Development and Validation of Lean Manufacturing Drivers, Barriers and Framework with a Focus on Ceramic Industry

THESIS

Submitted in partial fulfilment
of the requirements for the degree of
DOCTOR OF PHILOSOPHY

by

JAIPRAKASH BHAMU

Under the Supervision of
PROF. KULDIP SINGH SANGWAN

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI

2013

I DEDICATE THIS RESEARCH WORK

TO THE LOVING MEMORY OF

MY LATE YOUNGER BROTHER

MANPRAKASH BHAMU

WHOSE SUDDEN DEATH

WHEN I JUST STARTED

TO PICK THE THREADS OF

MY RESEARCH WORK

HAS RESULTED IN

A NEVER ENDING MISERY

BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI

CERTIFICATE

This is to certify that the thesis entitled **“Development and Validation of Lean Manufacturing Drivers, Barriers and Framework with a Focus on Ceramic Industry”** and submitted by **Jaiprakash Bhamu** ID No **2009PHXF402P** for award of Ph.D. of the Institute embodies original work done by him under my supervision.

Signature of the Supervisor

Dr. Kuldip Singh Sangwan

Associate Professor and Head of Department

Mechanical Engineering Department

Date: 19 Jan, 2013

ACKNOWLEDGEMENTS

My esteem indebtedness is first and foremost bestowed to the God and my most loving parents Mrs. Nanchhi Devi and Sh. Ramnath Bhamu, for granting me the wisdom, courage and health. My heartfelt gratitude to my respected supervisor Dr. Kuldip Singh Sangwan for his immeasurable insightfulness and guidance. He not only motivated me constantly but also gave appropriate suggestions whenever needed.

Special thanks to my sponsor institute Govt. Engineering College, Bikaner and the former principal Dr. M. P. Poonia for having faith in me.

I would like to extend my gratitude to the renowned persons of BITS, Pilani: Prof. L. K. Maheshwari (Professor Emeritus-cum-Advisor and former-Vice Chancellor), Prof. B. N. Jain (Vice-Chancellor), Prof. G. Raghurama (Director), Prof. R. N. Saha (Deputy Director, Administration), Prof. S. K. Verma (Dean, Academic Research, Ph.D. Programmes), Dr. M. S. Dasgupta (Unit Chief, Placement) and Prof. N. N. Sharma (Dean, ARCD) for providing the necessary facilities, moral support and motivation during the research work. I feel obliged to Prof. Ravi Prakash (former Dean, Research and Consultancy Division, BITS, Pilani) for his support.

I wish to express gratitude to my Doctoral Advisory Committee members, Dr. Abhijeet K. Digalwar, and Dr. R. P. Mishra, for their constructive and valuable suggestions.

I am also grateful to Dr. Devika Sangwan, Dr. Manoj Soni, and Dr. Sharad Shrivastva, Mr. Sachin U Belgamwar for providing me the guidance whenever I needed.

It has been a pleasurable experience knowing and working alongside colleagues at the BITS, Pilani. It is difficult to mention them all, but my honest appreciation goes to Mr. Girish Kant, Mr. J. S. Rathore, Mr. Navneet Khanna, Mr. Anil Jindal, Mr. Vikrant Bhakar, Mr. Ankur Jindal, Mr. Lakshminarayana, Mr. Onkar Bageria.

This research would not have been possible without the support from my colleagues at the Govt. Engineering College, Bikaner. I acknowledge; the support of Dr. Virendra Choudhary, Dr. Gourav Bissa, Mr. Manoj Kuri, Mr. Rajendra Singh Shekhawat, Mr. Prashant Bhakar, Mohd. Yunush Sheikh, Mr. Rajesh Kr. Ojha, Mr. Vineet Kumar, Mr. Ranjeet Singh Rathore, Mr. Amit Mathur, and all the supporting staff especially Mr. Onkar Singh.

It was a God send opportunity meeting with many CEOs, Directors and employees of various ceramic industries of Rajasthan. I would sincerely thank the employees of many ceramic industries specifically Mr. Anurag Saxena, Mr. Dhirendra Saraswat for helping me to understand the industrial environment.

I also express my gratitude for the kind and affectionate enquiries about the work and encouragement given by Dr. K. R. Bageria (Managing Trustee, VIT Campus), Mr. Madhukar Bageria (Director, MEC Bikaner), Mr. J. S. Poonia (Vice-Chairman, BIET Sikar), Dr. Ramesh Pacher and Mr. Manish Jhajharia. A very special expression of appreciation is extended to my brothers (Mr. Mahendra, Mr. Moolchand and Mr. Heeralal) and my in laws Sh. Madho Ram Rose, Mrs Sharwani Devi, Miss Anju and Mr. Surendra Rose. Without their encouragement, patience and understanding this endeavor would not have been possible.

Lastly but most importantly, I extend my deep and infinite love to my son Master Devang Choudhary (Honey) and my beloved wife Mrs. Anita Bhamu without whose encouragement and unconditioned support, I wouldn't have come this far.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchy Process
AM	Autonomous Maintenance
BEA	Bond Energy Analysis
BOP	Bottom of the Pyramid
CCTV	Close Circuit Television
CFA	Confirmatory Factor Analysis
C&G	Cutting & Grinding
CI	Continuous Improvement
CIM	Computer Integrated Manufacturing
CITC	Corrected Item Total Correlation
CM	Cellular Manufacturing
CMV	Cavity
COPQ	Cost of Poor Quality
COS	Chrysler Operating System
CR	Cement Rejection
CVSM	Current Value Stream Mapping
DP	Damaged Pug
ED	External Drivers
EFA	Exploratory Factor Analysis
ERP	Enterprise Resource Planning
FIFO	First In First Out
FMCG	Fast Moving Consumer Goods
FMS	Flexible Manufacturing System
FVSM	Future Value Stream Mapping
GT	Group Technology
HR	Human Resource
HRM	Human Resource Management
HVLV	High Variety Low Volume
ID	Internal Drivers
ISIC	International Standard Industrial Classification
INBT/INST	Inside Bottom/Inside Top
IT	Information Technology
ITC	Information Technology for Communication
JIT	Just-In-Time
KCA	Kaizen Circle Activity
KMO	Kaiser-Meyer-Oklin

KPM	Key Performance Metrics
KPS	*Kawasaki Production System*
LAI	Lean Advancement Initiative
LM	Lean Manufacturing,
LP	Lean Production
LSC	Lean Supply Chain
LSS	Lean Six Sigma
MAS	Management Accounting Systems
MRP	Material Resource Planning
MT	Metric Ton
NC	Neck Crack
NVA	Non-Value Added Activities
OD	Outer Diameter
OEE	Overall Equipment Effectiveness
OMCD	Operations Management Consulting Division
PC	Peticot Crack
PCD	Pitch Circle Diameter
PD	Policy Drivers
PED	Piezo Electric Dryer
PKT	Practical Kaizen Training
POUS	Point Of Use System
PMR	Pug Mill Reaming
PPC	Production Planning & Control
PT	Processing Time
QC	Quality Control
QFD	Quality Function Deployment
QIP	Quality Improvement Programme
RC	Round Crack
ROC	Rank Order Clustering
RTST	Raw Stock Take
SB	Shed Bend
SC	Shed Cut
SCADA	Supervisory Control and Data Acquisition
SEM	Structural Equation Modeling
SFC/IDCR	Surface Crack/Inner Dia crack
SMED	Single Minute Exchange of Dies
SMEs	Small and Medium Enterprises
SOPs	Standard Operating Procedures
SPC	Statically Process Control

SPSS	Statistical Package for Social Sciences
TOC	Theory of Constraints
TPM	Total Preventive Maintenance
TPS	Toyota Production System
TQM	Total Quality Management
TT	*Takt time*
VSM	Value Stream Mapping
WCM	World-Class Manufacturing
WIP	Work-In-Progress
WT	Waiting Time

ABSTRACT

The study aims at developing and validating drivers, barriers and framework of lean manufacturing implementation with a focus on the ceramic industries. This study also focuses on the review of literature in lean manufacturing to understand its evolution and current research issues.

To achieve the objectives of the proposed research, the following activities are to be carried out:

- A thorough review of literature on lean manufacturing.
- Development of lean manufacturing drivers and barriers through literature review and discussion with experts from industry.
- Validation of the lean manufacturing drivers and barriers by an empirical study using statistical tools.
- Development of models of lean manufacturing drivers and barriers using structural equation modeling technique.
- Review of existing lean manufacturing implementation frameworks to find the research gap.
- Development of a lean manufacturing implementation model.
- Validation of the developed framework through implementation of lean manufacturing in a case company.

It is expected that the research will be of significant importance to the managers in the industry and researchers in the field of lean manufacturing. The knowledge and understanding of lean drivers and barriers will help the managers in the industry to leverage the drivers and mitigate barriers effectively before implementing lean manufacturing. The proposed framework of lean manufacturing implementation will also be useful for the industry to effectively implement lean manufacturing for the

improvements in the performance to gain competitive edge. The study is also significant for researchers in the field of lean manufacturing as the study provides an extensive literature review of lean definitions, contributors, type of research methodologies used, types of industries implementing lean, lean tools and techniques, and lean implementation frameworks.

CHAPTER 1

INTRODUCTION

The chapter presents the overviews of lean manufacturing and ceramic industry in Rajasthan; research motivation; objectives and scope of the study; methodology; significance of the study; and organization of the thesis.

1.1 OVERVIEW OF LEAN MANUFACTURING

The lean concept originated in Japan after the second world war when Japanese manufacturers realized that they could not afford the massive investment required to rebuild the devastated facilities. Toyota began the process of developing manufacturing processes to minimize waste in all aspects of operations. They produced autos with less of everything – half the human effort, half the manufacturing space, half the investment, half the engineering hours – compared with mass production, the prevalent manufacturing process at that time. Also, it required fewer inventories, had fewer defects, and produced a greater and ever growing variety of products. This was possible primarily due to the Japanese effective management of production and human resources (Womack *et al.* 1990).

The term lean manufacturing came into existence from the International Motor Vehicle Programme (IMVP) researchers of the Massachusetts Institute of Technology. The project was focused to bridge the significant performance gap between Western and Japanese automotive industries. Womack *et al*. (1990) through their book *The Machine that Changed the World* popularized lean concept in manufacturing. In early 1990s lean manufacturing concept was viewed as a counter-intuitive alternative to traditional Fordism manufacturing model (Womack et al., 1990). The modern concept of lean manufacturing can be traced to the Toyota

Production System (TPS), pioneered by Japanese engineers Taiichi Ohno and Shigeo Shingo. Lean practices were implemented based on several prior ideologies such as JIT (Monden, 1983), Zero Inventory (Hall, 1983), Japanese Manufacturing Techniques (Schonberger, 1982), and TPS (Ohno, 1988; Monden, 1983).

The goal of Lean Manufacturing (LM) is to become highly responsive to customer demand by reducing the waste in human effort, inventory, time to market, and manufacturing space while producing quality products efficiently and economically. Lean manufacturing provides competitive edge to the manufacturer due to reduced cost, and improved productivity and quality. Lean manufacturing aims at producing products and services at the lowest cost and as fast as required by the customer. Several authors have posited lean production as the best possible production system that can be implemented in any company (Womack *et al.* 1990). A major step in the journey towards lean is the effective management of the flow of products and services through a series of activities involved in providing value to the customer, known as value stream.

Various authors have documented quantitative benefits of lean implementation such as improvement in production lead time, processing time, cycle time, set up time, change- over time, inventory, defects & scrap, overall equipment effectiveness, etc. The various qualitative benefits include improved employee morale, effective communication, job satisfaction, standardized housekeeping, team decision making, etc. Even in an industry with so many regulatory requirements, lean practices positively affect operational performance (Gebauer *et al*, 2006).

Lean manufacturing implementation started in automobile industry and soon its application was adopted by other industries like textile, construction, food, medical, electrical & electronics, services, etc. LM has been adopted by all types of manufacturing systems – product layout, process layout, and fixed layout; batch production and mass productions; discrete production and continuous production. It has found applications from manufacturing to service sector; mass production to high variety and small volumes production; labour-intensive industries to technology intensive industries; construction industry to assembly industry; and medical health care to communication industry. However, the implementation of lean manufacturing in the continuous process industry has been less partly because of certain difficulties in the implementation in these type of industries (Jimenez *et al*. 2011). Application of lean manufacturing in ceramic industry is also challenging as half the process is continuous type and the other half is discrete part manufacturing.

1.2 OVERVIEW OF CERAMIC INDUSTRY IN RAJASTHAN

In India, the ceramic industry has witnessed rapid growth in demand primarily due to growth in construction and housing sector. This has led to burgeoning demand for sanitary ware, floor and wall tiles. Ongoing reforms in the power sector and expansion of distribution infrastructure have resulted in demand for insulators, especially high tension insulators (for 33kv and above). This is likely to represent a captive market and a steady growth for at least 5-10 years as more and more states get into power sector reform (Rajasthan infrastructure Agenda 2025, Price Water Cooper house report). Rajasthan accounts for 25% of the production of sanitary and electric insulators (http://www.ceramics-india.com/category/ceramic-industry-india/). Despite being a raw material rich region, the ceramic industry is still largely underdeveloped in this region. This is partly because the production systems are not managed efficiently and effectively. It is expected that the implementation of performance improvement initiatives like lean manufacturing will improve the competitiveness of these organizations.

The opening of the Indian market has created both opportunities and challenges for all business enterprises in general and Micro, Small and Medium Enterprises (MSMEs) in particular. These challenges forced the companies to implement various productivity improvement initiatives to face the competition and to improve economic and social well being. Productivity growth and improvement have been the major concerns of a nation's economic and social progression (Mohanty and Deshmukh, 1998). Since 1980s, numerous businesses in various sectors of industry have continually been introducing programmes intended to improve productivity and quality (Cua *et al.,* 2001; White and Prybutok, 2001).

1.3 RESEARCH MOTIVATION

The state of Rajasthan is blessed with various minerals which also include rocks. Feldspar and clay are available in abundance in this place thus Rajasthan is the best location for the ceramic industry. From past many years it has been the biggest source of ceramics like porcelain units, bone-china, insulators, tiles, etc. Rajasthan leads in terms of clay production in India and produces 40% of the clay. The clay is used in the manufacturing of ceramic goods. Raw material for the production of ceramic good is also exported from Rajasthan. (http://www.ceramics-india.com/category/ceramic-industry-india).

Ceramic Industry has an important place in the Bikaner District of Rajasthan. There are huge deposits of raw marital for ceramic industry viz. china clay, bal clay, etc in Bikaner. The Rajasthan Govt. has established a ceramic laboratory at Govt. Engineer College, Bikaner at the cost of Rs. 710.78 lacs. This is fourth laboratory in public sector after Kolkata, Morvi and Khurja. As per the 2010 report of Bikaner District Industrial Centre, there are approximately 620 units of sanitary ware, glaze tiles, electrical insulators and related ceramic units. These Industries have given employment to 5846 people directly & indirectly and have gross investment of Rs. 100-125 crores. The investment is expected to increase to Rs. 500 crores within a span of 4-5 years, if the products are of good quality. (Rajasthan infrastructure Agenda 2025, Price Water Cooper house report). Most of these units are micro and small enterprises. However, productivity of these units is low because of various wastes. Moreover, the quality of the products is also low. These units are labour intensive and with the increase in labour cost, in conjunction with poor productivity and quality, many of these units have been closed, leading to unemployment. Also, a large number of defective products are dumped by the units in the city or at its outskirts leading to environmental problems. These problems motivated me to do this research to improve productivity and quality performance of ceramic industry in my hometown of Bikaner.

1.4 OBJECTIVES AND SCOPE OF THE STUDY

The study aims at developing and validating a lean manufacturing implementation framework. A lean manufacturing implementation model will be developed after the review of existing frameworks. The framework will be validated by a case study of ceramic industry. This study also focuses on the review of literature in lean manufacturing to understand its evolution and current research issues. Development of the implementation framework will not be worthy without developing the drivers and barriers of any philosophy, technique, system, etc. Therefore, the thesis also aims at developing and validating the drivers and barriers of lean manufacturing.

1.5 METHODOLOGY

To achieve the objectives of the proposed research, the following activities are to be carried out:

- A thorough review of literature on lean manufacturing.

- Development of lean manufacturing drivers and barriers through literature review and discussion with experts from industry.
- Validation of the lean manufacturing drivers and barriers by an empirical study using statistical tools.
- Development of models of lean manufacturing drivers and barriers using structural equation modeling technique.
- Review of existing lean manufacturing implementation frameworks to find the research gap.
- Development of a lean manufacturing implementation model.
- Validation of the developed framework through implementation of lean manufacturing in a case company.

1.6 SIGNIFICANCE OF THE STUDY

It is expected that the research will be of significant importance to the managers in the industry and researchers in the field of lean manufacturing. The knowledge and understanding of lean drivers and barriers is expected to help the managers in the industry to leverage the drivers and mitigate barriers effectively before implementing the lean manufacturing. The proposed framework of lean manufacturing implementation will also be useful for the industry to effectively implement lean manufacturing for the improvements in the performance to gain competitive advantage. The study is also significant for researchers in the field of lean manufacturing as the study provides an extensive literature review of lean definition, contributors, type of research methodologies used, types of industries implementing lean, lean tools and techniques, and lean implementation frameworks.

1.7 ORGANIZATION OF THE THESIS

Chapter 1 presents an introduction to the thesis. The chapter also includes the concepts of lean manufacturing and its importance to the industry. Chapter 2 presents an extensive review of literature on lean manufacturing, especially on lean definition evolution and contributions made by various researchers. Drivers and barriers of lean manufacturing implementation are developed and validated in chapter 3. Chapter 4 presents a literature review of existing lean implementation frameworks and the proposed framework. A case study of ceramic industry is presented in chapter 5 to validate the proposed framework. Finally, chapter 6 gives the conclusions of the research work with limitations and scope for future research.

CHAPTER 2

LITERATURE REVIEW

In this chapter a thorough review of the lean manufacturing literature has been done to find the evolution of lean manufacturing definition and research. Research issues in lean manufacturing have been identified and some lean concepts are also discussed.

2.1 INTRODUCTION

21st century manufacturing is characterized by customized products. This has led to the complex production planning and control systems making mass production of goods challenging. Many organizations, particularly automotive organizations, struggled in the new customer driven and globally competitive market. These factors presented a big challenge to organizations to look for new tools and methods to continue moving up the ladder in the changed market scenario. While some organizations continued to grow on the basis of economic constancy, others struggled because of their lack of understanding of the changed customer mind-sets and cost practices. To overcome this situation and to become more profitable, many manufacturers turned to lean manufacturing.

2.2 DEFINITIONS OF LEAN MANUFACTURING (LM)

This section presents a compilation of the various reported definitions of LM with connotation by various researchers. Principles of lean thinking have been broadly accepted by many production/operation managers and have been applied successfully across many disciplines. Some researchers and practitioners across the world have studied and commented on lean manufacturing definitions. Intention is to compile the scholarly definitions of lean manufacturing showing how the principles, objectives and scope of lean manufacturing have changed with time. Pettersen (2009) compared the contemporary literature and concluded that there is no consensus on a definition of LM between the examined authors. The authors also seem to have different opinions on which characteristics should be associated with lean concept. Table 2.1 presents various definitions of LM reflecting the changing goals, principles and scope.

Table 2.1: Definitions of lean manufacturing from literature

S. No.	Author	Lean manufacturing definition
1	Krafcik (1988)	Compared to mass production it uses less of everything-half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products.
2	Womack *et al.* (1990)	Lean is a dynamic process of change driven by a systematic set of principles and best practices aimed at continuous improvement. LM combines the best features of both mass and craft production.
3	Womack and Jones (1994)	Lean production can be defined as an alternative integrated production model because it combines distinctive tools, methods and strategies in product development, supply management and operations management into a coherent whole.
4	Hayes and Pisano (1994)	Briefly, it is called lean as it uses less, or the minimum, of everything required to produce a product or perform a service
5	Womack and Jones (1996)	The term lean denotes a system that utilizes less, in terms of all inputs, to create the same outputs, as those created by a traditional mass production system while contributing increased varieties for the end customer.
6	Liker's (1996)	A philosophy that when implemented reduces the time from customer order to delivery by eliminating sources of waste in the production flow.
7	Cooper (1996)	Lean production is a system designed to compete on the assumption that sustained product advantage is unlikely, and therefore rather than avoid competition, face it head-on.
8	Dankbaar (1997)	Lean production makes optimal use of the skills of the workforce, by giving workers more than one task, by integrating direct and indirect work, and by encouraging continuous improvement activities. As a result, lean production is able to manufacture a larger variety of products, at lower costs and higher quality, with less of every input, compared to traditional mass production: less human effort, less space, less investment, and less development time.
9	American Production and Inventory Control Society (APICS) 1998	Lean Production is a philosophy of production that emphasizes the minimization of the amount of all the resources (including time) used in the various activities in the enterprise. It involves identifying and eliminating non-value adding activities in design, production, supply-chain management, and dealing with the customers. Lean producers employ teams of multi-skilled workers at all levels of the organization and use highly flexible, increasingly automated machines to produce volumes of products in potentially enormous variety.
10	Singh (1998)	Lean Manufacturing is a philosophy, based on the Toyota Production System, and other Japanese management practices that strive to shorten the time line between the customer order and the shipment of the final product, by consistent elimination of waste.
11	Naylor *et al.* (1999)	Leanness means developing a value stream to eliminate all waste, including time, and to ensure *a level* schedule.

Table 2.1: Definitions of lean manufacturing from literature (contd.)

S. No.	Author	Lean manufacturing definition
12	Storch and Lim (1999)	Lean production is an efficient way to satisfy customer needs while giving producers a competitive edge.
13	Howell (1999)	A new way to design and make things differentiated from mass and craft forms of production by the objectives and techniques applied on the shop floor, in design and along supply chains aiming to optimize performance of the production system against a standard of perfection to meet unique customer requirements.
14	Framework of the Lean Advancement Initiative (LAI) (MIT, 2000)	…not being merely a set of practices usually found on the factory floor. Lean is rather a fundamental change in how the people within the organization think and what they value, thus transforming how they behave.
15	Comm and Mathaisal (2000)	Leanness is a philosophy intended to significantly reduce cost and cycle time throughout the entire value chain while continuing to improve product performance. This value chain is composed of a number of links. The links exist within government as well as within industry, and they exist between government and industry.
16	Liker and Wu (2000)	A philosophy of manufacturing that focuses on delivering the highest quality product on time and at the lowest cost
17	Cooney (2002)	Lean takes a broad view of the production and distribution of manufactures, developing a production concept that encompasses the whole manufacturing chain from product design and development, through manufacturing and distribution.
18	Shah and Ward (2003)	Lean manufacturing can be best defined as an approach to deliver the upmost value to the customer by eliminating waste through process and human design elements. Lean manufacturing has become an integrated system composed of highly inter-related elements and a wide variety of management practices, including Just-in-Time (JIT), quality systems, work teams, cellular manufacturing, etc.
19	Alukal (2003)	Lean is a manufacturing philosophy that shortens the lead time between a customer order and the shipment of the products or parts through the elimination of all forms of waste. Lean helpful firms reduce costs, cycle times and unnecessary, non-value added activities, resulting in a more competitive, agile and market responsive company.
20	Hopp and Spearman, (2004)	Lean production is an integrated system that accomplishes production of goods/services with minimal buffering costs.
21	Haque and Moore (2004)	Lean is by definition an enterprise initiative with a common format for all business processes with the single strategic goal of eliminating waste and improving the flow of value.
22	Rothstein (2004)	Lean production is more commonly considered as a broad production paradigm including an array of manufacturing systems containing some variety of lean practices, such as just-in-time inventory systems, teamwork, multi-tasking, employee involvement schemes, and policies for ensuring product quality throughout the production process.
23	Worley (2004)	Lean manufacturing is defined as the systematic removal of waste by all members of the organization from all areas of the value stream.
24	Simpson and Power (2005)	Lean is a practice with the objective to generate a system that is efficient and well organized and devoted to continuous improvement and the elimination of all forms of waste.
25	Seth and Gupta (2005)	Lean production refers to a manufacturing paradigm based on the fundamental goal of continuously minimizing waste to maximize flow.
26	Taj and Berro (2006)	Lean means "manufacturing without waste." The lean approach is focused on systematically reducing waste (Muda) in the value stream.
27	Narasimhan *et al.* (2006)	Production is lean if it is accomplished with minimal waste due to unneeded operations, inefficient operations, or excessive buffering in operations.

Table 2.1: Definitions of lean manufacturing from literature (contd.)

S. No.	Author	Lean manufacturing definition
28	De Treville and Antonakis (2006)	Integrated manufacturing system intended to maximize capacity utilization and minimize buffer inventories through minimizing system variability.
29	Shah and Ward (2007)	Lean is a management philosophy focused on identifying and eliminating waste throughout a product's entire value stream, extending not only within the organization, but also along its entire supply chain network.
30	Holweg (2007)	Lean manufacturing extends the scope of the Toyota production philosophy by providing an enterprise-wide term that draws together the five elements – product development process, supplier management process, customer management process, and policy focusing process.
31	Hallgren *et al.* (2009)	Lean manufacturing is a program aimed mainly at increasing the efficiency of operations.
32	Taj and Morosan (2011)	A multi-dimensional approach that consists of production with minimum amount of waste (JIT), continuous and uninterrupted flow (Cellular Layout), well- maintained equipment (TPM), well-established quality system (TQM), and well- trained and empowered work force (HRM) that has positive impact on operations/competitive performance (quality, cost, fast response, and flexibility).

From the above definitions it is clear that lean may be *a way* (Storch and Lim, 1999; Howell,1999), *a process* (Womack *et al.*, 1990), *a set of principles* (Womack *et al.*, 1990; Bonazzi, 1993), *a set of tools and techniques*, *an approach* (NIST, 2000; Taj and Morosan, 2011), *a concept* (Naylor *et al.*, 1999), *a philosophy* (Liker, 1996; American Production and Inventory Control Society, 1998; Singh, 1998; Comm and Mathaisal, 2000; Liker and Wu, 2000; Alukal, 2003; Holweg, 2007; Shah and ward, 2007; De Treville and Antonakis, 2006), *a practice* (Framework of the LAI, MIT, 2000; Simpson and Power, 2005), *a system* (Womack and Jones, 1994; Cooper, 1996; Shah and ward, 2007; Hopp and Spearman, 2004), *a program* (Hallgren *et al.*, 2009), or *a manufacturing paradigm* (Rothstein, 2004; Seth and Gupta, 2005). Scope of lean manufacturing includes product development (Krafcik, 1988), operations management (Narasimhan *et al.*, 2006), total supply chain (Womack and Jones, 1990; Rajender, 1998; Naylor *et al.*, 1999; Comm and Mathaisal, 2000, Cooney, 2002), human design element (Shah and Ward, 2003), manufacturing paradigm (Rothstein, 2004; Seth and Gupta, 2005). Various goals for which lean manufacturing is implemented are – to get large variety of products with fever defects (Krafcik, 1988), to integrate product development, supply chain management, and operation management (Womack and Jones, 1994), to reduce cost/produce more with less (Hayes and Pisano, 1994), to reduce time to delivery (Liker's, 1996), to level the production schedule (Naylor *et al.*, 1999), to improve quality at low cost (Liker and Wu, 2000), to remove waste from system (Worley, 2004), to maximize capacity and minimize inventory (De Treville and Antonakis, 2006), to improve productivity and quality (Bhamu *et al.*, 2012), etc.

In this chapter, a review of 200 research papers is presented and these papers were obtained containing key term 'lean manufacturing', or 'lean production' from 69 international journals and 7 conferences as shown in table 2.2. These papers include empirical research; literature review; conceptual, descriptive, exploratory and empirical studies including case studies, surveys and best practices. The chapter is structured as follows:

2.3 RESEARCH CONTRIBUTION MADE BY VARIOUS CONTRIBUTORS IN LEAN MANUFACTURING

This section presents the review of 200 scholarly articles identifying the research contribution, research methodology and type of industry where lean is applied as shown in table 2.3. The research papers are presented year wise with profile of the author and country of the authors for descriptive analysis. Various industries have been classified as per International Standard Industrial Classification of all economic activities (ISIC), Rev.4, Department of Economic and Social Affairs (Statistics Division), United Nations. (http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27)

Table 2.2: Distribution of the reviewed paper in various journals and conferences

	Number of References	Percentage (%)
(A) Journal		
International Journal of Production Research	32	16.0
International Journal of Operations & Production Management	27	13.5
Journal of Manufacturing Technology Management	15	07.5
Production Planning & Control	8	04.0
Integrated Manufacturing Systems	6	03.0
Journal of Operations Management	5	02.5
International Journal of Advanced Manufacturing Technology	5	02.5
International Journal of Quality & Reliability Management	5	02.5
Production Planning & Control: The Management of Operations	4	02.0
International Journal of Production Economics	4	02.0
The TQM Magazine	4	02.0
International Journal of Productivity and Performance Management	4	02.0
International Journal of Logistics: Research & Applications	3	01.5
International Journal of Physical Distribution & Logistics Management	3	01.5
Supply Chain Management: An International Journal	3	01.5
Total Quality Management	3	01.5
*Others (Two references of each Journal)	18	09.0
**Others (One reference of each Journal)	44	22.0
(B) International Conferences	07	03.5
Total	200	100

*Benchmarking: An international Journal, Business Process Management Journal, International Journal of Agile Management systems, Journal of Industrial Engineering and Management, Lean Construction Journal, Management Decision, Measuring Business Excellence, Total Quality Management & Business Excellence, Engineering, Construction and Architectural Management

**Journal of Psychosomatic Research, European Journal of Social Sciences, European Journal of Operational Research, African Journal of Business Management, Asia Pacific Journal of Marketing and Logistics, Asian Social Science, Assembly Automation, British Food Journal, Cityscape: A Journal of Policy Development and Research, Computers in Industry, European Journal of Business and Management, European Journal of Scientific Research, Indian Foundry Journal, Industrial Management & Data Systems, Industrial Marketing Management, International Journal of Management Practice, International Journal of Business and Management, International Journal of Flexible Manufacturing Systems, International Journal of Lean Six Sigma, International Journal of Manufacturing Technology and Management, International Journal of Service Industry Management, International Journal of Simulation and Process Modeling, Journal of Achievements in Materials and Manufacturing Engineering, Journal of Advanced Manufacturing Systems, Journal of Applied Sciences, Journal of Combinatorial Chemistry, Journal of Construction Engineering and Management, Journal of Intelligent Manufacturing, Journal of Management History, Journal of Manufacturing Systems, Journal of Medical Biochemistry, Logistics Information Management, Managing Service Quality, Manufacturing and service operations management, Neural Computing & Application, Online Journal of Workforce Education and Development, Procedia Computer Science, Quality and Reliability Engineering International, Quality Safety Health Care, Robotics and Computer-Integrated Manufacturing, The International Journal of Logistics Management, The Leadership & organization Development Journal, The TQM Journal, World Development.

Papadopoulou and Ozbayrek (2005) classified the lean literature into six categories – production floor management; product/process-oriented; production planning, scheduling and control; lean implementation; work-force management; and supply chain management. Moyano-Fuentes and Sacristan-Dıaz (2012) reviewed lean production literature and categorized the literature into four areas of internal aspects (shop floor), value chain, work organization, and impact of geographical context. The different research methodologies used by various researchers are divided into six types –conceptual, descriptive, empirical, exploratory cross-sectional, and exploratory longitudinal. The meaning of these research methodologies is given below:

- ***Conceptual***: Basic or fundamental concepts of LM
- ***Descriptive***: Explanation or description of LM content or process, performance measurement issues.
- ***Empirical***: Data for study has been taken from existing database, review, case study, taxonomy, or typological approaches.
- ***Comparative***: Comparison between two or more practices or solutions and the evaluation of the best practice or a solution
- ***Exploratory cross-sectional***: Objective of study is to become more familiar through survey, in which information is collected at one point of time.
- ***Exploratory longitudinal***: Survey methodology, where data collection is done at two or more points over time in the same organization.

