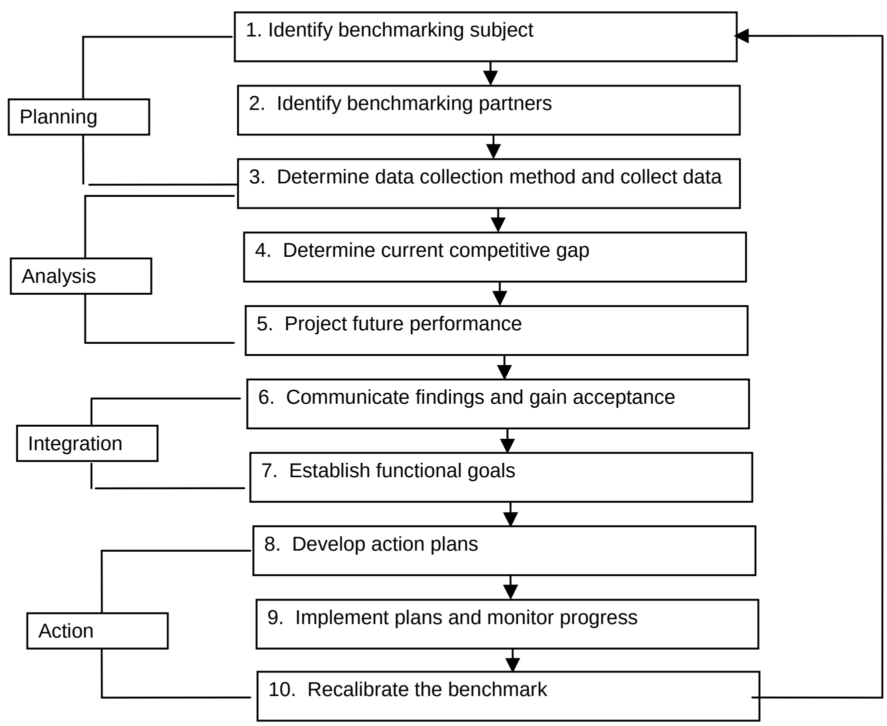

Figure 7.11: Xerox benchmarking model (Source: Camp, 1989)

7.3.1.3.1 Methodology

Phase 1: Planning

Step 1. Identify the benchmarking subject.

In this case, the subject itself is BM. To be precise, the aim of this benchmarking is to improve upon the most commonly used BM model – Xerox model.

Step 2. Identify the benchmarking partners.

All models, which have been reviewed, are considered to be the benchmarking partners. According to the theory of BM, it is dangerous to consider many partners because it may complicate and reduces the effectiveness of BM. This is true, when we try to perform real-time benchmarking in an organization. In this case, this theory can be relaxed as it is quite logical to assume that more the BM models analysed, many best practices can be obtained. Hence, around 35 models have been taken up for analysis. Watson (1993) reported that he has surveyed about 69 models of benchmarking, which were developed and proposed by various academics, researchers, consultants and experts in the field of BM. Similarly, Anderson and Moen (1999) have identified 60 different existing models, while he was designing a new model – the BM wheel. However, it would be impractical to cover all the available models, as literature regarding all the models was not available while carrying out this analysis. However, the models that are chosen for this study form the representative samples of the most common, relevant and widely published models in the literature. This is because, due care has been taken to ensure that the selected models were chosen from published books and journal papers. The BM models that are available in internet have been intentionally avoided, considering the fact these models were not verified and peer-reviewed.

Step 3. Determine data collection method and collect data.

In this case, the data collection method is literature review, where the published models from the print and online journals sources were analysed. The method of data collection can be considered as external data collection method, because the research papers and internet information are owned by online publishers (e.g. Emerald, Taylor and Francis), online database providers (e.g. EBSCO, ABI/Inform), web site owners, companies, academicians, consultants, individuals, etc.

Phase 2: Analysis

Step 4. Determine current competitive gap.

The gap was found by performing a comparative analysis of various benchmarking models. Table 7.10 shows the comparative analysis of different BM models. A matrix is formed by listing the various benchmarking models proposed by different author's (e.g. Spendolini's model) column-wise while the steps of Xerox model (which has to be benchmarked with other models) listed row-wise. The steps of each model are critically analysed. If it resembles a similar step in Xerox model, then a number (representing the sequence in the existing model) is marked against the corresponding row of Xerox model and corresponding column that contains the author's name.

Table 7.10: Comparative analysis of different BM models

S. No.	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
	Authors	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
1	Identify benchmarking subject	1	1	1	1		1	8	1	1		1	1	4	1	1	1	1	3	1	1	3	1	1	3	1	1	2	1			1	1	1		1	**30**	**85.71**
2	Identify benchmarking partners	2	2	3	3	4	3	8	4			3	2	5	4		6		6	5	6	4	1	3	8	3	1		3	6		4	2	5	3	6	**29**	**82.86**
3	**Determine data collection method** and collect data	3	3	4	4				3,4	4		2		6		4	10					5				4					3,4			6		7	**13**	**37.14**
4	Determine data collection method and **collect data**	3	3	5		5	4	8	4	4	2	5	3	7	5	14	11	6	7	8	7	5	4	4	9	4	4	4	4	8	3,4	10	3	7	6	14	**33**	**94.29**
5	Determine current competitive gap	4	4	6	4	6		9	5	4	3	6	4	8	6	15	15	7	8		8	6	6	6	10	5	5	5	4		6	11	3	7	7	15	**32**	**91.43**
6	Project future performance	5	5	8							3			9							8	7															**7**	**20.00**
7	**Communicate findings** and gain acceptance	6	6	9		7						6		10			17					8												10		18	**10**	**28.57**
8	Establish functional goals	7	7	10				10	6		4	6		10			18				9	9	7					6			7	12	4	9		19	**18**	**51.43**

S. No.	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
	Authors	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
9	Develop action plans	8	8	10	5	8	5	11		4	4	6	4	11	6	16	19	8	11	9	9	11	7	7	12	6	6	7		9		13		8		20	**30**	**85.71**
10	**Implement plans** and monitor progress	9	9	11	6	9	8			5	4		5	12	7	18		8		10		12	8	8	13	7			5	9	8	14	5			21	**25**	**71.43**
11	Recalibrate the benchmark	10	10	12	8	11		12		5			5	14,15		20	22			12	10	13	10	9		7				11		15			10		**19**	**54.29**
12	Leadership position attained		11			12																14															**3**	**8.57**
13	Practice fully integrated into process		12																			15															**2**	**5.71**
14	Define the existing process			2	2			8			1	3	1	1	5	7	3			4				2	7	5	3	3		3		5		4	2	4	**21**	**60.00**
15	**Identify the data resources** and select appropriate data collection method			4						3		3											3											4			**5**	**14.29**
16	Narrow down to 1 or 2 partners, based on some criteria			5					4			3					7			6			3			3						7					**8**	**22.86**
17	Implement plans and **monitor progress**	9	9	12	7	11	8				4	6	5	13	8	18	20			10		11	9	8		7		8	5	10			5	5	9	21	**25**	**71.43**

	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
S. No.	**Authors**	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
18	Determine key factors to measure				2	3	2	8	3		1	1	1	2	3	3	4			3	3		1	2	5	1	3				2	3			4	2	**23**	**65.71**
19	Measure your own performance on the key factors				2		4	8	3		2		1		5			3						3		5	3			4	5				5		**14**	**40.00**
20	Obtain top management support							7		1		1				2				1								1						3	1	11	**9**	**25.71**
21	Identify customers/Determine who the clients are					1		1		1				1								1	1			1					1						**8**	**22.86**
22	Identify key customer needs					2																2			4	1											**4**	**11.43**
23	Form a benchmarking team					10		6	2	2		2	1		2	11	2	2	1		2	10	2		6				2					2			**17**	**48.57**
24	Communicate findings and **gain acceptance**	6	6				6										17					8												10			**6**	**17.14**
25	Advance the clients from the literacy stage to the champion stage							2																													**1**	**2.86**
26	Test the environment (commitment of clients for buy-in and resources)							3																													**1**	**2.86**

	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
S. No.	**Authors**	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
27	**Establish priorities** and select benchmarking subject							4						4		6			3							2											**5**	**14.29**
28	Determine scope and type of benchmarking needed							5										2					3				2				2	2			1		**7**	**20.00**
29	Develop the benchmarking plan - prepare mission or purpose statement							8	1																2											5	**4**	**11.43**
30	Develop the benchmarking plan - does research **(collection of prior information about the companies selected for benchmarking)**							8			2	3													8					5							**5**	**14.29**
31	Make an initial proposal, which includes the subject, reason for selecting the organization, what you expect from them, when to visit them, agenda for the visit, format of information that will be exchanged etc.							8				4																								8	**3**	**8.57**
32	Establish a non-disclosure agreement that tells about the information that will be shared along with approval for benchmarking between the participating corporations							8				1								7			4													12	**5**	**14.29**

S. No.	Model No / Authors	1 Xerox Model (Finnigan, 1996)	2 Camp R.C. (1989)	3 Codling (1992)	4 NPC, India (Nandi, 1995)	5 (Vaziri H.K., 1992)	6 Boxwell (1994)	7 AT&T (Bemowski, 1991)	8 Alcoa (Bemowski, 1991)	9 Spendolini (1992)	10 Watson (1993)	11 Sole & Bist (1995)	12 Andersen and Moen (1999)	13 Balm (1992)	14 SME (Fridley et. al, 1995)	15 Harrington and Harrington (1996)	16 Andersen and Pettersen (1996)	17 Corning Company (Sweeney, 1994)	18 Macdonald and Tanner (1996)	19 Yellow Pages Model (Simpson and Kondouli, 2000)	20 The Employment service model, (Simpson and Kondouli, 2000)	21 Fong *et al.* (1998)	22 Yasin and Zimmerer (1995)	23 Bateman's Model (Elmuti and Kathuwala, 1997)	24 Matters and Evans Model (Elmuti and Kathuwala, 1997)	25 Freytag and Hollensen (2001)	26 Pulat (1994)	27 Tutcher (1994)	28 Drew's Model (Carpinetti and de Melo, 2002)	29 Longbottom (2000)	30 Avon's Product's Benchmarking (Leibfried and McNair,1992)	31 (Leibfried and McNair,1992)	32 Shetty's Model (Lema and Price, 1995)	33 Mass and Flake, 2001	34 Keehley and MacBride, 1997	35 Finnigan, 1996	No. of authors who have addressed this step	Percentage of occurrences
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
33	Validate the topic with respect to customers, company's mission, value and milestones, business needs, financial indicators, non-financial indicators, additional information that influence plans and actions								1																											9	**2**	**5.71**
34	Present your benchmark findings to your management and get their commitment on implementing recommendations				5				2		4	6				17																					**5**	**14.29**
35	Identifying the **strategic intent** of the business or process to be benchmarked										1														1	1				1				3			**5**	**14.29**
36	The process is to benchmarked is documented and characterized in order to determine its inherent capability / Document the selected process / Understand and document the process to be benchmarked										1		1				3																			4	**4**	**11.43**

	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
S. No.	**Authors**	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
37	Establish the requirements for the selection of benchmarking partners or for the characterization of the degree of relevance that any particular company may have as a potential benchmarking partner										1	4					5									3											**4**	**11.43**
38	**Organizing** and graphically presenting the data for identification of performance										3			7			12						4													14	**5**	**14.29**
39	Normalizing the performance to a common measurement base										3						14																				**2**	**5.71**
40	Determining their root causes for the gap			7							3		4				16		9						10											16	**7**	**20.00**
41	Close the benchmarking study with a final report										3		3			19	21		10				7														**6**	**17.14**
42	Evaluating the nature of process enablers to determine their adaptability to the company culture (checking for adaptability)										3															6									8		**3**	**8.57**

	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
S. No.	**Authors**	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	*O*	*C*	*C*	*O*	*C*	*C*	*O*	*O*	*C*	*C*	*C*	*A*	*C*	*O*	*C*	*A*	*O*	*C*	*O*	*O*	*A*	*A*	*A*	*C*	*A*	*C*	*C*	*A*	*A*	*O*	*C*	*A*	*C*	*C*	*C*		
	No. of Steps	*10*	*12*	*12*	*8*	*12*	*8*	*12*					*8*	*15*	*8*	*20*		*8*	*11*	*12*	*10*	*15*	*10*	*9*	*13*		*6*	*8*	*5*	*11*	*8*	*16*	*5*	*10*	*11*	*21*		
	Type of benchmarking model	*G*	*G*	*P*	*P*		*G*			*G*		*P*	*P*		*P*			*P*		*P*	*G*	*G*	*G*			*F*			*G*	*G*		*G*	*F*					
	No. of phases/stages/main steps	*4*	*5*	*4*				*2*	*6*	*5*	*4*	*6*	*5*	*5*		*5*			*4*			*6*	*5*		*5*	*7*	*4*	*4*		*4*	*3*	*5*		*5*		*5*		
43	Recognizing individual and team contributions/Structure rewards system to recognize continuous improvement										4												10														**2**	**5.71**
44	Establish contact with the selected partner(s) and **gain acceptance for participation in the benchmarking study**											4	2			5	8			7																	**5**	**14.29**
45	Register the benchmark in the database after your reached an agreement with the partner organization											4																									**1**	**2.86**
46	Prepare for reciprocal agreement, in case the benchmarking partner wishes to benchmark a different area in within the organization that wants to benchmark											4																		7							**2**	**5.71**
47	Write and review those questions with in your own benchmarking team, so that you are clear about the information you want											4						5		7																9	**4**	**11.43**