Table 2.3: Lean manufacturing literature review

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
1	Barker	A	UK	1994	Total time-based value added analysis which aids the design of lean manufacturing systems.	Exploratory longitudinal	Electrical Switchgear
2	Prickett	A	UK	1994	Major considerations in the design and implementation of a cell-based manufacturing system.	Exploratory cross-section	Fabrication
3	Sohal and Egglestone	AP	Australia	1994	Empirical investigation of LM implementation in Australian manufacturing companies.	Empirical	Automotive, metal processing, rubber etc.
4	Ramarapu *et al.*	A	USA	1995	A comparative analysis and review of JIT implementation where elimination of waste and production strategy are the most specific factors.	Comparative	…………
5	Karlsson and Ahlstrom	A	Sweden & UK	1995	The role of the remuneration system in lean production implementation process.	Exploratory longitudinal	Mechanical and electronic office equipments
6	Niepce and Molleman	A	Netherlands	1996	Analysis of human factors in LM through an empirical study in automotive organization within socio-technical system.	Exploratory longitudinal	Automotive
7	Boyer	A	USA	1996	Assessment of the managerial commitment to lean production to increase the productivity.	Empirical	Metal working
8	Burcher *et al.*	AP	UK	1996	Methodology to assist repetitive batch manufacturers in the adoption of certain aspects of the lean production principles for reduction of inventory.	Conceptual	…………
9	Forza	A	Italy	1996	Development of an empirical framework for linkages between human resource management and lean production practices.	Empirical	Electronics, auto supplier, machinery etc.
10	Kannan & Ghosh	A	USA	1996	Virtual cellular manufacturing for small batch production to increase productivity.	Conceptual	……….
11	Karlsson and Ahlstrom	A	Sweden & UK	1996	Model to assess the changes to introduce lean production principles.	Exploratory longitudinal	Mechanical and electronic office equipments
12	Ahlstrom and Karlsson	A	Sweden & UK	1996	The role of the management accounting system in the lean adoption process.	Exploratory longitudinal	Mechanical and electronic office equipments
13	Katayama and Bennett	A	Japan & UK	1996	The role of LP to overcome the contemporary pressure on Japanese companies.	Empirical	Automotive, electronics, refrigerator manufacturing
14	Sohal	A	Australia	1996	Improvements in product development through lean adoption in Australian windscreen wiper company.	Empirical	Windscreen wiper systems
15	Hines and Rich	A	UK	1997	Outline value stream mapping tools and decision-making process in LM.	Empirical	FMCG food product retailer
16	Jina *et al.*	P	UK	1997	Integration of supplier relationships, marketing and planning, and customer enquiry in a high product variety and low volume sector by applying lean principles.	Descriptive	Aerospace & Specialist Machinery

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
17	Ahlstrom, P	A	UK	1998	Supports core and supporting principles in parallel and sequence in the implementation of lean production	Conceptual	………..
18	Hines *et al.*	AP	U.K.	1998	Description of VSM approach with its weaknesses. Also a new approach is proposed which involves a strategic review of supply chain activities.	Descriptive	……….
19	Bowen and Youngdahl	A	USA	1998	Discusses the transfer of "lean" manufacturing logic into service operations to form the "lean" service.	Descriptive	Service
20	Singh	P	India	1998	LM principles and benefits in context of changing manufacturing paradigms.	Descriptive	………
21	Hines *et al.*	A	UK	1999	VSM approach for supplier integration in a distribution industry together with process benchmarking.	Exploratory longitudinal	Electrical & Electronic
22	Soderquist and Motwani	A	France	1999	Lean quality management in a French automotive supplier industry to gain competitive advantage.	Exploratory longitudinal	Automotive
23	Howell	P	USA	1999	Applicability of lean production in construction industry to maximize the performance for the customers.	Descriptive	Construction
24	Storch and Lim	A	Korea	1999	Potential application of flow, group technology and value stream lean principles in shipbuilding industry to gain better outputs.	Descriptive	Shipbuilding
25	Robertson & Jones	P	UK	1999	Lean production and agile manufacturing concepts in telecommunications industry.	Descriptive	Telecommunications
26	Biazzo and Panizzolo	A	Italy	2000	Assessment of the lean production in work organizations from workers perspectives.	Descriptive	…..………
27	Van-Hoek	A	UK	2000	Postponement and information decoupling as relevant contributions for making the agile supply chain a reality with lean capabilities.	Conceptual	…………..
28	Comm and Mathaisel	A	USA	2000	Eight step paradigms to assess and benchmark lean philosophy in an aerospace company for quality improvement and survival.	Descriptive	Aerospace
29	Bamber and Dale	AP	UK	2000	The effects of management approach, employee attitude, education and training in adopting Kawasaki Lean Production System in an aerospace company.	Exploratory longitudinal	Aerospace
30	Mathaisel and Comm	A	USA	2000	The relevance and value of the lean concepts to increase the productivity in the US defense aerospace industry.	Exploratory cross-section	Aerospace
31	Christopher	A	UK	2000	Comparisons and applications of "leanness" and "agility" as the business survival strategies for industries.	Descriptive/ Comparative	………….
32	Mason-Jones *et al.*	A	UK	2000	Material flow control principles for selection of lean, agile or leagile strategies as per marketplace need to gain the optimal supply chain performances.	Empirical	Precision products, carpet making & electronic

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
33	Sanchez and Perez	A	Spain	2001	Analysis of lean production indicators through integrated lean check-list to assess manufacturing changes.	Empirical	Automotive & industrial machinery
34	Gulyani	P	India	2001	Analysis of transportation system for dynamic gains from lean production and supply chain management.	Exploratory longitudinal	Automotive
35	Pheng and chuan.	A	Singapore	2001	Survey of main contractors in Singapore for adopting the JIT with agile in precast concrete construction operations to cope with schedule fluctuations.	Exploratory cross-section	Construction
36	Arkader	A	Brazil	2001	Formulation of a lean supply path for buyer-supplier relation in the Brazilian auto-firm with organizational, firm specific and environment barriers.	Empirical	Automotive
37	McCullen and Towill	A	UK	2001	Empirical study of agility and lean supply chain integration to reduce the sources of variability and the bullwhip effect respectively.	Empirical	Precision mechanical engineering machinery
38	Won *et al.*	A	USA	2001	Comparison of two approaches to develop frameworks of the TPS for successful manufacturing system design.	Comparative	……..…..
39	McDonald *et al.*	A	USA	2002	Simulation as a part of VSM tool in a manufacturing product line to facilitates process visualization and reduce the time required in process.	Exploratory longitudinal	Industrial Motors
40	Yusuf and Adeleye	A	UK	2002	Threats to lean and the drivers of agile manufacturing through a survey of UK manufacturing firms with a comparative study of these two strategies.	Comparative & Exploratory cross-section	Food, Automotive, aircraft etc.
41	Cooney	A	Australia	2002	Lean applicability in batch production in the Australian automotive industry.	Descriptive/ Empirical	Automotive
42	Aitken *et al.*	AP	UK	2002	Description of models of agile and lean, involving the workers, suppliers and sub-contractors.	Descriptive/ Exploratory longitudinal	Electrical
43	Kalsaas	A	Norway	2002	Analysis the subcontractor case of VSM in an Japanese automotive industry by restructuring the production of product families to improve the throughput time	Empirical	Automotive
44	Shah and Ward	A	USA	2003	Empirically examine the effects of plant size, plant age and unionization status on lean implementation.	Empirical	Chemical, primary metal, chemical etc.
45	Motwani	A	USA	2003	Examine the critical factors involved in the implementation of lean tools in an automotive industry through a framework.	Exploratory longitudinal	Automotive

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
46	McCarthy and Tsinopoulos	A	UK	2003	Introduces a strategic management framework based on the configurationally theory and an evolutionary classification method focusing on the agile concepts.	Conceptual	………….
47	Wu	AP	Taiwan/ USA	2003	Empirically examine the connection between lean production and various aspects of the logistics system with a comparison between lean V/S non-lean suppliers.	Empirical/ Comparative	Automotive
48	Pavnaskar *et al.*	A	USA	2003	Propose a classification scheme to serve as a link between manufacturing waste problems and lean manufacturing tools, and metrics.	Conceptual	….……...
49	Berry *et al.*	A	Denmark	2003	Establish links between strategic groups' specifically low prices and aesthetic design, and lean manufacturing factors and operational performance.	Empirical	Chemical, Metal, electronics etc.
50	Bruce *et al.*	A	UK	2004	Applications of lean, agile & leagile approaches in the supply chain management of textile and apparel industry to achieve quick response and reduced lead times.	Exploratory cross-section	Textile
51	Hines *et al.*	AP	UK	2004	Literature review of lean, expansion beyond the auto industry over time and propose a lean framework at strategic and operation level.	Descriptive	…..…..
52	Agrawal and Hurriyet	A	Australia	2004	Discusses the past, present and future of manufacturing technologies from craft to organic era through lean with the contribution to the growth of supply chain.	Descriptive	………
53	Hopp and Spearman	A	USA	2004	The academic and practitioner literature on pull and lean where specifically pull is a mechanism for limiting WIP and lean is about minimizing the cost of buffering variability.	Descriptive	………
54	Emiliani and Stec	AP	USA	2004	Use of Value- Stream maps for determining the beliefs, behaviors, and competencies possessed by business leaders to improve leadership effectiveness.	Conceptual/ Exploratory longitudinal	Stamped & Welded Metal Brackets and Service
55	Doolen and Hacker	A	USA	2005	Lean practices assessment in electronic manufacturers where implementation depends on the economic, operational, or organizational factors.	Exploratory cross-section	Electronics
56	Arnheiter and Maleyeff	A	USA	2005	Comparative study of the misconceptions, concepts and techniques of lean, Six-Sigma and lean Six-Sigma.	Comparative	………..
57	Furterer and Elshennaw	A	USA	2005	Implementation of TQM, lean and Six Sigma in local government to improve the quality and timeliness of providing services.	Exploratory longitudinal	Local Government

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
58	Huang and Liu	A	China	2005	Development of an algorithmic simulation model and application with VSM in the job shop and flow shop to decrease WIP, inventory and logistics cost.	Exploratory longitudinal	Oval-gear flow meter
59	Modarress *et al.*	A	USA	2005	Method to set kaizen costing to develop financial measurement metrics in lean production system through a case of airplane company.	Exploratory longitudinal	Aerospace
60	Salem *et al.*	A	USA	2005	The evaluation of lean construction tools in medium size construction firms to improve last planner, visualization, daily huddle meetings, and first run studies.	Exploratory longitudinal	Construction
61	Seth and Gupta	A	India	2005	Application of VSM in an auto industry to achieve improvement in productivity, production per person and reduction in WIP at supplier end.	Exploratory longitudinal	Automotive
62	Simons and Zokaei	A	UK	2005	Review literature on the applications of logistics and operations management concepts with the application of lean into the red meat industry.	Exploratory longitudinal	Food
63	Comm and Mathaisel	A	China	2005	Application of LM principles and simulation in a labor-intensive textile firm in China to improve the production efficiency.	Exploratory longitudinal	Textile
64	Simpson and Power	A	Australia	2005	Discusses empirically the supplier relationship, lean manufacturing and environment management practices.	Conceptual/ Exploratory cross-section	Automotive
65	Taj	A	China	2005	Lean assessment tool to help Chinese hi-tech industries in identifying the areas of productivity lag and opportunities for improvement.	Empirical	Electronics, Telecommunication & IT
66	Taylor	A	UK	2005	Application of lean/value chain analysis in agro-food sector to improve supply chain performance, profitability and relationships.	Exploratory cross-section	Agro- Food
67	Papadopoulou and Ozbayrak	A	UK	2005	Literature review of leanness to highlight the evolutional orbit, misconceptions, social aspects and universality.	Descriptive	…...…….
68	Bhasin & Burcher	A	UK	2006	The conceptual discussion of the success and failure of lean implementation.	Conceptual	…..…..…
69	Conti *et al.*	A	UK/USA	2006	Assess the effects of LP on physical and mental job stress through a multi-industry empirical study by using Karasek job stress model.	Empirical	Automotive, process, metal working etc,
70	Andersson *et al.*	A	Sweden	2006	Describe the similarities and differences between the TQM, Six Sigma and lean with an evaluation and criticism of each concept.	Comparative/ Descriptive	………...
71	Bendell	A	UK	2006	Comparative literature review of six sigma and the lean approaches with the description of a model of business process improvement.	Descriptive/ Comparative	…………

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
72	Emiliani	A	USA	2006	The role and importance of Connecticut business and business leaders in discovery and dissemination of lean management in America.	Descriptive	…………
73	Kumar *et al.*	A	India	2006	Integrating lean tools within six sigma methodology to achieve dramatic results in cost, quality and time by focusing on process performance in an Indian SME.	Exploratory longitudinal	Die Casting SME
74	Parry and Turner	A	UK	2006	The use of lean visual process management tools in aerospace companies to help drive operations and processes in real time.	Exploratory cross-section	Aerospace
75	Weller *et al.*	A	USA	2006	Application of VSM in drug discovery and parallel synthesis to improve the timeliness.	Exploratory longitudinal	Drugs
76	Worley and Doolen	A	USA	2006	Analysis of the role of communication and management support in driving leanness in an electronic industry.	Exploratory longitudinal	Electronics
77	Taj and Berro	A	USA	2006	Application of principles of constrained management and lean manufacturing in an auto-assembly plant to improve the productivity.	Exploratory longitudinal	Automotive
78	Achanga *et al.*	A	UK	2006	Analysis of the critical success factors such as leadership, management, finance, organizational culture and skill and expertise for lean implementation in SMEs.	Exploratory cross-section	Manufacturing SMEs
79	Bonavia & Marin	A	Spain	2006	Use of LP practices in the Spanish ceramic tile industry, and empirically setting their relationship with plant size and effect on the operation performance.	Empirical	Ceramic tile
80	Braglia *et al.*	A	Italy	2006	Application of 'Improved Value Stream Mapping' for a complex Bill of Material case environment to find the critical production path for reducing the WIP level.	Exploratory longitudinal	Electro-domestic equipments
81	Narasimhan *et al.*	A	USA	2006	Literature review and empirical validation of leanness and agility as manufacturing paradigms to improve performance capabilities in manufacturing plants.	Empirical	Computers, machine tools, food etc.
82	Hines *et al.*	A	UK	2006	Six-step theoretical holistic framework for guiding applied research within the field of new lean product lifecycle management.	Conceptual	……….
83	Shen and Han	A	China	2006	Analyzes the benefits of VSM in Electrical Manufacturing Services of China with agile information flow and ERP to achieve sustainable and profitable growth.	Conceptual/ Exploratory longitudinal	Electrical & Electronic
84	Maguad	A	USA	2006	Literature review comprising the origins, development, & trends of the modern quality movement philosophies, principles, set of ideas and methods.	Descriptive	….…..

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
85	Krishnamurthy and Yauch	A	USA	2007	Analyze a theoretical model of leagile manufacturing with a case study in a single corporation with multiple business units.	Exploratory cross-section	Forging and die casting, machining etc,
86	Abdulmalek and Rajgopal	A	USA	2007	Analyze the VSM via Simulation in a process sector (steel mill) to see the significant benefits in reduction of production lead time and lower WIP inventory	Exploratory longitudinal	Large integrated Steel mill
87	Alhourani and Seifoddin	A	USA	2007	New concepts of similarity coefficient and the algorithms required in the designing of a cellular manufacturing system to reduce the material handling cost and WIP.	Conceptual	………….
88	Black	A	USA	2007	The four design rules for TPS implementation to reduce the sources of variation in time, while waste and delay in the system are systematically removed.	Conceptual	……..…..
89	Fraser *et al.*	A	Australia	2007	Development and evaluation through a case study of multi-phase model consists technical and human aspects, for Cellular Manufacturing implementation.	Exploratory longitudinal	Electrical & Electronics
90	Lander and Liker	A	USA	2007	Application of VSM in a low volume highly customized artistic clay tile company to gain stability, good control and profit.	Exploratory cross-section	Clay tile
91	Lee	A	USA	2007	Artificial intelligence heuristics evaluation for a simultaneous Kanban controlling and scheduling system to minimize the total production control.	Conceptual	………….
92	Lee and Jo	A	South Korea	2007	Analysis of spread of TPS through Korea through focusing on the experience of Hyundai Motor Company for gaining better manufacturing utilization, product quality etc.	Exploratory longitudinal	Automotive
93	Lian and Landeghem	A	Belgium	2007	Analyze a VSM based simulation generator to generate current and future VSM quickly and automatically to see the effects of lean from push to pull system.	Exploratory longitudinal	Poultry & Pig raising equipments
94	Miltenburg	A	Canada	2007	Examine the best algorithms for finding an optimal schedule and analyses for mixed model JIT production in which *takt* time and cycle time are design variables.	Conceptual	……….
95	Oliver *et al.*	A	UK	2007	Examine the interplay in lean product development practices, product attributes and market performance for premium autos and audio products.	Exploratory cross-section	Automotive and high-end audio equipment
96	Reichhart and Holweg	A	UK	2007	Explore the wider conflicts between distribution and LP along through literature review and an automotive case study.	Empirical	Automotive

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
97	Swamidass	A	USA	2007	Empirical investigation of the effect of TPS on high and low performing US manufacturing firms during 1981-1998 on the ratio of total inventory/sales.	Empirical	Computers, Machinery Metal fabrication, etc.
98	Takahashi *et al.*	AP	Japan	2007	Comparison of the performances of Kanban control system with theory of constraints by using Markov analysis in JIT production system.	Comparative	….……..
99	Towill	A	UK	2007	The four level prism model of TPS which assists visualization of the system processes for performance improvement.	Conceptual	…..…….
100	Yavuz and Akaal	A	USA	2007	Review the current analytical literature of production smoothing in mixed-product JIT manufacturing with the description of the practical and modeling issues.	Descriptive	…..……..
101	Jensen and Jensen	AP	Denmark	2007	Discuss start-up phase of implementing lean tools in two SMEs and suggests that 5S tool is good for small and VSM for medium size company.	Exploratory longitudinal	Pumps , Valves, and Agricultural equipments
102	Rivera and Chen	A	USA	2007	Propose the cost-time profile tool and the cost-time investment concept to evaluate the cost and performance improvements in LM implementation.	Conceptual	……….
103	Shah and Ward	A	USA	2007	Literature review to find the confusion and inconsistency in LP along with empirical validation of operational measurements in manufacturing firms.	Conceptual/ Empirical	Electrical, Metals, Rubber (from SIC code 20-39)
104	Johansen and Walter	AP	German	2007	Survey for German construction companies to disclose the understanding of lean principles, perceptions of lean and trends in lean.	Empirical	Construction
105	Bayo-Moriones *et al.*	A	Spain	2008	Analysis the role of organizational size and age contexts with AMT, quality management, and work organization practices in JIT implementation.	Exploratory cross-section	Food, Textile, Chemical etc.
106	Naslund	A	USA	2008	Comparison of the goals, approaches, tools, history and critical success factors of lean with JIT, six sigma and TQM through literature review.	Comparative	…………..
107	Seth *et al.*	AP	India	2008	Analysis of various wastes in the supply chain of the Indian edible cottonseed oil industry using VSM approach to improve productivity and capacity utilization.	Exploratory longitudinal	Cottonseed edible oil
108	Brown *et al.*	AP	UK	2008	Compare quality (TQM and six-sigma) and productivity improvement strategies (lean and TOC) along with their implementation investigations in medical sector.	Comparative/ Empirical	Medical

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
109	Lasa *et al.*	A	Spain	2008	Application of VSM in a Spanish plastic parts industry to obtain the highest performance with redesigning of productive system.	Exploratory longitudinal	Plastic casing for mobile phones
110	Shah *et al.*	A	USA	2008	Analyze empirically the combined implementation of lean-six sigma approach in manufacturing plants to see the significant performance benefits.	Empirical	SIC code ranging from 20 (food) to 39 (Miscellaneous manufacturing)
111	Sahoo *et al.*	A	India	2008	Application of lean philosophy, Taguchi's method, and design of experiments in an Indian forging company to improve the performance.	Exploratory longitudinal	Forging
112	Jørgensen and Emmitt	AP	UK & Denmark	2008	Review extensive literature on lean construction field for researchers, as a valuable resource which is less mature in comparison to lean production.	Descriptive	……….
113	Jayaram *et al.*	A	USA	2008	Examine the relationships in relationship building, lean design, lean manufacturing and firm performance through an automotive supplier case study.	Exploratory cross-section	Automotive
114	Olivella *et al.*	A	Spain	2008	Analysis of work organization practices such as standardization, discipline and control, multi skilling and adaptability, etc. in LP through literature review.	Conceptual	………
115	Pham *et al.*	A	UK	2008	A 'Fit' manufacturing paradigm which integrates the manufacturing efficiencies achieved through lean and agility for sustainability in the casting industry.	Conceptual/ Empirical	Casting
116	Bhasin	A	UK	2008	Propose dynamic multi-dimensional performance framework which focuses on the intangible and intellectual assets to examine the organizational success in LP.	Conceptual	………
117	Serrano *et al.*	A	Spain	2008	Evaluate the real applicability of VSM to redesign of disconnected flow lines based on manufacturing environments with a diversity of logical problems.	Exploratory cross-section	Kit furniture, Water heater, forging etc.
118	Grewal	A	India	2008	Adoption of VSM in an Indian small bicycle manufacturing firm to achieve reduction in lead time, cycle time and inventory level.	Exploratory longitudinal	Bicycle
119	Piercy and Rich	A	UK	2009	Lean application in a pure service sector to minimize the waiting time in response, cost position with minimal investment and improved quality.	Exploratory cross-section	Call Service Center (Pure service)
120	Wong *et al.*	AP	Malaysia	2009	Empirical investigation of the actual implementation of lean manufacturing in the Malaysia electrical and electronics industry.	Empirical	Electrical and Electronics

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
121	Braglia *et al.*	A	Italy	2009	Presents two alternative approaches based on statistics and fuzzy algebra to include variability analysis in VSM to support practitioners of industries.	Conceptual/ Exploratory longitudinal	Motor cycle helmet
122	Gupta and Snyder	A	USA	2009	Review the journal articles with the comparative outlines of TOC, MRP and JIT manufacturing philosophies.	Comparative	………..
123	Cooper Jr.	A	USA	2009	Development of the lean manufacturing curriculum implementation model in university in conjunction with competency- based learning activities.	Conceptual	Academic Institution
124	Yu *et al.*	A	Canada	2009	Presents data collection, value stream selection, current practice analysis, and specific changes proposed for LP model with a case of construction sector.	Exploratory longitudinal	Construction
125	Fullerton and Wempe	A	USA	2009	Analyze empirically the utilization and impact of non-financial manufacturing performance measures on the LM implementation in the US manufacturing firms.	Empirical	SIC codes 20-39 (Chemical, industrial machinery, electronics etc.)
126	Lasa *et al.*	AP	Spain	2009	Analyses the key factors necessary to exploit the full potential of lean concepts and redesign the productive systems of six manufacturing companies using VSM.	Exploratory cross-section	Kit furniture, Water heater, forging etc.
127	Hallgren and Olhager	AP	Sweden	2009	Empirically Investigates the leanness and agility in different manufacturing firms with discussions of internal and external drivers, and the performance outcomes.	Empirical	Electronics & Automotive
128	Boyle and Scherrer-Rathje	A	Canada & Switzerland	2009	Empirically identify the best practices, tools, and techniques for improving the flexibility in manufacturing organizations.	Empirical	Textile, leather and allied products, plastics etc.
129	Stump and Badurdeen	A	USA	2009	Proposes integration of the strategies POLCA, TOC and FMS, and agile with lean principles in Mass Customization environments with an applicability framework.	Conceptual & Exploratory longitudinal	Boat
130	Riezebos *et al.*	A	UK	2009	Review the role of IT in achieving the principles of lean production with special references to production planning & control and computer aided production.	Descriptive	………..
131	Wee and Wu	AP	Taiwan	2009	Summarizes the suggestions and ideas for industries to implement lean and demonstrates lean supply chain to reduce cost and improve quality using VSM.	Exploratory longitudinal	Automotive
132	Alvarez *et al.*	A	Spain	2009	Application of the Kanban, Milkrun and VSM techniques in the automotive assembly line to reduce inventories, transportation and idle times.	Exploratory longitudinal	Automotive

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
133	Puvanasvaran *et al.*	A	Malaysia	2009	Evaluate the degree of leanness and the roles played by communication process in lean through a case study of a Malaysian aerospace manufacturing company.	Empirical	Aerospace
134	Pettersen	A	Sweden	2009	Investigates the definitions of lean production, methods and goals associated with the LP concept through the review of contemporary articles.	Conceptual	……..….
135	Anand and Kodali	A	India	2009 (a)	Application of VSM and simulation in a brake lining manufacturing firm having high volume & variety of products to improve the productivity and quality.	Exploratory longitudinal	Automotive
136	Anand and Kodali	A	India	2009 (b)	Application of ANP methodology based on the impacts on the functions of the operations department for selecting LM system in an automotive industry.	Exploratory longitudinal	Automotive
137	Christopher *et al.*	A	UK & New-Zealand	2009	Propose a logical framework for implementation of a scheme for value stream classification and evaluates through a range of industries.	Conceptual	………….
138	Dentz *et al.*	AP	USA	2009	Application of VSM to identify wastes and target processes for improving labor efficiency and quality in factory home building operations.	Exploratory Cross-section	Construction
139	Silva *et al.*	AP	Brazil	2009	Continuous improvement in quality system of a Brazilian automotive parts industry through the CIM, DFMA and LSS methodologies.	Empirical	Automotive
140	Singh *et al.*	A	India	2009	Discussion of the survival strategy to overcome recession by means of lean principles and philosophies followed by interaction with industrial personnel.	Exploratory longitudinal	Automotive, IT, Service etc.
141	Singh and Sharma	A	India	2009	Application of VSM in an Indian railway sophisticated components manufacturing firm to reduce the lead time, processing time, WIP inventory and manpower.	Exploratory longitudinal	Diesel traction fleet processed component
142	Bergmiller and McCright	A	USA	2009	Discuss the parallel models for Lean and Green systems which include management systems, identification and reduction of waste to achieve business goals.	Comparative	………
143	Villa	P	Italy	2010	Highlights some key concepts of lean, six sigma and automation, and their fit in laboratory organization for improving performance by eliminating the wastes.	Exploratory longitudinal	Healthcare laboratory
144	Rashid *et al.*	A	Malaysia	2010	Assess the lean manufacturing in Malaysian Food SME using VSM to reduce the lead time and number of operators.	Exploratory longitudinal	Food

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
145	Kemper *et al.*	A	Netherland	2010	Presents a clear, precise and consistent framework for flowcharts and value-stream flow diagrams in process improvement.	Conceptual	……..……
146	Pepper and Spedding	A	Australia	2010	Examine the literature of integration of lean principles with Six Sigma methodology and provides a conceptual successful integration model.	Descriptive	………..….
147	Miller *et al.*	AP	USA	2010	Integrates lean and green manufacturing with simulation in a small furniture company to make a positive impact on the environment, society and its finance.	Exploratory cross-section	Small furniture
148	Anand and Kodali	A	India	2010 (a)	Compares the existing literature on LM frameworks and proposes a new conceptual framework to overcome some of the shortcoming of existing frameworks.	Comparative/ Conceptual	….…….
149	Perez *et al.*	A	Spain & UK	2010	Analyze the cultural capability in lean supply and application of lean model in the Catalan pork supply chain to see the impact on the characteristics and the performance.	Conceptual & Empirical	Pork Sector
150	Chen and Meng	A	China	2010 (a)	Propose a VSM based production system for Chinese enterprises to help them deploy lean production systematically to increase the competitive ability.	Descriptive	………….
151	Saurin *et al.*	A	Brazil	2010	Introduces a framework for assessing the use of LP practices in manufacturing cells of an automotive parts supplier industry.	Exploratory longitudinal	Automotive
152	Vinodh *et al.*	A	India	2010	Application of VSM for enabling leanness in an Indian camshaft manufacturing industry with the improvements in lead time, total cycle time and on time delivery.	Exploratory longitudinal	Cam shaft
153	Singh *et al.*	A	India	2010	Discusses the concept of leanness and development of leanness index for an Indian automotive industry based on judgments of experts.	Conceptual	Automotive
154	Al-Tahat	A	Jordan	2010	Investigates the performance of traditional methods and fully automated pattern making processes using VSM to improve process and decision making.	Exploratory longitudinal	Foundry
155	Mollenkop *et al.*	A	USA	2010	Examine the relationships among the green, lean, and global supply chain strategies through existing literature.	Conceptual	…….
156	Chen *et al.*	A	USA	2010	Describe the benefits and pitfalls associated with lean philosophy by considering the different organizational elements with some recommendations to new adopters of lean.	Descriptive	……..

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
157	Pool *et al.*	A	Netherland	2010	Application of lean approach in semi-process industry by introducing the cyclic schedules to improve production quality and supply-chain coordination.	Exploratory longitudinal	Semi-process (Liquid coffee)
158	Snee	P	USA	2010	Assessment of the development of lean six-sigma over the years through identifying the critical issues and emerging trends for improving the business performances.	Conceptual	…….
159	Demeter and Matyus	A	Hungary	2010	Empirically analyze the impact of lean practices on inventory turnover and the effect of contingency factors to improve the inventory turnover performance.	Empirical	Fabricated products, machinery, transport etc.
160	Delgado *et al.*	AP	Portugal	2010	Implementation of lean six-sigma in a financial services company to improve processes, product quality and efficiency, and lowering the operational costs.	Exploratory longitudinal	Financial Services
161	Chen and Meng	A	China	2010 (b)	Reviews the status of lean; analyze LP in Chinese mainland, and the importance of culture reforms in the organizations to implement lean.	Descriptive	………
162	Anand and Kodali	A	India	2010 (b)	Review the LM implementation frameworks and propose a new conceptual framework which consist several levels with associated lean tools/techniques/practices.	Conceptual	………
163	Grove *et al.*	A	UK	2010	Application of VSM to map out essential tasks for the health visiting services which also includes stakeholders to remove waste processes.	Exploratory longitudinal	Health Care visiting services
164	Taj and Morosan	A	China	2011	Empirical investigation of the impact of lean operation practices and the production system design on the performance factors of the Chinese manufacturing plants.	Empirical	Electronics, Garments, Chemical etc.
165	Hodge *et al.*	A	USA	2011	Exploratory analysis of the appropriate lean principles in the textile industries and finds VSM is an initial tool from the developed lean implementation model.	Exploratory cross-section	Textile
166	Eswaramoorthi *et al.*	A	India	2011	Survey to identify the status of lean practices and major reasons of snail-paced lean implementation in the Indian machine tool manufacturing.	Exploratory cross-section	Machine tool
167	Staats *et al.*	AP	India	2011	Empirically examine the applicability of LP system in Indian software services firm and the identification of significance of lean in a knowledge-based industry.	Empirical	Software Services firm
168	Eroglu and Hofer	A	USA	2011	Examine the inventory leanness for improvements in the US manufacturing firm’s performance as it varies substantially across industries.	Empirical	Paper mill, Automotive, Pharmaceutical etc.