	Model No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**		
S. No.	**Authors**	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
48	Before mailing, answer the same, which will help in finding the gap after benchmarking study											4																									**1**	**2.86**
49	Mail a formal written questionnaire to the partner to understand each other's requirement	4										4							4													8					**4**	**11.43**
50	Create an agenda and review it with your partner											5																									**1**	**2.86**
51	Revise and improve current enterprise performance (short term operational improvements)													3				4														7					**3**	**8.57**
52	Review benchmarking integration and **learn the results**													13																							**1**	**2.86**
53	Select potential internal benchmarking sites															8																					**1**	**2.86**
54	**Identify internal data sources** and method of collection															9			2		4					3											**4**	**11.43**

S. No.	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
	Authors	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
55	**Collect internal data / Interview key internal staff** & gather information															10,12					4,5										3			4			**2**	**5.71**
56	Collect external published information/															13																					**1**	**2.86**
57	Assess the information needs																9																				**1**	**2.86**
58	Quality control the information and data/Check if data make sense																13						5														**2**	**5.71**
59	Recycle the benchmarking process, i.e. perform new benchmarking studies for new areas/ processes																23															16			11		**3**	**8.57**
60	A benchmarking team was formed **and educated /** Have a workshop for the benchmarking team																		1															2			**2**	**5.71**
61	The returns were analysed (preliminary questionnaire for selecting partners)																		5																		**1**	**2.86**
62	Include both benchmarking supporters and sceptics in team																						2														**1**	**2.86**

	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
S. No.	**Authors**	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
63	Keep in touch/Make results available to benchmarking partners																			11			7														**2**	**5.71**
64	Prioritize implementation of different practices																						8														**1**	**2.86**
65	The lead team is responsible for maintaining commitment to the process throughout the organization. The preparation team is responsible for carrying out detailed analysis, and the visit team must carry out the benchmarking visit																								6											10	**2**	**5.71**
66	Analysis of strengths and weaknesses internally																													2							**1**	**2.86**
67	Validate drivers																															6					**1**	**2.86**
68	Select the best performance measurement for critical success factors																																			3	**1**	**2.86**

S. No.	Model No	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35		
	Authors	**Xerox Model (Finnigan, 1996)**	**Camp R.C. (1989)**	**Codling (1992)**	**NPC, India (Nandi, 1995)**	**(Vaziri H.K., 1992)**	**Boxwell (1994)**	**AT&T (Bemowski, 1991)**	**Alcoa (Bemowski, 1991)**	**Spendolini (1992)**	**Watson (1993)**	**Sole & Bist (1995)**	**Andersen and Moen (1999)**	**Balm (1992)**	**SME (Fridley et. al, 1995)**	**Harrington and Harrington (1996)**	**Andersen and Pettersen (1996)**	**Corning Company (Sweeney, 1994)**	**Macdonald and Tanner (1996)**	**Yellow Pages Model (Simpson and Kondouli, 2000)**	**The Employment service model, (Simpson and Kondouli, 2000)**	**Fong *et al.* (1998)**	**Yasin and Zimmerer (1995)**	**Bateman's Model (Elmuti and Kathuwala, 1997)**	**Matters and Evans Model (Elmuti and Kathuwala, 1997)**	**Freytag and Hollensen (2001)**	**Pulat (1994)**	**Tutcher (1994)**	**Drew's Model (Carpinetti and de Melo, 2002)**	**Longbottom (2000)**	**Avon's Product's Benchmarking (Leibfried and McNair,1992)**	**(Leibfried and McNair,1992)**	**Shetty's Model (Lema and Price, 1995)**	**Mass and Flake, 2001**	**Keehley and MacBride, 1997**	**Finnigan, 1996**	**No. of authors who have addressed this step**	**Percentage of occurrences**
	Categorization of benchmarking model	***O***	***C***	***C***	***O***	***C***	***C***	***O***	***O***	***C***	***C***	***C***	***A***	***C***	***O***	***C***	***A***	***O***	***C***	***O***	***O***	***A***	***A***	***A***	***C***	***A***	***C***	***C***	***A***	***A***	***O***	***C***	***A***	***C***	***C***	***C***		
	No. of Steps	***10***	***12***	***12***	***8***	***12***	***8***	***12***					***8***	***15***	***8***	***20***		***8***	***11***	***12***	***10***	***15***	***10***	***9***	***13***		***6***	***8***	***5***	***11***	***8***	***16***	***5***	***10***	***11***	***21***		
	Type of benchmarking model	***G***	***G***	***P***	***P***		***G***			***G***		***P***	***P***		***P***			***P***		***P***	***G***	***G***	***G***			***F***			***G***	***G***		***G***	***F***					
	No. of phases/stages/main steps	***4***	***5***	***4***				***2***	***6***	***5***	***4***	***6***	***5***	***5***		***5***			***4***			***6***	***5***		***5***	***7***	***4***	***4***		***4***	***3***	***5***		***5***		***5***		
69	Narrow down the number of subject areas (from the brainstorming stage) to a few areas in which benchmarking might have a considerable impact																									2											**1**	**2.86**
70	Specify the data in terms of units and intervals to make the comparison and the analysis phase easier																									4											**1**	**2.86**
71	Provide training to the employees on new practices																									7											**1**	**2.86**

Legend:

O- Organization based models C- Consultant/Expert based models A - Academic/Research based models

P- Process benchmarking F - Functional benchmarking G - Generic benchmarking O - Others

For example, in Table 7.10, the step “Establish functional goals” (i.e. S. No. 8) represents the seventh step in Xerox model. Other models identified have also got a similar step, but the sequence of performing this step is different. For instance, in the AT&T’s model it is the tenth step. Hence, the number “10” has been marked against that corresponding row under the column of AT&T. Similarly, other steps have been benchmarked. If a new/unique step (i.e. a step that is not listed in the Xerox’s model), is found, then it is added to a new row below the Xerox model. These steps were also compared with the rest of the models. In addition to the comparison of different steps, the parameters like number of stages and number of steps involved were also compared. In this analysis, a total of about 71 steps were identified. The ABC analysis, which is used for classifying the materials based on value and cost has been adapted for identifying the best practices of benchmarking. Instead of value and cost, the percentage of occurrence of each step has been considered as the decision parameter. If the percentage of occurrence of a step is greater than 40 percent (i.e. at least 14 out of 35 authors have emphasized on that particular step), then it is considered as a “common step” for benchmarking. Out of the 71 steps, around 13 steps were considered as “common steps”. The common steps in the BM process are shown in Table 7.11. The remaining steps (excluding “common” steps) were subjected to further analysis because all practices cannot be incorporated, as it may dilute the BM process.

Table 7.11: Common steps in the BM process

S. No.	Steps
1	Identify benchmarking subject
2	Identify benchmarking partners
3	Perform benchmarking study
4	Determine current competitive gap
5	Establish functional goals
6	Develop action plans
7	Implement of action plans to bridge the gap
8	Recalibrate the benchmark
9	Understand the current situation by collecting and analysing the existing information on the subject to be benchmarked
10	Monitor results of the implemented actions

S. No.	Steps
11	Identify the critical success factors or indicators of the subject to be benchmarked
12	Measure the existing state of the subject to be benchmarked with respect to the critical success factors/indicators
13	Form a benchmarking team and identify a leader of the team to carry benchmarking study

Hence, the following criterion was adopted to filter out the best practices: if the percentage of occurrence of a step is equal to or greater than 14% but less than 40% (i.e. at least five authors have supported the use of such a step) then they are considered as “best practices” in BM. In this case, around 18 best practices were identified. They have to be integrated within the existing BM process. Table 7.12 shows the best practices in the BM process. If the percentage of occurrence of a step is less than 14 percent, then they are called as “unique practices”, which are subjected again to further scrutiny. The unique practices in the BM process are shown in Table 7.13.

Table 7.12: Best practices in the BM process

S. No.	Steps
1	Determine the data collection method
2	Project future performance
3	Communicate benchmark findings to both management and employees
4	Identify the information sources for collecting pre-benchmarking information by searching different technical and business journals, internal database, external databases, and public libraries
5	Narrow the list to few benchmarking partners by comparing the candidates
6	Prepare a proposal for benchmarking and submit it to management to get their commitment, with clear explanation on the benefits, costs involved, resources required etc.
7	Identifying the customers for the benchmarking information
8	Gain acceptance from management and employees through commitment and participation respectively
9	Evaluate the importance of each subject area based on priorities
10	Determine the purpose and scope of the benchmarking project
11	Collect lower level detail on that partner prior to contacting them (E.g., location, when did they get started, no. of employees, product line, key managers, market share, revenue and profit, customer satisfaction, etc.)
12	Establish a protocol for performing the benchmarking study and also develop a non-disclosure agreement that tells about the information that will be shared along with approval for benchmarking between the participating corporations
13	Present your benchmark findings to your management and get their commitment on implementing recommendations

S. No.	Steps
14	Identify the strategic intent of the business or process which is to be benchmarked
15	Sort the collected information and data
16	Identification of possible causes and the practices that are responsible for the gap
17	Establish contact with the selected partner(s) and gain acceptance for participation in the benchmarking study
18	Establish benchmarking report which provides the information on the best practices, how it was implemented in the benchmarked company and how it was adapted in the existing organization and a comparative analysis of the reported benefits

Table 7.13: Unique practices in the BM process

S. No.	Steps
1	Check whether the target is reached
2	Practice fully integrated into process
3	Identify key customer expectations
4	Advance the clients from the literacy stage to the champion stage
5	Test the environment (commitment of clients for buy-in and resources)
6	prepare mission statement
7	Make an initial proposal, which includes the subject, reason for selecting the organization, what you expect from them, when to visit them, agenda for the visit, format of information that will be exchanged etc.
8	Validate the topic with respect to customers, company's mission, value and milestones, business needs, financial indicators, non-financial indicators, additional information that influence plans and actions
9	The process is to benchmarked is documented and characterized in order to determine its inherent capability
10	Establish the requirements for the selection of benchmarking partners or for the characterization of the degree of relevance that any particular company may have as a potential benchmarking partner
11	Normalizing the performance to a common measurement base/Normalise the data
12	Evaluating the nature of process enablers to determine their adaptability to the company culture (checking for adaptability)
13	Structure rewards system to recognize continuous improvement
14	Register the benchmark in the database after your reached an agreement with the partner organization
15	Prepare for reciprocal agreement, in case the benchmarking partner wishes to benchmark a different area in within the organization that wants to benchmark
16	Write and review those questions with in your own benchmarking team, so that you are clear about the information you want
17	Before mailing, answer the same, which will help in finding the gap after benchmarking study
18	Mail a formal written questionnaire to the partner to understand each other's requirement
19	Create an agenda and review it with your partner
21	Review benchmarking integration and learn the results
22	Select potential internal benchmarking sites
23	Collect internal original research information

S. No.	Steps
24	Conduct interviews and surveys
25	Collect external published information/
26	Assess the information needs
27	Quality control the information and data/Check if data make sense
28	Recycle the benchmarking process, i.e. perform new benchmarking studies for new areas/ processes
29	Have a workshop for the benchmarking team
30	The returns were analysed (preliminary questionnaire for selecting partners)
31	Include both benchmarking supporters and sceptics in team
32	Make results available to benchmarking partners
33	Prioritize implementation of different practices
34	The lead team is responsible for maintaining commitment to the process throughout the organization. The preparation team is responsible for carrying out detailed analysis, and the visit team must carry out the benchmarking visit
35	Analysis of strengths and weaknesses internally
36	Validate drivers
37	Select the best performance measurement for critical success factors
38	Narrow down the number of subject areas (from the brainstorming stage) to a few areas in which benchmarking might have a considerable impact
39	Specify the data in terms of units and intervals to make the comparison and the analysis phase easier
40	Provide training to the employees on new practices

About 40 unique practices were identified and it was found that some of the practices are not relevant, as it do not fit within the context of a general BM model. Hence, based on the domain knowledge, logical analysis and judgemental approach, only relevant steps from this group are taken up for the inclusion in the proposed BM process. In few cases, some of the unique steps were not incorporated and it was discarded. For example, the 17th and 18th steps in Table 7.13 were discarded, as it is applicable only if the data collection method is a survey, in which case a questionnaire needs to be prepared. Similarly, the 24th and 26th steps in Table 7.13 were combined with 3rd step in Table 7.11 and 16th step in Table 7.13, respectively. At the end of this analysis, 54 best practices in benchmarking were identified. Once the best practices were identified, it is necessary to provide a structured approach to incorporate these best practices. To accomplish the same, the best practices of BM were grouped together under different phases based on the domain knowledge and logical analysis. In this case, the identified best practices are grouped under 12 phases. The proposed 12 phase, 54 step benchmarking process is shown in Figure 7.12. Different activities of benchmarking were sequenced and clustered into each phase as shown in Table 7.14.