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
169	Antony	A	UK	2011	Comparison in between Six-Sigma and lean, based on the views of a few academicians and practitioners.	Comparative	………..
170	Roy	P	India	2011	Documents a structured approach to overcome practical difficulties in implementing lean management practices in Indian SMEs.	Descriptive	………..
171	Yang and Lu	A	Taiwan	2011	Application of lean in conjunction with multiple-attribute decision-making approach and simulation to solve pacemaker location problems in a case company.	Empirical	Thin film transistor-crystal display manufacturer
172	Singh *et al.*	A	India	2011	Review literature of VSM and apply this tool in small manufacturing Indian industry to reduce lead time, processing time and WIP inventory.	Exploratory longitudinal	Piston pin SME
173	Shahin	A	Iran	2011	Propose a conceptual model for enhancing productivity through Group Technology and lean production system, and analyze it for automotive industry.	Conceptual/ Empirical	Automotive
174	Wong and Wong	A	Malaysia	2011	Empirical study of the approach of adopting lean, the tools and techniques, the problems and lessons learnt in the Malaysian electrical and electronic industry.	Empirical	Electrical & Electronics
175	Losonci *et al.*	A	Hungary	2011	Investigates the employee perceptions during a successful lean transformation in an automotive industry.	Exploratory longitudinal	Automotive
176	Jimenez *et al.*	A	Spain	2011	Applicability of lean tools mainly VSM in wine sector to reduce production lead time and raw material reduction.	Exploratory longitudinal	Wine
177	Anand and Kodali	A	India	2011	Application of VSM and simulation during the design of lean manufacturing system in PVC door and window manufacturing industry to gain significant improvements in performance.	Exploratory longitudinal	PVC Door and window
178	Vinodh and Joy	A	India	2011	Empirical analysis to measure the lean manufacturing practices prevailing in Indian SMEs through structural equation modeling technique.	Empirical	Indian Manufacturing SMEs
179	Cottyn *et al.*	A	Belgium	2011	Introduces an alignment method between manufacturing execution system and lean objectives to prevent the system becoming obsolete with a case example analysis.	Conceptual/ Exploratory longitudinal	Small Furniture
180	Ramesh and Kodali	A	India	2011	Proposes a decision framework for choosing VSM tool in conjunction with AHP-preemptive goal programming for maximizing performances in the shortest timeframe.	Conceptual/ Exploratory longitudinal	Automotive
181	Behrouzi and Wong	A	Malaysia	2011	Presents an innovative approach to evaluate the lean performance systematically by using fuzzy membership functions.	Conceptual	……….

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
182	Gnanaraj *et al.*	A	India	2011	Sensitize through a model the management of SMEs to successfully implement lean Six Sigma in the organizations to improve the delivery time and quality.	Exploratory longitudinal	Automotive SME
183	Tan *et al.*	A	UK	2012	Proposes a framework and process to assist firms in managing lean capabilities through flexible/temporary workforce to improve the efficiency and effectiveness.	Conceptual/ Exploratory longitudinal	Cookware manufacturers
184	Vimal and Vinodh	A	India	2012	Propose leanness assessment and evaluation model based on fuzzy IF-THEN mechanism, and apply it in a case company also.	Conceptual/ Empirical	Relay
185	Atkinson and Mukaetova-Ladinska	A	UK	2012	Describe the lean thinking approach in an ongoing nurse-led liaison service for older adults resulted in improving access to mental health services for elderly medically ill inpatients.	Descriptive	Health services
186	Gupta *et al.*	A	India	2012	Application of lean Six-Sigma methodology in an Indian tyre manufacturing company to reduce the percentage of defective tyres from total monthly production.	Exploratory longitudinal	Tyre
187	Assarlind *et al.*	AP	Sweden	2012	Discusses the multifaceted views on lean Six-Sigma applications.	Empirical	Large Swedish Manufacturing company
188	Psychogios *et al.*	A	Greece	2012	Develops a multi-factor application approach for lean Six Sigma in the telecommunications industry along with exploring the critical success factors.	Exploratory cross-section	Telecommunication
189	Powell *et al.*	A	Norway and The Netherlands	2012	Analysis of a capability maturity model to assess the functionality offered by ERP systems to support pull production in small-and medium- sized enterprises.	Exploratory cross-section	Agricultural machinery, Electronics, Hinges etc. SMEs
190	Psychogios and Tsironis	A	Greece	2012	Investigate the critical factors influencing the application of lean Six Sigma in an airline company and proposes an integrated framework for the same.	Exploratory longitudinal	Airline
191	Meiling *et al.*	A	Sweden	2012	Evaluate the lean management principles in off-site manufacturing firms having a sustainable approach of continuous improvement evolving processes, people and long term thinking.	Empirical	Timber-framed module prefabrication SMEs
192	Hilton and Sohal	A	Australia	2012	Identify the factors for success in deploying lean six-sigma and proposes a conceptual model for the same.	Conceptual	……….
193	Subha and Jaisankar	A	India	2012	Elucidate the balanced adoption of lean manufacturing practices for achieving operational benefits.	Empirical	Motors, pumps, valves, and auto components
194	Soni and Kodali	A	India	2012	Evaluate reliability and validity of lean, agile and leagile supply chain constructs in Indian manufacturing industry and proposes a model.	Empirical	Automotive, Textile, Machinery etc

Table 2.3: Lean manufacturing literature review (contd.)

S. No.	Author(s)	Profile of Author(s)	Country	Year	Contribution to research	Methodology	Type of Industry
195	Bortolotti and Romano	A	Italy	2012	Analyses lean implementation and process automation through an information based framework in a banking group to improve efficiency and customer satisfaction.	Empirical	Pure service sector (Banking)
196	Agus and Hajinoor	A	Malaysia	2012	Explores lean production supply chain management in Malaysian manufacturing industry towards enhancing product quality and business performance.	Empirical	Non-food Malaysian manufacturing
197	Suarez-Barraza *et al.*	A	Mexico, Spain, Sweden	2012	Analyses the extensive literature which includes applications, conceptual models and categories of lean service.	Descriptive	Services
198	Panizzolo *et al.*	A	Italy, India	2012	Investigates the adoption of current state of lean practices in the Indian SMEs to drive significant improvement in manufacturing performance.	Empirical	Disposal needles, Bearing Balls, Iron Handicraft and brakes and clutches. Indian SMEs
199	Ming-Te *et al.*	A	Taiwan	2012	Set up lean service performance model and employee characteristic analysis for enhancing production and service performance and human resource utilization.	Empirical	Food service
200	Robinson *et al.*	A	UK	2012	Demonstrates theoretical and empirical perspective of discrete-event simulation and lean approaches to improve processes and service delivery of healthcare.	Empirical	Healthcare

A-Academician, P-Practitioner, AP-Academician & Practitioner (Both)

2.4 REVIEW OBSERVATIONS, RESULTS AND DISCUSSION

Some of the observations, results and discussion based on the literature review are presented in this section.

2.4.1 Research Methodology

Results derived from table 2.4 show that around one fourth papers are conceptual or descriptive in nature discussing the fundamental concepts or description of LM process including performance measurement issues. Three fourth papers deal with the theory verification based on empirical or survey methodologies. Exploratory cross-section studies are less reported as compared to longitudinal and other approaches. This is a very healthy sign in lean manufacturing research compared with research in other areas where more research is based on exploratory cross-section studies. There are few studies based on the combination of various research methodologies.

Table 2.4: Research methodologies in LM literature

S. No.	Type of methodology	No. of references	Percentage
1	Exploratory Longitudinal	54	27.0
2	Empirical	43	21.5
3	Conceptual	26	13.0
4	Descriptive	25	13.0
5	Exploratory Cross-Section	22	11.0
6	Comparative	11	05.5
7	Comparative and Exploratory Cross-Section	1	00.5
8	Conceptual & Empirical	5	02.5
9	Comparative & Conceptual	1	00.5
10	Conceptual & Exploratory Longitudinal	7	03.5
11	Empirical & Comparative	2	01.0
12	Descriptive & Exploratory Longitudinal	1	00.5
13	Conceptual & Exploratory Cross-Section	1	00.5
14	Descriptive & Empirical	1	00.5
	Total	200	100

2.4.2 Distribution of Research Papers Over Regional Basis

As shown in figure 2.1, around half the papers are published by authors from USA and UK. Indian authors have also published around 13% of the papers. Most of these papers are based on the empirical study of Indian automotive industry. There are authors from many European nations. This demographic representation of authors shows that the lean manufacturing research and application is spread all over the globe. Surprisingly, the number of articles published by Japanese is less. One of the reasons for this may be that Japanese prefer the term Toyota production over lean manufacturing.

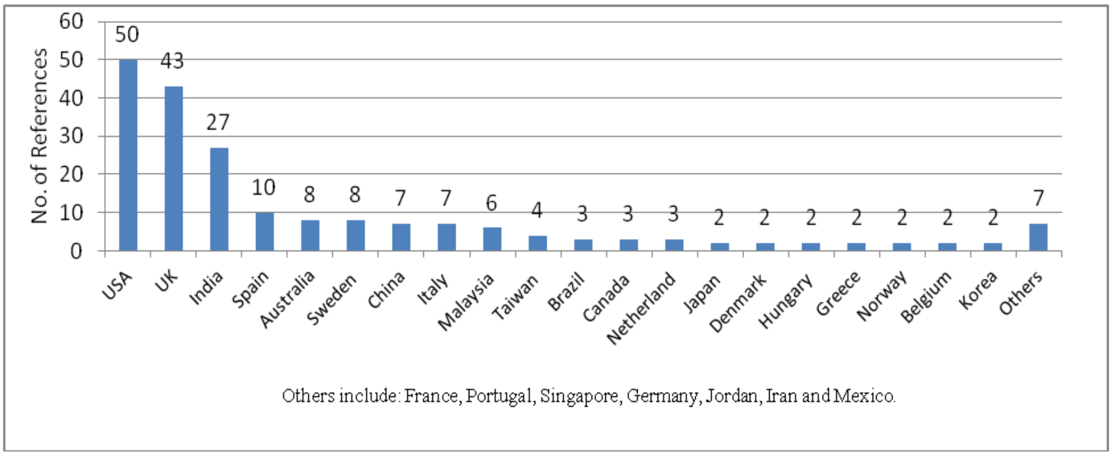


Figure 2.1: Number of research papers published by researchers from different countries (as per first author)

2.4.3 Distribution of Author Profile

Most of the research in lean manufacturing is done by academicians using industry data.

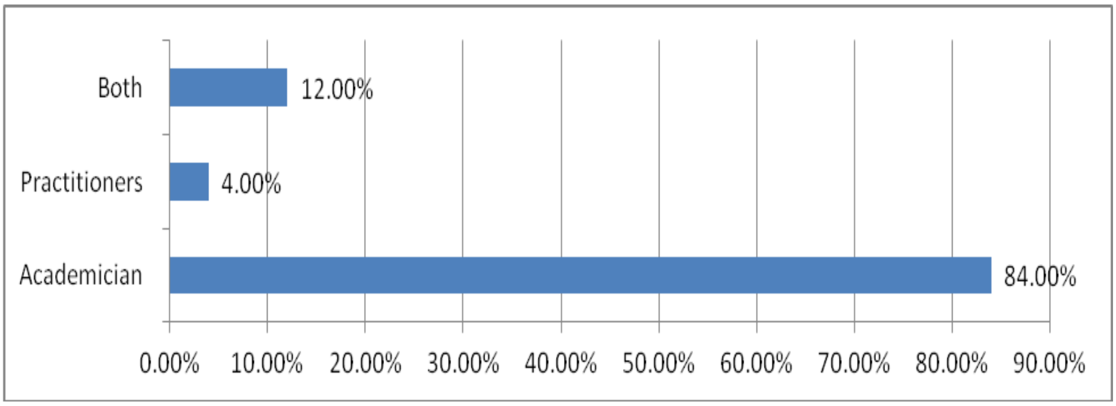


Figure 2.2: Distribution of author profile

168 authors (84%) are basically academicians and only eight authors (4%) are practitioners 24 authors (12%) are both academician as well as practitioners as shown in figure 2.2.

2.4.4 Distribution of Papers over Time

Figure 2.3 presents the year wise distribution of all 200 articles. It can be inferred from the data that the research in lean manufacturing has picked up from the beginning of the 21st century assuming that the research takes few years to compile and publish. One of the reasons for this is the recession in market during this time. The recession forced the organizations and researchers to come out with solutions to decrease the production cost.

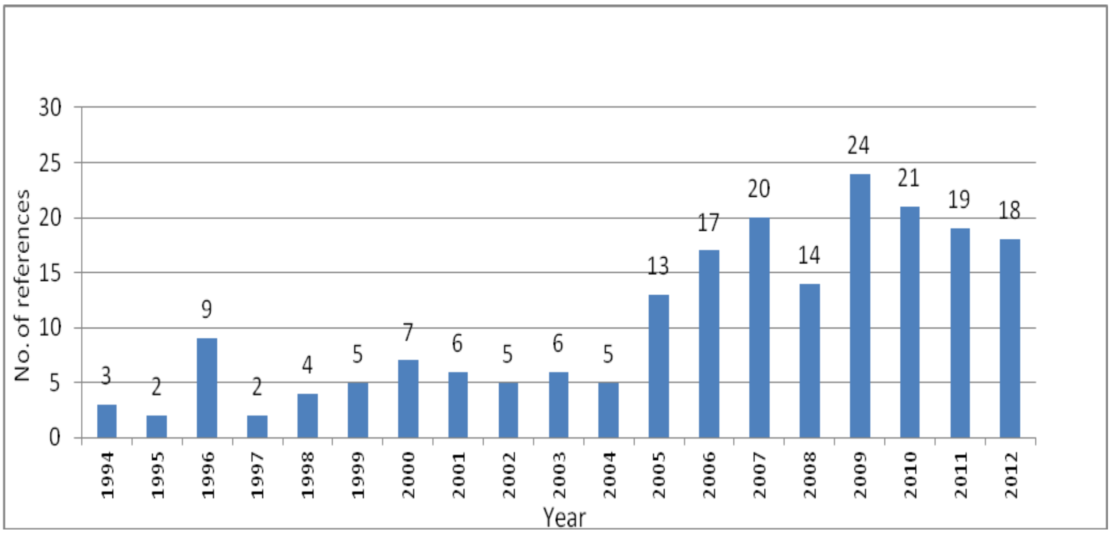


Figure 2.3: Year wise distribution of reviewed papers

Lean manufacturing was widely seen to cut cost through waste reduction. Due to the high interest in the subject from early 1990, *International Journal of Operations & Production* brought out a special edition on lean production (Vol. 16, No. 2, 1996). These days, there are many international journals on lean manufacturing.

2.4.5 Distribution of Papers by Type of Industry

Table 2.5 below shows the LM contribution in different industries compiled as per International Standard Industrial Classification (ISIC), Rev. 4.

Table 2.5: Distribution of references by industry sector

Section	Industry	References
Section C- Manufacturing	Electrical, Computer, electronic & optical production	Barker (1994), Hines *et al.* (1999), McDonald *et al.* (2002), Aitken (2002), Doolen and Hacker (2005), Worley and Doolen (2006), Shen and Han (2006), Fraser *et al.* (2007), Wong *et al.* (2009), Hallgren and Olhager (2009), Yang and Lu (2011), Wong and Wong (2011), Vimal and Vinodh (2012)
	Fabricated metal production & Basic metals	Pricket (1994), Boyer (1996), Emiliani and Stec (2004), Sahoo *et al.* (2008), Pham *et al.* (2008)
	***Machinery and equipment n.e.c,	Karlsson and Ahlstrom (1996), Karlsson and Ahlstrom (1995), Ahlstrom and Karlsson (1996), McCullen and Towill (2001), Demeter and Matyus (2010), Abdulmalek and Rajgopal (2007), Lian and Landeghem (2007), Jensen and Jensen (2007), Krishnamurthy and Yauch (2007), Al-Tahat (2010), Eswaramoorthi *et al.* (2011)
	Motor vehicles, trailers and semitrailers	Niepce and Molleman (1996), Sohal (1996), Soderquist and Motwani (1999) , Sanchez and Perez (2001), Gulyani (2001), Arkader (2001), Cooney(2002), Kalsaas (2002), Motwani (2003), Wu (2003), Huang and Liu (2005) , Seth and Gupta (2005), Simpson and Power (2005), Conti *et al.*(2006), Kumar *et al.* (2006), Taj and Berro (2006), Lee and Jo (2007), Oliver *et al.* (2007), Reichhart and Holweg (2007), Jayaram *et al.* (2008), Grewal (2008), Braglia *et al.* (2009), Hallgren and Olhager (2009), Wee and Wu (2009), Alvarez *et al.* (2009), Anand and Kodali (2009a), Anand and Kodali (2009b), Silva *et al.* (2009), Abreu Saurin *et al.* (2010), Vinod *et al.* (2010), Singh *et al.* (2011), Shahin (2011), Losonei *et al.* (2011), Ramesh and Kodali (2011), Gnanaraj *et al.* (2011)
	****Other transport equipment	Jina *et al.* (1997), Storch and Lim (1999), Comm And Mathaisel (2000), Bamber and Dale (2000), Mathaisel and Comm (2000), Modarress *et al.* (2005), Perry and Turner (2006), Stump and Badurdeen (2009), Puvanasvaran *et al.* (2009), Singh and Sharma (2009), Singh *et al.* (2011), Psychogios and Tsironis (2012)
	Textile	Bruce *et al.* (2004), Comm and Mathaisel (2005), Hodge *et al.* (2011)
	Food production, Manufacture of beverages	Taylor (2005), Simons and Zokaei (2005), Seth *et al.* (2008), Rashid *et al.* (2010), Perez *et al.* (2010), Pool *et al.* (2011), Pool *et al.* (2011), Ming-Te *et al.* (2012), Jimenez *et al.* (2011)
	*Other manufacturing	Weller *et al.* (2006), Bonavia and Marin (2006), Lander and Liker (2007), Braglia *et al.*(2006), Tan *et al.* (2012)
	Human health & social work activities sector	Brown *et al.* (2008), Villa (2010), Grove *et al.* (2011), Atkinson and Mukaetova-Ladinska (2012), Robinson *et al.* (2012)
	Plastic products	Lasa *et al.* (2008), Anand and Kodali (2011), Gupta *et al.* (2012)
	Furniture	Miller *et al.* (2010), Cottyn *et al.* (2011), Meiling *et al.* (2012)
Sec. (J)	Information & Communication	Taj (2005), Robertson and Jones (1999), Staats *et al.* (2011), Psychogios *et al.* (2012)
Sec. (O) & (N)	**Administration	Furterer and Elshennaw (2005) , Bowen and Youngdahl (1998), Emiliani and Stec (2004), Piercy and Rich (2009)
Sec. (K)	Financial and Insurance Activities	Delgado *et al.* (2010), Bortolotti and Romano (2012)
Sec. (P)	Education	Cooper (2009)
Sec. (F)	Construction	Howell (1999), Pheng and Chuan (2001), Salem *et al.* (2005), Johansen and Walter (2007), Yu *et al.* (2009), Dentz *et al.* (2009)

* Pharmaceuticals, medicinal chemical & botanical products, other non-metallic mineral products, Domestic appliances

** Public Administration & Defense; Compulsory Social Security, Administrative & Support Service Activities

*** Machinery for metallurgy, Machinery for food, beverages & tobacco processing, Agricultural and forestry machinery, Metal-forming machinery & machine tools

**** Along with manufacture of air and spacecraft & related machinery, Transport and storage (H)

It shows that the maximum numbers of publications are related to transportation sector (automotive and aerospace industry). This sector has seen fierce competition and almost stagnant demand in USA and European countries for almost a decade. At the same time there has been an increase in demand from the emerging economies like China and India. This forced almost all top industries in automotive sector to woo these emerging markets. However, the customers in the emerging markets were very sensitive to price and operational costs which made the automotive sector to look forward to lean implementation to reduce cost. However, the lean manufacturing implementation started in automobile industry and soon its application is adopted by other industries including textile, construction, food, medical, electrical & electronics, ceramic, furniture, services, etc. LM has been adopted by all types of manufacturing systems – product layout, process layout, and fixed layout; batch production and mass productions; discrete production to continuous production. It has found applications from manufacturing to service sector; mass production to high variety and small volumes production; labour-intensive industries to technology intensive industries; construction industry to assembly industry; medical health care to communication industry.

2.4.6 Research Issues in LM

It can be conjectured from the literature review that lean manufacturing has acquired a multidimensional nature on all aspects of manufacturing management. The latest research in lean manufacturing can be grouped in the following seven areas:

2.4.6.1 Application of lean in small and medium enterprises (SMEs)

SMEs play a tremendous role in manufacturing sector all over the world in term of production volume and employment generation. Globalization and emerging technologies have an enormous impact on SMEs around the world. SMEs are trying hard to include new methodologies/principles like lean to achieve performance improvement. Unfortunately, the idea of applying lean manufacturing has not been adopted by a large number of SMEs due to the fear of implementation cost and the subsequent benefits of lean. Some critical factors for implementation of lean within SMEs include: leadership and management, finance, skill and expertise, the establishment of performance evaluation system, and culture of the recipient organization (Achanga *et al.*, 2006; Pingyu and Yu, 2010). Panizzolo *et al.,* (2012) explored the lean manufacturing penetration in the Indian SMEs and found that lean implementation strategy drive significant improvement in manufacturing performance. Some of the observations for failure of LM implementation in SMEs are: use of wrong tool, use of one tool to solve all the problems, lack of understanding, and poor decision making environment. External support from government, suppliers, customers and outside consultants could enhance the successful implementation of lean in SMEs (Rose *et al.*, 2010).

2.4.6.2 Cultural, work organizational and HRM issues in LM implementation

The relationship between the LM implementation and culture is very sensitive. Different countries have different customs, labor density, degrees of development, industrialization, education, traffic situation, price of land, etc. Companies have to take these issues into consideration when applying lean production. Cultural support for lean collaboration is recommended as a precursor to the application of the lean principles (Perez *et al.,* 2010; Chen and Meng, 2010). Cultural differences pertain mainly to internal resistance and openness to change (Delgado, 2010). Success of LM depends largely on the work organization practices. For example, in 1990s Toyota adopted skill–based practices from a seniority-based scheme. Some important work organization practices common to the factories that successfully adopted lean production are: standardization, discipline and control, continuous training and learning, team-based organization, participation and empowerment, multi-skilling and adaptability, common values, compensation and reward system to support lean production, belief, commitment, communication, work methods, etc. (Emiliani and Stec, 2004; Olivella *et al.,* 2008). The early research in LM has pointed out the role of management support, remuneration system, accounting system, etc (Karlsson and Åhlström, 1995; Boyer, 1996; Karlsson and Åhlström, 1996; Worley and Doolen, 2006). Conti *et al.,* (2006) used Karasek job stress model to link lean shop floor practices to expected worker stress and found that the stress is significant only at managerial level in designing and operating a lean system and not on the shop floor. Globalization has brought increased competition in labour market and many firms today are employing contractual workers in order to help them stay lean and flexible. Firms should manage and train temporary workers to improve the efficiency and effectiveness of the implementation of lean improvement initiatives (Tan *et al.*, 2012).

2.4.6.3 LM implementation process

During recent years, the application of lean manufacturing in different types of industries is growing rapidly. Some of the organizations have reported huge benefits, while many industries have not obtained the desired results. One of the reasons for this can be attributed to improper understanding of LM by both the management and employees of an organization (Anand and Kodali, 2010). None of the available frameworks/models on lean manufacturing provide a stepwise guideline or process to implement lean manufacturing. Some of these frameworks are devoid of lean concepts. Unfortunately many of these frameworks have large number of elements different to each framework. This is perhaps the most undesirable effect of empirical/exploratory study in lean manufacturing. There is a strong need to converge these divergent views to some standard framework.

2.4.6.4 LM performance measurement system

Undeniably, there are certain guidelines which organizations need to contemplate in their efforts to implement an effective performance measurement system for lean manufacturing. Frequently, organizations use generic measures with little consideration of their relevance (Bhasin, 2008). The challenge is to choose the right measures for the appropriate level of the organization (Booth, 1996). If inappropriately planned, the measures can run counter to the strategy and thus encourage the wrong type of behavior in the lean journey. Bhasin (2008) provided a LM performance template including performance metrics related to finance, customer/market, process, people, and future. However, some of the information required to use the template is hard to get and the information required is exhaustive also. Vimal and Vinod (2012) computed leanness level using IF-THEN rules. There is a need to develop few critical metrics to justify LM adoption before, during and after implementation.

2.4.6.5 Lean manufacturing tools, techniques and methodologies

Since the beginning of the new century many organizations are trying to be lean. This has led to the development/identification of many lean manufacturing tools, techniques and methodologies and every day new ones are being proposed. Lean manufacturing has become an integrated system composed of highly inter-related elements and a wide variety of management practices, including 5S, JIT, quality systems, work teams, cellular manufacturing, TPM, Kanban, etc. There are plethora of different tools and techniques for different purposes and waste elimination (Green and Dick, 2001). However, the lean manufacturing tools and techniques have multiple names; some of them overlap with other tools and techniques, and particular tools/techniques might even have a different method of implementation proposed by different researchers (Pavnaskar *et al.*, 2003). Many of these tools and techniques are used in conjunction with each other to achieve the optimum results. The table 2.6 presents a review of the literary contributions to identify the tools, techniques and methodologies used in lean manufacturing in different types of industry.

Table 2.6 shows that VSM has the maximum appearances followed by Kanban/Pull production, JIT, 5S, TPM, cellular manufacturing, *Kaizen*, TQM, SMED, etc. Many of these tools/techniques/methodologies are used in conjunction with each other. A detailed description of some of the tools/techniques/methodologies has been given below:

Kanban

Kanban is a signaling system through which pull scheduling or alternatively called Just-In-Time (JIT) is implemented. Material should be scheduled through pull instead of push. In a push system, master schedule and more detailed production schedule control the production of the forecasted number of parts, whether they are needed or not. In this sense, material and parts are “pushed” through the factory. The pull principle is in stark contrast to this way of scheduling material. With pull, the starting point is a customer order, which goes to final assembly who orders parts from the preceding process. This process, in turn, orders parts from its preceding process, and so on. This means that nothing that has not been ordered is produced (Karlsson and

Åhlström, 1998). The most common types of *kanban* are the withdrawal, production and supplier *kanban*. The *kanban* carries information regarding the part number, quantity, location, delivery frequency, etc. The *kanban* travels with the actual parts and this system is a simple and seemingly foolproof way to make sure that the right parts are made at the right time in the right quantity (Rajinder, 1998).

Table 2.6: Lean tools, techniques and methodologies used in research

Lean tools/ techniques/ methodologies	References
VSM	Hines *et al.* (1998), Hines *et al.* (1999), McDoland *et al.* (2002), Kalsaas (2002), Emiliani and Stec (2004), Huang and Liu (2005), Modarress *et al.* (2005), Seth and Gupta (2005), Comm and Mathaisel (2005), Taylor (2005), Kumar *et al.* (2006), Parry and Turner (2006), Weller *et al.* (2006), Worley and Doolen (2006), Braglia *et al.* (2006), Shen and Han (2006), Abdulmalek and Rajgopal (2007), Lander and Liker (2007), Lian and Landeghem (2007), Johansen and Walter (2007), Krishnamurthy and Yauch (2007), Seth *et al.* (2008), Lasa *et al.* (2008), Sahoo *et al.* (2008), Serrano *et al.* (2008), Grewal (2008), Wong et al (2009), Braglia *et al.* (2009), Yu *et al.* (2009), Lasa *et al.* (2009), Boyle and Rathje (2009), Stump and Badurdeen (2009), Wee and Wu (2009), Alvarez *et al.* (2009), Puvanasvaran *et al.* (2009), Anand and Kodali (2009), Dentz *et al.* (2009), Singh and Sharma (2009), Piercy and Rich (2009), Villa (2010), Rashid *et al.* (2010), Miller *et al.* (2010), Chen and Meng (2010), Vinod *et al.* (2010), Al-Tahat (2010), Grove *et al.* (2011), Hodge *et al.* (2011), Yang and Lu (2011), Singh *et al.* (2011), Jimenez *et al.* (2011), Anand and Kodali (2011)
Kanban/ Pull	Barker (1994), Sohal and Egglestone (1994), Karlsson and Ahlstrom (1996), Niepce and Molleman (1996), Hines *et al.* (1998), Pheng and Chuan (2001), McDoland *et al.* (2002), Wu (2003), Berry *et al.* (2003), Furterer and Elshennaw (2005), Huang and Liu (2005), Taylor (2005), Conti *et al.*(2006), Weller *et al.* (2006), Worley and Doolen (2006), Taj and Berro (2006), Bonavia and Marin (2006), Braglia *et al.* (2006), Abdulmalek and Rajgopal (2007), Lander and Liker (2007), Lian and Landeghem (2007), Jensen and Jensen (2007), Shah and Ward (2007), Lasa *et al.* (2008), Serrano *et al.* (2008), Bayo-Moriones *et al.* (2008), Wong *et al.* (2009), Boyle and Rathje (2009), Puvanasvaran *et al.* (2009), Villa (2010), Rashid *et al.* (2010), Perez *et al.* (2010), Saurin *et al.* (2010), Pool *et al.* (2011), Hodge *et al.* (2011), Singh *et al.* (2011)
JIT	Barker (1994), Prickett (1994), Sohal and Egglestone (1994), Boyer (1996), Forza(1996), Karlsson and Ahlstrom (1996), Katayama and Bennett (1996), Sohal (1996), Niepce and Molleman (1996), Storch and Lim (1999), Sanchez and Perez (2001), Gulyani (2001), Pheng and Chuan (2001), Yusuf and Adeleye(2002), Kalsaas (2002), Shah and Ward (2003), Wu (2003), Berry *et al.* (2003), Comm and Mathaisel (2005), Conti *et al.*(2006), Taj and Berro (2006), Abdulmalek and Rajgopal (2007), Swamidass (2007), Shah and Ward (2007), Johansen and Walter (2007), Bayo-Moriones *et al.* (2008), Brown *et al.* (2008), Shah *et al.* (2008), Jayaram *et al.* (2008), Wong *et al.* (2009), Fullerton and Wempe (2009)
TPM	Katayama and Bennett (1996), Niepce and Molleman (1996), Hines *et al.* (1998), Shah and Ward (2003), Berry *et al.* (2003), Huang and Liu (2005), Conti *et al.*(2006), Kumar *et al.* (2006), Bonavia and Marin (2006), Abdulmalek and Rajgopal (2007), Black (2007), Shah and Ward (2007), Sahoo *et al.* (2008), Wong *et al.* (2009), Boyle and Rathje (2009), Puvanasvaran *et al.* (2009), Villa (2010), Perez *et al.* (2010), Chen and Meng (2010), Saurin *et al.* (2010), Hodge *et al.* (2011), Jimenez *et al.* (2011)

Table 2.6: Lean tools, techniques and methodologies used in research

Lean tools/ techniques/ methodologies	References
5S	Hines *et al.* (1998), Salem *et al.* (2005), Kumar *et al.* (2006), Parry and Turner (2006), Worley and Doolen (2006), Bonavia and Marin (2006), Abdulmalek and Rajgopal (2007), Jensen and Jensen (2007), Johansen and Walter (2007), Krishnamurthy and Yauch (2007), Grewal (2008), Wong *et al.* (2009), Boyle and Rathje (2009), Stump and Badurdeen (2009), Puvanasvaran *et al.* (2009), Silva *et al.* (2009), Villa (2010), Rashid *et al.* (2010), Chen and Meng (2010), Vinod *et al.* (2010), Hodge *et al.* (2011), Jimenez *et al.* (2011), Anand and Kodali (2011)
Cellular Manufacturing/ GT	Barker (1994), Prickett (1994), Huang and Liu (2005), Modarress *et al.* (2005), Bonavia and Marin (2006), Abdulmalek and Rajgopal (2007), Alhourani and Seifoddin (2007), Fraser *et al.* (2007), Shah and Ward (2007), Shah *et al.* (2008), Jayaram *et al.* (2008), Wong *et al.* (2009), Fullerton and Wempe (2009), Boyle and Rathje (2009), Puvanasvaran *et al.* (2009), Saurin *et al.* (2010), Hodge *et al.* (2011), Shahin (2011)
Continuous Improvement	Barker (1994), Karlsson and Ahlstrom (1996), Sanchez and Perez (2001), Wu (2003), Berry *et al.* (2003), Simons and Zokaei(2005), Comm and Mathaisel (2005), Conti *et al.*(2006), Swamidass (2007), Shah and Ward (2007), Johansen and Walter (2007), Brown *et al.* (2008), Lasa *et al.* (2008), Shah *et al.* (2008), Puvanasvaran *et al.* (2009), Silva *et al.* (2009), Chen and Meng (2010), Saurin *et al.* (2010)
TQM	Boyer (1996), Forza(1996), Katayama and Bennett (1996), Niepce and Molleman (1996), Yusuf and Adeleye(2002), Shah and Ward (2003), Berry *et al.* (2003), Furterer and Elshennaw (2005), Conti *et al.*(2006), Abdulmalek and Rajgopal (2007), Johansen and Walter (2007), Brown *et al.* (2008), Wong *et al.* (2009), Fullerton and Wempe (2009), Boyle and Rathje (2009), Pettersen (2009)
Kaizen	Sohal and Egglestone (1994), Katayama and Bennett (1996), McDoland *et al.* (2002), Modarress *et al.* (2005), Worley and Doolen (2006), Taj and Berro (2006), Braglia *et al.* (2006), Jensen and Jensen (2007), Grewal (2008), Wong *et al.* (2009), Boyle and Rathje (2009), Dentz *et al.* (2009), Silva *et al.* (2009), Hodge *et al.* (2011), Roy(2011), Anand and Kodali (2011)
SMED	Hines *et al.* (1998), Berry *et al.* (2003), Huang and Liu (2005), Worley and Doolen (2006), Jensen and Jensen (2007), Krishnamurthy and Yauch (2007), Grewal (2008), Bayo-Moriones *et al.* (2008), Wong *et al.* (2009), Boyle and Rathje (2009), Stump and Badurdeen (2009), Chen and Meng (2010), Hodge *et al.* (2011), Singh *et al.* (2011)
Multifunctional Teams/ Employee Involvement	Karlsson and Ahlstrom (1995), Karlsson and Ahlstrom (1996), Sohal (1996), Sanchez and Perez (2001), Pheng and Chuan (2001), Comm and Mathaisel (2005), Weller *et al.* (2006), Bonavia and Marin (2006), Shah and Ward (2007), Johansen and Walter (2007), Shah *et al.* (2008), Fullerton and Wempe (2009), Chen and Meng (2010), Saurin *et al.* (2010)
Production Smoothing (Heijunka)	Hines *et al.* (1998), Storch and Lim (1999), McDoland *et al.* (2002), Yusuf and Adeleye(2002), Wu (2003), Weller *et al.* (2006), Braglia *et al.* (2006), Lander and Liker (2007), Yavuz and Akaal (2007), Jensen and Jensen (2007), Lasa *et al.* (2008), Serrano *et al.* (2008), Wong *et al.* (2009), Saurin *et al.* (2010), Pool *et al.* (2011)
Visual Control (Andon)	Hines *et al.* (1998), Furterer and Elshennaw (2005), Salem *et al.* (2005), Parry and Turner (2006), Bonavia and Marin (2006), Johansen and Walter (2007), Wong *et al.* (2009), Boyle and Rathje (2009), Rashid *et al.* (2010), Chen and Meng (2010), Saurin *et al.* (2010), Hodge *et al.* (2011), Jimenez *et al.* (2011),
Supplier Relationship	Hines *et al.* (1999), Sanchez and Perez (2001), Pheng and Chuan (2001), Berry *et al.* (2003), Seth and Gupta (2005), Comm and Mathaisel (2005), Simpson and Power (2005), Conti *et al.*(2006), Taj and Berro (2006), Johansen and Walter (2007), Jayaram *et al.* (2008)

Table 2.6: Lean tools, techniques and methodologies used in research (contd.)

Lean tools/ techniques/ methodologies	References
Poke Yoke	Hines *et al.* (1998), Conti *et al.* (2006), Krishnamurthy and Yauch (2007), Shah *et al.* (2008), Wong *et al.* (2009), Boyle and Rathje (2009), Pettersen (2009), Chen and Meng (2010), Vinod *et al.* (2010), Hodge *et al.* (2011)
Standardized Work	Furterer and Elshennaw (2005), Simons and Zokaei (2005), Lander and Liker (2007), Wong *et al.* (2009), Boyle and Rathje (2009), Rashid *et al.* (2010), Saurin *et al.* (2010)
Simulation	McDoland *et al.* (2002), Huang and Liu (2005), Comm and Mathaisel (2005), Abdulmalek and Rajgopal (2007), Lian and Landeghem (2007), Yu *et al.* (2009), Pool *et al.* (2011), Yang and Lu (2011), Anand and Kodali (2011), Robinson *et al.* (2012)
Automation (Jidoka)	Hines *et al.* (1998), Lander and Liker (2007), Wong *et al.* (2008), Stump and Badurdeen (2009), Pettersen (2009), Villa (2010), Saurin *et al.* (2010)

Work standardization

Work standardization or standardization of work, often called the 'Sixth S', is the establishment of uniformity of working conditions, tools, equipment, technical procedures, administrative procedures, workplace arrangements, motion sequences, materials, quality requirements, and similar factors which affect the performance of work. A tool that is used to standardize work is called "*takt time". *Takt, a German word for rhythm refers to how often a part should be produced in a part family based on the actual customer demand. The target is to produce at a pace not higher or lower than the takt time. Takt time is calculated based on the following formula (Feld, 2000)

Takt Time (TT) = (Available work time per day) / (Customer demand per day)

Takt is the elapsed time between units of production output, when the production rate is synchronized with customer demand. Over-production leads to buffer inventories which require resources that are not directly devoted to production. Buffer inventories are often costly to store and handle, hinder movement from one product design to another and hide production errors. Hence, by avoiding overproduction, Takt is fundamental to lean production (Simons and Zokaei, 2005). Motwani (2003) in his case study describes the implementation of work standardization in the company. The implementation strategy that this company embraced involved establishing the work sequence, measuring the cycle time for work sequence, calculating the takt time and comparing the cycle time against the required takt time.

Constant process analysis or *Kaizen*

Kaizen, a Japanese term that basically means 'continuous improvement' or 'change to become good', is a management concept which originated in Japan as a result of continuously effect incremental changes for the better, involving everybody within the organization from workers to managers. Kaizen is aimed at producing more and more value with less and less waste (higher efficiency), attaining better working environment and developing stable processes by standardization. A continuous improvement culture in the company consistently removes this waste to become better & better (Rajinder, 1998). Kaizen costing activities focus on continual small incremental product cost improvements in the manufacturing phase, as opposed to improvements in the design and development phase. The successful implementation of kaizen costing is twofold. First after the cost reduction target is established, then the work cell should be held accountable to these. Second, the kaizen process needs to be consistent and repeatable.

Mistake proofing or *Poka-yoke*

Poka Yoke is a quality management concept developed by Shigeo Shingo to prevent human errors from occurring in the production line. It is a behavior-shaping constraint, or a method of preventing errors by putting limits on how an operation can be performed in order to force the correct completion of the operation.

Autonomation or *Jidoka*

Jidoka the Japanese word for autonomation, implements some supervisory functions rather than production functions. Autonomation prevents the production of defective products, eliminates overproduction and focuses attention on understanding the problem and ensuring that it never recurs. Lander and Liker (2007) compare the traditional usage of *jidoka* in Toyota Production System and the present usage.

Production smoothing or *Heijunka*

In LM system, it is important to move to a higher degree of process control in order to reduce waste. Another practice to accomplish this is production smoothing. Heijunka which is a Japanese word for production smoothing in which the manufacturers try to keep the production level as constant as possible from day to day (Womack *et al*., 1990). Motwani (2003) in a case study provided the details about the implementation sequence of Heijunka in the company. The sequence included determining the finished goods stores requirement in terms of both sales and floor space, determining the withdrawal frequency based on takt time, conveyance manner and walk time, finished producer container size and designing/producing the appropriate *heinjunka* withdrawal tags, assuring that completed product racking on the cell is designed to trigger a production Kanban based on the *heinjunka* withdrawal and training the *heinjunka* material operator.

Single Minute Exchange of Dies (SMED)

It is a metric used to minimize the tool change-over and startup time. Performing faster change-over is important in manufacturing, or any process, because it makes low cost flexible operations possible. The phrase ‘single minute’ does not mean that all changeovers and startups should take only one minute, but that they should take less than 10 minutes (in other words, single digit minute). It evolved from the technique followed by Shigeo Shingo, chief engineer of Toyota in the late 1960s.

Total Productive Maintenance (TPM)

TPM refers to a management system for optimizing the productivity of manufacturing equipment through systematic equipment maintenance involving employees at all levels. Under TPM, everyone is involved in keeping the equipment in good working condition to minimize production losses from equipment repairs, assists, set-ups, and the like. There are three main components of a total productive maintenance program: preventive maintenance, corrective maintenance and maintenance prevention. Preventive maintenance deals with the regular planned maintenance on all equipment rather than random check ups. Workers have to carry out the regular equipment maintenance to detect anomalies as they occur. By doing so, sudden machine breakdowns can be prevented, which leads to improvement in the throughput of each machine (Feld, 2000).

5S

One of the most important tools for implementation of the lean philosophy of waste minimization is the 5S which forms the basis of an effective lean company. 5S is a systematic process of housekeeping to achieve a serene environment at the work place involving all the employees, with a commitment to sincerely implement & practice housekeeping. The basic objective of 5S is to create an organized clean, safe and comfortable work environment so that quality products are manufactured; service is delivered in most cost effective manner. 5S basic disciplines are foundation for high performance manufacturing techniques as TQC, TQM, TPM, KAIZEN, JIT etc.

Without the implementation of 5S other techniques become less effective & implementation may be tough. The 5S shown in figure 2.4 are as follows:

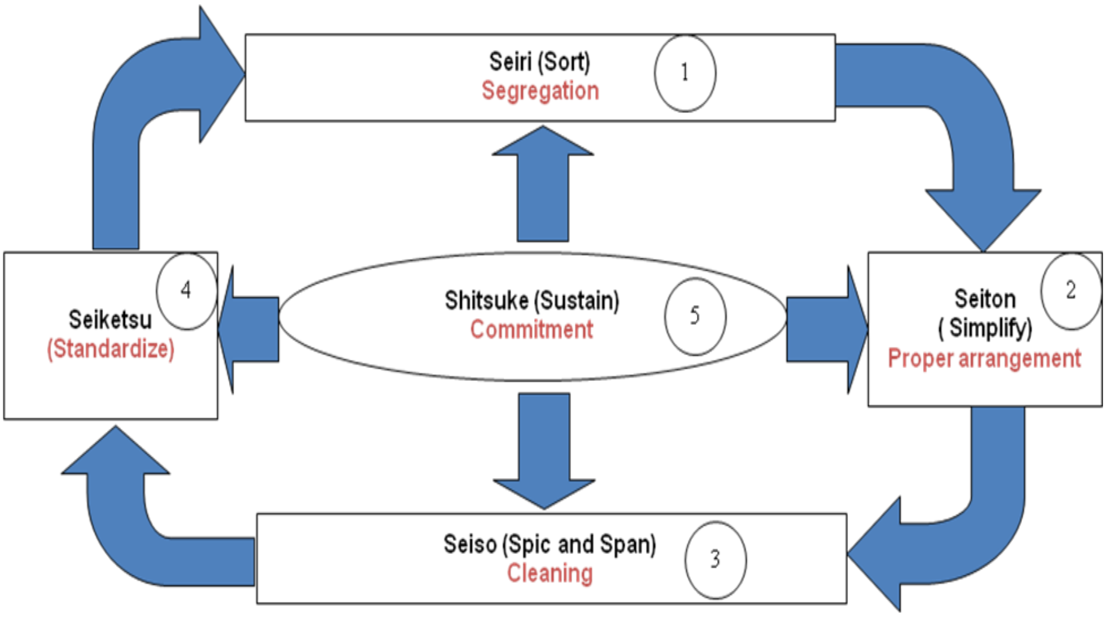


Figure 2.4: Elements of 5S

Seiri (Sort) - Move out the items that are not currently being used. Moving and tossing away needless items will make material flow smoothly and workers move and work easily.

Seiton (Simplify) - Items that do not belong to that area must not be in that area. The work-place tools must be marked and arranged as belonging to that area.

Seiso (Sweep and Clean) - This deals with cleaning and sweeping the work-place methodically. The work place should be maintained on a regular basis as it creates a healthy environment to work.

Seiketsu (Standardize) - It maintains a high standard of house-keeping and work-place arrangement. A regular audit should run and scores should be assigned for areas of responsibilities.

ShitSuke (Sustain) – Management should be accountable to train people to follow house-keeping rules and sustain the improvements made.

The benefits from implementation of 5S include improved safety, productivity, quality, set up time improvement, creation of space, reduced lead time, cycle time, increased machine uptime, improved morale, teamwork, and continuous improvement (Salem *et al.*, 2005).

Value stream mapping (VSM)

The process of mapping the material and information flows of all components and sub-assemblies in a value stream that includes manufacturing, suppliers and distribution to the customer is known as value stream mapping (Seth and Gupta, 2005). It provides a road map to tackle improvement areas like excessive WIP, lead time and cycle time to bridge the gap between the existing state and the proposed state of a manufacturing firm (Singh and Sharma, 2009). It is a qualitative tool that gives an understanding of the value stream/value chain as a basis of reducing the pipeline of inventory and compresses the throughput time, thereby helping manufacturing companies to go lean and to achieve larger control of their value stream (Kalsaas, 2002).

In recent years, value stream mapping has emerged as the preferred way to implement lean manufacturing. Jones and Womack (2000) explain VSM as the process of visually mapping the flow of information and material as they are and preparing a future state map with better methods and performance. Womack and Jones (1996) define VSM as the simple process of directly observing the flows of information and materials as they now occur, summarizing them visually, and then envisioning a future state with much better performance. This visual representation facilitates the process of lean implementation by helping to identify the value-added steps in a value stream, and eliminating the non-value added steps/waste (muda) (Rother and Shook, 1999). A value stream map is a tool used to visually represent the value stream process sequence, material flow and information flow for a product or product family using standard icons as shown in figure 2.5.

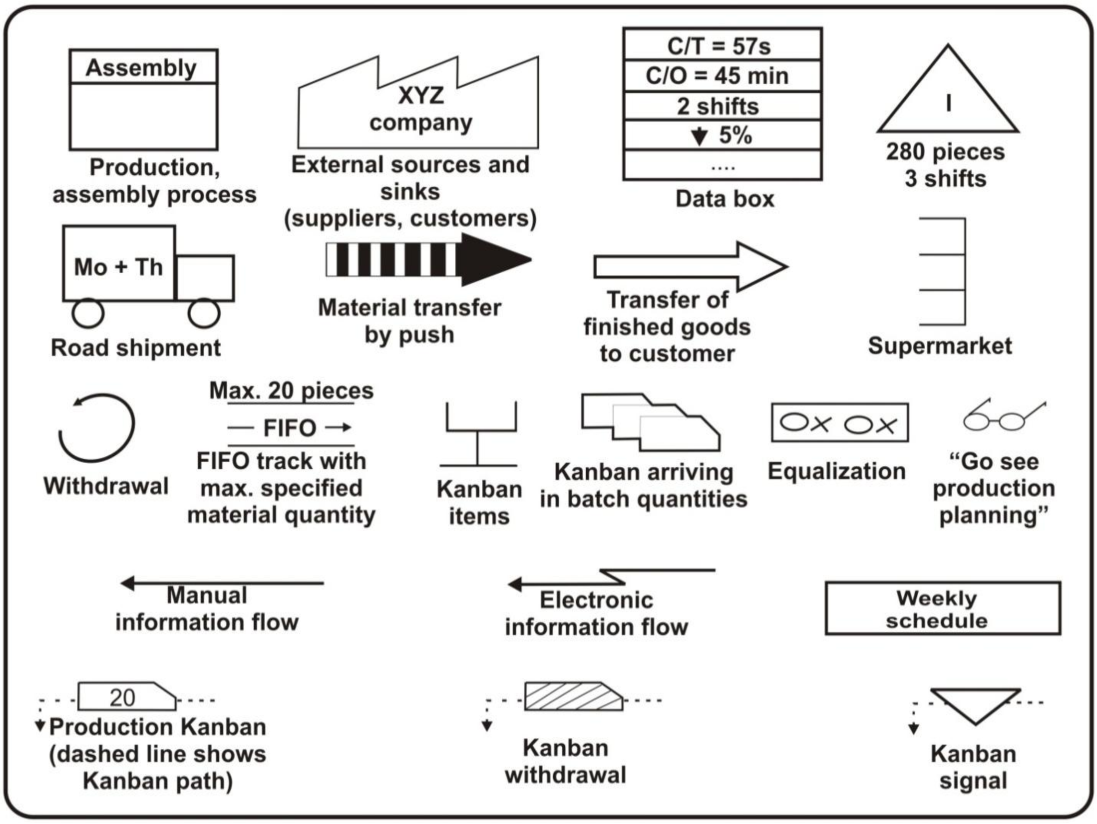


Figure 2.5: Icons for Value Stream Mapping

A value stream consists of everything including the non-value added activities and provides a pictorial view of what elements of the process the customer is willing to pay for (Tapping and Shuker, 2003). The future state map serves as a blueprint for the working of value stream after improvements and provides a basis for developing the implementation plan. VSM provides a means to visualize process sequence, material flow and information flow for the entire value stream; facilitates the identification of waste and the sources of waste; supports the prioritization of continuous improvement activities at the plant and value stream levels; and provides the basis for the development of an overall improvement plan. VSM has been used in many types of industries e.g. automotive industries (Vinodh *et al.*, 2010; Singh and Sharma, 2009; Singh *et al.*, 2011; Huang and Liu, 2005), foundry (Al-Tahat Mohammad, 2010), textile industry (Hodge *et al.*, 2011), health care sector (Grove *et al.*, 2011), electronic industry (Yang and Lu, 2011; Shen and Han, 2006), small scale industries (Grewal, 2008; Kumar *et al.*, 2006), process industry (Seth *et al.*, 2008; Abdulmalek and Rajgopal, 2007), service sector (Emiliani and Stec, 2004) and agro-food industries (Taylor, 2005).

Key advantages of VSM (Pingale and Deepak, 2010)

Operational Advantages:

- Reduction in lead time (cycle time)
- Increase in productivity
- Reduction in work-in-process inventory
- Improvement in quality
- Reduction in space utilization

Administrative Advantages:

- Reduction in order processing errors
- Streamlining of customer service functions so that customers are no longer placed on hold
- Reduction of paperwork in office areas
- Reduced staffing demands, allowing the same number of office staff to handle orders in large numbers

- Documentation and streamlining of processing steps, enabling non-critical functions to be outsourced and allowing the company to focus its efforts on customers' needs
- Implementation of job standards and pre-employment profiling, ensuring the hiring of only above-average performers

Strategic Improvements:

- Reduced lead time, costs and improved quality provide opportunities for new marketing campaigns, allowing the company to gain market share from competitors
- Increased RoIC and reduced working capital

Six- Sigma

A well-known quality standard and mathematical tool in lean circles, six-sigma refers to a quality improvement and business strategy concept, started by Motorola in the United States in 1987. In statistical terms, six-sigma is the abbreviated form of 6 standard deviations from the mean, which mathematically translates to about 2 defects per billion. Thus, strictly speaking, the process is said to have achieved six-sigma if it is producing no more than 2 defects per billion parts produced (Andersson *et al*., 2006). Eventually the main aim is to increase customer satisfaction by minimizing defects and improving or maintaining quality. Lately, lean and six sigma practitioners are integrating the two strategies into a more powerful and effective hybrid technique called lean six-sigma (LSS), addressing many of the weaknesses and retaining most of the strengths of each strategy. Lean sigma combines the variability reduction tools and techniques from six-sigma with the waste and non-value added elimination tools and techniques from lean manufacturing, to generate savings to the bottom-line of an organization (Kumar *et al.*, 2006). LSS is an approach focused on improving quality, reducing variation and eliminating waste in an organization (Furterer and Elshennawy, 2005). Antony (2011) discussed some perspectives from leading academics and practitioners with the fundamental and critical differences between lean and six-sigma in a process excellence initiative in an organization. Arnheiter and Maleyeff (2005) describe what lean organizations can gain from six sigma and what six sigma organizations can gain from lean management. They try to eliminate many misconceptions regarding six sigma and lean management by describing each system and the key concepts and techniques that under lies their implementation. Finally some suggestions are made regarding concepts and methods that would constitute a lean, six sigma organization. Kumar *et al.,* (2006) in a case study proposes a lean sigma framework to reduce the defect occurring in the final product manufactured by a die casting process. Combining lean practices with six-sigma has gained immense popularity in recent years (Shah *et al.,* 2008).

Simulation

Before an enterprise turns to lean implementation, it needs to visualize its present value chain. This is done with the help of value stream mapping as discussed previously. Simulation is an extensively used process-modeling tool used to reduce uncertainty and create consensus by visualizing dynamic views of the process for a given state. In recent years VSM has become a popular implementation method for lean manufacturing. However, its limitations such as being time-consuming, its inability to detail dynamic behavior of production processes and to encompass their complexity have led to turn to simulation beyond ‘traditional’ manufacturing (Lian and Landeghem, 2007; Anand and Kodali, 2009a). Manufacturing factory floor simulations are invaluable tools in the implementation of lean manufacturing. Many manufacturers will not make a change to the process before a simulation is performed to determine the impact of the change. Simulation can be considered as inexpensive insurance against costly mistakes. Lian and Landeghem (2007) present a VSM based simulation model by successfully adapting special VSM objects to simulation. Simulation is used to study the effect of lean when transforming a system from push production to pull production. McDonald *et al.* (2002) demonstrate how simulation can be integrated with VSM to visualize better dynamic features of the future state before implementation. Furthermore, simulation facilitates process visualization, creating a shared consensus about the process and the improvements. McDonald *et al.* (2002) conclude through a study of the simulation for the assembly line for high-volume manufacturing firms, that simulation can be used to support and evaluate lean manufacturing techniques and the value stream mapping process. Several of the obvious steps where simulation can support these processes are; current state assessment, VSM team training, and future state evaluation.

Cellular manufacturing (CM) or Group technology (GT)

Cellular manufacturing is one of the corner stone when one has to become lean. It is a well known strategy in removing many of the inefficiencies experienced in functional batch-type manufacturing environments. It has been established that the implementation of CM can have improved benefits such as reducing delivery lead times and work-in-process inventory, while improving product quality and worker productivity (Fraser *et al.*, 2007). This includes the formation of machine cells and part families. The formation of machine-part families is an important task in the design of cellular manufacturing systems. Manufacturing cell grouping has the effect of reducing material handing cost and work in process inventory (Alhourani and Seifoddini, 2007). Fraser *et al.* (2007) develops a comprehensive framework for practitioners for improving the implementation effectiveness of cellular manufacturing. Motwani (2003) in a case study describes how Single-piece flow or cell formation was implemented in the company. The implementation strategy for this company involved completing a line balance based on observed times and modifying work stations so only one part can be stored between them. This frequently involved major rearrangement when first attempted. The company decided to use a ‘U” shaped layout with operators inside the configuration. Prickett (1994) describes a practical approach to the design implementation of Cell-based manufacturing system (CMS). In the current production environment with demand increasingly characterized by shorter life cycles, smaller batches and greater part variety, this flexibility can offer premium competitive values.

Just-in-time (JIT)

JIT, named after a phrase originated at Toyota Motor Company, recommends designing and controlling the manufacturing processes such that the required items are produced in the quantity needed when they are needed (Yawuz and Akcali, 2007). It is a management philosophy aimed at eliminating manufacturing wastes by producing only the right amount and combination of parts at the right place at the right time. The implementation and the commitments of the metal working industries to JIT are discussed by Boyer (1996). Yawuz and Akcali (2007) discussed the practical and modeling challenges that arise in production smoothing in the context of JIT manufacturing and reviews the existing literature that focuses on analytical models and solution algorithms. Ramarapu *et al.* (1995) presented a literary review of the various JIT elements proposed and the identified the critical elements to JIT implementation.

Total quality management (TQM)

TQM is a term first coined by the U.S. Naval Air Systems Command to describe its Japanese style management approach to quality improvement. TQM is a structured system for managing the quality of products, processes, and resources of an organization in order to satisfy its internal and external customers, as well as its suppliers. Its main objective is sustained customer satisfaction through continuous improvement, which is accomplished by systematic methods for problem solving, breakthrough achievement, and sustenance of good results (Andersson *et al.*, 2006). Soderquist and Motwani (1992) analyses lean quality management in a French automotive supplier firm. It's essential role was to disseminate continuously quality improvement for creating customer value.

Toyota Production System (TPS)

Even though TPS and lean are similar paradigms, it stands true that lean evolved out of the principles and practices laid by TPS and thus TPS serves as a fundamental philosophy based on which lean production operates. TPS is a philosophy that can be better described as a set of general principles of organizing and managing an enterprise which can help any organization get on a path of positive learning and improvement. It has led to the movement of lean production by focusing on taking wastes out of value streams (Lander and Liker, 2007). They also discussed a case study of the transformation to TPS thereby introducing benefits such as reducing defects, besides reducing costs, increased reliability of the production process and reduced variability. Black (2007) proposes four design rules to implement TPS namely conforming to takt time, single piece flow, cell formation and pull system. Towill (2007) has described in detail the four associated levels of the TPS prism model namely vision, principles, toolkit and learning. Lee and Jo (2007) examine the spread of TPS in Korea by focusing on a single auto firm. The case study reveals that the adoption of TPS involves complex evolutionary process of organizational learning, interpretation and interactions between management's strategic choices so that the emulation is best suited to the recipient's environment. Swamidass (2007) presents the results of his research on the effects of the TPS on the US manufacturing firms during 1981-1998 and tries to prove the literary claim that TPS decreases inventory.

Agile manufacturing (Leagile manufacturing)

Lean and agile manufacturing are often described as two distinct manufacturing philosophies with different set of goals. Lean basically emphasizes reduction in wastage of resources and agile focuses on the efficiencies of mass production, while producing a greater variety of products in a manufacturing industry. An agile system aims to be more flexible and adaptive to changes in the environment and thus has the potential to use more resources (Christopher and Towill, 2000). Despite the differences in end objective, some researchers present lean and agile as strategies that are mutually supportive in the organization (Katayama and Bennett, 1999; Naylor *et al.,* 1999; Robertson and Jones, 1999). Other researchers have advanced the idea of lean and agile manufacturing strategies coexisting through leagile manufacturing applied within a manufacturing system or supply chain. The system being defined as leagile could be an entire supply chain for a single corporation (Mason-Jones *et al.,* 2000) or it could be applied to a single corporation with multiple business units (Krishnamurthy and Yauch, 2007) and found that it is possible for a corporation to simultaneously pursue both lean and agile manufacturing strategies by adopting a leagile infrastructure. Lean and agile allow companies to deliver bottom-line savings in production terms although their effectiveness depends upon the volume and demand profile of their products (Pham *et al.,* 2008).

Agile manufacturing is a strategy that can create flexible or virtual organizations to meet increasing customer expectations. It has developed from the concept of lean production currently being employed increasingly in manufacturing industry (Robertson and Jones, 1999). Agile manufacturing is a competitive strategy underpinned by four principles (Yusuf and Aspinwall, 2000). These principles are; customer enrichment through products at the cost of mass production, organizing to master change by competing from multiple fronts with reconfigurable resources, intra and inter-enterprise cooperation, and leveraging of organizational knowledge by means of advanced technologies. Both lean and agile initiatives significantly affect quality conformance, delivery speed and delivery reliability (Hallgren and Olhager, 2009). Leagile, a paradigm developed as a combination of the agile and lean manufacturing techniques is the combination of the lean and agile paradigms within a total supply chain strategy by positioning the decoupling point (point where the customer order penetrates the material flow stream) so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the market place (Mason-Jones *et al.,* 2000). Towill and Christopher (2002) discuss the successful combination of lean and agile paradigms. McCarthy and Tsinopoulos (2002) present a framework to examine the key components and characteristics that define a strategy for agile manufacturing systems. This facilitates the processes of strategic analysis, choice and information.

World-class manufacturing

World-class manufacturing essentially means having the right production capability to make money from totally satisfying the customer, with high quality services and products at the right price delivered at the right time. Just in time, manufacturing resource planning, and total quality management are all techniques which help to achieve world-class manufacturing. World-class plants are able to operate with one-seventh the amount of inventory of their non-world-class competitors. So, obviously to be a world-class manufacturer requires more than high capacity utilization and low inventory levels. Burcher *et al.* (1996) describes a methodology relevant to manufacturers of repetitive batches, to assist them in their journey to world-class manufacturing in the previously mentioned two important areas namely; higher capacity utilization and smaller batch sizes.

Elimination of zero-value adding activities

Eliminating waste and zero-value added activity is one of the main goals of lean production. If the task does not add value from the customer's point of view it should be eliminated. It is believed that by minimizing waste and zero-value added activities, companies can reduce production costs and the overall production system will be more efficient.

Continuous improvement

Continuous improvement is a process that requires involvement of employees at different levels and support of management. This process relates to the Jidoka concept, which states that since people are not working for the machines, they have the ability to use their best judgment to improve the process. In addition, they will assume more than minimum responsibilities making sure the machines function correctly. All members in the company should strive for continuous improvement in products and processes. This would require the creation of improvement teams to lead the organization to move toward zero defects. The search for increasing quality levels turned to new methods for improving processes, such as computer integrated manufacturing, lean manufacturing and six-sigma with continuous improvement strategy in automotive industries (Silva *et al.,* 2009).