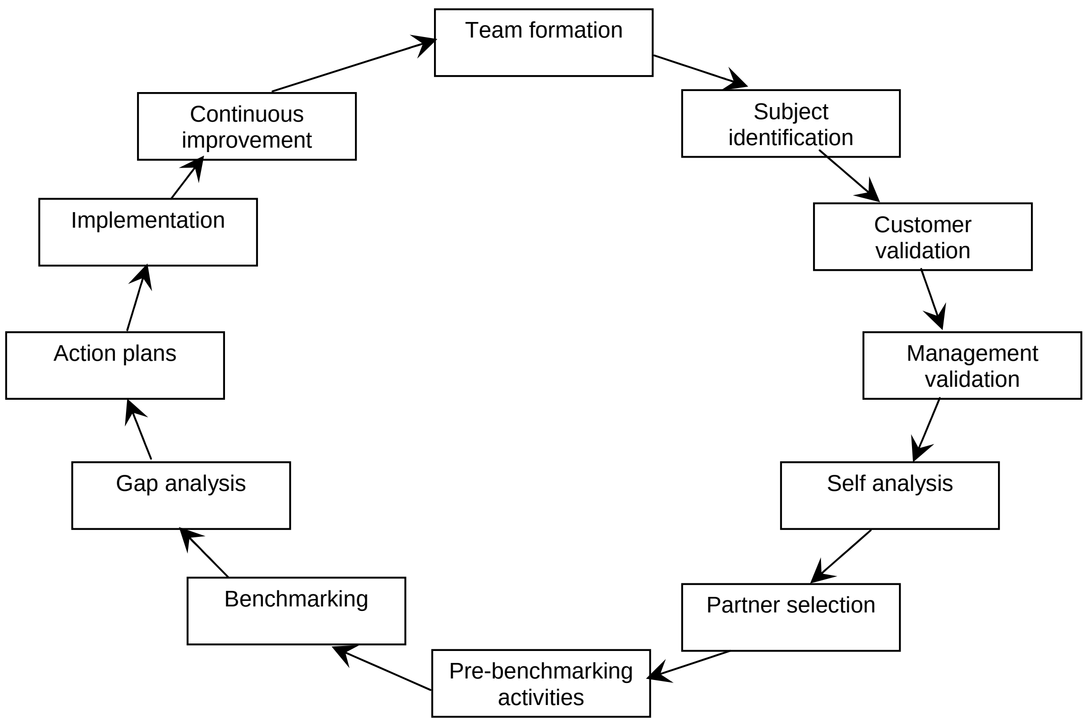

Figure 7.12: Proposed 12-phase, 54 step benchmarking process

Table 7.14: Detailed steps of the proposed benchmarking process

Phase	Step No.	Description
Team formation	1	Identify a leader of the team to carry out the benchmarking study
	2	Form a benchmarking team with a clear-cut definition of responsibility for each team member
	3	Identify the capability of team and provide necessary training if required.
Subject identification	4	Identify the strategic intent/area of the business which is to be benchmarked
	5	Narrow down the number of subject areas (from the brainstorming stage) to a few areas in which benchmarking might have a considerable impact

Phase	Step No.	Description
	6	Evaluate the importance of each subject area based on priorities
	7	Identify benchmarking subject
Customer validation	8	Identifying the customers for the benchmarking information
	9	Identify key customer expectations
	10	Validate the topic with respect to customers, company's mission, value and milestones, business needs, financial indicators, non-financial indicators, additional information that influence plans and actions
Management validation	11	Prepare the mission of benchmarking and outline the purpose and scope of the benchmarking project
	12	Identify different resources required for benchmarking study. It includes resources like financial, travelling, man hours etc.
	13	Prepare a proposal for benchmarking and submit it to management to get their commitment, with clear explanation on the benchmarking project, its objectives, tentative time plan of benchmarking activities with target dates, the benefits, costs involved, resources required etc.
Self analysis	14	Understand the current situation by studying and analysing the existing information on the subject to be benchmarked
	15	Identify the Critical Success Factors (CSFs) based on the subject of benchmarking, strategic intent, core competencies and capability maps
	16	Select the best performance measurement for critical success factors
	17	Specify the data in terms of units and intervals to make the comparison and the analysis phase easier
	18	Measure the existing state of the subject to be benchmarked with respect to the critical success factors/indicators
	19	The subject to benchmarked is documented and characterized in order to determine and understand its inherent capability
Partner selection	20	Identify the external published information sources for collecting pre-benchmarking information by searching different technical and business journals, internal database, external databases, and public libraries
	21	Identify the potential benchmarking partners based on the above data
	22	Establish the requirements for the selection of benchmarking partners or for the characterization of the degree of relevance that any particular company may have as a potential benchmarking partner
	23	Narrow the list to few benchmarking partners by comparing the candidates

Phase	Step No.	Description
Pre-benchmarking activities	24	Collect lower level detail on benchmarking partner prior to contacting them (E.g., location, when did they get started, no. of employees, product line, key managers, market share, revenue and profit, customer satisfaction etc.)
	25	Establish contact with the selected partner(s) and gain acceptance for participation in the benchmarking study
	26	Make an initial proposal, which includes the subject, reason for selecting the organization, what you expect from them, when to visit them, agenda for the visit, format of information that will be exchanged etc.
	27	Determine the data collection method – which can be a questionnaire or site visits or interview or a combination of all methods
	28	Validate it after discussing with various experts including partners
	29	Establish a protocol for performing the benchmarking study and also develop a non-disclosure agreement that tells about the information that will be shared and define the ethics of benchmarking
	30	Prepare for reciprocal agreement, in case the benchmarking partner wishes to benchmark a different area in within the organization that wants to benchmark
	31	Assess the information needs - write and review the questions, information required and other details to be collected with the benchmarking team members, so that there is a clear consensus and understanding about the information to be collected
Benchmarking	32	Perform benchmarking study which might include collecting information through questionnaire/survey, interview, site visit etc.
	33	Collect data on methods, procedures, performance measure and practices that are considered superior
	34	Sort the collected information and data
Gap analysis	35	Determine current competitive gap
	36	Identification of possible root causes and the superior practices that are responsible for the gap
	37	Evaluate the nature of practices/methods/procedures (enablers) to determine their adaptability to the benchmarking company's culture by performing the feasibility study
Action plans	38	Prepare the report and communicate the findings of benchmarking throughout the organization and project the benefits in terms of dollars and get the management commitment
	39	Make results available to the benchmarking partners
	40	Establish functional goals
	41	Project future performance

Phase	Step No.	Description
	42	Develop the action plan with necessary recommendations and time frame for implementation
	43	Gain acceptance from management and employees through commitment and participation respectively for implementing the action plans
Implementation	44	Prioritize the implementation of different practices
	45	Deploy the action to the concerned product process owners with the target date for implementation and completion
	46	Implement action plans to bridge the gap
	47	Provide training to the employees on new practices
Continuous Improvement	48	Monitor results of the implemented actions
	49	Check whether the target is reached
	50	Recalibrate the benchmark and improve continuously.
	51	Ensure that best practices are fully integrated into process
	52	Structure rewards system to recognize continuous improvement to the benchmarking team and the implementation team
	53	Update the benchmarking report which provides the information on the best practices, how it was implemented in the benchmarked company and how it was adapted in the existing organization and a comparative analysis of the reported benefits etc., which will help in learning purposes
	54	Recycle the benchmarking process, i.e. perform new benchmarking studies for new areas/ processes

Step 5. Project future performance.

Since the best practices are incorporated, the number of steps for the proposed model have increased, which in turn have increased the number of phases. Some researchers may argue that the proposed BM process might be complex with increased steps and phases. It may be true, but considering the fact that a universal BM process model is developed, it may not be a critical problem, as the aim of this study is to ensure that the proposed model should be comprehensive and should be applied uniformly for different BM types.

Phase 3: Integration

Step 6. Communicate findings and gain acceptance.

As part of this step, the proposed model has been submitted for publication to communicate among the readers of the Benchmarking – An international journal to gain the acceptance of the reviewers, experts, readers and practitioners.

Steps 7 and 8 are meant to be applied in an industrial setting and hence it may not be applicable in this case. On the other hand, Step 9 is explained in the next section, where the proposed BM framework is validated by utilising it to perform a preliminary assessment regarding the implementation of LMS for a case organisation.

Phase 4: Action

Step 10. Recalibrate the benchmark.

Further studies can be carried out to improve the proposed model. New practices, which may evolve in the future, can also be incorporated.

7.3.2 Application of the benchmarking process for the assessment of lean manufacturing systems

It is evident from a survey among Fortune 1000 companies that 65 percent of the organizations use BM as a management tool to gain competitive advantage (Korpela and Tuominen, 1996). Similarly, a survey in France taken up by *Chambre de Commerce et d'Industrie* estimates that 50 percent of the 1,000 companies use BM regularly, and

80 percent of them regard it as an effective approach of change (Maire *et al.*, 2005). In India too, a survey was conducted by NPC-IFC Group (1994), which showed that about 70 organizations were using BM. Jarrar and Zairi (2001) have conducted a survey of about 227 organizations from 32 different countries and concluded that it has been applied in most of the sectors such as manufacturing, health services, insurance, financial services, construction, banking, government, etc. In recent times, Henderson-Smart *et al.* (2006) have used benchmarking for learning and teaching, while Boisvert and Caron (2006) utilized it to benchmark website functions. Costa *et al.* (2006) described about the use of BM in construction industry. Graham (2005) has reviewed the applications of BM in airports and concluded that BM techniques have become well established in recent years within the airport sector, but the fundamental difficulties associated with inter-airport comparisons (particularly from different countries) and problems of comparability arising largely from the diversity of inputs and outputs, still remain and yet to be resolved effectively. In the case of manufacturing sector, a plethora of study exists to demonstrate its application. For example, Ma *et al.* (2004) used BM to identify the best distributors for building the distribution channel for an organization, Chan and Burns (2002) benchmarked Manufacturing Planning and Control (MPC) systems and Van Landeghem and Persoons (2001) developed a causal model to benchmark logistics.

Similar applications of BM at a strategic level of an organization can also be found in the literature. Simatupang, and Sridharan (2004) used BM to benchmark supply chain collaboration, Muthu *et al.* (2000) used it in the field of maintenance to benchmark 'Strategic Maintenance Quality Improvement', Spencer and Loomba (2001) presented a BM study of Total Quality Management (TQM) adoption in Small- and Medium-sized Enterprises (SMEs), while Sarkis (2001) discussed about benchmarking agility. Although, similar studies relating BM and Lean Manufacturing (LM) are available in the literature; the number of such publications is very less despite the increasing popularity of LM and BM in the business circles and the long history and development of LM. Already in Chapter 2, a review of literature dealing with BM and JIT/LM was carried out, which revealed that

- Most of papers that relate BM and LM are based on empirical approaches.
- None of the papers discussed about the utilization of a well-defined BM models that are proposed by various researchers such as Camp (1989), Spendolini (1992), etc. to conduct the BM study in the field of LM.

Voss *et al.* (1994) commented that BM and self-assessment is being used increasingly by industry as a tool to help identify “best practice” apart from identifying the areas for improvement. They noted that the impact has been particularly striking in the quality management area, as the Malcolm Baldrige National Quality Award (MBNQA) has been used by many companies in US and Europe for both benchmarking and self-assessment, leading to great improvements in quality practices and performance. Even Comm and Mathaisel (2000), who described the development of an eight-step paradigm to implement lean principles and practices emphasized on the application of BM as the fifth step in their paradigm. They also noted that BM can be used to assess and benchmark lean practices especially in the production and operation of military aerospace products. They mentioned that leanness is a relative measure and BM can be used to measure the relative value of one’s leanness. They presented six overarching characteristics and some of the supporting metrics, which needed to be considered in the development of BM instrument, which can be used to assess whether or not an entity is lean. Similarly, a review of literature related to assessment and LM was carried out in Chapter 2, which revealed that none of the papers demonstrated the application of BM for the assessment/self-assessment in the literature related to assessment of LM. Hence, an attempt has been made to resolve these research gaps by utilising the BM process proposed in the earlier section for performing an assessment of LMS in a case organization.

Voss *et al.* (1994) commented that to be successful in BM, the participants must have a common model of the processes to be benchmarked and the metrics to be used. Furthermore, they noted that frameworks and tools based on good reference to literature and research, with proper attention to content validity, are more likely to be successful. This is the reason why the standard process proposed in the previous section is utilised for benchmarking the LM. Furthermore, it will complete the Step 9 of the Xerox benchmarking process – namely "implement plans and monitor action", which was not carried out while performing the benchmarking of benchmarking models. Another reason for utilizing the proposed BM process is that, it was not validated. In this study, the validation can be carried out by utilising the proposed BM model to benchmark the LM implementation in a case organisation.

7.3.2.1 Case study

The organisation considered for the study is from the consumer goods segment – in particular, from the home and life style segment. It manufactures different types of Air Conditioners (ACs) and is also involved in trading refrigerators and washing machines. For the sake of confidentiality, the organisation is named as ABC India Limited (ABCIL). It is located in the north-western part of India and has a total installed capacity of 150,000 units a year and a turnover of over Rs. 4466 million in the year 2007. It has 14 branches, 250 sales and service dealers, 800 showroom dealers and 350 service points. The number of people on roll at present is around 450. ABCIL started off as a joint venture between an Indian company and a Japanese company. As the time progressed, the Japanese company acquired a majority stake and established it as a subsidiary in India in the year 2003 and the new management established the vision and mission statements. The case company's vision is "to create richer lives and a better society by providing products, systems and services with a new level of value and potential based on the latest advances in technology, especially knowledge and information technology", while its mission is "to identify the real needs of the society and customers and to set and achieve goals that surpass their needs by developing and applying new technology without being bound by traditional thinking." To achieve this vision and mission, the top management initiated lot of changes. However, they could not achieve significant progress due to the following problems:

- **High variety**: The organisation manufactures ACs for both consumer and industrial purposes. In consumer segment, it has three types – namely, window, split and ceiling types. Further, in each of these types, there are different models having different cooling capacities (such as 0.75, 1, 1.5 and 2 tons). In the case of industrial ACs, it has building air conditioners and water chillers, with varied capacities. In total, the case organisation has about 193 models and as many Stock Keeping Units (SKU).
- **Inventory**: The organisation has a policy of providing technical support of 7 years for every model of a product. Hence, they were bound to have the stock of some of the old models and its associated spare parts. Due to high variety and the 7-year technical support policy, the inventory of the organisation is quite high. Naturally, the floor space utilisation of stores and warehouse is also very high. The value of raw material, Work-In-Progress (WIP) and finished goods inventory was found to be Rs. 810 million.
- **Quality concerns**: The products are preferred by the customers due to its brand image and its tie-up with the parent Japanese organisation. However, the level of scraps, rework and warranty returns are very high. Recently, they found that Rs.140 million was spent on warranty and sales commission, while around Rs. 3 to 5 lakhs per month is wasted on scrap and rework.