Waste minimization

Waste reduction is one of the foremost aims of lean manufacturing. All the known tools, techniques, policies and practices are intended to follow this philosophy. It involves eliminating all activities that do not add value or maximize use of scarce resources (capital, people and land). Lean focuses on abolishing or reducing the wastes or 'Muda' (the Japanese word for waste) and on maximizing or fully utilizing the activities that add value from the customer's perspective. The value adding steps need to be arranged in a sequence such that the material flows in a continuous flow in the direction of the customer, without any stoppage or back flows to reduce waste (Rajinder, 1998). The eight main sources those are primarily responsible for waste generations which are as follows:

i. Defects; Defects prevent the customers from accepting the product. The effort to create these defected products is waste and it has a direct impact to the bottom line. Quality defects resulting in rework or scrap are a tremendous cost to organizations. Associated costs include quarantining inventory, re-inspecting, re-scheduling, and capacity loss. In many organizations the total cost of defects is often a significant percentage of total manufacturing cost. Through employee involvement and continuous process improvement, there is a huge opportunity to reduce defects at many facilities.

ii. Overproduction; Simply put, overproduction is to manufacture an item before it is actually required. Overproduction is highly costly to a manufacturing plant because it prohibits the smooth flow of materials and may result in degrading quality and productivity. This creates excessive lead times, results in high storage costs, and makes it difficult to detect defects. The simple solution to overproduction is turning off the tap; this requires a lot of courage because the problems that overproduction is hiding will be revealed. The concept is to schedule and produce only what can be immediately sold / shipped and improve machine changeover/set-up capability.

iii. Transportation; Each time a product is moved it stands the risk of being damaged, lost, delayed, etc. as well as being a cost for no added value. Transportation does not make any transformation to the product that the consumer is supposed to pay for. Excessive movement and handling cause damage and are an opportunity for quality to deteriorate. Material handlers must be used to transport the materials, resulting in another organizational cost that adds no customer value. Transportation can be difficult to reduce due to the perceived costs of moving equipment and processes closer together. Furthermore, it is often hard to determine which processes should be next to each other. Mapping product flows can make this easier to visualize.

iv. Waiting; This waste refers to both the time spent by the workers waiting for resources to arrive, the queue for their products to empty as well as the capital sunk in goods and services that are not yet delivered to the customer. Whenever goods are not moving or being processed, the waste of waiting occurs. Typically more than 99% of a product's life in traditional batch-and-queue manufacture will be spent waiting to be processed. Much of a product's lead time is tied up in waiting for the next operation; this is usually because material flow is poor, production runs are too long, and distances between work centers are too far. Linking processes together, so that one feeds directly into the next can dramatically reduces waiting.

v. Inventory; Inventory; be it in the form of raw materials, work-in-progress (WIP), or finished goods; represents a capital outlay that has not yet produced an income either to the producer or for the consumer. Any of these three items not being actively processed to add value is waste. WIP is a direct result of overproduction and waiting. Excess inventory tends to hide problems on the plant floor, which must be identified and resolved in order to improve operating performance. Excess inventory increases lead times, consumes productive floor space, delays the identification of problems, and inhibits communication. By achieving a seamless flow between work centers, many manufacturers have been able to improve customer service and slash inventories and their associated costs.

vi. Motion; As compared to conveyance, motion refers to the producer or worker or equipment. This has significance to damage, wear, and safety. It also includes the fixed assets, and expenses incurred in the production process. This waste is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching. These are also health and safety issues, which in today's litigious society are becoming more of a problem for organizations. Jobs with excessive motion should be analyzed and redesigned for improvement with the involvement of plant personnel.

vii. Over processing; Using a more expensive or otherwise valuable resource than is needed for the task or adding features that are designed in but unneeded by the customer. There is a particular problem with this item as regarding people. People may need to perform tasks that they are over qualified for so as to maintain their competency. This training cost can be used to offset the waste associated with over processing. This often results in poor plant layout because preceding or subsequent operations are located far apart. In addition they encourage high asset utilization (over-production with minimal changeovers) in order to recover the high cost of this equipment. Toyota is famous for their use of low-cost automation, combined with immaculately maintained, often older machines. Investing in smaller, more flexible equipment where possible; creating manufacturing cells; and combining steps will greatly reduce the waste of inappropriate processing.

viii. Untapped resources: This waste is mainly related with not using people's abilities (mental, creative, physical, and skill). There are lot of causes of this such as management by fear and directive, politics, poor hiring practices, low or no investment in training, low pay, high turnover strategy etc. Other significant wastes identified are the complexity, energy, space and knowledge (Taj and Berro, 2005).

Other lean tools, techniques, practices and principles

Comm and Mathaisel (2005) propose that 'multi-functional teams' acts as a lean policy. Multifunctional teams are related to the Jidoka concept in that floor workers are not tied to one machine and do not work in isolated islands. Workers should be trained to work on multiple tasks and thus allow the company to flexibly accommodate changes in production levels. Karlsson and Åhlström (1998) also agree with the importance of multi-functional teams and the related policies like decentralized responsibilities and integrated functions. Multi-functional teams perform multiple tasks, often organized around a cell-based part of the product flow. Each team is given the responsibility to perform all the tasks in this part of the product flow. The important characteristic of a lean work organization is that responsibilities are decentralized onto the multifunctional teams. There is no supervisory level in the hierarchy in a lean production system. The multifunctional team is expected to perform supervisory tasks. A second important principle concerning the multifunctional team is the integration of different functions into the teams. This means that tasks previously performed by indirect departments are integrated into the team, increasing the work content of these teams. Tasks such as procurement, materials handling, planning and control, maintenance, and quality control, are performed by the team. Thus, the number of tasks performed by the team increases, and consequently the number of indirect employees can be reduced. They also stress on the need of 'vertical and horizontal information systems'. Since information is important for the multifunctional teams to perform according to the company's goals, elaborate information systems are necessary to provide timely information continuously, directly in the production flow.

Other policies proposed by him are supplier integration and flexible information system. Suppliers can play an important role in achieving the just-in-time production concept. By reducing the amount of time required to wait for parts and arrival of materials, manufacturing companies can place an order after they are certain of the quantity and products desired by their customers. This can greatly reduce just-in-case inventories in the system and production lead-time. Flexible information system is advisable since excessive paper work is considered to be one of the traditional areas of waste. Lean production requires the diffusion of useful and relevant information to the production line. By decentralizing responsibilities to the first line workers, the amount of time wasted in processing documents can be reduced. Bhasin and Burcher (2006) proposed 'reducing the supplier base' and 'step change' as significant lean policies. Step change or *kaikaku* in Japanese signifies that the lean transformations need not be radical to achieve success but best if done in stages.

Apart from the commonly agreed upon policies, one is Point of Use System (POUS). POUS requires that the parts, raw materials, tools, and fixtures as close as possible to where they are being used.

‘Visual factory’ is cited as essential. Visual factory requires that information is made available and understandable at a glance for each operator to see and to use in achieving continuous improvements. Parry and Turner (2006) discuss about the ‘Visual control’ as a lean practice. Visual tools form an important part of the communication process which drives lean factories. The best visual aids include graphical representations, pictures, posters, schematics, symbols, transparencies and colour coding and these can be enhanced with audio signals. In fact the usage of Kanban cards for pull scheduling is in accordance with the need of visual control. While the scope of the above tool is to integrate all the information in the concerned enterprise, ‘Information centralization’ is also a similar tool but has a wider scope that incorporates all the stages and components in the supply chain to extract maximum benefits.

Balmer and Dale (2000) cites Kawasaki Production System *(KPS)* as a philosophy from which the lean techniques developed. Though the KPS was initiated for aerospace environment, its implementation has been successful in the automobile industry too. Though KPS, TPS, JIT and many other philosophies originated in different situations, they follow certain common strategies that are collectively termed and evolved into lean.

According to Katayama and Bennett (1996) the essential elements of lean production are resource inputs, manufacturing system, customer satisfaction and performance outputs. A key feature is 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). 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.

2.5 CONCLUSIONS AND FUTURE RESEARCH ISSUES

This chapter presents a review of research papers on lean manufacturing/lean production. The review focuses on research contribution, research methodologies, type of industry, and author profile. Following conclusions can be drawn from the review:

- There are many lean manufacturing definitions with divergent objectives and scope.
- Theory verification through empirical and exploratory studies has been the focus of research in LM. More research is based on exploratory longitudinal studies rather than exploratory cross-section studies. Research on LM is conducted across the globe. There are papers from the developed, emerging and under developed countries. However, USA and UK lead the research with more publications.
- The research in LM has picked up from early 21st century. Automotive industry has been the focus of LM research but LM has been adopted by other type of industries also. However, the adoption of LM in SMEs is not widespread. Because of the fear of high implementation cost and uncertain future benefits. Some sort of external support is required to enhance adoption of LM in SMEs. Success of LM depends largely on the cultural and work practices prevalent in organizations.
- LM has been adopted by all types of manufacturing systems – product layout, process layout, and fixed layout; batch production and mass productions; discrete production and continuous production. LM has found applications from manufacturing to service sector; mass production to high variety and small

volumes production; labour-intensive industries to technology intensive industries; construction industry to assembly industry; medical health care to communication industry.

- One of the critical implementation factors of LM is simultaneous adoption of leanness in supply chain. One of the reasons for the slow adoption of LM under variable demand scenario is to link the production pull signal to the variable demand.
- LM adoption led to more stress at managerial level rather than the shop floor level people.
- There is no standard LM implementation process/framework. LM has become an integrated system composed of highly integrated elements and a wide variety of management practices.

Research Issues

- The research on LM through empirical and exploratory studies has led to many frameworks with divergent views. Use of a wide variety of management practices has led to different views devoid of concepts. There is a strong and urgent need to converge these divergent views to some standard framework/process. Development of stepwise guidelines/process for LM implementation, like existing TPM, TQM or six-sigma implementation guidelines, is strongly required.
- The use of wide variety of management practices in LM implementation has led to a wide variety of generic performance indicators. There is a need to develop LM standard/critical metrics for its evaluation before implementation, during implementation, and after implementation.

- Various researchers in LM have used more than 18 tools/techniques/methodologies. Most of these tools/techniques/methodologies are standalone methods developed and used previously. Further research is required to distinguish the standard tools/techniques/methodologies for LM. Similarly, there are other systems like six sigma, agile manufacturing and green manufacturing which have some elements of lean manufacturing. More research is also required to distinguish the common and different elements of LM, agile manufacturing, six sigma and green manufacturing.

- Lean manufacturing has not been adopted by a large number of SMEs due to fear of implementation cost and benefits. External support from government, suppliers, customers and outside consultants could enhance the successful implementation of lean manufacturing in SMEs. More focused research is required for LM implementation in SMEs.

- A large number of organizational practices have been reported in the literature for the successful implementation of LM. These include standardization, discipline and control, continuous training and learning, team-based organization, participation and empowerment, multi-skilling and adaptability, common values, compensation and reward system to support lean production, belief, commitment, communication, work methods, management support, remuneration system, accounting system, etc. It may be worthwhile to prioritize these practices to help managers in decision making.

- The genesis of divergent views on LM perhaps lies in its divergent definitions, objectives and scopes. The researchers have developed LM as a way, process, set of principles, approach, concept, philosophy, system, program, and paradigm. The urgent needs are to standardize the LM definition, converge LM scopes and synthesize the LM objectives to converge to a few critical objectives.

CHAPTER 3

DRIVERS AND BARRIERS OF LEAN MANUFACTURING IMPLEMENTATION

This chapter addresses the process of development of models for drivers and barriers to implementation of LM.

3.1 INTRODUCTION

There are number of factors that act as drivers or barriers to the implementation of lean manufacturing. Understanding of these drivers and barriers is necessary to implement lean manufacturing effectively. This chapter aims at identifying these drivers and barriers for implementation of lean manufacturing. It also develops a model each for drivers and barriers using statistical analysis and tests these models using structural equation modeling technique. A proper understanding and analysis of drivers and barriers to implementation of lean manufacturing will help Indian industries to figure out the most effective way to implement lean and improve efficiency of production.

Singh *et al.,* (2010) conducted a survey of 127 Indian industries, identified 26 barriers to implementation of lean manufacturing and categorized them into five broad categories using factor analysis. These are: customer issues, organizational issues, supplier issues, market issues, and top management issues. Some of the barriers mentioned are small range of products, high rejection rate, lack of funds, and lack of multi-skilled manpower. Bhasin (2012) undertook a survey through questionnaires in 68 manufacturing industries and subsequently complemented it by extensive case studies undertaken in seven organizations to study prominent obstacles to lean. He lists four drivers to implementation of lean manufacturing that are persistent amongst all sizes of organizations. These are: improving performance, increasing competitive pressure, increasing customer pressure, and building team spirit.

Achanga *et al.,* (2005) carried out a comprehensive literature review and visited ten SMEs based in the UK to identify critical success factors for lean implementation within SMEs. According to him leadership, management, finance organizational culture and skills, and expertise are the most pertinent issues critical for successful adoption of lean manufacturing within SMEs environment. Dowlatshahi and Taham (2009) analyzed aspects of Just-In-Time (JIT) philosophy applicable to SMEs and developed a conceptual framework for JIT implementation in SMEs. Barriers to implementation of JIT in SMEs include: a lack of supplier cooperation and partnerships; an inability to develop the necessary technologies and methodologies to reduce or eliminate waste; difficulties in managing demand fluctuations; a lack of capital to acquire advanced technologies; quality control problems; and, inadequate employee training and development. Enablers include the ability to: empower employees; reduce JIT implementation time; overcome employee resistance to change; and, receive various forms of governmental support.

This chapter aims at identifying the drivers and barriers to implementation of lean manufacturing through literature survey. Later, these drivers and barriers will be validated through a survey of ceramic industry in Rajasthan. This chapter focuses on a study undertaken among ceramic industries of Rajasthan to validate these drivers and barriers through statistical analysis and develop models of these drivers and barriers which reflect the causal relationship among drivers and barriers using structural equation modeling (SEM) technique. Structural equation modeling is a statistical methodology that takes a confirmatory (i.e. hypothesis-testing) approach to the analysis of a structural theory. Typically, this theory represents 'causal' processes that generate observations on multiple variables (Bentler, 1989). SEM is applied to test the full structural model for assessing the impact of latent variables on each other. SEM methodology has been widely used in various areas of research for empirical testing of frameworks in sustainable manufacturing (Vinodh and Joy, 2012), pull production (Koufteros, 1999), operations management (Shah and Goldstein, 2006), etc. SEM is widely used because it provides a quantitative method for testing substantive theories and it explicitly accounts for measurement error, which is present in most areas (Raykov and Marcoulides, 2006).

The remainder of the chapter will proceed as follows: Section 3.2 focuses on the identification of drivers and barriers to implementation of lean manufacturing. Section 3.3 explains the research methodology adopted in the study followed by section 3.4 which is devoted the development of models for drivers and barriers to lean manufacturing. Section 3.5 discusses the results and discussions of the study. Section 3.6 contains the conclusions.

3.2 IDENTIFICATION OF DRIVERS AND BARRIERS TO LM IMPLEMENTATION

A number of researchers have analyzed the various factors that help or hinder the implementation of lean manufacturing. A two step methodology was used to identify the major drivers and barriers.

Table 3.1 Driver summary

Drivers \ Authors	Sohal & Egglestone 1994	Hallgren & Olhager 2009	Singh *et al.* 2010	Nordin *et al.* 2010	Ghosh 2012	Panizzolo *et al.* 2012	Bhasin 2012	Zhou 2012
1.High level of stock/inventory	✔		✔			✔		✔
2.Low manpower productivity	✔	✔			✔		✔	
3.Poor skills/capabilities of workers	✔		✔			✔		
4.Unavailability of skilled workers								
5.High Labour Cost	✔	✔	✔		✔			✔
6.High scrap/rework/rejection	✔	✔	✔			✔		✔
7.Poor commitment of employees	✔						✔	
8.Customer wants reliable and prompt deliveries	✔	✔	✔	✔	✔	✔	✔	✔
9.Fluctuating customer orders	✔		✔					✔
10.High product variety or customer specific products	✔	✔		✔			✔	✔
11.Unbalanced workload on different workstations						✔	✔	
12.Poor workplace organization and housekeeping				✔		✔		
13.High cost of energy (Electricity or Fuel Cost)		✔	✔					✔
14.Weak process control	✔		✔		✔			✔
15.Low capacity to fulfil the regular demand of customers	✔					✔		✔
16.Lack of standard operating procedures	✔		✔	✔		✔		✔
17.Short time to fulfil customer orders		✔		✔	✔	✔	✔	✔
18.Low quality material or parts by suppliers			✔			✔		
19.Suppliers take long time to deliver			✔			✔		
20.Frequent changes in supply schedule by customers			✔					

Table 3.2 Barriers summary

Barriers \ Authors	Emiliani (2000)	Achanga *et al.*, (2005)	Kumar *et al.*, (2006)	Bonavia and Marin (2006)	Kumar and Antony (2008)	Dowlatshahi and Taham (2009)	Bollbach (2010)	Valentinova (2010)	Comm and Mathaisel (2000)	Nordin *et al.*, 2010	Eswaramoorthi *et al.*, 2011	Subha and Jaisnakar (2012)	Zhou, 2012	Bhasin (2012)	Panizzolo *et al.*, (2012)
1. High cost of consultant fee for training		✔	✔	✔	✔	✔	✔	✔		✔	✔		✔		✔
2.Low awareness of lean manufacturing	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
3.Misconception of high investment	✔	✔	✔						✔	✔	✔				
4.No immediate results or low perceived benefits	✔	✔	✔	✔				✔			✔			✔	✔
5.Low system flexibility to change or Poor organizational culture	✔	✔	✔	✔				✔		✔	✔		✔	✔	✔
6.Lack of top management commitment	✔	✔	✔	✔	✔	✔		✔	✔	✔		✔	✔	✔	✔
7.Lack of change management agents or lack of Human resources		✔	✔	✔	✔	✔	✔	✔	✔	✔				✔	✔
8.Inadequate training opportunity	✔	✔	✔	✔	✔	✔	✔	✔			✔		✔	✔	✔
9.Procedures are too generic and not industry specific							✔				✔				
10.Resistance to change and adopt innovations		✔	✔		✔	✔		✔		✔			✔	✔	✔
11.Too much time & effort required to implement lean			✔				✔		✔				✔		
12.Not an industry norm like ISO											✔				

In the first step various research papers were reviewed to identify drivers and barriers of LM implementation. For this a literature study of 19 articles (Hallgren & Olhager, 2009; Panizzolo *et al.*, 2012; Bhasin ,2012; Singh *et al.,* 2010; Nordin *et al.*, 2010; Sohal & Egglestone, 1994; Ghosh, 2012; Zhou, 2012; Achanga *et al.*, 2005; Kumar *et al.*, 2006; Dowlatshahi and Taham , 2009; Emiliani , 2000; Kumar and Antony, 2008; Bollbach, 2010; Valentinova , 2010; Bonavia and Marin, 2006; Comm and Mathaisel, 2000; Subha and Jaisnakar , 2012; Eswaramoorthi *et al.*, 2011) was taken up and a lists of possible drivers and barriers to lean implementation were identified. These lists were then discussed with industrial experts in the ceramic industry for their suggestions and improvements. The lists were modified as per their convincing suggestions. An example of this modification is the inclusion of 'unavailability of skilled workers' in the drivers list. During the semi structured interviews with senior managers in the industry, there was an overwhelming response that this is a motivating factor to implement LM. Experts believe that LM implementation on one hand will decrease the requirement of skilled workers and on the other hand the level of skill required will also decrease. The resulting list of twenty drivers and twelve barriers to lean implementation, showing a summary of the literature review, is given in tables 3.1 and 3.2 respectively.

3.3 DESCRIPTION OF DRIVERS TO LM IMPLEMENTATION

This section develops brief descriptions of the drivers identified in last section based on the literature and the discussions held with experts in ceramic industry.

3.3.1 High Level of Stock/Inventory

High level of stock and inventory is a key driver for lean implementation in Indian ceramic industries. Higher the level of stock, higher is the storage cost and space required. So reduction of stock/inventory levels is important for any manufacturing firm. The issue of high inventory is considerably important in Indian scenario and there is much scope for improvement in this area with the help of lean implementation (Singh *et al.*, 2010). Lean tools such as kanban, JIT production and pull system help in reducing the level of work in process inventory as well as finished goods inventory. LM implementation has shown significant improvements in work in process inventory and inventory rotation index (Panizzolo *et al.*, 2012; Gunasekaran and Lyu, 1997).

3.3.2 Low Manpower Productivity

Manpower productivity is an operational performance parameter to check firm's condition. It is an important parameter for labour intensive SMEs such as textile, leather, ceramics, etc. Lower manpower productivity ultimately leads to higher labour cost as the firm will have to hire more workers. Implementation of lean manufacturing in the organization can help improve the manpower productivity through lean tools like 5S, JIT, etc. which reduce the unnecessary motion of workers. A firm may expect to attain improvement in many operational performance measures if lean principles are applied properly (Hallgren and Olhager, 2009; Ghosh, 2012). Creation of multifunctional teams during LM implementation imparts different skills to the workers which reduce the dependence on particular person for the particular job.

3.3.3 Poor Skills/Capabilities of Workers

Poor skills of workers might lead to sub-standard quality of products and low productivity as well. Training of workers is essential particularly in labour intensive industries. The training improves skills and job capabilities of the workers which also helps in boosting worker morale (Panizzolo *et al.*, 2012). Training of workers and creation of multifunctional teams is an essential aspect of lean implementation in an organization, so poor skills of workers can be a major driver for lean implementation. A survey shows that implementation of lean manufacturing has helped organizations to create multi skilled workforce (Singh *et al.*, 2010).

3.3.4 Unavailability of Skilled Workers

Unavailability of skilled workers might lead to fall in production volume and quality of products. Lean emphasizes on training of workers to improve worker skills. Unavailability of skilled workers has been a major concern to Indian industry. The manufacturing policy of India visualizes unavailability of skilled manpower as one of the major obstacle in achieving a 12% per annum growth in manufacturing (National Manufacturing Competitiveness Council, 2006). Confederation of Indian Industry (CII) has even started skill development programmes. The industry believes that LM implementation on the one hand will reduce the skilled manpower requirement and on the other hand will also reduce the level of skills required.

3.3.5 High Labour Cost

Labour is an important part of manufacturing sector industries, and labour cost contributes significantly to the operational cost of any organization particularly in India. Increase in labour cost has direct negative impact on the profit margin of the company. So it is important for the companies to find the ways to reduce manpower in order to decrease overall cost and improve profitability. As the literature suggests lean is the choice of firms with cost leadership strategy (Hallgren and Olhager, 2009; Zhou, 2012). In a survey it was found that market issues like stiff competition and low sales revenue are the major issues that motivate industry towards lean initiatives (Singh *et al.,* 2010). The company can reduce overall workforce by implementing lean (Sohal and Egglestone, 1994) and reduce the labour costs.

3.3.6 High Scrap/Rework/Rejection

Poor quality will result in higher rate of rejection; this in turn increases the cost for raw material as well as cost for waste disposal. Thus for many SMEs improvement in quality is a key driver for lean implementation (Zhou, 2012). First pass correct output is a key to reduce rejection. LM improves first pass correct output and this has motivated many companies to implement lean (Ghosh, 2012). Implementation of lean improves overall quality of products (Sohal and Egglestone, 1994; Hallgren and Olhager, 2009) and reduces the waste/scrap/rejection (Panizzolo *et al.*, 2012).

3.3.7 Poor Commitment of Employees

Employee commitment is an essential part for every organization. Especially in labour intensive sectors if the employees are not committed than it might lead to less productivity and poor quality of products. There is a common belief that implementation of lean helps in creating team spirit and motivating the employees (Bhasin, 2012). Lean implementation emphasizes heavily on employee training; this helps them to understand their work better and they are more committed towards it. Workers are given more responsibility after training, thereby, increasing their commitment towards the work. Organizations could also improve employee motivation by passing down some monetary benefits that arise because of lean implementation.

3.3.8 Customer Wants Reliable and Prompt Deliveries

In today's scenario where the customer has ample choices, it is important to deliver the product as fast as possible. Reduction in the lead time is one of the key drivers for implementation of lean in any manufacturing organization (Ghosh, 2012; Zhou, 2012).

Implementation of lean increases overall customer satisfaction in terms of response time, delivery time and reliability (Singh *et al.*, 2010; Nordin *et al.*, 2010). Implementation of lean improves delivery reliability and reduces customer complaints and rejections.

3.3.9 Fluctuating Customer Orders

Fluctuating customer orders is almost an inevitable thing, in today's volatile market, which all the companies have to deal with. A company cannot change the order pattern of the customers but it should be adequately prepared to deal with it. Implementation of lean manufacturing helps the companies to become more flexible towards volume flexibility of the customer orders (Hallgren and Olhager, 2009). This is also evident from the industry surveys that improving flexibility is an important driver for implementation of LM in organizations (Sohal and Egglestone, 1994; Zhou, 2012).

3.3.10 High Product Variety or Customer Specific Products

Today's business environment is characterized by customized products. This has led to ever increasing product varieties. Some traditional mass producing organizations find it difficult to cater to the product variety needs of the customer. The companies even need to be flexible to respond quickly to the market changes if they want to stay ahead in the competition. For many companies, increasing flexibility is a key driver for lean implementation (Zhou, 2012). The companies have become more flexible and responsive towards market changes after implementation of lean (Sohal and Egglestone, 1994; Hallgren and Olhager, 2009).

3.3.11 Unbalanced Workload on Different Workstations

Unbalanced load on different work stations unnecessarily increases product lead time and also decreases overall labour output. Balanced workload on workstations reduces lead time and increases productivity. So balancing the line and increasing overall efficiency of production ia a key driver for implementation of lean (Bhasin, 2012). Results show that manufacturing process times have improved after implementation of lean (Panizzolo *et al.*, 2012). Heijunka (lean tool) helps in leveling the load.

3.3.12 Poor Workplace Organization and Housekeeping

Workplace organization plays a crucial role in increasing productivity indirectly. Better housekeeping is one of the essential elements of organization's continuous improvement programme. Continuous improvement programme is a key factor for many companies who have implemented lean (Nordin *et al.*, 2010; Sohal and Eggleston, 1994; Zhou, 2012). Results also show that improvement is achieved in the parameters like set up time (Panizzolo *et al.*, 2012) which are directly related to workplace organization after implementation of lean. Lean tools like 5S help in improving workplace organization and housekeeping.

3.3.13 High Cost of Energy (Electricity or Fuel Cost)

High energy cost is a cause of concern for many companies as it can significantly lower the profit margins. The companies are looking for various ways to cut down on overall cost. Many companies strongly agree that lean implementation will help them lower total cost (Zhou, 2012) and stay ahead in stiff market competition (Hallgren and Olhager, 2009; Singh *et al.*, 2010). Lean implementation helps companies in reducing cost of energy as it reduces all types of waste.

3.3.14 Weak Process Control

Process control is an important aspect for any manufacturing firm. Process control should detect any defect as early as possible and prevent the defective piece to be processed further. In lean manufacturing, workers are involved in inspection of the parts after every stage thereby preventing any defective piece being carried down further. JIT or small lot size in lean manufacturing improves process control. Poka Yoke is an important lean tool which helps in error proofing. The literature also shows that organizations achieved significant process improvement after implementation of lean manufacturing (Sohal and Egglestone, 1994).

3.3.15 Low Capacity to Fulfill the Regular Demand of Customers

Low capacity is one of the issues faced by many companies. Capacity expansion might always not be feasible because of capital constraints or other factors. Lean helps in increasing the production by increasing overall equipment efficiency and productivity (Panizzolo *et al.*, 2012; Sohal and Egglestone, 1994). This is the reason that improvement in the utilization of plant or facility is seen as key driver for implementing lean within SMEs (Zhou, 2012). Lean implementation helps to increase productivity as it emphasizes on eliminating the waste and line balancing (Bhamu and Sangwan 2012).

3.3.16 Lack of Standard Operating Procedures

It is essential to adapt to standard operating procedures for especially labour intensive manufacturing firms as lack of it can affect productivity and safety of workers.

Parameters like setup time and changeover time which have direct impact on production volumes are of particular importance in Indian scenario and there is a considerable scope of improvement in these areas (Singh *et al.*, 2010). The surveys show that there is a belief among the companies that implementation of lean manufacturing will help them in their continuous improvement programme (Zhou, 2012; Nordin *et al.*, 2010; Sohal and Egglestone, 1994). Desire to implement best practices is also a major driver for implementation. The companies used techniques like SMED and TPM to achieve continuous flow and to avoid frequent breakdowns respectively (Panizzolo *et al.,* 2012).

3.3.17 Short Time to Fulfill Customer Orders

It is necessary to reduce lead time in case of short time to fulfill customer demand. Reduction in lead time is a driver for lean implementation for many companies (Ghosh, 2012; Zhou, 2012). Implementation of lean has positive impact on delivery speed performance (Hallgren and Olhager, 2009). Lean implementation reduces the unwanted motion which does not add any value to the final product which helps in improving the cycle time (Panizzolo *et al.*, 2012). Smaller lot sizes and implementation of pull system contribute significantly to shorten the lead time.

3.3.18 Low Quality Material or Parts by Suppliers

Many organizations receive supplies of low quality from the suppliers. This either increases the lead time if supplies are rejected or decreases the quality of product if supplies are selected. A survey by Singh *et al.*, (2010) shows that in India, development and communication with the suppliers is not up to the mark and work needs to be carried out in terms of vendor development to create reliable sources of supply. Panizzolo *et al.*,

(2012) has shown that the quality performance from the supplier side has improved after the companies implemented lean manufacturing.

3.3.19 Suppliers Take Long Time to Deliver

Panizzolo *et al.* (2012) has shown that delivery lead time, on-time delivery performance and the delivery frequency from the supplier side improved in a case after the company implemented lean manufacturing. In addition to the low quality supplies, supplies do not come on time thereby increasing the manufacturing lead time, lowering the productivity and increasing uncertainty. Organizations believe that LM implementation will improve the on-time delivery from suppliers.

3.3.20 Frequent Changes in Supply Schedule by Customers

Sometimes customer changes the order schedule due to urgent necessity of the product (Singh *et al.*, 2010), which means shorter lead time to fulfill the customer order. At certain levels this can be achieved through lean implementation without adding much of additional resources.

3.4 DESCRIPTION OF BARRIERS TO LM IMPLEMENTATION

This section develops brief descriptions of the barriers identified in last section based on the literature and the discussions held with experts in ceramic industry.

3.4.1 High Cost of Consultant Fee for Training

Financial capacity is a crucial factor in the determination of any successful project. This is due to the fact that finance covers the avenues through which other useful provisions like consultancy and training can be made. Most small businesses are financially inept and harbor poor financing arrangements. Financial inadequacy is thus a major hindrance to the adoption and subsequent implementation of successful lean manufacturing (Achanga *et al.*, 2005). Most of the SMEs research focuses on factors that contribute to their survival such as financing, rather than a greater understanding of the growth process and the achievement of sustainable competitive advantage (Singh, *et al.*, 2008).

3.4.2 Lack of Human Resources/Change Management Agents

Unlike other companies, the process industries lack the human resources and materials necessary for organisational change and project implementation. Most of ceramic industries employ people with low skill levels. Particularly SMEs do not foster the ideology of skill enhancement and competence to develop and improve their production systems (Powell *et al.*, 2012). In addition, small companies do not have the slack to free highly talented people to engage in training as they are crucial to the day-to-day operations and problem solving within the company (Antony *et al.*, 2005).

3.4.3 Lack or Low Awareness of Lean Concepts

The highly ranked barrier in implementing any new technique in industry is lack of awareness about the benefits and future prospects of these techniques (Panizzolo *et al.*, 2012). Owners and the management team may have a limited amount of formal education and are not usually willing to listen to the new breed of young managers that switch jobs every two to three years (Emiliani, 2000). Research had shown that Six Sigma initiatives in many organisations have failed either due to lack of understanding of how to get started or due to failure to link the initiative to strategic business goals and measurable objectives (Kumar *et al.*, 2009).

3.4.4 Misconception that Lean Implementation Requires High Investment

Although lean manufacturing is becoming a popular technique for productivity improvement, many of the organizations are still not certain of the cost of its implementation and the likely tangible and intangible benefits they may achieve. These companies specifically SMEs fear that implementing lean manufacturing is costly and time consuming (Achanga *et al.*, 2005). Companies also view improvements made by a large company as unattainable in smaller businesses due to a perceived lack of resources (Emiliani, 2000). There is a common misconception that lean, six sigma and other practices involve lots of investment and statistics, which are beyond their domain (Kumar and Antony, 2008; Kumar *et al.*, 2006).