- **Delivery**: The ACs has a seasonal sale. Hence during the lean months, production happen for two shifts and the organisation has enough capacity to meet the delivery requirements. However, during the peak season, they had a poor delivery performance, even after having a three-shift operation per day. They had a lead time of about a week to complete an order and it may extend to about 20 to 25 days for the industrial products during the peak season.
- **High cost**: The cost of the product is comparatively higher than that of competitors. Adding fuel to the above problems, with more number of multi-national companies starting to establish their presence in India, the number of competitors too has started to increase, resulting in increased cost pressure for the organisation. In addition to this, the material cost, labour cost and energy costs have spiralling upwards due to inflation, which has lead to erosion of profit margins.

Hence, to overcome the above-mentioned problems they implemented LM. Being a subsidiary of Japanese company, it is natural for the case organisation to implement the principles and concepts of LM. Almost a year has passed by since their implementation and they could gain reasonable amount of improvements. However, the top management were interested in assessing their level of LM implementation and gauge where they stand in comparison with a similar company or a best-in-class company. Hence, a BM study was planned to conduct the assessment.

7.3.2.2 Assessment of lean manufacturing systems for the case organisation based on the proposed benchmarking process

Phase 1: Team formation

Step 1. Identify a leader of the team to carry out the benchmarking study.

The Executive Director, Supply Chain of the plant was appointed as the leader, as he is one of the representatives of the top management. Naturally, it also helped in securing the management commitment for BM apart from obtaining necessary resources without any hassles.

Step 2. Form a benchmarking team with a clear-cut definition of responsibility for each team member.

A BM team was formed, which comprises of the plant manager and the engineers from production engineering, quality control and purchasing department of the case organization. Each member was given the responsibility of gathering the data from their respective departments apart from interpreting the results and identifying the action plans for their department.

Step 3. Identify the capability of team and provide necessary training if required.

Since every member of BM team was already aware of LM principles, only a brief overview regarding the BM was provided to the remaining team members.

Phase 2: Subject identification

Step 4. Identify the strategic intent/area of the business which is to be benchmarked.

The strategic intent of the organization is to become a 'lean enterprise', so that they can achieve their goal of becoming a leading AC manufacturer in India.

Step 5. Narrow down the number of subject areas (from the brainstorming stage) to a few areas in which benchmarking might have a considerable impact.

Step 6. Evaluate the importance of each subject area based on priorities.

The team felt that Step 5 and 6 can be performed simultaneously. Karlsson and Åhlström (1996) viewed lean enterprise as lean development (research and development) + lean procurement (supplier involvement) + lean manufacturing + lean distribution. However, the organization has implemented LM concepts only in the shop floor and it is yet to implement LM in the remaining areas such as product development, distribution etc. Furthermore, the problems, which were discussed earlier, had a direct relationship with shop floor, when compared to other functional areas. Hence, the team was more particular about assessing LM implementation in the shop floor.

Step 7. Identify benchmarking subject.

Finally, the team identified the BM subject as 'assessing the level of LM implementation in the shop floor'.

Phase 3: Customer validation

Step 8. Identify the customers for the benchmarking information

The customers for the BM information include the director, the managing director and chairman of the organization, plant manager and also the employees of shop floor. Since the resources and investment decisions are made by top management, they have to be informed about the results of BM. In addition to this, the employees have to be briefed about the results as they are the agents for implementing the action plans.

Step 9. Identify key customer expectations.

The top management expected that the BM activity should be carried out with minimum resources, but should provide maximum benefits, while the employees expected that the changes brought about by BM should be minimal and should be easily implemented. In addition to that, they expressed that it should not affect their job prospects.

Step 10. Validate the topic with respect to customers, company's mission, value and milestones, business needs, financial indicators, non-financial indicators, additional information that influence plans and actions

As mentioned earlier, the organization embarked on the journey of LM to achieve their vision. Hence, the proposed study was inline with the business requirements of the organization. Furthermore, the customers were already taken into confidence by updating them about the objective, purpose and benefits of the BM study.

Phase 4: Management validation

Step 11. Prepare the mission of benchmarking and outline the purpose and scope of the benchmarking project.

The mission of BM is to assess the level of LM implementation for the purpose of understanding where does the organization stand in comparison with other lean manufacturers. It helps them to understand, which lean tools / techniques / procedures / practices (in short they will be called as 'elements' from now on) they have implemented and what is its effect on the performance measures apart form identifying which other lean elements can be implemented. The scope of the BM is restricted only to assess the implementation of LM principles in the shop floor.

Step 12. Identify different resources required for benchmarking study. It includes resources like financial, travelling, man hours etc.

Step 13. Prepare a proposal for benchmarking and submit it to management to get their commitment, with clear explanation on the benchmarking project, its objectives, tentative time plan of benchmarking activities with target dates, the benefits, costs involved, resources required, etc.

Step 12 and 13 were carried out simultaneously. A detailed report regarding the list of resources required such as time required for conducting the study, cost for data collection, consultancy, etc. were identified and a detailed budget was prepared for the BM study, which was presented to the management.

Phase 5: Self analysis

Step 14. Understand the current situation by studying and analyzing the existing information on the subject to be benchmarked.

To understand the current situation and the subject to be benchmarked, the elements of LM were studied in detail. Even, one of the requirements of BM is that, in addition to understanding the performance difference between the benchmarking and benchmarked companies, it is also necessary to understand the superior practices which have created such a performance difference. The list of elements of LM identified in Chapter 3 represent the best practices followed in the TPS, as these practices only enabled the Toyota Motor Corporation (TMC) to achieve significant competitive advantages over their competitors.

Step 15. **I**dentify the Critical Success Factors (CSFs) based on the subject of benchmarking, strategic intent, core competencies and capability maps.

The CSFs refer to the competitive priorities which have to be improved for the case organisation. To understand the strategic intent and core-competencies, the framework for Lean Manufacturing System (LMS) proposed in Chapter 3 is used. This framework provides details about the pre-requisites, principles (strategic intent), relationship between the elements of LM (core competencies) with respect to the stakeholders and decision levels of the organization (capability maps) in a clear and concise manner.

Step 16. Select the best performance measurement for critical success factors.

Step 17. Specify the data in terms of units and intervals to make the comparison and the analysis phase easier.

Step 16 and 17 were carried out simultaneously. Another important requirement for the BM study is the identification of appropriate performance measures. To identify the list of performance measures, the framework of performance measurement system proposed in Chapter 4 is utilized.

Step 18. Measure the existing state of the subject to be benchmarked with respect to the critical success factors/indicators

To measure the existing state, it is necessary to understand the list of elements of LM and performance measures that are actually implemented in the case organization. Hence, to identify the same, a proforma was circulated among the different employees of the organization. Table 7.15 shows the proforma for assessment of lean practices and performance measures in Indian Industries. In Part A of the proforma, general details about the organisation and employee was collected, while in Part B, the employees were asked to place a tick mark against the elements that were implemented. Similarly, in the part C of the proforma, the performance measures were listed and the employees were asked to place a tick mark against the measures that were used apart from mentioning the current performance. This proforma was given to multiple employees in the organization to check for the consistency.

Step 19. The subject to be benchmarked is documented and characterized in order to determine and understand its inherent capability.

Thus the data collected in the previous stage was documented, which clearly listed out what are the inherent capability of the organization in terms of LM implementation.

Phase 6: Partner selection

Step 20. Identify the external published information sources for collecting pre-benchmarking information by searching different technical and business journals, internal database, external databases, and public libraries.

Table 7.15: Proforma for assessment of lean practices and performance measures in Indian Industries

Proforma for assessment of lean practices and performance measures in Indian Industries

Dear Sir/Madam,

The purpose of this proforma is for assessing the lean practices and performance measures that are implemented in Indian Industries, which I am carrying out as part of my doctoral research studies. I request you to kindly provide me necessary details about your organization, which will be helpful for my studies:

PART-A

Name of the person filling up this proforma:

Designation:

Company Name:

Company Address:

Please tick the industrial sector to which your organization belongs:

Automobile/Auto components/Electronics or semi conductor manufacturing/FMCG/Others

In case of others, please write the industrial sector:

Year of establishment:

Year of starting lean implementation:

Market share:

PART-B

Table below shows the list of lean elements (tools, techniques, practices and procedures) identified from the review of research papers. Please identify which of these elements can be used/have been used in your organization (Place a tick mark or a bullet in the corresponding column). Please identify the sequence in which it will be implemented by marking 1, 2, 3 against them in the sequence of implementation column.

S. No.	Functions in an organization	Element	Elements applicable in your organization	Sequence of implementation
1.	Design	Product and Process Simplification		
2.		Commonization and Standardization of Parts		
3.		Modular Design		
4.		Concurrent Engineering		
5.		Design for Manufacturing		
6.		Supplier Involvement in Design		
7.		Computer Integrated Manufacturing (CAD/CAM/CAE)		
8.	Production Engineering	Process Sharing		
9.		Cellular Manufacturing		
10.		Group technology		
11.		New Process or Equipment Technologies		
12.		Use of Multiple Small Machines		
13.		Workload or Line Balancing		
14.		Layout change or U-Shaped Cell		
15.		One Piece Flow		
16.		Work Standardization		
17.	Supplier or purchasing	Sole Sourcing or supplier reduction		
18.		Just-In-Time delivery (from suppliers and within workstations)		
19.		Supplier Training and Development		
20.		Long Term Supplier Relationship		
21.		Information Sharing with Suppliers		
22.		Supplier Proximity		
23.	Production planning and control	Small Lot Production		
24.		Storage Space Reduction		
25.		Use of EDI with suppliers		
26.		Kanban System		
27.		Pull Production		
28.		Mixed Model Manufacturing/Scheduling		
29.		Production Smoothing or Load Levelling		
30.	Operations	Automation		
31.		Visual Control		
32.		Single Minute Exchange of Dies		
33.		Andon (Warning lights)		
34.		Jidoka (Autonomation)		
35.		Standardized Containers		
36.		Maintain Spare Capacity		
37.		Focused Factory Production		

S. No.	Functions in an organization	Element	Elements applicable in your organization	Sequence of implementation
38.		Housekeeping (5S)		
39.		WIP Reduction		
40.		Elimination of buffers		
41.		Cycle time and Lead time Reduction		
42.	Quality	Statistical Process Control		
43.		Defects at Source (Self inspection)		
44.		Successive Checking		
45.		Total Productive Maintenance		
46.		Total Quality Management		
47.		Pokayoke or Mistake proofing or Defect Prevention		
48.		Quality Circles		
49.		Use of Problem Solving Tools		
50.		Autonomous Maintenance		
51.		Quality Certification (suppliers and manufacturers)		
52.	Top management	Long Term Employment		
53.		Flat Organisation Structure		
54.		Value Stream Mapping		
55.	Human resources	Safety Improvement Programs		
56.		Multi Skilled Workforce		
57.		Employee Empowerment		
58.		Employee Participation		
59.		Rewards and Recognition		
60.		Cross Functional Teams		
61.		Suggestion Schemes		
62.		Job Enlargement or Nagara System		
63.		Communication Between Employees		
64.		Multi Functional Training		
65.		Job Rotation or Flexible Job Responsibilities		

This list is not an exhaustive list. In case you are following some more lean practices, which are not found in this list, kindly write the same here along with its sequence of implementation.

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PART-C

Table below shows the list of performance measures identified from the review of research papers. Please identify which of these measures can be used/have been used in your organization (Place a tick or bullet in the corresponding column). Please identify the current performance and your expected performance once LM is/was implemented.

S. No.	Performance measures of LM	Units	Measures currently used in your organization	Current performance
1.	Scrap and rework costs	Rs./$		
2.	Manufacturing cost per unit	Rs./$		
3.	Value of work in progress in relation to sales	Rs./$		
4.	Total productive floor space out of overall space	Sq m.		
5.	Reduction in overall plant investment	%		
6.	Gross annual profit	Rs./$		
7.	Total sales	Rs./$		
8.	Reduced product cost or price	%		
9.	Reduced inventory investment	%		
10.	Warranty cost	Rs./$		
11.	Cost of poor quality	Rs./$		
12.	Reduced purchased cost	%		
13.	Increase in revenue	%		
14.	Number of employees	Nos.		
15.	PPM defective products shipped to customer	PPM		
16.	Customer lead time	No. of days		
17.	Takt time	Min/ Sec		
18.	Rate of customer returns	%		
19.	Number of new products introduced	Nos.		
20.	Time to market for new products	Years		
21.	Use of visual management or aids	%		
22.	No. of certified suppliers	%		
23.	Average distance between the supplier and manufacturer	Kms		
24.	Percentage of parts delivered directly to the point of use from supplier without incoming inspection or storage	%		
25.	Number of suppliers	Nos.		
26.	No. of sole sourcing suppliers	Nos.		
27.	Number of suggestions made to suppliers	Nos.		
28.	Average number of suppliers for the most important parts	Nos.		
29.	Percentage of parts co-designed with suppliers	% and Nos.		
30.	Supplier or delivery lead time	No. of days		
31.	Percentage on time delivery	%		
32.	Frequency of the deliveries	Per day		
33.	No. of years a supplier is associated with the manufacturer	Years		
34.	Percentage of parts that arrive in standardized containers	% and Nos.		
35.	Penalties due to short quantity	Rs. / $		

S. No.	Performance measures of LM	Units	Measures currently used in your organization	Current performance
36.	Adherence to schedule	%		
37.	Percentage of procedures which are written or documented in the company	%		
38.	Amount of training given to newly employed personnel	Days/ year		
39.	No. of suggestions per employee per year	Nos./ year		
40.	Percent of employees cross trained to perform three or more jobs	%		
41.	Percentage of inspection carried out by autonomous defect control	%		
42.	First Pass Yield	%		
43.	Manufacturing cycle time	In days		
44.	Percentage of defective parts adjusted by production line workers	%		
45.	Percent of products accepted as good without inspection	%		
46.	Percentage of manufacturing process under statistical control	%		
47.	Percentage of preventive maintenance over total maintenance	%		
48.	Number of kanbans (Average)	Nos.		
49.	Throughput time or manufacturing lead time	In days		
50.	Work in process inventory	In days		
51.	Setup time	Mins/ hour		
52.	Finished goods inventory	In days		
53.	Production capacity	Nos.		
54.	Batch size (Average)	Nos.		
55.	Length of product runs	No. of days		
56.	Percentage of production equipment that is computer integrated or automated	%		
57.	No. of mixed models in a line	Nos.		
58.	Raw material inventory	No. of days		
59.	Labour productivity	%		
60.	Value added time	Mins/ hours		
61.	Non value added time	Mins/ hours		
62.	No. of inventory rotations	Nos.		
63.	Equipment utilization	%		
64.	Percentage of unscheduled downtime	%		
65.	Increase in productivity	%		
66.	Labour utilization	%		
67.	Ratio of indirect labour to direct labour	%		
68.	Utilization of capacity	%		
69.	Frequency of preventive maintenance (average)	Per day / week		
70.	Level of housekeeping (Poor – Good – Excellent)			
71.	Increase in production volume	%		
72.	No. of shifts	Nos.		

S. No.	Performance measures of LM	Units	Measures currently used in your organization	Current performance
73.	Production rate	Units/ hour		
74.	Overtime	In hours /month		
75.	Improved equipment efficiency (OEE)	%		
76.	Employee turnover rate	%		
77.	Reduction in number of workers/employees	%		
78.	Percentage of parts delivered just in time between sections in the production line	%		
79.	Percentage of people involving in stopping the line due to problems	%		
80.	No. of teams	Nos.		
81.	Percentage of employees working in team	%		
82.	Reduction in direct labour	%		
83.	Reduction in indirect labour	%		
84.	No. of awards and rewards provided for workers	Nos.		
85.	Time spent on engineering changes	No. of days		
86.	No. of total parts in Bill of Materials (BOM)	Nos.		
87.	Percentage of standardized parts	%		
88.	Percentage of common parts across models	%		
89.	No. of products manufactured in plant	Nos.		

This list is not an exhaustive list. In case you are following some performance measures, which are not found in this list, kindly write the same here along with its current performance values and units.

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Thank you for your kind help.

Yours sincerely,

(G. Anand)

Various databases and journals were searched to identify the list of research papers that chronicled the LM implementation and improvements achieved in the form of case studies. Various case studies were obtained. For instance, Seth and Gupta (2005) described about the utilisation of VSM in the plant of an auto component supplier. Dunstan *et al.* (2006) described about the implementation of LM in mining environment.

Step 21. Identify the potential benchmarking partners based on the above data.

The purpose of the step 20 is to identity the case studies of companies that fall under the category of AC manufacturers. However, no case study is found that discussed about implementing LM in an organisation in the consumer segment – especially in the category of AC manufacturer.

Step 22. Establish the requirements for the selection of benchmarking partners or for the characterization of the degree of relevance that any particular company may have as a potential benchmarking partner.

Various authoritative books on BM written by Camp (1989), Spendolini (1992), etc., described about different types of BM such as functional benchmarking, competitive benchmarking, etc., which highlighted the fact that benchmark company need not be from the same industry. Hence, the benchmarking companies were identified based on the following criteria:

- it should be either a ‘best-in-class’ organization or
- it should be in the same field

So that depending upon the requirement of case organization, necessary benchmarking partners can be selected.

Step 23. Narrow the list to few benchmarking partners by comparing the candidates.

For the first criteria described above, TMC is selected as it is the ‘best-in-class’ organisation in the world in implementing TPS/LM. For the second criteria, XYZ Limited (XYZL), a leading AC manufacturer in South Eastern part of India is selected as one of the benchmarking company, as they are in the same industrial sector.

Phase 7: Pre-benchmarking activities

Step 24. Collect lower level detail on benchmarking partner prior to contacting them (E.g., location, when did they get started, no. of employees, product line, key managers, market share, revenue and profit, customer satisfaction etc.).

The details regarding TMC can be obtained from various authoritative books written by experts such as Monden (1987), Ohno (1988), Shingo (1989), Womack *et al.* (1990), Womack and Jones (1996), etc. These books gives out details regarding the tools, techniques used, benefit achieved, etc. Apart from this, there are many studies which highlighted the performance differences achieved by Japanese manufacturers. For instance, Oliver *et al.* (2002) benchmarked the level of LM implementation in the British automobile industry. In this paper, he compared and discussed about the performance differences, revenue, profit, etc. between the British companies and Toyota and other Japanese companies.

The data regarding XYZL was collected from the annual reports and other information available publicly in the internet. XYZL is the pioneer in cooling appliances in India, as they have sold their ACs to over a million customers in the past four decades. It is the first company to manufacture India's first indigenous room air conditioners in 1954 and setup the first integrated AC plant in 1969. It also has a joint venture between PQR International of USA, a leader in the room conditioning segment. Furthermore, XYZL also entered to the business of water coolers catering to offices, small shops and small scale units apart from marketing a range of commercial refrigerators. It has a good support structure of a 1700-strong dealer base and 700 retailers. It also has a good R&D as evident from the fact that XYZL has launched close to 74 new products in the last decade. They have two plants located in the South Eastern part of India and all these plants have ISO 9000:2000 certification. Currently, it has 266 people delivering a turnover of over Rs. 5000 million. Analysing the profile of the benchmark company, it can be found that there are many similarities between the case organisations. For instance, both the case and benchmark organisations started as a joint venture, products range was similar, while XYZL is an old company, but ABCIL is a more recent organisation. Considering all these factors, the team felt that XYZL is a suitable candidate for performing benchmarking.

Step 25. Establish contact with the selected partner(s) and gain acceptance for participation in the benchmarking study.

The team contacted XYZL. But, they did not give consent for the study immediately as they were implementing organisation changes due to Business Process Re-engineering (BPR). However, the team members decided to proceed with the BM study based on the publicly available data and use it as a preliminary assessment. The reason for the same is that team members can benefit from understanding how to utilise BM. Apart from this, it will enable them to at least understand the 'ideal condition' in a LM environment apart from helping them to assess themselves where does the case organization stand with respect to best-in-class organization.

Step 26 to Step 32 were not conducted, because, they are not applicable, as activities such as questionnaire construction, visiting the site etc. are not required for this preliminary assessment.

Phase 8: Benchmarking

Step 33. Collect data on methods, procedures, performance measure and practices that are considered superior.

Step 34. Sort the collected information and data.

Both these steps were carried out together. The various elements of LM, which were identified earlier from various research papers and authoritative books, were used for data collection. Already, the data regarding the performance measures of the case organization was collected in the Step 18. Hence, in this step, the performance measures of Toyota were identified. For example, Womack *et al.* (1990) expressed that a lean manufacturer (i.e. Toyota) typically uses less of everything – i.e., half the inventory, half the defects, half the manpower, half the resources etc. Similarly, from other research papers and books, details regarding the performances of Toyota were obtained.

Phase 9: Gap analysis

Step 35. Determine current competitive gap.

The current competitive gap was determined based on the differences in the following:

- Practice differences between the case organization and Toyota based on the list of LM elements implemented
- Performance differences between the case organisation and Toyota and,
- Performance differences between the case organisation and XYZ Limited

Table 7.16 shows the practice differences between the case organisation and Toyota. Since, Toyota is considered to be birthplace of LM; it is assumed that all the elements identified earlier in Chapter 3 would have been implemented. Apart from this, it should be remembered here that these elements were collected from the literature related to JIT/TPS, which further acts as the documented evidence for the assumption. From, this table, it can be found that many LM elements that are related to suppliers and strategic aspects are not implemented by ABCIL. Since the benchmark organisation did not give the consent, the practices implemented in XYZL could not be collected. Hence, it is not shown here.

Table 7.16: Practice differences between the case organisation and Toyota

LM element	In short	Implemented at Toyota	Implemented in the case organisation
WIP Reduction	WIP	•	•
Cycle time and Lead time Reduction	CTR	•	•
Layout change or U-Shaped Cell	LAY	•	•
Workload or Line Balancing	WLB	•	•
Focused Factory Production	FFP	•	•
One Piece Flow	OPF	•	•
Design for Manufacturing	DFM	•	•
Single Minute Exchange of Dies	SMD	•	•
Process Sharing	PRS	•	
Flat Organisation Structure	FOS	•	
Defects at Source (Self inspection)	DAS	•	
Successive Checking	SUC	•	
Statistical Process Control	SPC	•	•
Pokayoke or Mistake proofing or Defect Prevention	POK	•	•
Quality Circles	QUC	•	
Computer Integrated Manufacturing (CAD/CAM/CAE)	CIM	•	•
Total Quality Management	TQM	•	
Quality Certification (suppliers and manufacturers)	QUC	•	•
Just-In-Time delivery (from suppliers and within workstations)	JIT	•	•
Synchronization	SYN	•	
Small Lot Production		•	•
Kanban System	KAN	•	
Rolling production plans	RPP	•	•
Production Smoothing or Load Levelling	PSM	•	
Use of EDI with suppliers	EDI	•	
Pull Production	PUL	•	
Maintain Spare Capacity	MSC	•	
Use of Multiple Small Machines	UMS	•	
Cellular Manufacturing	CEM	•	•
Group technology	GRT	•	
Takt time or takt calculations	TAK	•	•
Value Stream Mapping	VSM	•	
Mixed Model Manufacturing / Scheduling	MMM	•	•
Commonization and Standardization of Parts	CSP	•	•
Concurrent Engineering	CEG	•	
Supplier Proximity	SPR	•	•
Supplier Involvement in Design	SID	•	
Standardized Containers	STC	•	•
Supplier Training and Development	STD	•	
Long Term Supplier Relationship	LTR	•	•

LM element	In short	Implemented at Toyota	Implemented in the case organisation
Information Sharing with Suppliers	ISS	•	
Sole Sourcing or supplier reduction	SSO	•	
Housekeeping (5S)	HOK	•	•
Andon (Warning lights)	AND	•	•
Jidoka (Autonomation)	JID	•	•
Work Standardization	WST	•	•
Use of Problem Solving Tools	PST	•	•
Safety Improvement Programs	SIP	•	•
Product and Process Simplification	PPS	•	•
Elimination of buffers	ELB	•	•
Storage Space Reduction	SSP	•	•
Automation	AUT	•	•
Total Productive Maintenance	TPM	•	
Multi Functional Training	MFT	•	•
New Process or Equipment Technologies	NPE	•	•
Long Term Employment	LTE	•	
Multi Skilled Workforce	MSW	•	•
Employee Empowerment	EEM	•	
Employee Participation	EPA	•	•
Rewards and Recognition	RRE	•	•
Cross Functional Team working	CFT	•	
Suggestion Schemes	SUS	•	•
Job Enlargement or Nagara System	JEL	•	
Communication Between Employees	CBE	•	
Job Rotation or Flexible Job Responsibilities	JOR	•	•

On the other hand, Table 7.17 shows the comparison of performance measures that were used by Toyota and the case organisation (ABCIL). Extending the same logic as described above, it is believed that all the performance measures listed in Table 7.17 are followed at Toyota. Analysing the Table 7.17, it can be found that there exists a significant difference between the adoption of performance measures between Toyota and the case organisation. Similarly, the performance difference between the ABCIL, Toyoto and XYZL was identified as shown in Table 7.18.