3.4.5 No Immediate Results or Low Perceived Benefits

The benefits are not always obvious since the association between financial and non-financial measures is fragile (Bhasin, 2012). Patience for the final results is needed because often the prediction for the superior performance may take into consideration the exact time horizon of the implementation process. The large upfront costs and delayed benefits can be a deterrent to implementation of sustainable improvement program. In the process industry, the perceived benefits of lean are low and the management is often reluctant to invest in consultants due to the high consultancy fees. Hence, they invest in capacity expansion rather than quality (Panizzolo *et al.*, 2012).

3.4.6 Low System Flexibility to Change or Poor Organizational Culture

The process of lean implementation may also require a major change in the overall organisational culture. Any strategy, regardless of its strengths, will not be accepted if it is outside the bounds of an organization's culture (Bhasin, 2012). Managing organizational culture effectively requires clarity in the minds of managers about the type of culture and specific norms and values that will help the organizations reach its strategic objectives (Singh *et al.*, 2008). Top management must create a culture of decentralization of powers to the middle managers as well as to workers so that they can gain 'grass-root level' decision making powers. Before any focus on the lean techniques it is imperative to achieve a conducive culture; unless the organisation manages to anchor the appropriate behaviors' into its culture, the transition is destined to fail (Shah *et al.*, 2008).

3.4.7 Lack of Top Management Commitment

The application of lean manufacturing is to reduce the operational inefficiencies and wastes which require top management involvement and commitment in order to provide appropriate resources and training (Kumar *et al.*, 2006; Antony *et al.*, 2005). Managers lack not only crucial skills in problem solving, coaching and performance management but also the industry-specific expertise needed to accurately diagnose complex technical problems and to rapidly develop effective solutions (Panizollo *et al.*, 2012). Perhaps the most important component in labour intensive enterprises is management's view of the enterprise. A limited view, such as only including shop floor activity, will limit application of lean (Subha and Jaisnakar, 2012). Strong leadership and management permeate a vision and strategy for generating, while permitting a flexible organisational structure (Achanga *et al.*, 2005).

3.4.8 Poor Education and Training Opportunities

Education and training are prime requirements for achieving success in any organization due to new or revamped technology. The need for training extends throughout the company and reaches up and downstream (Ravi and Shankar, 2005). Ceramic industries in which majority are SMEs may, however, have a limited ability to allocate the proper budget for education and training for their employees and workers. Industries do not often have a training department while limited funds also make the hiring of an outside consultant impractical (Dowlatshahi and Taham, 2009). It is not just the role of outside teachers to impart knowledge, the owners also have a responsibility to read some of the great books and articles published over the years to gain added depth of understanding, teach their employees, and reinforce their leadership role (Emiliani, 2000) to make lean a success.

3.4.9 The Procedures are Too Generic not Industry Specific

Lean techniques are not specific to the type of business a company operates in. The generic techniques are not considered fruitful by many businesses. Industries are motivated to adopt improvement techniques that give more flexibility to their production process as the industry is dynamic and international competition is continuously increasing. It might be argued that the nature of the production process constitutes an insurmountable obstacle to implementing them (Bonavia and Marin, 2006).

3.4.10 Resistance to Change and Adopt Lean Principles

When workers veterans encounter the challenge of changing their way of working, a variety of negative attitudes leads to the building up of internal resistance. The employees of the organisation think that implementation of the new strategies could endanger their job opportunities and poor performance result in losing their jobs (Kumar *et al.*, 2006). Any staff involved in the operation of the cell should be part of the decision-making process at the design stage and be invited to share their views, skills and experience. This involvement and input often releases stifled talents and skills, including leadership, innovation and forward planning, and without it is very difficult to change working practices (Kumar *et al.*, 2006).

3.4.11 Too Much Time and Efforts Required to Implement Lean

The implementation of lean in a process industry requires start up of cellular structure and visual management practices. Also, identification and disposal of everything that is undesirable has to take place along with making the workplace compliant with 5S. A major hindrance in adoption is that becoming lean is a complex business - there is no single thing that will make an organization lean (Comm and Mathaisel, 2000). So for lean starters, it requires time and efforts to make an organization, lean.

3.4.12 Not an Industry Norm Like ISO

There’s also the problem that since lean is not yet an industry norm like ISO, there is nothing pushing the companies to take the extra effort to implement lean. Industries have a lot to gain if they implement lean principles but they have nothing to lose if they do not. For e.g., ISO certification enhances a company’s market value and provides them with certain benefits. But lean does not have any such advantages yet.

3.5 RESEARCH METHODOLOGY

The basic steps of the research methodology are development of drivers and barriers, development of survey instrument, data collection, data analysis, model proposition and model validation. The outline of research methodology is shown in figure 3.1. Twenty drivers and twelve barriers to lean implementation were developed in the first step as presented in the last section. This section focuses on development of survey instrument, data collection and data analysis while model proposition and model validation are discussed in the next section.

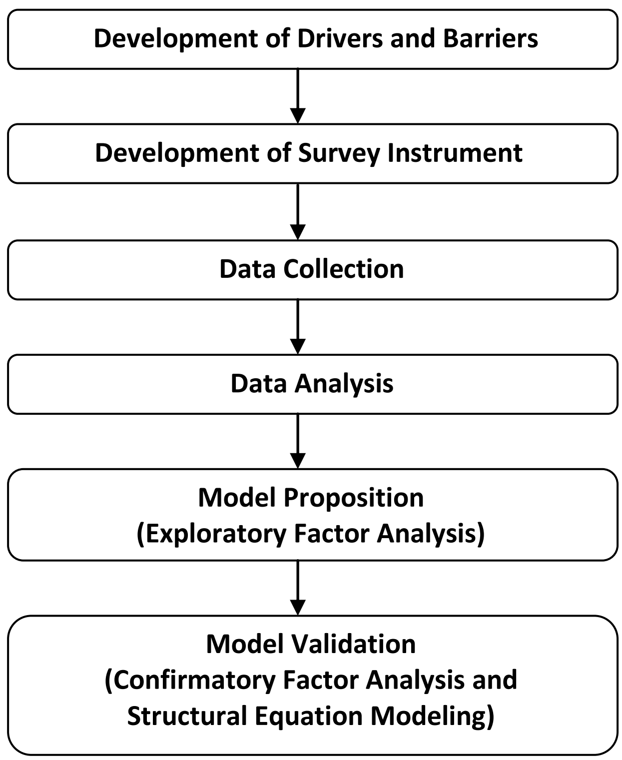


Figure 3.1: Research methodology outline

3.5.1 Development of a Survey Instrument

On the basis of the drivers and barriers developed in the last section, a questionnaire was developed. The questionnaire had two sections- one contained questions related to drivers to lean manufacturing in the ceramic industry and the other one, barriers. This survey questionnaire asked the participants to rate the given factor in terms of the impact it had as a driver or barrier to implementation of lean manufacturing. The rating was to be done on a 5-point Likert scale; where 1 means very low impact, 2 means low impact, 3 means medium impact, 4 means high impact and 5 means very high impact. This type of scale is used in an effort to force respondents to make an exclusive and decisive choice.

Pre-testing was carried out in two stages. In the first stage, a draft of the questionnaire was provided to two academicians and they were requested to critically evaluate the items from the standpoint of item specificity and clarity of construction. Based on critique received, some items were revised to improve their specificity and clarity.

The second pre-test involved administering the questionnaire to industrial professionals. The professionals were asked to complete the revised questionnaire and indicate any ambiguity or other difficulty they experienced in responding to the items, as well as to offer any suggestions they deemed appropriate. The pre-testing was done with the three practitioners from a reputed ceramic company. After second pre-test, the questionnaire was reviewed based on expert’s comments and phrasings of some items were modified to make the final research instrument more effective. The questionnaire so developed is given in Appendix. A pre-test indicated a questionnaire completion time of 20-25 minutes.

3.5.2 Data Collection

Most ceramic industries are in the category of Small and Medium Enterprises (SMEs) in Rajasthan. 150 survey questionnaires were sent to engineers, managers, production managers and directors of companies from the ceramic industry in Rajasthan. The addresses were taken from the District Industrial Centre (DSC), a government of Rajasthan venture, related to the Bikaner and Jaipur ceramic clusters. Personal visits were made to the industries in Bikaner cluster and telephonic calls were made to some of the industries in Jaipur cluster. Since the primary objective of the study is to get the factors which help or hinder the improvement of productivity, it was decided that the person who best understands the production process should fill the questionnaire. The identified people in the industries were personally explained the questions and the purpose of the survey either face to face or over telephonic calls. 67 sound responses were collected from a group of people with minimum one year of experience and maximum forty years of experience in the ceramic industry. The average experience of the people in the group was sixteen years. The response rate was 44.66%.

3.5.3 Data Analysis

The survey data collected for drivers and barriers ought to be both reliable and valid to be useful for other studies and analyses. Reliability refers to consistency. It is the degree to which the enlisted drivers and barriers will yield similar results for the same individuals at different times i.e. similar results under consistent conditions. Validity refers to the degree to which the drivers and barriers accurately measure the factors that they are intended to measure.

Reliability is determined through Cronbach's alpha, the most common measure of internal consistency, for multiple Likert questions in a survey, which form a scale. Internal consistency analysis was carried out using SPSS to measure the reliability of each driver and barrier in terms of Cronbach's alpha. The value of Cronbach's alpha could lie between 0 and 1. A minimum alpha value of 0.70 is considered as a criterion for establishing internal consistency in most cases but a minimum alpha value of 0.60 is also considered acceptable for new measures like the present one. If the Cronbach's alpha value is too low, some items may be deleted in order to improve the alpha value.

Validity is determined through factor analysis, one of the methods to determine construct validity (Muttar, 1985). Factor analysis uses regression modeling techniques to test hypotheses producing error terms (Bartholomew *et al.*, 2008). Appropriateness of data for factor analysis may be determined on the basis of minimum number of observations required per variable. Flynn *et al.* (1994) have suggested that a sample size of 30 or more is statistically sufficient to carry out factor analysis. It is necessary to determine the strength of the relationship among variables before carrying out factor analysis. Correlation matrix, Barlett's test of sphericity and Kaiser-Meyer-Oklin (KMO) measure of sampling adequacy are the three measures recommended in the literature for this purpose (Hair *et al.* 1995, Norusis 1994). Corrected Item Total Correlation (CITC) refers to the correlation of an item with the composite score of all items, other than the particular item in question, forming the set. Items from a given scale exhibiting item-total correlations less than 0.50 are usually candidate for elimination (Koufteros, 1999).

3.5.4 Data Analysis for Drivers to Lean Implementation

The first set of tests carried out using a set of 20 drivers to implementation of lean manufacturing in ceramic industry did not yield satisfactory results. While the value of Cronbach's alpha was acceptable (0.741), there was poor correlation between the items indicated by the negative values and extremely low positive values in the inter item correlation matrix. KMO measure of sampling adequacy also had a value less than 0.58 which can be improved. According to Koufteros (1999) items from a given scale exhibiting item-total correlation less than 0.50 are usually candidate for elimination. But a CITC value of less than 0.3 becomes too low to consider including the drivers at all in the factor analysis. Hence 8 drivers with CITC values less than 0.3 were dropped and a second set of analysis was carried out using 12 drivers.

Table 3.3: Descriptive statistics of data for drivers to lean implementation

Drivers	Mean	Std. Deviation	Corrected Item-Total Correlation	Cronbach's Alpha if item deleted
Low manpower productivity	3.45	0.838	0.425	0.836
High scraps/rework/rejection	3.78	0.792	0.521	0.829
Poor skills/capabilities of workers	3.47	0.839	0.460	0.833
Unavailability of skilled workers	3.69	0.900	0.566	0.825
Weak process control	2.92	1.003	0.741	0.809
Unbalanced workload on different workstations	2.39	0.832	0.395	0.838
Poor workplace organization/ housekeeping	2.15	0.779	0.465	0.833
Lack of standard operating procedures	2.71	0.897	0.610	0.822
Customer orders are highly fluctuating/ varying	3.81	0.919	0.579	0.824
Low quality of material/ parts by suppliers	2.28	0.825	0.469	0.833
Suppliers take long time to deliver	1.92	0.621	0.337	0.841
High product variety/ customer specific product	3.60	0.862	0.461	0.833

The results for this second set of tests are shown in table 3.3. Cronbach’s alpha has a value of 0.842 indicating that the data used for analysis is reliable. A visual inspection of the inter item correlation matrix shows that most values are greater than 0.3. This implies that the items are likely to have common factors. Barlett’s test shows sufficiently high values at significance level $p<0.001$. The KMO measure has a value 0.714 which is well above the suggested minimum standard of 0.5 for carrying out factor analysis. Hence, based on the above test results, it is concluded that the drivers listed in table 3.3 are suitable for applying factor analysis. As can be seen from table 3.3, there are still five drivers with CITC values less than 0.5 but these need not be eliminated since the CITC values are close to 0.5 and all these five drivers have high value of Cronbach's alpha.

3.5.5 Data Analysis for Barriers to Lean Implementation

The first set of tests carried out using 12 barriers showed unacceptable results. The value of Cronbach's alpha was 0.738 indicating that the data for the analysis was reliable. The value of KMO measure for sampling adequacy was 0.695 which is acceptable but a lot of values in the inter-item correlation matrix were low indicating poor correlation between items. There are 3 barriers having CITC values less than 0.3. These are dropped and a second round of tests is carried out.

The results for the second set of tests are shown in table 3.4. Cronbach's alpha has a value of 0.802 indicating that the data used for analysis is reliable. A visual inspection of the inter item correlation matrix again shows that most values are greater than 0.3. This implies that the items are likely to have common factors. Barlett's test shows sufficiently high values at significance level $p<0.001$. The KMO measure has a value 0.728 which is well above the suggested minimum standard of 0.5 for carrying out factor analysis. Hence, based on the above test results, it is concluded that the barriers listed in table 3.4 are suitable for applying factor analysis. As can be seen from table 3.4, there are still four barriers with CITC values less than 0.5 but these need not be eliminated since the CITC values are close to 0.5 and all these four barriers have high value of Cronbach's alpha.

Table 3.4: Descriptive statistics of data for barriers to lean implementation

Barriers	Mean	Std. Deviation	Corrected Item-Total Correlation	Cronbach's Alpha if item deleted
Lack of top management commitment	2.39	0.709	0.347	0.801
High cost of consultant fee for training	3.22	0.807	0.542	0.777
Misconception of high investment	3.81	0.732	0.607	0.768
Inadequate training opportunity	3.78	0.661	0.724	0.755
Not an industry norm like ISO	3.51	0.881	0.631	0.763
Resistance to change and adopt innovations	4.06	0.661	0.357	0.799
Too much time and effort required to implement lean	3.62	0.740	0.411	0.794
Procedures are too generic and not industry specific	3.44	0.586	0.311	0.803
Low awareness of lean manufacturing	3.99	0.732	0.526	0.779

3.6 DEVELOPMENT OF MODEL

Development of a model consists of two parts: model proposition using exploratory factor analysis and model validation using confirmatory factor analysis and structural equation modeling.

3.6.1 Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) is used to form a structure consisting of a few groups or factors representing a relatively large number of variables. It is carried out with a prior assumption that any variable may be associated with any group and factor loadings are then used to determine the structure of the data. Factors are extracted using maximum likelihood method followed by varimax rotation. Kaiser criterion (eigen values > 1) is employed to extract factors.

3.6.2 EFA Model for Drivers to Lean Implementation

EFA conducted on the drivers of lean manufacturing implementation shows that the proposed model has three factors with eigen values greater than one. After analyzing the group of drivers under each factor, these three factors are named as: Policy drivers (PD); Internal Drivers (ID); and External Drivers (ED).

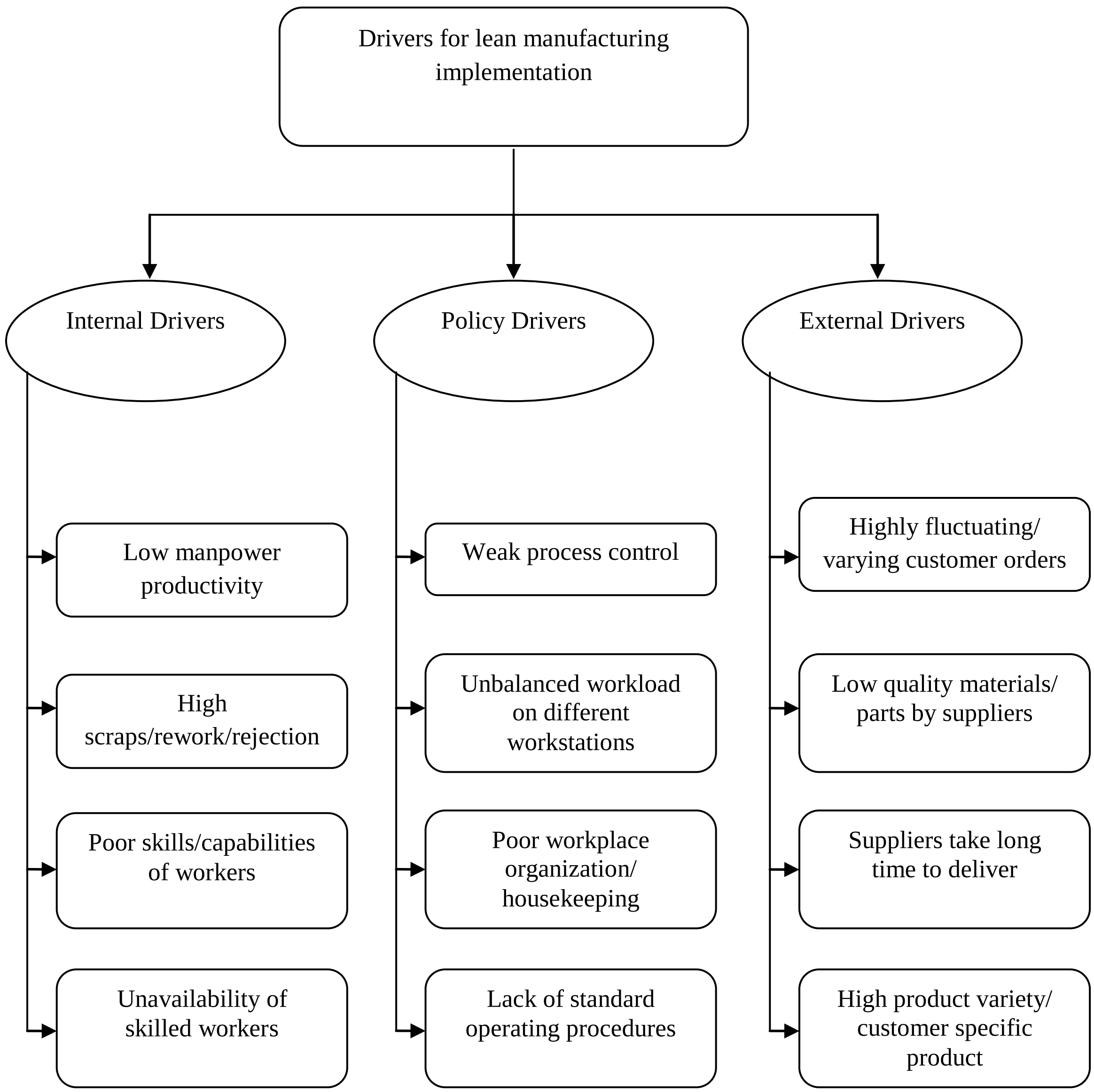


Figure 3.2: Model for drivers of lean manufacturing implementation in ceramic industry

The factor loading of all factors is greater than 0.525 (Minimum recommended value is 0.45 by Hair *et al.* 1995). Hence all items contribute well to the represented factors. The model for drivers of lean manufacturing implementation in ceramic industry is shown in figure 3.2.

3.6.3 EFA Model for Barriers to Lean Implementation

EFA conducted on barriers to lean manufacturing implementation shows that the proposed model with ten barriers has two factors with eigen values greater than one.

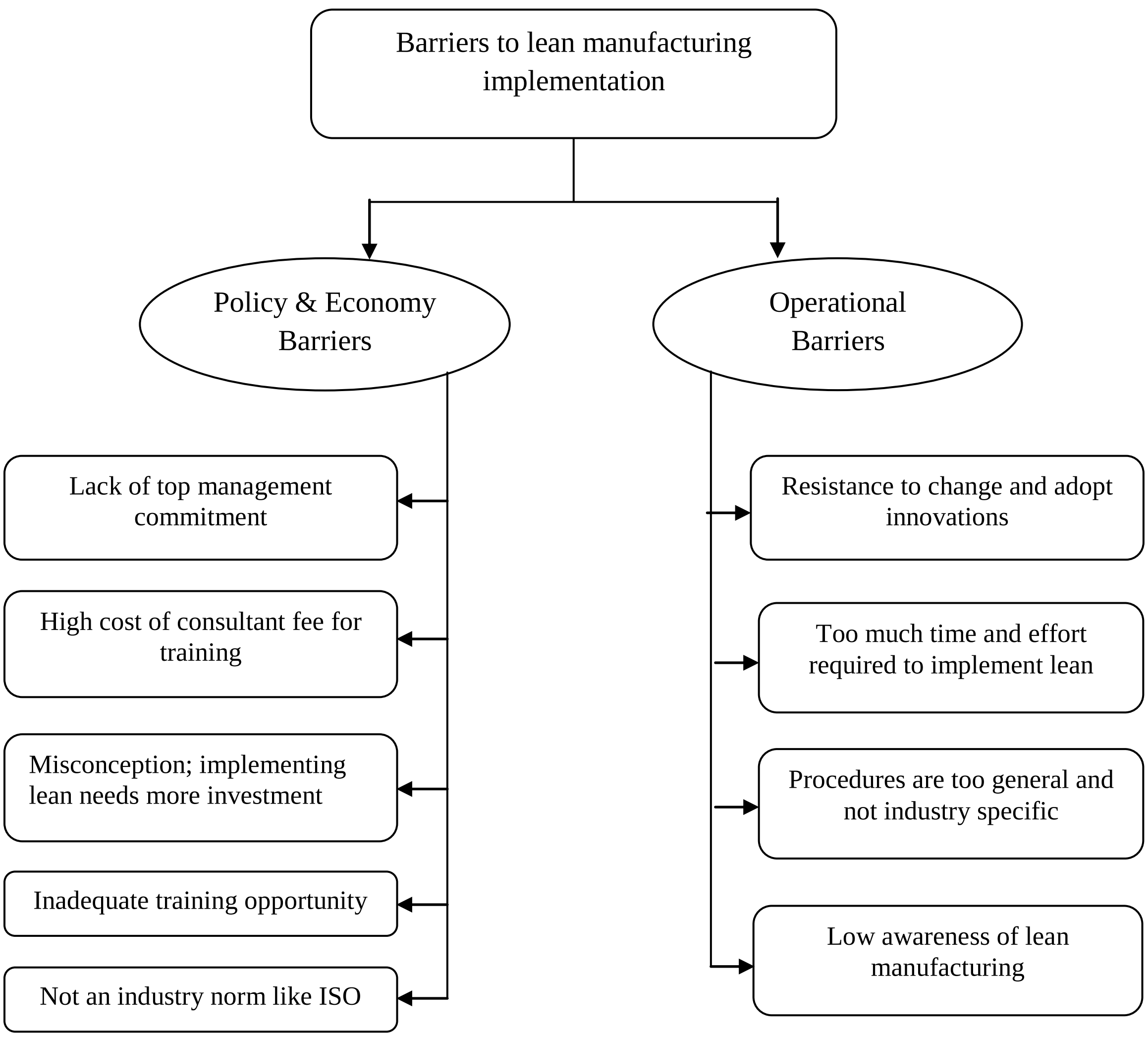


Figure 3.3: Barriers to implementation of lean manufacturing in ceramic industry

The group of barriers under each factor is named as: Economy & Policy barriers and Operational barriers. The factor loading of all barriers is greater than 0.531 (the minimum recommended value is 0.45 by Hair *et al.* 1995). The model for barriers to lean manufacturing implementation is showed in figure 3.3.

3.7 CONFIRMATORY FACTOR ANALYSIS

The exploratory factor analysis carried out in the last sub-section is not sufficient to assess all the essential measurement properties of the constructs like unidimensionality (Koufteros, 1999). EFA may be used for generating basic explanatory theories and identifying the underlying latent variable structure; however, CFA testing is needed to confirm the EFA findings (Haig, 2005). CFA is used to test whether the items are related to the hypothesized latent variables as expected, which indicates structural (or factorial) construct validity (Koeske, 1994).

3.7.1 CFA Model for Drivers to Lean Implementation

The proposed EFA model for drivers of lean manufacturing in ceramic industries was transferred to SEM tool to carry out CFA as shown in figure 3.4. The path diagram shows a measurement model containing three latent variables and corresponding twelve observed variables. The oval blocks on the left represent the latent variables while the observed variables are represented by the rectangular blocks. The small oval blocks connected to the observed variables through single headed arrows represent measurement errors (e1, e2, e3…, e12) in measuring the value of an observed variable. Double headed arrows are used to represent the correlation between latent variables. The statistics from the CFA model for drivers of lean implementation is summarized in table 3.5.

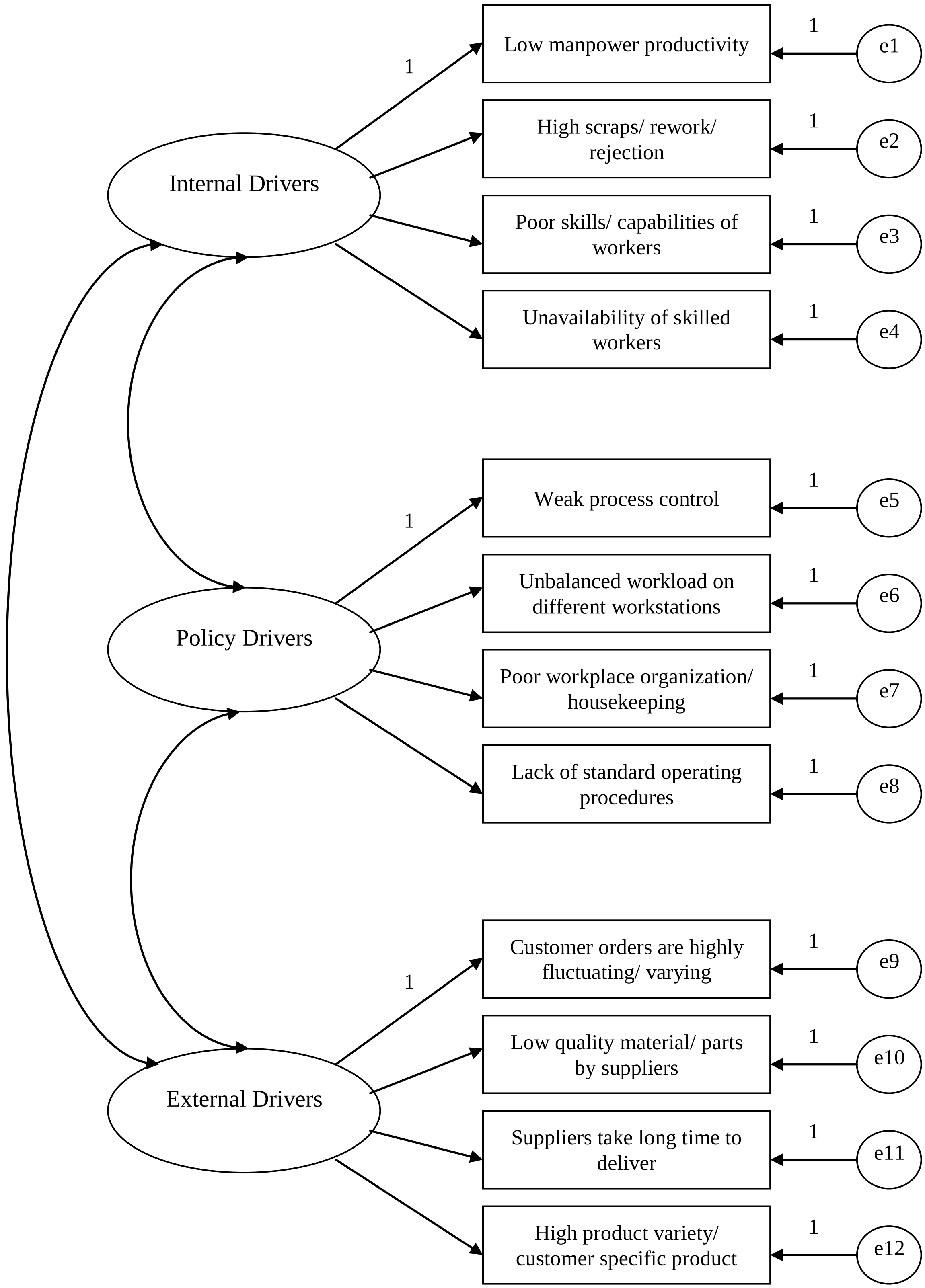


Figure 3.4: Path diagram representing drivers of lean implementation in ceramic industry

Table 3.5: Confirmatory factor analysis statistics for drivers of lean implementation

Drivers	Factor Loadings			Regression Weights*		
	ID	PD	ED	Estimate	Standard Error	Critical Ratio
Low manpower productivity	0.57	---	---	1	---	---
High scraps/reworks/rejection	0.635	---	---	1.053	0.251	4.189
Poor skills/capabilities of workers	0.700	---	---	1.230	0.278	4.429
Unavailability of skilled workers	0.707	---	---	1.332	0.299	4.452
Weak process control	---	0.816	---	1	---	---
Unbalanced workload on diff workstations	---	0.482	---	0.491	0.117	4.177
Poor workplace organization/housekeeping	---	0.580	---	0.552	0.109	5.081
Lack of standard operating procedures	---	0.761	---	0.834	0.125	6.695
Customer orders are highly fluctuating/varying	---	---	0.781	1	---	---
Low quality materials/parts by suppliers	---	---	0.557	0.640	0.148	4.325
Suppliers take long time to deliver	---	---	0.516	0.446	0.110	4.040
High product variety/customer specific product	---	---	0.620	0.774	0.158	4.725

P<0.001 for all coefficients
** Unstandardized*

The factor loadings of drivers, as shown in table 3.5, show a minimum value of 0.482 for unbalanced workload on different workstations. Table 3.5 also contains the regression weights of the data. The minimum value of critical ratio is 4.04 which are well above |2| which is considered significant at the 0.001 level. The goodness of statistics values for CFA of drivers to lean implementation are shown in table 3.6 along with the recommended values. It is evident from table 3.6 that the values are either in the recommended range or very close to it. Hence it is concluded that the measurement model presented in figure 3.4 is accepted (confirmed) and the full structural model can be tested to validate the final model of drivers.

Table 3.6: Goodness-of-fit statistics for drivers to lean implementation

Index	**Estimated Value**	**Recommended Value**	**Reference**
CMIN	168.428	---	---
DF	51	---	---
P-Value	0.000	0	---
CMIN/DF	3.303	<5.0	Marsch and Hocevar, 1985
RMSEA	0.166	close to zero	Hair *et al.*, 2006
RMR	0.078	<0.08	Hu and Bentler, 1999
GFI	0.772	close to one	Dawes *et al.*, 1998
AGFI	0.651	close to one	---
CFI	0.691	>0.90	Byrne, 2001

3.7.2 CFA Model for Barriers to Lean Implementation

Similar to the proposed EFA model for drivers, the EFA model for barriers to implementation of lean manufacturing in ceramic industries was also transferred to SEM tool to carry out CFA as shown in figure 3.5.

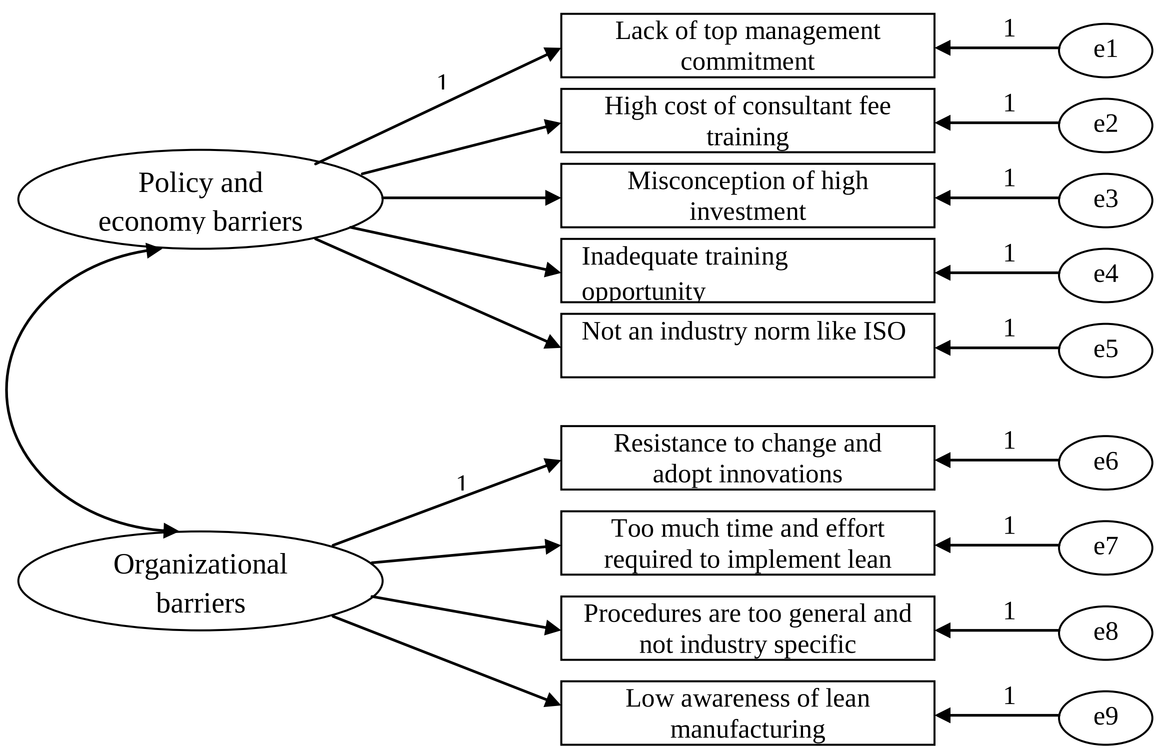


Figure 3.5: Path diagram representing barriers to lean implementation in ceramic industry

The path diagram shows a measurement model containing two latent variables (represented by the oval blocks) and corresponding nine observed variables (represented by the rectangular blocks). The circular blocks connected to the observed variables through single headed arrows represent measurement errors (e1, e2, e3…, e9) in measuring the value of an observed variable. The double headed arrow represents the correlation between the two latent variables. The statistics from the CFA model for barriers to lean implementation is summarized in table 3.7.

Table 3.7: Confirmatory factor analysis statistics for barriers to lean implementation

Barriers	**Factor Loadings**		**Regression Weights***		
	PEB	**OB**	**Estimate**	**Standard Error**	**Critical Ratio**
Lack of top management commitment	0.420	---	1	---	---
High cost of consultant fee for training	0.665	---	1.803	0.523	3.448
Misconception that implementing lean needs more investment	0.677	---	1.663	0.479	3.469
Inadequate training opportunity	0.840	---	1.866	0.506	3.687
Not an industry norm like ISO	0.687	---	2.033	0.583	3.488
Resistance to change and adopt innovations	---	0.443	1	---	---
Too much time and effort required to implement lean	---	0.476	1.201	0.427	2.811
Procedures are too general and not industry specific	---	0.403	0.808	0.317	2.550
Low awareness of lean manufacturing	---	0.661	1.652	0.509	3.246

P<0.001 for all coefficients
** Unstandardized*

The factor loadings of barriers, as shown in table 3.7, show a minimum value of 0.403 for 'procedures are too general and not industry specific' variable. Table 3.7 also contains the regression weights of the data. The minimum value of critical ratio is 2.55 which is above |2| considered significant at the 0.01 level. The goodness of statistics values for CFA of barriers to lean implementation are shown in table 3.8 along with the recommended values. It is evident from table 3.8 that the values are either in the recommended range or very close to it. Hence it is concluded that the measurement model presented in figure 3.5 is accepted (confirmed) and the full structural model can be tested to validate the final model of barriers.

Table 3.8: Goodness-of-fit statistics for barriers to lean implementation

Index	**Estimated Value**	**Recommended Value**	**Reference**
CMIN	55.008	---	---
DF	26	---	---
P-Value	0.001	0	---
CMIN/DF	2.116	<5.0	Marsch and Hocevar, 1985
RMSEA	0.115	close to zero	Hair *et al.*, 2006
RMR	0.038	<0.08	Hu and Bentler, 1999
GFI	0.897	close to one	Dawes *et al.*, 1998
AGFI	0.821	close to one	---
CFI	0.857	>0.90	Byrne, 2001

3.8 STRUCTURAL MODEL

Structural equation modeling is a statistical technique for testing and estimating causal relations using a combination of statistical data and qualitative causal assumptions (Herbert 1953, Pearl 1998). SEM usually starts with a hypothesis that is represented in a causal model.

3.8.1 Structural Model for Drivers of Lean Implementation

After careful examination of results of CFA, the following hypotheses are proposed to test the full structural model.

Hypothesis 1 (H1): Policy drivers for implementation of lean in ceramic industries are positively correlated to the internal drivers.

Hypothesis 2 (H2): External drivers for implementation of lean in ceramic industries are positively correlated to the policy drivers.

Hypothesis 3 (H3): External drivers for implementation of lean in ceramic industries are positively correlated to the internal drivers.

The full structural equation model, shown in figure 3.6, was tested using maximum likelihood estimation, which showed 26 degrees of freedom, CMIN=51, p=0.000, GFI=0.772, CFI=0.691 IFI=0.703, TLI=0.600, RMSEA=0.166 and RMR=0.078. The results of the hypotheses test are shown in table 3.9. The first two hypotheses are accepted on the basis of their β and p values while the third hypothesis is rejected owing to its low β-value and high p-value.

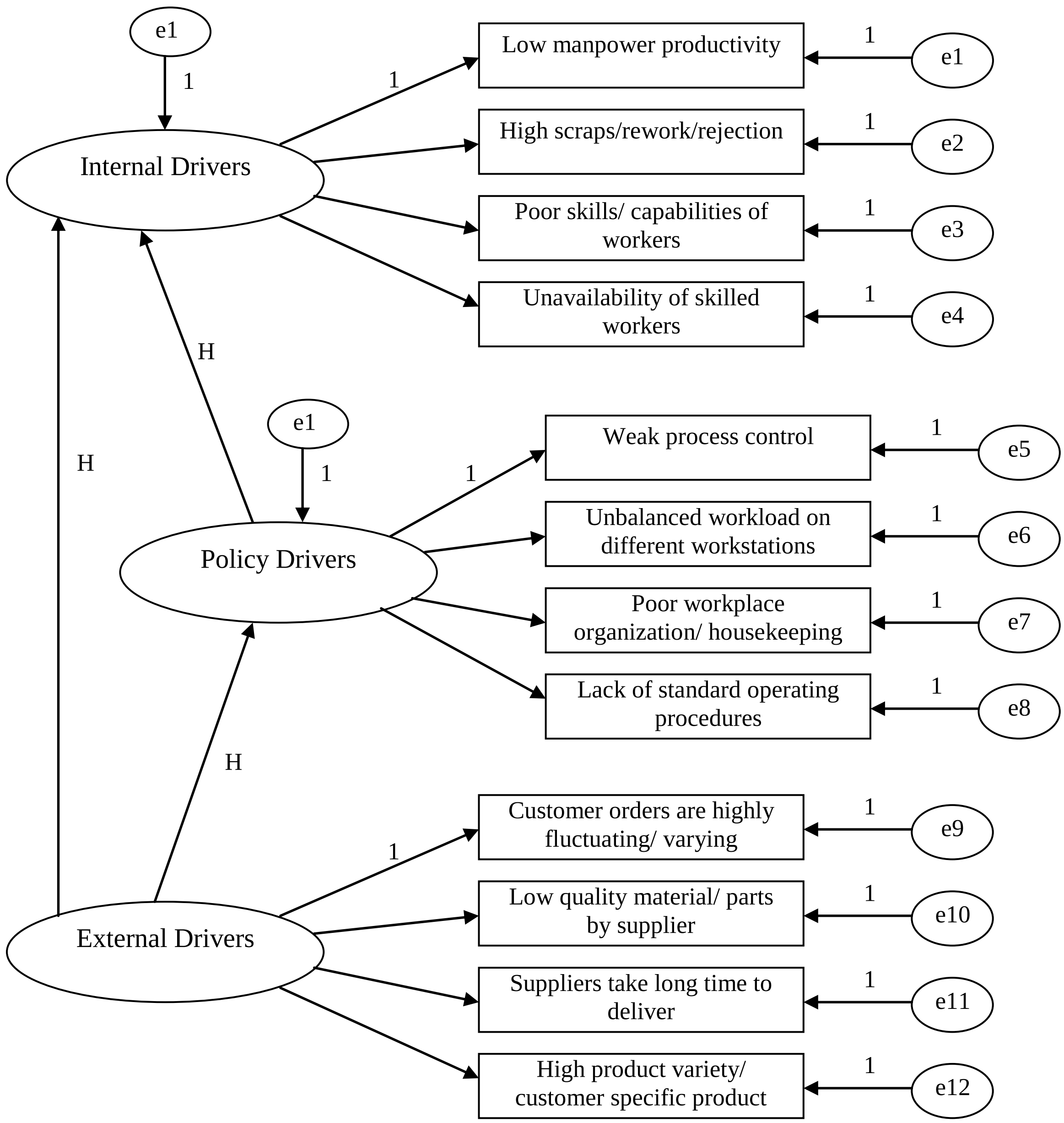


Figure 3.6: Structural model of drivers of implementation of lean manufacturing

Table 3.9: Result of hypotheses test for drivers of lean implementation

	Hypotheses	**β value**	**p value**	**Result**
H1	Policy drivers to lean implementation are positively related to internal drivers	0.391	0.002	Accepted
H2	External drivers to lean implementation are positively related to policy drivers	0.722	<0.001	Accepted
H3	External drivers to lean implementation are positively related to internal drivers	0.084	0.471	Rejected

3.8.2 Structural Model for Barriers to Lean Implementation

The model for barriers to lean implementation contains only two latent variables. The following hypothesis is proposed to test the full structural model,

Hypothesis (H1): The policy & economy barriers to implementation of lean in ceramic industry is positively related to operational barriers

The full structural model, shown in figure 3.7, was tested using maximum likelihood estimation, which showed 26 degrees of freedom, CMIN=55.008, p=0.001, GFI=0.897, CFI=0.857 IFI=0.863, TLI=0.802, RMSEA=0.115 and RMR=0.038. The result of the hypothesis test yields a β value of 0.826 with p=0.008. These values are acceptable and hence the hypothesis is accepted.

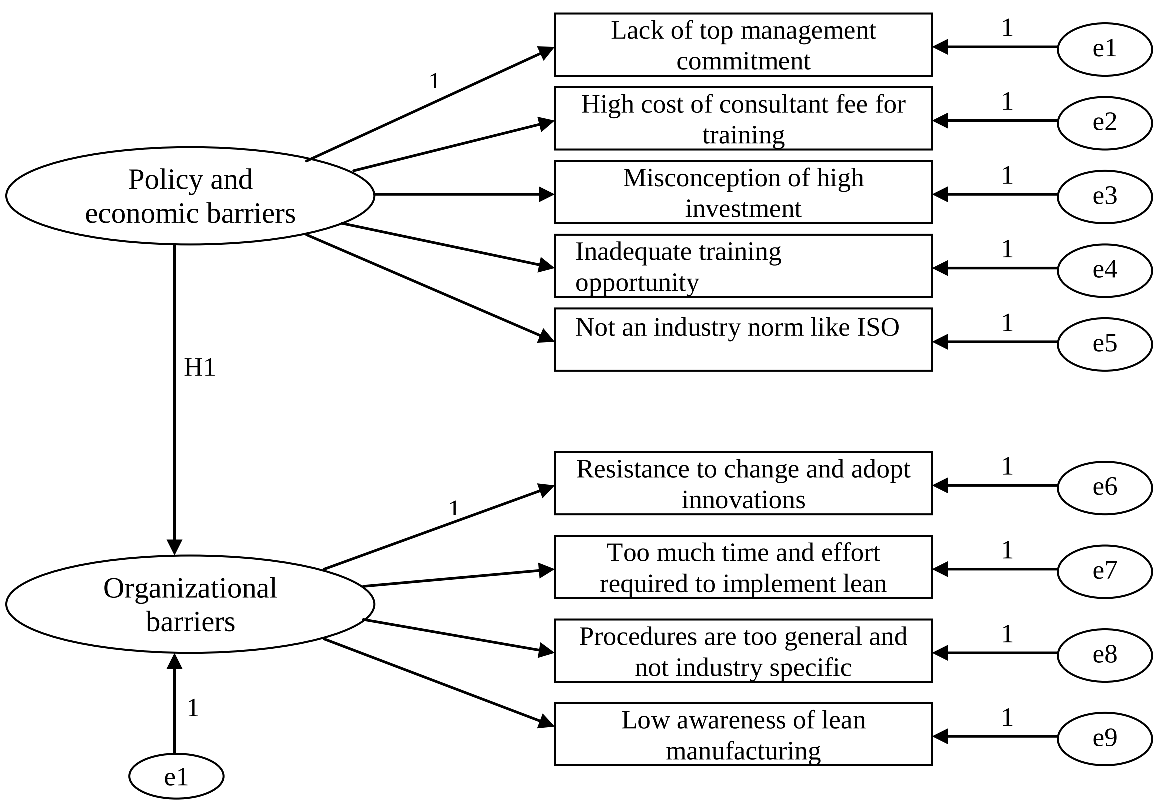


Figure 3.7: Structural model for barriers to implementation of lean manufacturing

3.9 SUMMARY

The literature review of lean manufacturing identified 20 drivers and 12 barriers to its implementation. A survey was conducted through semi-structured interviews with practitioners in the ceramic industry to validate the significance of these drivers and barriers in the ceramic industry. On the basis of data analysis carried out on the survey results, 8 drivers and 3 barriers were dropped owing to very low values of item total correlation.

The survey results show that the 12 drivers to implementation of lean manufacturing in the ceramic industry have mean values ranging from 1.92 to 3.81 on a scale of 5. As perceived by the ceramic industry, 'suppliers take a long time to deliver' is the least important driver of LM implementation of lean manufacturing whereas 'customer orders are highly fluctuating/varying' is the most important driver. This indicates that customer satisfaction is held in high esteem by the ceramic industry. Implementation of lean manufacturing would make the companies much more flexible in terms of volume and lead time flexibility. These drivers were tested for reliability through the value of Cronbach alpha. The cronbach alpha values for all drivers lie between 0.8 and 0.9 which indicate that the data is highly reliable. Exploratory factor analysis grouped all the drivers in three categories – internal, policy and external drivers. This categorization was confirmed by confirmatory factor analysis providing construct validity to the drivers. In other words, the internal, policy and external drivers are truly measured by the respective variables (drivers) given in figure 3.2. The results of hypotheses testing through structural equation modeling indicates that external drivers are positively related to policy drivers and policy drivers are positively related to internal drivers for implementation of lean manufacturing in ceramic industries.

The nine barriers have mean values ranging from 2.39 to 4.06 on a scale of 5. This indicates that these barriers are perceived as important barriers to implementation of lean manufacturing in ceramic industries. 'lack of top management commitment' is considered to be the least important barrier while 'resistance to change and adopt innovations' is considered to be the most important barrier by the ceramic industry. It should be noted that most of the responses have been taken from the top management so there might be some bias in 'lack of top management commitment' being seen as the least important barrier. There is a high resistance from employees towards lean implementation since they are not aware of the implications of such a change and fear that they might end up losing their jobs. This problem could be addressed by involving employees in the decision making process for implementing lean. This would help in increasing their confidence in the process and make them more willing to adopt the change. The Cronbach alpha value for all barriers is greater than 0.755 indicating high reliability of data. As a result of exploratory factor analysis, the barriers to lean implementation in ceramic industry were grouped under two categories – policy and economic barriers, and operational barriers. This categorization was confirmed through confirmatory factor analysis providing construct validity to the barriers. This means that policy & economic barriers, and operational barriers are truly measured by the respective variables (barriers) given in figure 3.3. The result of hypothesis testing through structural equation modeling indicates that policy and economic barriers are positively related to operational barriers. This implies that for the effective implementation of lean manufacturing in ceramic industries, policy & economic barriers are to be mitigated first as these are the root barriers to lean implementation. For example, due to inadequate training opportunities a lot of time and effort are currently required to implement lean. Similarly, lack of top management commitment could be one of the reasons for low awareness of lean manufacturing in the industry. If lean manufacturing becomes an industry norm, extra efforts need not be put in to spread awareness about it. This would also encourage more research in implementation of lean manufacturing in various industries.

3.10 CONCLUSIONS

This chapter develops statistically reliable and valid models for drivers and barriers of lean manufacturing implementation based on a survey of the ceramic industries. Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) techniques have been used for modeling. The drivers and barriers to lean manufacturing, developed on the basis of literature review and discussions held with relevant academicians and industry experts are divided into groups using SPSS statistical tool. Drivers are divided into three groups - internal drivers (low manpower productivity, high scraps/reworks/rejection, poor skills/ capabilities of workers, unavailability of skilled workers), policy drivers (weak process control, unbalanced workload on different workstations, poor workplace organization/ housekeeping, lack of standard operating procedures) and external drivers (fluctuating customer orders, low quality material by suppliers, suppliers take a long time to deliver, high product variety/customer specific product). Barriers are divided into two groups - policy & economic barriers (lack of top management commitment, high cost of consultant fee for training, misconception of high investment to implement lean, inadequate training opportunity, not an industry norm like ISO) and operational barriers (resistance to change and adopt innovations, too much time and effort required to implement lean, too general and not industry specific procedures, low awareness of lean manufacturing). Structural equation modeling technique has been used to test these models. Hypotheses testing affirm that external drivers are positively related to policy drivers, and policy drivers are positively related to internal drivers. Policy and economic barriers are positively related to operational barriers and hence these should be mitigated first.

CHAPTER 4

DEVELOPMENT OF A FRAMEWORK FOR LEAN MANUFACTURING IMPLEMENTATION

In this chapter, existing lean manufacturing implementation frameworks have been reviewed and based on the limitations of existing frameworks a new framework has been proposed which includes three major phases namely pre-implementation, implementation and post implementation.

4.1 INTRODUCTION

In recent years, the application of LM in different types of industries has grown rapidly. Some of the organizations have reported huge benefits, while some organizations have not obtained the desired results. Mohanty *et al.,* (2007) observed that many of the companies that reported initial gains from lean implementation often fond that improvements remain localized, and the companies were unable to have continuous improvements. One of the reasons for this can be attributed to lack of well developed lean manufacturing frameworks.

Womack and Jones (1996) proposed five well known theoretical phases – specify value, identify the value stream, avoid interruptions in value flow, let customers pull value, and start pursuing perfection again – for the basic implementation of lean manufacturing. Since then, several authors have used these principles. A detailed LM implementation guide and an illustration of other companies that have applied LM in practice were produced by Hines *et al.,* (2004).

Lean implementation is seen as a process of adoption. The term implementation process is taken for a meaning of "progression of events" (Ahlstrom and Karlsson, 2000). The lean implementation as a process of adoption involves the necessity of innovation and adaptation of the organization, not just following a certain sequence of steps from a preliminary designed plan. The research tries to explore to what extent the implementation process includes certain improvement initiatives and what are the success factors which would enhance the implementation process in the organization.

Storhagen (1993) suggested that the lean implementation process should begin with techniques and methods that change the features of the manufacturing systems and then continue with those that permit improved material flows. Foundations are laid with zero defects and delayering, followed by management effort to start a continuous improvement initiative using multifunctional teams to solve problems as a natural part of day-to-day work.

It has been proposed by Harrison and Storey (1996) that the following should be done before lean manufacturing is put in place in the company:

- Identified barriers should be eliminated, considering implementation as a whole and not simply the implementation of a series of techniques.
- Integration should be improved within the system.
- Employees' commitment level should be rewarded in the organization.
- The agenda for management change should be extended throughout the organization including the supply chain.
- The organization culture should be changed.

4.2 REVIEW OF FRAMEWORKS

Frameworks have been defined in different ways by different researchers. Some of the connotations of frameworks are:

- 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 (Aalbregtse *et al.,* 1991).
- A framework is a prescriptive set of things to do (Yusuf and Aspinwall, 2000).
- A framework helps in translating a theory into practice through some systematic means (Hakes, 1991).
- A framework is a guiding torch that helps a manager in providing necessary direction during the change management programs that are implemented in an organization (Anand and Kodali, 2010a/b).

A framework may be defined as an organized outcome-based plan which defines clear standards to be set by the organization. It outlines the possible course of action to be followed in order to achieve the goals and helps the organization to detect its own strengths and weaknesses. A well structured framework facilitates in prioritizing various issues and challenges faced by the organization, clearly defining the role of the employees and relations among the departments.

An extensive literature review involving 30 frameworks has been done by Anand and Kodali (2010a). Certain limitations were found in some of these frameworks. The parameters used for analysis were the number of elements, comprehensiveness, abstractness, purpose of the framework and the degree of clarity. Number of elements represented the count of the elements in the LM framework. Comprehensiveness represented the number of elements addressed by the framework. Frameworks consisting of more than thirty elements were assumed to have high degree of comprehensiveness and those with less than ten elements were assumed to have a low degree of comprehensiveness. Abstractness represented the clarity of the framework in explaining the entire implementation procedure. It also refers to whether a reader is able to understand LM implementation or not. Purpose of the framework represented the usefulness of the framework to researchers, consultants and academicians. Degree of clarity represented the clarity in role definition of stakeholders in LM implementation. This could include the definition of roles for engineers, supervisors, managers, and stakeholders' etc. This section provides a review of 21 frameworks taken from literature by the name of the authors.

Smeds (1994)

A generic framework proposed by Smeds (1994) is the management of change framework. It starts from a strategic vision and an overall umbrella strategy to the stabilization of new mode of operation leading towards a lean enterprise.

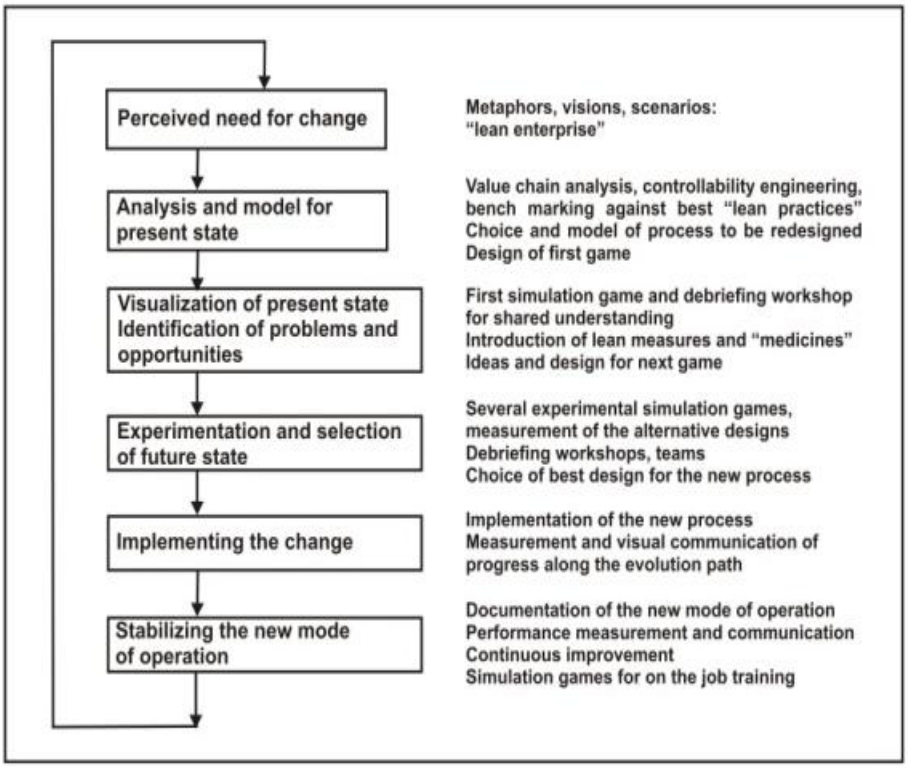


Figure 4.1: Framework for the management of change towards a lean enterprise (Smeds, 1994)

The various steps of the framework, as shown in figure 4.1, are: perceived need for change, analysis and model of the present state, visualization of present state and identification of problems and opportunities, experimentation and selection of future state, implementing the change, and stabilizing the new mode of operation. Continuous improvement which is a key element of lean manufacturing is included in this generic framework. When incremental improvements reach a critical threshold during the stabilization phase of change project, there is a necessity of reorganization. The framework advocates the repetition of development process leading to continuous improvement.

This framework provides possible methods and tasks for the different phases of framework as suggested on the right side of the figure 4.1. The role of top management is critical during the whole process as it provides the vision and creates scenarios for the others to achieve. The game designers and facilitators act as champions during implementation phase. The employees act as experimenters and innovators in the games. However, this framework presented is still a hypothesis and needs to be further tested in longitudinal case studies of process innovations and organizational transitions. Also, the tools needed for the implementation are not mentioned.

Womack and Jones (1996)

It is a time bound descriptive framework. It contains the four major phases and there are specific steps in each phase with time frame as can be seen in the figure 4.2. The four major phases of the framework are: get started, create a new organization, install business systems, and complete the transformation. The whole process is to be completed in 21 steps includes acquiring lean knowledge, devising a policy for excess people, introducing lean learning, applying the steps to suppliers/customers, and end with transition from top-down to bottom-up improvement by the end of five years.

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

Figure 4.2: Time frame for lean leap (Womack and Jones, 1996)

The framework works on the five basic principles of lean implementation – specify value, identify the value stream, create a flow, let the customer pull, and pursue perfection. However, this framework doesn't specify any operational strategy, and ignores lean prerequisites and various other contingent factors, thus rendering it ineffective in an organizational context.

James-Moore and Gibbons (1997)

The key aspect of this framework is the reinforcement of the linkages between drivers in the business environment and the strategic responses to these drivers. The elements of this model are based on the core business processes and practices adopted by an organization. The main focus is to satisfy the customers through optimization of resource utilization, maintaining the flexibility, eliminating the wastes and controlling the processes.

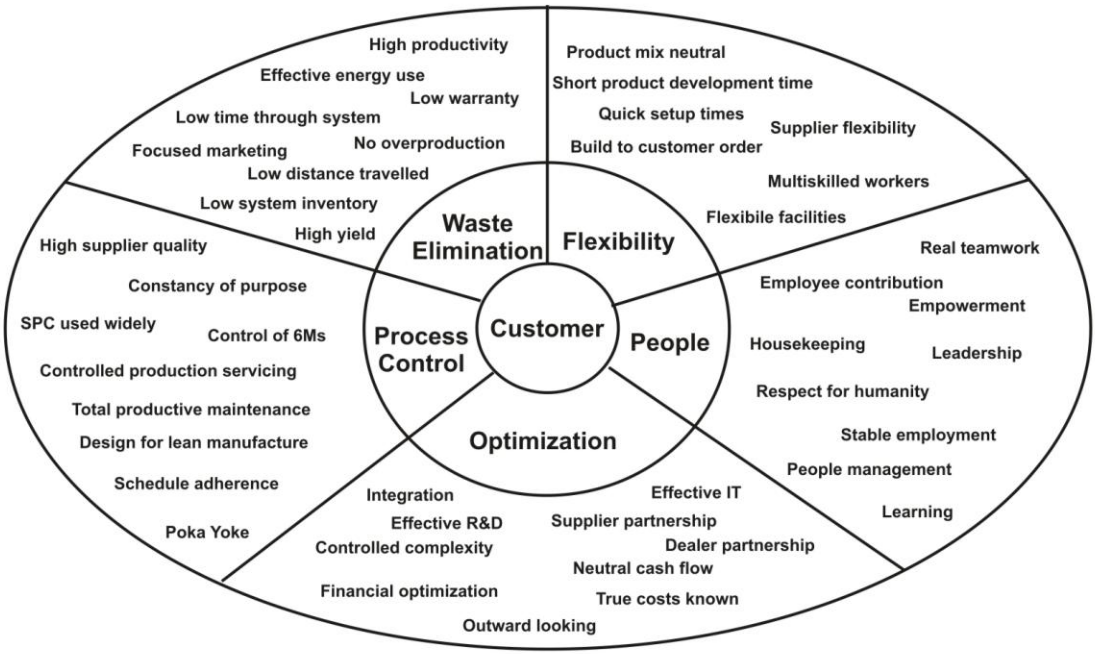


Figure 4.3: Lean automotive vision model (James-Moore and Gibbons, 1997)

The framework as shown in figure 4.3 discusses measures required to achieve an initial non-quantified vision of a lean company in five areas, namely: flexibility, waste elimination, process control, optimization, and people. Each of five key areas includes many practices/tools/techniques or elements which are an integral part of the lean implementation and this whole exercise is focused on a central theme i.e. customer. These characteristics would contribute towards the achievement of leanness in a best-in-class company. However, even though it is fairly comprehensive, some key areas-like planning, safety, lean performance measurement etc., have been ignored in this framework.

Jina *et al.* (1997)

This framework is geared towards production of the High Variety Low Volume (HVLV) items. It has three interconnected 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 proposed framework as shown in figure 4.4.

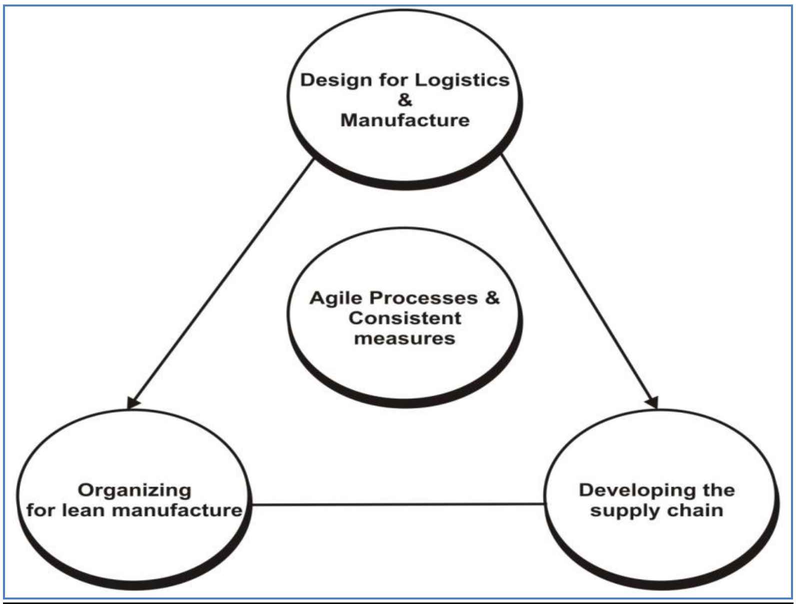


Figure 4.4: Lean framework for HVLVs (Jina *et al.* 1997)

The various elements under these four major components are:

- Design for logistics and manufacture – Communizing raw material parts, common finished parts and use of modular designs, staged engineering change control, and multifunctional teamwork.
- Organizing manufacturing – Organizing for high level demand, organizing for lower level demand, runner parts, stranger parts, and repeater parts.
- Integrative supplier relationships – Single sourcing for defined commodity groups rather than individual parts and learning from a larger supplier who may already be a partner in a supply chain with leading high volume LM end assemblers.
- Process orientation and consistent performance measures – Melding the previous three elements, using agile processes, taking account of "local" ground level measures such as batch sizes, etc.