Table 7.17: Comparison of performance measures that were used by Toyota and the case organisation (ABCIL)

Performance measures of LM	Implemented at Toyota	Implemented in ABCIL
Scrap and rework costs	•	•
Manufacturing cost per unit	•	•
Value of work in progress in relation to sales	•	
Total productive floor space	•	
Reduction in overall plant investment	•	

Performance measures of LM	Implemented at Toyota	Implemented in ABCIL
Gross annual profit	•	•
Total sales	•	•
Reduced product cost or price	•	
Reduced inventory investment	•	
Warranty cost	•	•
Cost of poor quality	•	
Reduced purchased cost	•	
Increase in revenue	•	•
Number of employees	•	•
PPM defective products shipped to customer	•	•
Customer lead time	•	
Takt time	•	•
Rate of customer returns	•	•
Number of new products introduced	•	•
Time to market for new products	•	
Improved time-based competitiveness	•	
Use of visual management or aids	•	•
No. of certified suppliers	•	
Average distance between the supplier and manufacturer	•	
Percentage of parts delivered directly to the point of use from supplier without incoming inspection or storage	•	
No. of sole sourcing suppliers	•	
Number of suggestions made to suppliers	•	
Average number of suppliers for the most important parts	•	
Level of integration between suppliers delivery and the company's production information systems	•	•
Percentage of parts co-designed with suppliers	•	
Supplier or delivery lead time	•	
Percentage on time delivery	•	•
Frequency of the deliveries	•	
Number of suppliers	•	•
No. of years a supplier is associated with the manufacturer	•	
Container size	•	
Penalties due to short quantity	•	
Adherence to schedule	•	
Percentage of procedures which are written or documented in the company	•	
Amount (in hours) of training given to newly employed personnel	•	•
No. of suggestions per employee per year	•	•
Percent of employees cross trained to perform three or more jobs	•	
Percentage of inspection carried out by autonomous defect control	•	
First Pass Yield	•	
Manufacturing cycle time	•	
Percentage of defective parts adjusted by production line workers	•	
Percent of products accepted as good without inspection	•	
Percentage of manufacturing process under statistical control	•	
Percentage of preventive maintenance over total maintenance	•	
Number of kanbans	•	
Throughput time or manufacturing lead time	•	
Work in process inventory	•	•
Setup time	•	•
Finished goods inventory	•	•
Production capacity	•	•

Performance measures of LM	Implemented at Toyota	Implemented in ABCIL
Batch size	•	
Length of product runs	•	
Percentage of production equipment that is computer integrated or automated	•	
Increased flexibility	•	•
No. of mixed models in a line	•	•
Raw material inventory	•	•
Labour productivity	•	
Value added time	•	
Non value added time	•	
No. of inventory rotations	•	
Equipment utilization	•	•
Percentage of unscheduled downtime	•	
Increase in productivity	•	•
Labour utilization	•	
Ratio of indirect labour to direct labour	•	
Utilization of capacity	•	•
Frequency of preventive maintenance	•	
Level of housekeeping	•	
Increase in production volume	•	•
No. of shifts	•	•
Production rate	•	•
Overtime	•	•
Improved equipment efficiency (OEE)	•	
Employee turnover rate	•	
Reduction in number of workers/employees	•	
Percentage of parts delivered just in time between sections in the production line	•	
Percentage of people involving in stopping the line due to problems	•	
No. of teams	•	•
Percentage of employees working in team	•	•
Reduction in direct labour	•	
Reduction in indirect labour	•	
No. of awards and rewards provided for workers	•	
Time spent on engineering changes	•	
No. of total parts in Bill of Materials (BOM)	•	
Percentage of common or standardized parts	•	

Table 7.18: Performance differences between the ABCIL, Toyota and XYZL

Performance measures of LM	ABCIL	TMC	XYZL
Gross annual profit (Rs in millions)	422.49	675126.45	553.1
Total sales (in Nos.)	134787	8913000	338651
Total sales (Rs in millions)	4466.06	9754456.5	8192
Increase in revenue (in %) compared to previous year	37	9.5	35
Number of employees	452	316121	266
Number of new products introduced (in the last 1 year)	7	14*	5
No. of shifts (Approximately)	2	2	2
Increase in production volume (in %) compared to previous year	34.6	4.5	11.2
Raw material inventory (Rs in millions)	442.6	117745.2	1229.8

Performance measures of LM	ABCIL	TMC	XYZL
Work in process inventory (Rs in millions)	79.2	94295.24	2703
Finished goods inventory (Rs in millions)	289.6	476146.62	2463.5
Production capacity in Nos/year	150,000	4505000	25050
Value of work in progress in relation to sales	1.74	0.9	32.76
Market share	8.5	42	16

* TMC has launched 6 new products and remodelled 8 existing products.

This comparison is made with reference to some of the performance measures that were listed in Table 7.17. Based on the data obtained for the limited performance measures, a comparison between the ABCIL, Toyota and XYZL is carried out. It can be found that in some of the performance measures the case organisation is better, while in many of the measures, XYZ Limited is better. However, if a complete BM study could have been carried out, a broader picture of the performance differences can be brought out. In addition to this, based on the publicly available information such as annual report and internet information, a comparison is made between the ABCIL and XYZL with respect to performance measures that are not present in the Table 7.17. For instance, the annual report for TMC can be found in the following website[1]. Table 7.19 shows the comparison of other performance measures between the ABCIL and XYZL

Table 7.19: Comparison of other performance measures between the ABCIL and XYZL

Performance measures of LM	ABCIL	XYZL
Profit after tax as % of sales	9.27	12
Investment in R&D (Rs in millions)	6.99	2.04
Windows ACs: Split ACs	38:62	43:57
Value of exports (Rs in millions)	42.7	382
Value of imports (Rs in millions)	1403.42	4894.94
Product warranty cost (Rs in millions)	140.43	438.8
Value of imported items (Rs in millions)	1297.89	572
Value of indigenous items (Rs in millions)	1647	2288.9
Imported items as % of total consumption	44	20
Indigenous items as % of total consumption	56	80

Step 36. Identification of possible root causes and the superior practices that are responsible for the gap

[1] http://www.toyota.co.jp/en/ir/library/annual/pdf/2008/ar08_e.pdf (accessed on 8 August 2008)

The differences between case organisation and Toyota in terms of performance and practices are very huge. For instance, from Table 7.16, it can be found that the case organization is not following group technology, though it has a variety of ACs to be made. Similarly, adequate importance is not given for the use of small and flexible machines, value stream mapping, flat organisation structure, etc. In the case of comparison with XYZ Limited, it was found that the production of air conditioners for the white goods market (i.e., general customer) has been completely outsourced or purchased from a contract manufacturer, while the case organization fabricates most of critical components and assembles them in-house. In addition to this, the benchmark organization has a service business, which undertakes turnkey projects from construction and engineering industries to design, install and maintain the Heating Ventilation and Air Conditioning (HVAC) systems. Hence, both the commercial and industrial products have a ready market.

Step 37. Evaluating the nature of practices/methods/procedures (enablers) to determine their adaptability to the benchmarking company's culture by performing the feasibility study.

The feasibility of the above discussed LM elements, which were not implemented and the practice of contract manufacturing can be analyzed for its suitability to implement the same in the case organisation.

Phase 10: Action plans

Step 38. Prepare the report and communicate the findings of benchmarking throughout the organization and project the benefits in terms of dollars and get the management commitment.

A detailed report is prepared and presented to the top management, in which the differences in performance measures between the case organisation and that of best-in-class organization was presented. Similarly, the elements of LM, which are yet to be implemented in the case organization was also listed out apart from explaining the benefits, which will be derived by implementing the same.

Step 39. Make results available to benchmarking partners.

Since, the current BM study was preliminary in nature and no partners were involved, this step was not carried out.

Step 40. Establish functional goals.

Step 41. Project future performance.

The practitioners felt that the above two steps can be combined. Though, only a preliminary BM activity was carried out, different functional goals were established in such a way that they are not far-fetched. For instance, the purchase department was giving the target of reducing its suppliers by 10% (from 160 suppliers to 144 suppliers) within the end of the year. The stores department was asked to group the parts and components with respect to the similarity of design and process steps. The production engineering department was given the task of studying the feasibility of establishing kanban system, apart from minimizing the existing setup time for the machines in sheet metal area by 15%. Based on the above goals, the management expected that their performance with respect to competitive priorities will increase. Hence they predicted that number of components/parts will go down by 10%, overall cost will be reduced by 8%, while the production capacity to increase by 12% with the same manpower.

Step 42. Develop the action plan with necessary recommendations and time frame for implementation

The action plans that have to be carried out immediately were identified as follows: development of VSM for the highly selling model, reduction in number of suppliers, setup time reduction, grouping of components and parts, reduction in current WIP, apart from improving the productivity through major/minor process improvements. The total time frame for all these improvements activities was fixed as 4 months. Each department and its associated manager or supervisor was given the task of implementing the same.

Step 43. Gain acceptance from management and employees through commitment and participation respectively for implementing the action plans.

A detailed presentation regarding the results of BM study was communicated to the entire organization by the Executive Director, Supply Chain of the organization and the employees and managers were taken in to confidence before fixing the action plans.

Phase 11: Implementation

Step 44. Prioritize implementation of different practices.

The team felt that VSM has to be done immediately, as they believed that it will clearly show the quantum of value-added and non value-added activities apart from identifying the areas of improvement. Second, they believed that the setup time can be reduced further with the use of group technology to group similar parts, as it will enable the operators to use similar tools and fixtures to produce a family of parts, with minimal setup. They also believed that it will also help in establishing a mixed model assembly line. Finally, they were focused on reducing the suppliers. The purchasing department was asked to get rid of worst suppliers apart from providing more orders to the loyal suppliers. In addition to that, the purchasing manager was informed to eliminate redundant suppliers for similar parts.

Step 45. Deploy the action to the concerned product process owners with the target date for implementation and completion

As mentioned in the previous steps, the departmental managers were made responsible for the implementation of improvements, which are of high priority. The time frame for the above improvements is fixed as 10 weeks. It should be understood here that 4 month target discussed earlier is to ensure that these changes are completely implemented and stabilised; however, the above target of 10 weeks is for only implementation.

Step 46 to Step 54 is not carried out, since the LM implementation is not complete. As explained earlier, the action plans identified will be slowly implemented only in the future. It may take at least 3 to 4 months to completely implement the same. Hence, the 12th phase is not carried out currently.

7.3.3 Results and discussion

The benchmarking of various BM models revealed that each models differs in terms of various factors such as number of steps involved, number of phases, type of benchmarking, etc. For example, among the surveyed models, the number of steps varies from five to 21 steps and similarly the number of phases varies from two to seven. Figure 7.13 shows the graph showing number of steps and number of phases in different BM models. Similarly, analysing the number of BM models proposed under each types of benchmarking also reveals that number of models which can be used commonly across different benchmarking types (general) is the highest, followed by process benchmarking and functional benchmarking models. A separate group – “others” include those benchmarking models, which cannot be clearly classified based on its applicability for the particular type of benchmarking. This analysis proves that attempts were made earlier to develop a generic benchmarking model, which can be applied irrespective of the type of benchmarking. Figure 7.14 shows the number of models under each BM type.

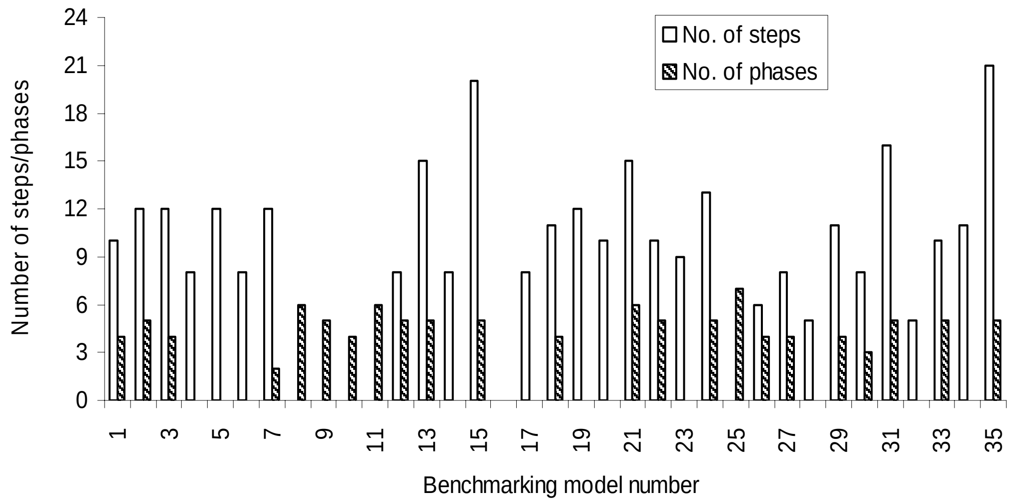

Figure 7.13: Graph showing number of steps and number of phases in different BM models

Similarly, an analysis regarding the number of benchmarking models under each taxonomy reveals that percentage of models under consultant/expert-based is higher (about 48 percent), while the percentage of models under academic/research-based and organization-based are equal (26 percent each). This is a clear evidence that BM as a tool has more practical or industrial utility than academic/research utility. Figure 7.15 shows the percentage of BM models under each categorisation.

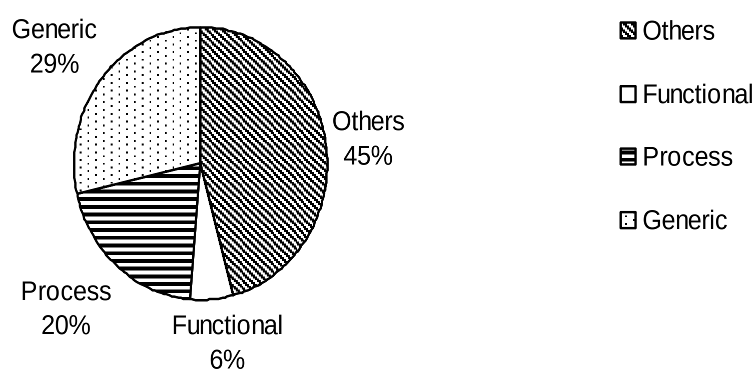

Figure 7.14: Number of models under each BM type

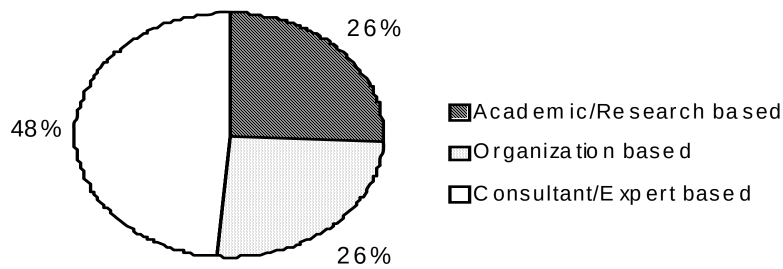

Figure 7.15: Percentage of BM models under each categorisation

It was evident from the earlier discussion that the proposed universal 12-phase, 54-step BM model have incorporated the best practices spanning different areas and types of BM. Thus, it attempts to provide a solution to some of the pitfalls identified by DeToro (1995) and Vaziri (1993). For example, the pitfall – "focusing on metrics rather than process" has been overcome by the step in the "Benchmarking" phase – "Collect data on methods, procedures, performance measure and practices that are considered superior". Similarly another pitfall – "teams not understanding their own work" has been addressed by the step "The subject to be benchmarked is documented and characterized in order to determine and understand its inherent capability" under "Self analysis" phase, as it helps them to understand the status quo and thereby can perform better benchmarking. Though, it is not possible to claim that due care has been taken to address all pitfalls, it is assumed that majority of the pitfalls can be eliminated through the proposed universal benchmarking model.

Also, the proposed universal BM model has been validated using a case study approach in which it was used as a framework for both the purpose of self-assessment and benchmarking the LM implementation. The LM practices and performance measures that were identified in Chapter 3 and Chapter 4 respectively can be used as a template. The self-assessment can be carried out by performing an internal BM, where the organisation can compare with the templates to identify which practices have been implemented till now, which practices are yet to be implemented, what was the performance measure before implementing LM and what is the performance improvement after implementing the LM elements, etc. In a similar manner, the proposed BM process along with the practices and performance measures can also be used for performing external benchmarking – i.e., by comparing the organization with suitable benchmark organization by utilising the practices and performance measures template. A similar approach was followed by Fong *et al.* (2001), who developed an analytical framework for benchmarking Value Management (VM). They identified several critical success factors and its related performance metrics. They noted that such a framework will provide a foundation for researchers to undertake further research on benchmarking VM apart from serving as an evaluation platform for VM teams to assess their performance. Apart from this, the following inferences can be made from this preliminary BM study:

- A cursory analyses of the Tables 7.16 - 7.19 revealed that a huge gap exist between the world's best lean company (i.e. Toyota) and ABCIL. This performance difference is obvious, since the case organization has just started with its LM implementation, while TMC has established its production system a couple of decades back. However, it provided an idea to the managers of the ABCIL about the ideal conditions, which will enable them to improve continuously.
- When analyzing the practices implemented using Table 7.16, it was found that from a list of 65 practices implemented in TMC, only 39 practices has been implemented by ABCIL. Thus, it has adequate scope to implement few more of these practices. For instance, many LM elements that deal with suppliers were not implemented. Similarly, LM elements such as pull system, kanban, production levelling, synchronisation, group technology etc. were not

implemented. Hence, necessary action plans can be made to implement the same.

- Analysing the use of performance measures between the ABCIL and Toyota from Table 7.17, it is found that only 34 measures are used, which also includes some of the traditional performance measures. It should be remembered here that the traditional performance measures, which are financial in nature may not account for intangible benefits offered by LM. Thus, it can be said that the organization need to adopt certain new performance measures that are unique for LM, so that the improvements can be properly reflected.
- A cursory review of the performance measures in Table 7.18 reveals that the case organisation has outperformed TMC in some areas such as increase in production volume, increase in % of revenue, etc. However, in the remaining performance measures, TMC is way ahead of both the case organization and benchmark organisation. Being a global company, it is natural to see a vast performance difference in the sales, number of people employed, raw materials consumed, rate of new product introduction, production capacity, etc. However, if the WIP in relation to sales is compared, it can be found that TMC has the least ratio, which highlights the fact that TMC's focuses extensively on reducing inventory and other wastes.
- In Table 7.18, some of the performance measures identified from the Table 7.17 were used for comparing both the ABCIL and XYZL. It revealed that significant differences exist between both the organisations. For instance, the total sales for XYZL are 83% more than that of ABCIL, the number of employees is 1.6 times more and the inventory levels were much higher. These differences clearly reveal that the XYZL is a well-established and a professional organisation. Furthermore, the size and operations are much larger when compared to the ABCIL, as it deals with providing the HVAC services for various

commercial organisations such as construction industries, factories, airports, etc apart from manufacturing ACs. However, in some of the performance measures, the ABCIL has outscored the XYZL. For instance, the case organisation introduced about 7 products, while the benchmark organisation could implement only 5. The reason is that since ABCIL is striving to capture the market share, the rate of product introduction is higher. Similar is the case with the production volume, which has increased by 34% while only a 11% increase was shown by XYZL. This also supports the fact that the case organisation is growing under the Japanese leadership.

- Comparing the performance differences between ABCIL and XYZL with respect to performance measures shown in Table 7.19, it can be found that XYZL has outperformed ABCIL. Although both companies have a joint venture, the usage of components that were indigenously developed is about 80% for XYZL, while it is just 56% of ABCIL. Since, XYZL has been in the business for long time, they could achieve significant indigenisation. Another important observation is that, the ABCIL is trying to focus on Split ACs as potential revenue generator as it accounts for 62% of its total sales. On the other hand, the benchmark organisation focuses on window AC segment apart from the split ACs, as window ACs accounts for 43% of the sales of XYZL. The reason being that the XYZL is still considering window ACs have a significant market opportunity. Hence, currently they are providing low cost ACs for less than Rs. 10,000 to the aspiring middle class population of the India.
- Discussing about the proposed BM process, some of the steps were not implemented. But, those steps which were implemented are quite logical and sequential. However, the practitioners felt that some of the steps are redundant, while some steps can be combined. For instance, Steps 5 and 6, Steps 12 and 13, Steps 33 and 34, Steps 40 and 41 can be combined. Thus, the proposed

benchmarking model can be improved further by eliminating some of the steps. However, an attempt has been made to demonstrate that the proposed BM process can be used for both self-assessment and benchmarking. For instance, the comparison of ABCIL with TMC can be considered as a self assessment, while the comparison of case organisation with XYZL can be considered as external benchmarking. Of course, the utility of the proposed BM model can be assessed only after performing the complete BM study with the benchmark organisation.

Following are some of the research limitations of this study:

- Many practitioners may criticize the current approach of selecting the ‘best-in-class’ organisation as there is no similarity between the ABCIL and Toyota. However, BM allows for such comparisons in terms of the classification schemes such as functional benchmarking or performance benchmarking.
- Similarly, another criticism which might be encountered is that the BM study could have been completed after getting the consent from any other organisation in the same field. The team could have contacted the professional benchmarking consultants or chambers of commerce, to obtain relevant information. However due to budgetary and time constraints, the same could not be taken up. It should also be noted that a thorough BM study will be conducted soon, by comparing it with another leading AC manufacturer.
- Discussing about the utility of the proposed benchmarking model, some of the steps were not carried out. Hence the proposed model may not be completely validated.

7.4 Conclusions

This chapter started with the claim that 'assessment' plays a key role in any organisational change programme. Hence, the focus of this chapter was in assessing how much the HR of an organisation contributed in implementation of LMS by evaluating what are the roles and responsibilities of HR apart from assessing the entire organisation for its LM implementation. In the former case, a literature review revealed that many papers are available relating HR and LM, while very few papers exist that discuss about the assessment of roles and responsibilities of HR in LM environment. No paper in the literature provided information about 'who will be responsible for carrying out or implementing which elements of LM?' Hence to overcome this issue, a comprehensive list of LM elements identified in Chapter 3 is utilised and a framework for these LM elements is proposed from the perspective of internal and external stakeholders of the organisation. The framework helped in developing the taxonomy for the LM elements and clearly established the roles and responsibilities of every stakeholder involved in the LM implementation. Furthermore, the GT model is demonstrated in a step-by-step manner for assessing the roles and responsibilities of various categories of HR involved in the LM implementation. From this analysis, the roles and responsibilities of individual stakeholders are quantified by considering the degree of implementation of LM elements and the degree of relationship between LM elements under a particular category of stakeholder. On the other hand, the permanent of system level matrix called as CAI, representing the overall quantification of roles and responsibilities of HR in a LM environment and the permanent values of sub-systems (i.e., Per B_{SS1} to Per B_{SS6}) can be used by organisations to benchmark with respect to other best-in-class organisations.

In the latter case of the assessment, various definitions, types and models of BM were reviewed and a classification scheme for the reviewed models is developed. Few questions were also raised regarding the classification scheme and role of different benchmarking models available in the literature for which the following solutions were provided: a simple classification scheme is proposed by reducing the classifications to internal and external benchmarking; and a new BM process is proposed which is developed by benchmarking the commonly used “Xerox model” with other models available in the literature. The best practices identified from this analysis have been categorized into different phases and was included in the proposed model. It consists of 12 phases and contains the 54 steps. Apart from this, a discussion on how the proposed model can eliminate some of the pitfalls of benchmarking is also presented. Since, the proposed BM process was conceptual; it was validated by utilising it to assess the level of LM implementation in a case organisation. A review of recent literature revealed that number of papers that related BM and LM was quite less. In particular, the literature using a standard BM process in the field of LM for assessment is not available. Hence, an attempt has been made to fill in this research gap by using the universal BM process proposed earlier to conduct a preliminary benchmark study of a case organization to assess its lean implementation. The LM implementation of the case organization (ABCIL) was benchmarked with that of Toyota – the best-in-class lean manufacturer and XYZL, a market leader in India in the AC segment. Discussing about the results, it was found that there exist a huge difference between the practices implemented and performance measures followed in the case organization with respect to Toyota and the XYZL. Thus, it can be concluded that the case organization has a good scope for continuously improving their performance, if they focus on implementing other LM elements properly. Being a preliminary study, the last two phases of the proposed 12 phase, 54 step benchmarking process could not be validated. But as a whole, the process seemed to be logical and sequential; however it was felt that some steps can also be eliminated.

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Chapter 8

Conclusions

Manufacturing industries are under immense pressure from the increasingly competitive global market to improve the efficiency and productivity of their production activities. Under such circumstances, many industries are implementing various change management programmes such as Total Quality Management (TQM), Total Productive Maintenance (TPM), Six-Sigma (SS), Lean Manufacturing Systems (LMS), etc. Among such programmes, LMS has attracted the attention of managers significantly, as evident from the number of case studies and participating organization in the surveys that are reported in the literature. However, many organizations are failing in their attempts to implement LMS. Although many publications and books are available that discusses about Lean Manufacturing (LM), it is ironical to hear about such failures. One of the reasons put forth by the researchers is that 'there is an improper understanding of LMS among the employees of organization'. But implementing LMS requires a thorough understanding about the 'constituents of LMS', 'performance measures of LMS', 'implementation procedure of LMS' and 'assessment of LMS'. In addition, it is also necessary to analyze 'whether implementing LMS is justified'. However, it is believed that such fundamental issues are not yet addressed completely in the literature. Hence, there is a need to study the design and assessment of LMS in Indian industry.

This research is aimed at examining some of the fundamental issues in the field of LMS. Therefore, the main objective of this research is to explore the above-mentioned fundamental issues and the necessary solutions were obtained for these issues by carrying out the following activities:

- In chapter 2, various research papers pertaining to LM, which were published in renowned national/international journals and conferences, were reviewed and a taxonomy model was established to classify the same. Apart from this, various research gaps were identified under the proposed classification of LM literature.

- Chapter 3 started with a claim that one of the reasons for not achieving the true benefits of LM by the organization is that the managers and employees do not understand clearly what constitute LMS. Hence, to facilitate a better understanding of LM, two frameworks for LMS were proposed. The first framework – i.e., the conceptual framework for LMS attempts to provide comprehensive information about "what constitute LMS", while the second framework – i.e., the implementation framework for LMS attempts to provide a step-by-step approach of "how to implement LMS". During the course of developing the frameworks, various shortcomings of the existing frameworks were identified apart from establishing necessary taxonomies. Finally, a case study of an organisation implementing LM was presented and it was found that elements and the approach for implementing these elements in the organisation seems to be supporting the proposed frameworks.

- Chapter 4 too started with a claim that 'there is no comprehensive Performance Measurement System (PMS) and metrics available for organisation that has implemented or about to implement the principles of LMS'. Hence, a three-phase methodology that was available in the literature was used for designing the PMS for LMS. In the first phase, to design the performance measures, a frequency analysis was carried out and around 90 performance measures were identified for the development of PMS for LMS. During the second phase of implementing the performance measures, the taxonomy for the identified performance measures of LM based on the competitive priorities, relationship between the elements of LM and relationship with different business processes of an organisation was established. After such classifications, the PMS for LMS is proposed based on the most commonly used framework for performance measurement, namely, the Balanced Score Card (BSC). It was modified suitably to include the perspective of suppliers. Finally, the case studies pertaining to implementation of JIT or LM in SMEs were reviewed to analyse the performance measures that were used by various SMEs. From this review, it was found that most of the performance measures identified from the case studies were also present in the proposed framework.

- Chapter 5 presented a case of a valve manufacturing company, in which the management has to decide between implementing a technically sophisticated Computer Integrated Manufacturing Systems (CIMS) or highly successful management based and people oriented philosophy - LMS. Since such decisions are strategic in nature, it was analysed from various perspectives – namely, the capability of alternative manufacturing systems, the impact of these alternative manufacturing systems on each functions of the operations department, different costs that will be incurred, the impact on the stakeholders such as shop floor associates, engineers/supervisors, managers and top management, suppliers and customers of the organisation, the benefits that can be obtained from alternate manufacturing systems and the impact of these alternate manufacturing systems on the performance measures. Three Multi-Attribute Decision Making (MADM) models, namely the Analytic Network Process (ANP), Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE) and the Performance Value Analysis (PVA) were used to analyse the above-mentioned perspectives. The results of these models indicated that the LMS is superior, when compared to the other alternatives for the case organisation.

- Chapter 6 noted that even though Value Stream Mapping (VSM) can depict how an organisation will be in the future after it gets transformed by the principles of LM, it suffers from various shortcomings. Hence, researchers have suggested the use of simulation in conjunction with the VSM to resolve the shortcomings of VSM. However, a review of literature related to simulation and LM/JIT revealed that most of the simulation studies focused on studying about the LM elements such as kanbans (finding the optimal number of kanbans), push and pull systems (comparison), mixed model assembly (sequencing and scheduling), etc. Other LM elements such as multi-machine activity (job enlargement), machine grouping (cell manufacturing), pokayoke, process improvements, cycle time reduction, layout changes, automation, etc. has not been given adequate importance in the simulation studies. Hence, to overcome such issues, simulation is used in conjunction with VSM to model the current state and future state VSM of the following case organisations: a brake lining manufacturer following a batch production process; a gear manufacturer following a mass production system; and a furniture manufacturer following a job shop production. The impact of implementing some of the LM tools on the performance of these organisations was analysed by comparing the performance measures for current and future state VSM and it was found that there was significant improvement in the productivity and quality, while there was significant reduction in inventory, cycle time, floor space and other wastes. Finally, the results of the simulation model were found identical with the results obtained after the implementation of improvement activities in the shop floor.

- Chapter 7 focussed on assessing how much the Human Resources (HR) of an organisation contributed in implementing LM and where does the entire organisation stand in terms of LM implementation, when compared against best-in-class LM organisations. For the first case, a Graph Theoretic (GT) model was utilised for assessing the roles and responsibilities of various categories of HR involved in the LM implementation. From this analysis, the roles and responsibilities of individual stakeholders are quantified by considering the degree of implementation of LM elements and the degree of relationship between LM elements under a particular category of stakeholder. For the second case, BenchMarking (BM) was utilised. Various definitions, types and models of BM were reviewed and a classification scheme for the reviewed models is developed. Few questions were also raised regarding the classification scheme and role of different benchmarking models available in the literature for which the following solutions were provided: a simple classification scheme is proposed by reducing the classifications to internal and external benchmarking. Furthermore, a new benchmarking process is proposed and the proposed benchmarking process was utilised for the assessment of LMS by conducting a preliminary benchmarking study of a case organization that has implemented LM in recent years. The LM implementation of the case organization (ABCIL) was benchmarked with that of Toyota – the best-in-class organisation in LM implementation and XYZL, a market leader in India in the Air Conditioner (AC) segment. It was found that there exist a huge difference between the practices implemented and performance measures followed in the case organization with respect to Toyota and the XYZL and the case organization has a good scope for continuously improving their performance, if they focus on implementing other LM elements properly. Being a preliminary study, the last two phases of the proposed 12 phase, 54 step benchmarking process could not be validated. But as a whole, the process seemed to be logical and sequential.

Implications of the study

Following are some of the managerial implications of this study, which are relevant for the practitioners:

- The proposed frameworks describing what constitute LMS and how to implement LMS will help the managers and practitioners in understanding clearly about LM. Apart from this, it will resolve the problem of 'incomplete understanding and lack of employee education in the concept and principles of LM', which was identified by the researchers as one of the major reason for failure of LM implementation.
- The proposed PMS for LMS will help the practitioners in understanding which performance measures have to be considered for organisations implementing LMS. Apart from this, it will help them in choosing a relevant performance measures to reflect the impact of LM implementation on their organisation.
- Similarly, the MADM models such as ANP, PROMETHEE and PVA will help the managers in making a decision of identifying suitable manufacturing systems as per their manufacturing strategy. The detailed step-by-step algorithm may also enable them to apply it in real-life situations for various other strategic decision problems and thereby ensures that decisions are made systematically.
- The simulation models developed for various case studies will also help the managers understand in a better way about 'how an organisation will be affected by the design of LMS'. It will help them analyse various 'what if' cases by changing the parameters in the simulation model and observe its impact on the performance measures. Furthermore, it will provide a real-life picture of manufacturing systems. Hence, the feasibility of changes can be studied before the actual implementation takes place. Thus, it also helps the managers in making more meaningful decisions.

- A graph theoretic model was used for the assessment of the roles and responsibilities of the various stakeholders of the HR in an organisation which is about to implement LMS. In this case, taxonomy for the LM elements from the perspective of HR was proposed, which can be used by the managers to distribute the roles and responsibilities during the LM implementation. Apart from this, a detailed step-by-step methodology for the GT approach has been presented. Hence, if a manager of the organisation is interested in quantifying the degree of roles and responsibilities of HR during LM environment, they can utilise the same. They can also use it as an index to benchmark against other organisations to assess, compare and identify the gaps. Similarly, the benchmarking process was used for assessing the implementation of LMS. The proforma containing the practices (i.e., list of LM elements) and the performance measures can be used as a template by the managers for self-assessment or for collecting data from other organisations. Furthermore, a step-by-step procedure of assessment of LM implementation using the proposed BM process was provided, which can help the managers to understand how BM can be utilised for LM assessment.

Similar to the managerial implications, following are some of the implications, which are relevant for the academicians:

- Various research gaps were identified from the literature review. However, this study provided answers only for some of the research gaps. Further work can be taken up to provide the missing link for other research questions such as: ‘how many companies have implemented LM in different sectors’, ‘what are the differences in LM implementation, when it is implemented in different business sectors’, ‘which of the LM elements are most commonly used and which are least used’, etc.

- Most of the research questions are supported with necessary case examples. These case studies can be used as a pedagogical tool in courses such as ‘world-class manufacturing’, ‘production planning and control’, etc.
- Even though the proposed frameworks for LMS, the proposed PMS for LMS and the proposed benchmarking process for assessing the implementation of LMS are partially validated through case studies, it can eliminate the problem of improper understanding of LMS which were identified by the researchers as the major problem during the implementation of LMS.

Avenues for further research

This thesis attempted to answer various fundamental issues in the design and assessment of LMS. However, adequate scope exists to further the research. The literature review can be improved by performing a frequency analysis which can provide details regarding the number of books and papers that are published in various top-notch operations management journals every year. Similarly, the proposed frameworks for LMS and PMS for LMS, which were partially validated, can be validated through an empirical approach in the form of a clinical approach or surveys.

List of Publications and Presentations

Journal Articles (Peer-reviewed)

Published

1. **Anand, G.** and Kodali, R. (2008) 'A conceptual framework for lean supply chain and its implementation', *International Journal of Value Chain Management (IJVCM)*, Vol. 2 No. 3, pp.313-357.
2. **Anand, G.** and Kodali, R. (2008) 'Benchmarking the benchmarking models', *Benchmarking-An International Journal (BIJ)*, Vol. 15 No. 3, pp. 257-291.
3. **Anand, G.** and Kodali, R. (2008) 'Development of a conceptual framework for lean new product development process', *International Journal of Product Development (IJPD)*, Vol. 6 No. 2, pp.190-224.
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6. **Anand, G.** and Kodali, R. (2008) 'A multi-criteria decision-making model for the justification of lean manufacturing systems', *International Journal of Management Science and Engineering Management (IJMSEM)*, Vol. 3 No. 2, pp.100-118.

Accepted

1. **Anand, G.** and Kodali, R. 'A mathematical model for evaluating the roles and responsibilities of human resources in a lean manufacturing environment', *International Journal of Human Resources Development and Management (IJHRDM)*
2. **Anand, G.** and Kodali, R. 'Simulation model for the design of lean manufacturing systems - a case study', *International Journal of Productivity and Quality Management (IJPQM)*
3. **Anand, G.** and Kodali, R. 'Development of a framework for lean manufacturing systems', *International Journal of Services and Operations Management (IJSOM)*
4. **Anand, G.** and Kodali, R. 'Selection of lean manufacturing systems using the analytic network process – a case study', *Journal of Manufacturing Technology Management (JMTM)*
5. **Anand, G.** and Kodali, R. 'Application of the benchmarking process for assessing the lean manufacturing implementation' *Benchmarking: An International Journal (BIJ)*
6. **Anand, G.** and Kodali, R. 'Analysis of lean manufacturing frameworks', *Journal of Advanced Manufacturing Systems (JAMS)*

7. **Anand, G.** and Kodali, R. 'Application of value stream mapping and simulation for the design of lean manufacturing systems - a case study', *International Journal of Simulation and Process Modelling (IJSPM)*

Communicated

1. **Anand, G.** and Kodali, R. 'Design of lean manufacturing systems using the simulation approach – a case study of a furniture manufacturer', *Journal of Indian Business Research (JIBR)*
2. **Anand, G.** and Kodali, R. 'Development of a conceptual implementation framework for lean manufacturing systems', *International Journal of Management Practice (IJMP)*

Under preparation

1. **Anand, G.** and Kodali, R. 'Lean manufacturing – a literature review'

Papers published/presented in conferences

2008

1. **Anand, G.** and Kodali, R. (2008) 'A simulation approach for the design of lean manufacturing systems', *Presented in the International Conference on Frontiers in Design and Manufacturing Engineering (ICDM-08)*, February 01-02, 2008, Coimbatore, India (Organized by Karunya University, Coimbatore)
2. **Anand, G.** and Kodali, R. (2008) 'Lean manufacturing – past, present and the future', *Proceedings of the All India Seminar on "New Vistas In Manufacturing*", January 05-06, 2008, Jaipur, India. (Organized by Institute of Engineers, Rajasthan State Chapter)

2007

3. **Anand, G.** and Kodali, R. (2007) 'Performance value analysis for justification of lean manufacturing systems', *Proceedings of the IEEE International Conference on Industrial Engineering and Engineering Management (IEEM 2007)*, December 2-5, 2007, Singapore.

2006

4. **Anand, G.** and Kodali, R. (2006) 'A conceptual framework for lean new product development', *Proceedings of the National Conference on Design for Product Life Cycle (DPLC-2006)*, February 17-18, 2006, Pilani, India, (Organized by BITS, Pilani, Rajasthan)

Brief Biography of the Candidate

G. ANAND was born on 18th May 1978 at Kumbakonam, a temple town in the Thanjavur district, Tamil Nadu. He completed his schooling in Chennai, Tamil Nadu and enrolled for the Bachelors of Engineering (BE) degree programme with specialization in Mechanical Engineering at Sri Venkateswara College of Engineering (SVCE), Sriperumbudur, Tamil Nadu (affiliated to the University of Madras) in the year 1995. He completed his BE degree with honours (first class with distinction) in the year 1999. He started his career with TVS Electronics Limited (TVSE), a leading computer peripheral manufacturing company in India, where he joined as a Graduate Engineer Trainee (GET) after getting placed through the campus interview. Subsequently after one year, he was promoted as a Production Engineer. He played a key role in establishing the assembly line for a new product apart from establishing the ISO 9000 quality system.

In the quest of seeking additional knowledge, he joined Birla Institute of Technology & Science (BITS), Pilani, Rajasthan in the year 2002, to pursue his Master's in Manufacturing Systems Engineering. He completed the same in the year 2003 and joined his almamater as a faculty member in the Mechanical Engineering Group of BITS, Pilani, India. He is currently working as a lecturer and simultaneously pursuing his PhD in the area of lean manufacturing. His current research interests are in the areas of lean manufacturing, world-class manufacturing, operations management and maintenance management. He has published around 15 papers in peer-reviewed international/national journals and has presented about 5 papers in various international/national conferences.

Brief Biography of the Supervisor

PROFESSOR RAMBABU KODALI is the Group Leader of the Mechanical Engineering Group and Engineering Technology Group of Birla Institute of Technology & Science (BITS), Pilani, Rajasthan, since 1994 and 2004 respectively. He obtained his Bachelor's Degree (BE Mechanical Engineering) in 1980 and his Master's degree (MTech) in 1984 from Maulana Azad National Institute of Technology (MANIT), Bhopal. After 3 years of teaching experience as lecturer, he joined as a Research Scholar in the Department of Mechanical Engineering, Indian Institute of Technology, Kharagpur in 1986, where he also worked as a Teaching Assistant for 6 semesters. After the submission of his PhD thesis, he joined as a Lecturer in the Department of Mechanical Engineering at IIT Delhi in 1990. He obtained his PhD in the year 1991 for the research in the areas of Flexible Manufacturing Systems (FMS) and Knowledge-based Systems. He moved to BITS, Pilani in 1992 as Assistant Professor, where he has been teaching ever since. He was promoted as Associate Professor (Scale: 16200-450-20900) in 1995 and as Professor (Scale: 16200-450-20900-500-22400) in 2000. Till date, he has around 25 years of teaching/research experience and 14 years of administrative experience as Group Leader.

As an academician and administrator, he was involved in initiating and developing various on-campus programmes such as integrated first degree programme in manufacturing engineering and higher degree programmes in design engineering and manufacturing systems engineering at BITS, Pilani. He has also played an active role in the curriculum development of 16 off-campus work-integrated learning and collaborative programmes for BS and MS degrees in diverse fields such as engineering technology, manufacturing engineering, design engineering, manufacturing management, marine engineering, etc. for the Distance Learning Programmes Division (DLPD) of BITS, Pilani. He has also developed and established the FMS Laboratory apart from modernizing various laboratories at BITS Pilani. In addition to this, he is also involved in the academic planning of Mechanical Engineering Group Laboratories for the BITS Pilani Dubai campus, Goa Campus and Hyderabad Campus.

His research interests are diverse, which include Lean Manufacturing Systems, World-class Manufacturing (WCM)/Manufacturing Excellence, Manufacturing Strategy, Total Productive Maintenance (TPM), FMS, Innovative Product Development, Empirical studies and Decision Support Systems. He has published around 200 papers in various national/international journals and conference proceedings. He has also participated in number of conferences presenting technical papers and delivered invited lectures as a key note speaker. He has been a reviewer for many international journals. In addition, he has been a member of various advisory and technical committees of national and international conferences and other governmental agencies. He was also the examiner for 13 PhD theses from various national/international universities and institutes. He has supervised 7 PhDs and currently supervising 4 more doctoral candidates. He has completed 7 research projects on FMS, Computer Integrated Manufacturing Systems (CIMS) and WCM, which includes a project from Department of Science and Technology (DST) under the "Young Scientist Scheme". Currently, he is working on two projects under the thrust areas of Manufacturing Excellence and Innovative Product Design and Development. He has conducted four seminars/refresher courses on topics such as FMS, WCM and Manufacturing Excellence. He has received three best paper awards apart from three other awards in recognition of his academic and scientific contribution.