The framework provides a structure for explaining both the process and content aspects of the lean. However, the framework is highly abstract with no mention of several important tools required for implementation and there is no clarity on the role of stakeholders.

Ahlstrom (1998)

The proposed framework could be used by a company to explore the question of whether to implement improvement initiatives in parallel or sequence. It consists of a series of steps to introduce lean production. The framework elements and methodologies are given below:

- Elimination of waste – Reducing set-up times, using preventive maintenance to reduce machine downtime, and changing layouts to reduce transportation distances for parts.
- Pull scheduling – Reducing batch sizes and manufacturing parts free from defects.
- Zero defects – Quality training for operators, installing systems for tracing parts in the operation, statistical process control, and corrective action.
- Multifunctional teams – Organizing teams around manufacturing cells and process flows.
- Delayering – Removing layers of hierarchical levels in an organization.
- Team leaders – Changing the role of team leaders as advisers rather than bosses.
- Vertical information systems – Using information systems to enable teams to perform according to the company goals.
- Continuous improvement – The final goal.

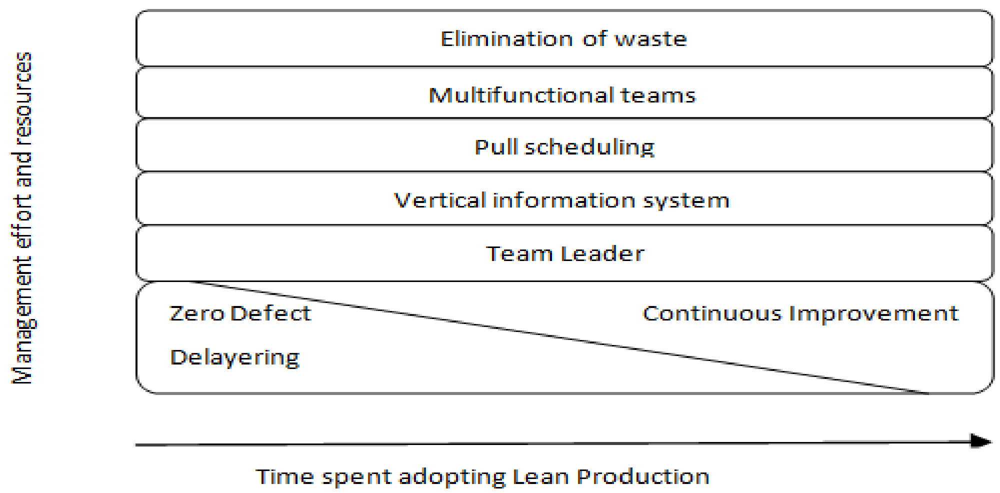


Figure 4.5 Sequences in the implementation of lean production

The figure 4.5 illustrates the manner in which management effort and resources need to be devoted to the core and supporting principles in parallel. There is a foundation of zero defects and delayering due to which management effort and resources can shift to starting a continuous improvement initiative. Waste elimination, multifunctional teams, pull scheduling, vertical information systems, and team leaders as advisers are the core ingredients for the successful implementation of lean production. The height of each block in the framework represents the management efforts and resources. This framework shows a sequence of steps for implementation of lean production. However, it has a low degree of clarity in role definition. This framework is primarily used to investigate whether management needs to devote effort and resources in implementing lean production principles in parallel or sequence.

Flinchbaugh (1998)

The proposed a framework known as Chrysler Operating System (COS) based on the lean manufacturing principles is shown in figure 4.6. The core beliefs and values of the framework are inspired people, customer focus and continuous improvement to determine the enablers, and then proceed to identifying the various sub-systems and support processes. Eventually, using the processes, the framework identifies various tools and measurement techniques to improve company reputation, financial success, safety, quality, delivery, cost, and morale.

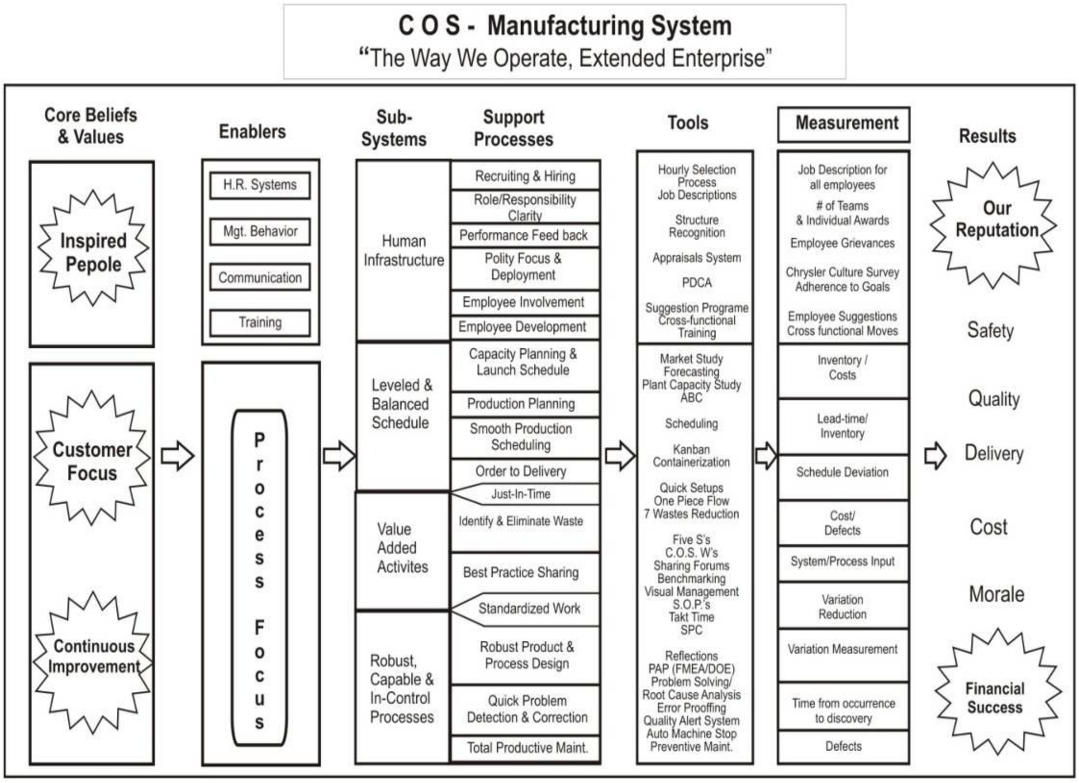


Figure 4.6: Chrysler operating system (Flinchbaugh, 1998)

The four primary sub-systems of the COS are:

- Human infrastructure – This includes introducing a system where the human infrastructure can be made to work in conjunction with the rest of the operating system by training the employees and thus adding to the existing skill base level.
- Leveled and balanced schedules – This is introduced to minimize wild swings in demand so that it doesn't affect the production process.
- Value-added activities – These include the activities concerning continuous improvement and long-term waste elimination in the production.
- Robust, capable, and in-control processes – These include activities concerning process control and maintenance.

This framework shows various elements of lean production and their relationships. However, the role definitions are not very clear in this model.

Sanchez and Perez (2001)

This framework, called as “an integrated checklist”, analyzes the changes towards lean production to achieve competitiveness. The checklist has six groups of indicators grouped according to the most common lean production practices as given below:

- Elimination of zero-value activities: Percentage of common parts, value of work in progress, inventory rotation, number of times parts transported, die changeover time, and preventive maintenance percentage.
- Continuous improvement (kaizen): Number of suggestions per employee, percentage of implemented suggestions, savings from suggestions, inspection percentage, defective parts percentage, value of scrap and rework, and number of people in quality control.
- Multifunctional teams: Percentage of employees in teams, percentage of tasks performed by teams, and task rotation.
- JIT production and delivery: Lead time, parts delivered JIT percentage, level of integration, and lot sizes.
- Supplier integration: Parts co-designed with supplier percentage, suggestions to suppliers, supplier visit frequency, documents interchange percentage, length of contracts, number of suppliers, etc.
- Flexible information systems: Information interchange frequency, number of meetings, computer integrated production, and number of employee decisions without supervisors.

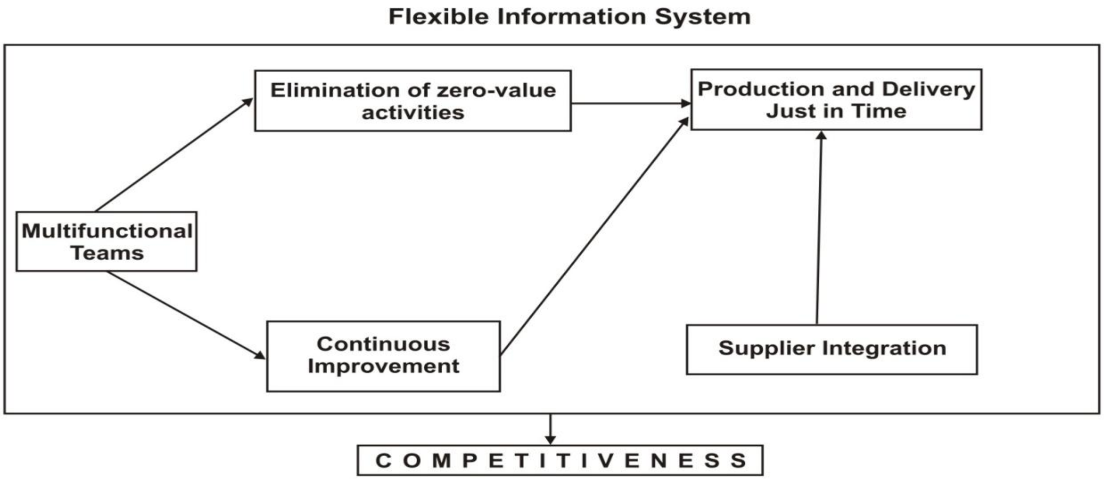


Figure 4.7: Integrated checklist (Sanchez and Perez, 2001)

Each group comprises of common basic lean production practices which help to improve the performance of the company. However, this framework (Figure 4.7) was only designed for the purpose of preparing a checklist, and thus, doesn't mention the need of top management commitment and training for employees.

Oliver *et al.* (2002)

Oliver *et al.* (2002) proposed a lean production model based on the empirical study through a questionnaire. plant performance, plant characteristics, process control, work organization, problem solving and improvement, relations with suppliers, and relations with customers are the main areas of concern of this model.

	Inside the Factory	**Along the Supply Chain**
Flow	JIT, low inventories of WIP, 'pull' systems of production control, simple work flow, team based work organization, visual control	JIT deliveries, low inventories of incoming parts and finished goods
Error Prevention	High process control, work standardization, poke yoke, design for manufacture	Joint planning, design and development, high visibility of process along the supply chain, schedule stability, staff exchanges
Improvement	Problem solving and continuous improvement groups, suggestion schemes	Joint problem solving and cost reduction, supplier associations

Figure 4.8: Lean production model (Oliver *et al*. 2002)

The questionnaire was designed to get data for analytical comparisons of performance between the plants in a production area. This helps the management of each plant to verify how much lean production principles are in use in each area. Specific quantitative indicators of plant performance such as production units per labor hour and defects in parts per million are used to measure the performance. The framework (Figure 4.8) uses a questionnaire comprising of the following set of tools to be implemented both inside the factory and along the supply chain for an organization to become lean:

- Flow: This includes implementation of JIT, pull systems and visual control inside the factory and low inventories along the supply chain.
- Error prevention: This includes implementation of poka yoke and work standardization inside the factory and joint planning along the supply chain.
- Improvement: This includes implementation of continuous improvement and suggestion schemes inside the factory and joint problem solving and cost reduction along the supply chain.

This highly abstract framework was only designed for the purpose of preparing a questionnaire for evaluation and comparison.

Flinchbaugh (2003)

It presents an organization learning framework (Figure 4.9), which would help an organization examine lean through the eyes of vision, systemic structures and mental models. It provides the rules for designing and improving the production systems to make them more usable for people. The rules are; structure every ACTIVITY, clearly CONNECT every customer –suppliers, specify and simplify every FLOW path, and IMPROVE through experimentation at the lowest level possible towards the ideal state.

The tenet of this framework is that “lean starts with rules, not tools”. It provides five principles and each principle carries with it leverage, that can yield significant gains in the overall performance of the organization. These five principles, given below, are a major contribution to the understanding of lean and help design better business systems:

- 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.

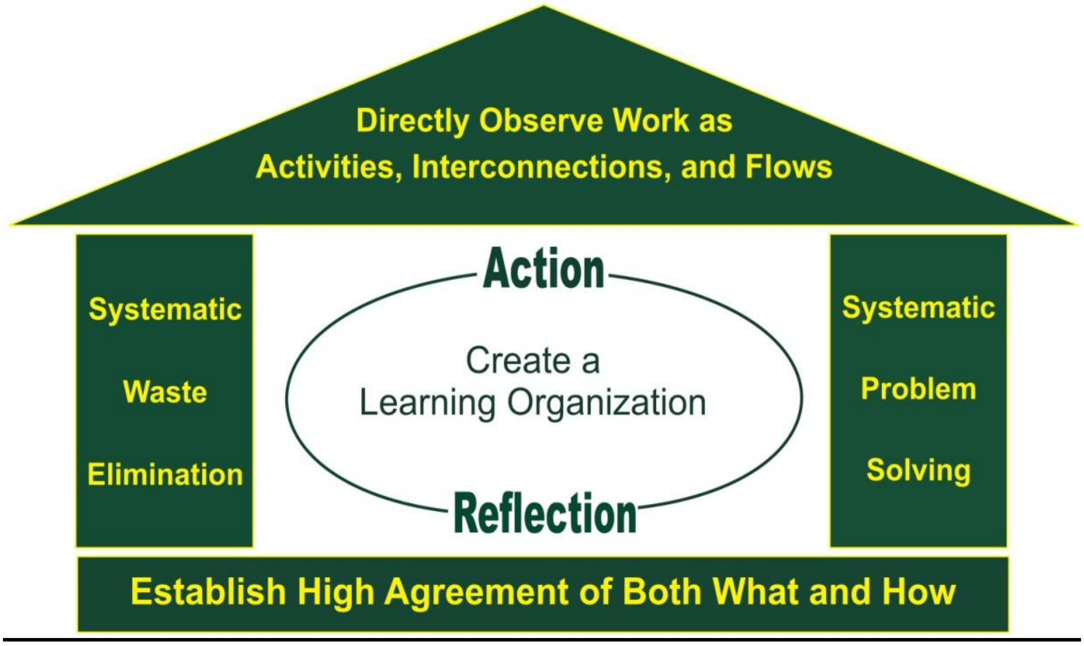


Figure 4.9: Leap framework (Flinchbaugh, 2003)

Motwani (2003)

Motwani (2003) adapted the Business Process Change (BPC) model of Kettinger and Grover (1995) and presented a theoretical model for the implementation of LM as shown in figure 4.10. This framework comprises of the following components:

- Strategic initiatives- This involves visioning, commitment and enabling from the senior management team.
- Cultural readiness- This involves diagnosing and influencing cultural readiness for change.
- Learning capacity- This involves developing and utilizing informal networks for knowledge acquisition and learning.
- IT leveragability and knowledge-sharing capability- This involves improving the capability of an organization to share and leverage knowledge and IT.
- Relationships balancing- This involves reengineering the value chain by leveraging boundaries and relationships.
- Process management- This combines methodological approaches with human resource management by using processes such as total quality management, process modeling, etc.
- Change management- This involves addressing required cultural shifts in values and beliefs.

Motwani opined that the implementation of lean manufacturing would result in business process change in the organizations. Any significant business change requires:

- Top level managers to take up the initiatives and act as leaders,
- Existence of a culturally developed environment and
- Sharing of knowledge and willingness to learn.
- Balanced network
- Process and change management activities

However, the framework ignores employee involvement activities completely.

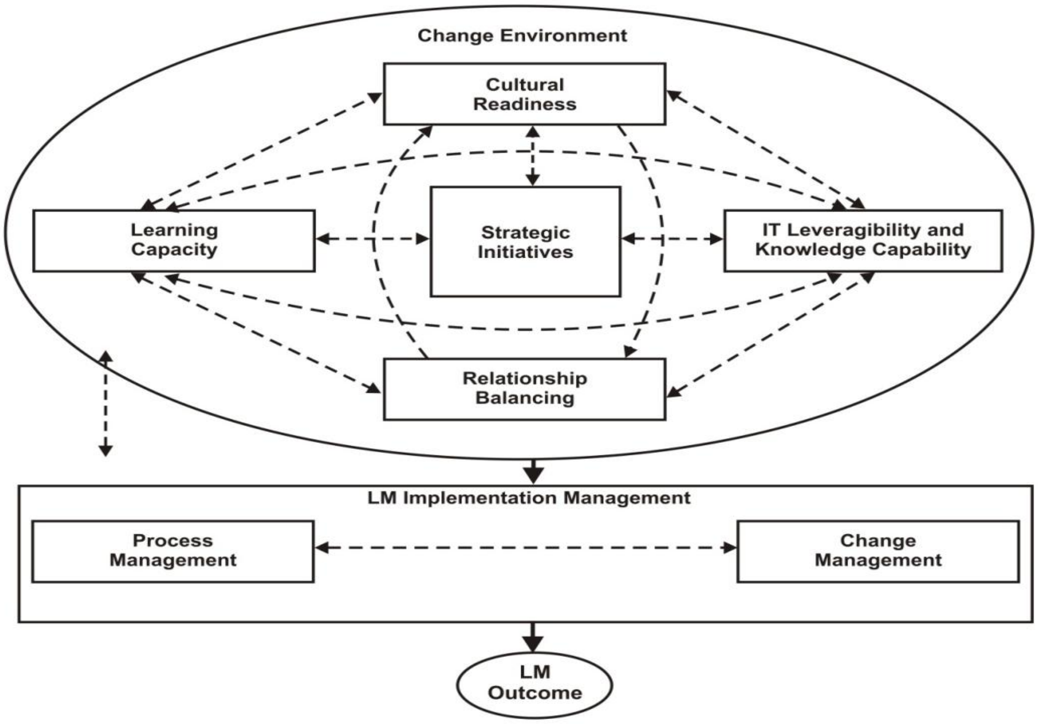


Figure 4.10: LM implementation management model (Motwani, 2003)

Hines *et al.* (2004)

Hines *et al*. noted that from strategic point of view one can integrate other approaches including their tools without modifying the core aim of lean (customer value). In other words, any approach that offers customer value can be aligned towards a lean strategy; even if lean production tools on the shop-floor are not used. The proposed framework (Figure 4.11) representing this aspect also highlights the concepts of production capacity, quality, responsiveness of the manufacturing system, variability in demand, and availability of production resources to support a wider lean strategy. This framework distinguishes between the lean thinking at the strategic level and lean production at the operational level to apply the right tools to provide customer value. At strategic level, five principles of lean thinking have been suggested to understand the value. At operational level, there are complimentary approaches that can and have been used in conjunction with lean.

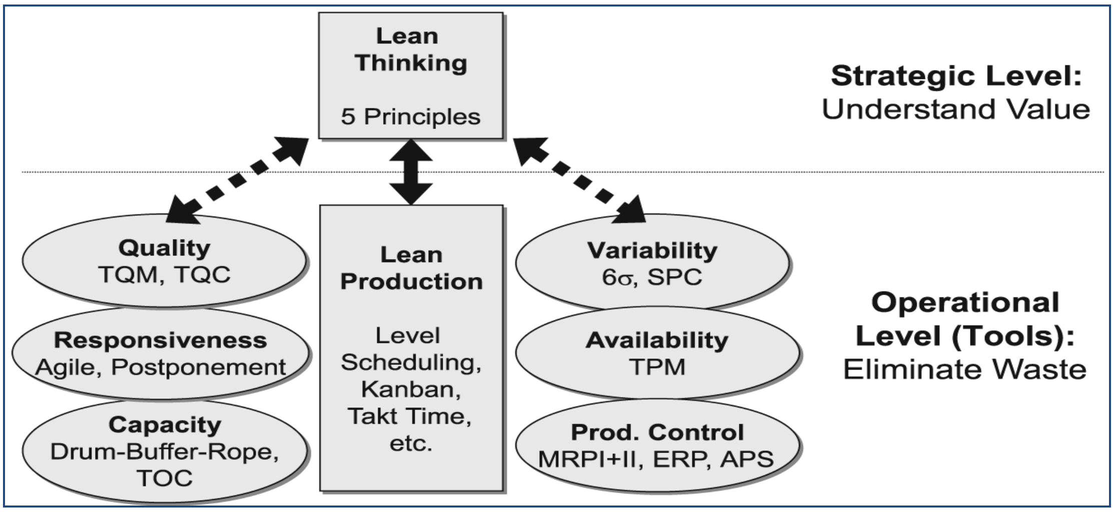


Figure 4.11: Strategic and operational level framework (Hines *et al.* 2004)

The framework presents a value-adding network of operations with a focus on the final customer. However, with an incomplete and unorganized set of tools, the framework fails to integrate lean planning and production.

Pascal (2007)

This model known as "*The house of lean*" (Figure 4.12) offers a graphic view of the lean production system with its elements and their interrelationships.

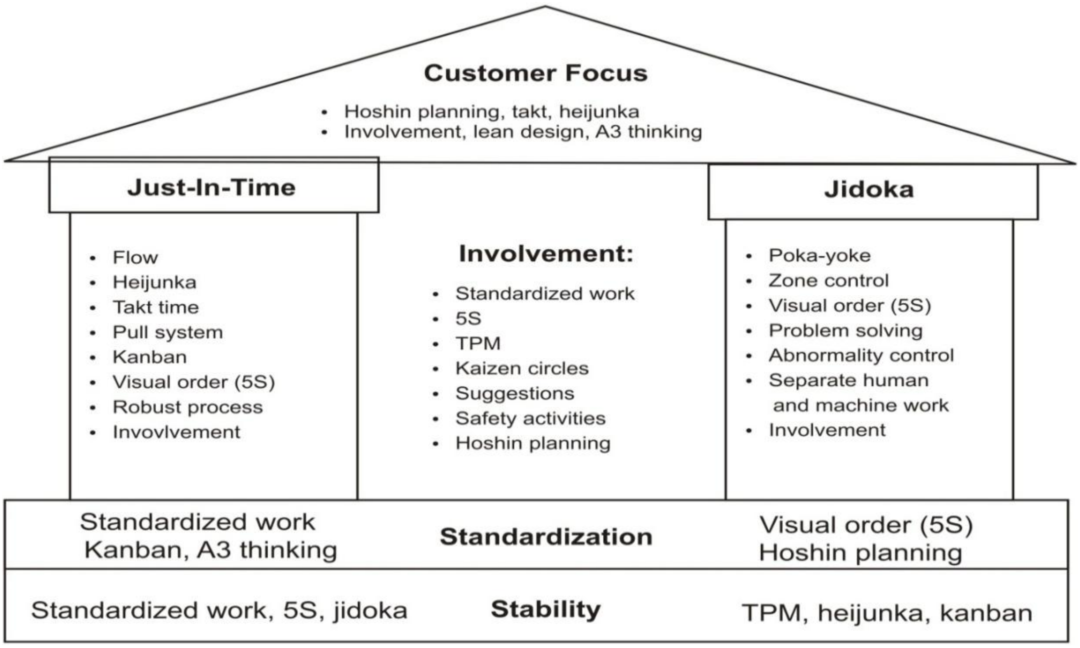


Figure 4.12: House of lean (Pascal, 2007)

This is considered to be a quintessential framework by many organizations. The foundation of the lean system is stability and standardization. The walls are JIT and Jidoka. The roof (system goal) is customer focus aiming for high quality, low cost and short lead time. The heart of the system is employee involvement. Thus, each activity is interrelated and together they all combine to reinforce the core concepts of lean manufacturing. Most of the lean tools and techniques have been incorporated in the house. However, this framework neither explains the role of stakeholders.

Mohanty *et al.* (2007)

To strengthen the lean system movement and its ability to cope with the future economic and market conditions, some relevant propositions have been made to bridge the gaps between the principles and practices by implementing a lean model using seven pillars of support.

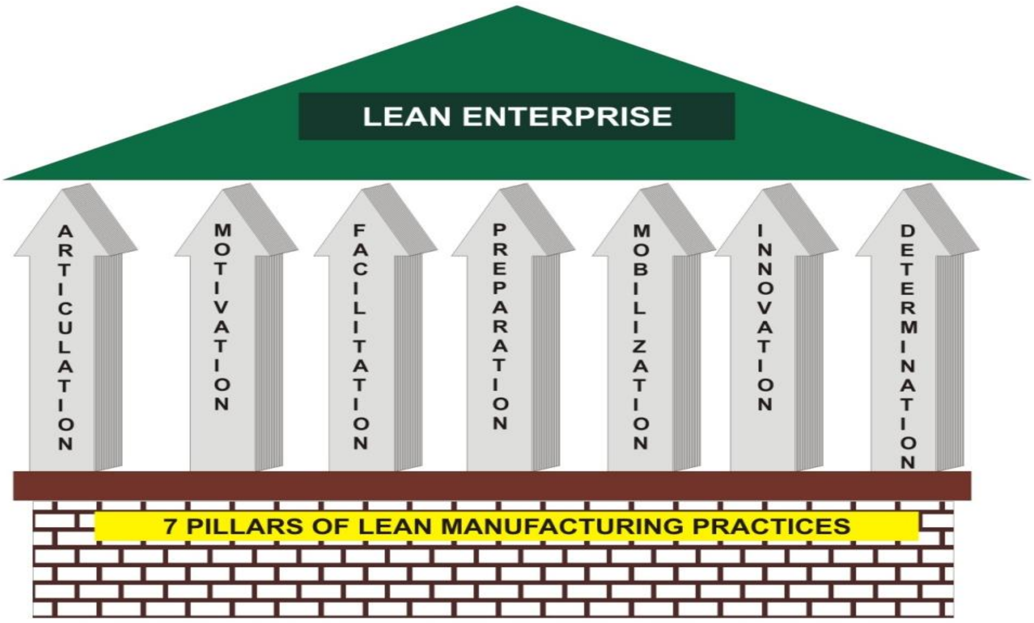


Figure 4.13: Lean enterprise framework (Mohanty, 2007)

The seven pillars of support, as shown in figure 4.13, are: articulation, motivation, facilitation, preparation, mobilization, innovation and determination. The competent companies working on strengthening their competencies and technical capabilities, and producing intent for transforming their enterprise into lean will succeed in the long term. However, this framework doesn’t explain different tools, top management commitment, A3 thinking and training for employees involved in detail.

Anand and Kodali (2010a)

The conceptual framework identifies the list of LM elements comprehensively and thus helps the organizations to understand clearly the constitution of LM. This pyramid shape as shown in figure 4.14 also indicate that 20% of the employees making up the top management, remain on the top of the pyramid, while the rest 80% of the employees are at the Bottom of the Pyramid (BOP), and earn comparatively lesser than the top 20% of the employees of the organization.

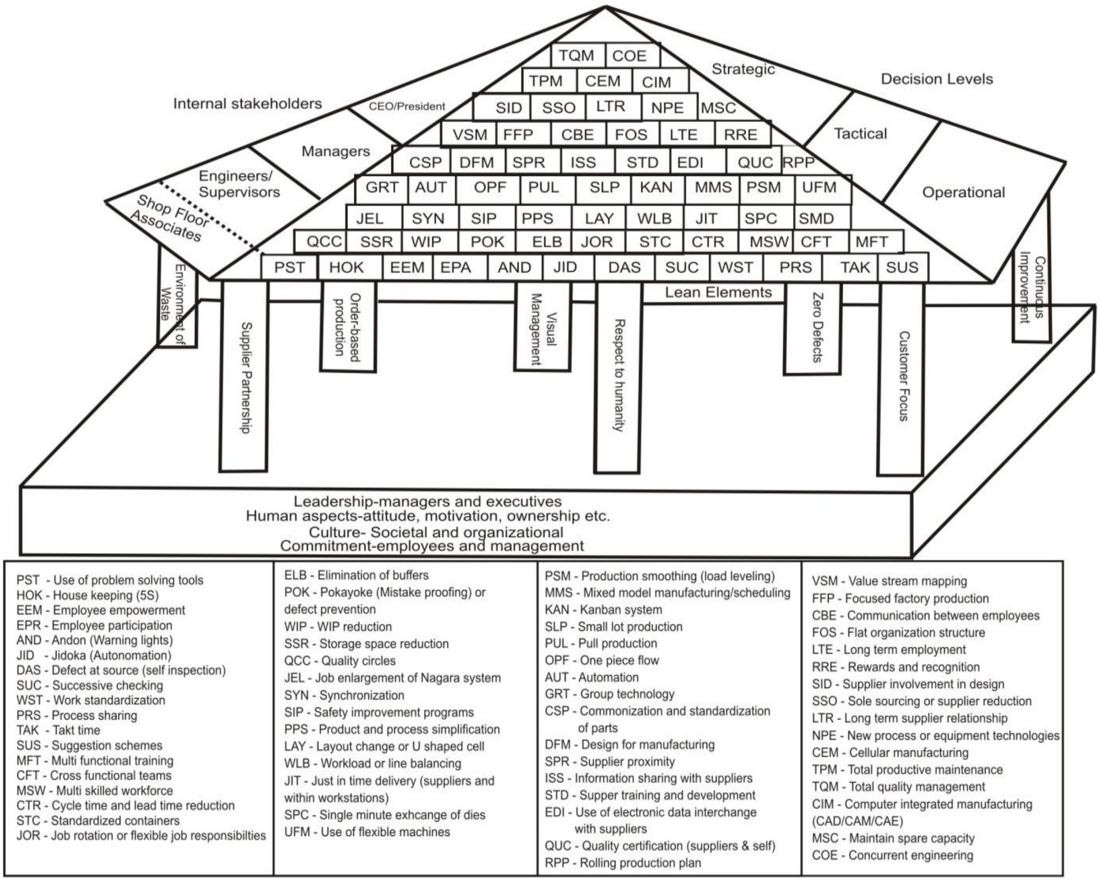


Figure 4.14: LM implementation framework (Anand and Kodali, 2010a)

The framework proposes that the success of any organization in changing the organization culture or implementing any change management programs is dependent on the 80% of the people at the BOP. Moreover, an organization will be successful, if the top management can convince those employees at the BOP. This framework has 65 elements identified from an extensive literature review involving the top management and employees at the BOP. The proposed framework consists following structures:

Foundation: It refers to universal pre-requisites which should be taken care in lean implementation. Good leadership, commitment, culture and human aspects form the foundation.

Pillars: 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. These pillars represent the basic LM development principles.

Decision levels: Three decision levels i.e. strategic, tactical and operation has been presented in the framework and at each level various elements are given.

Role of stakeholders*:* 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; has been identified.

The framework is self- explanatory. However, the proposed framework is conceptual and needs to be validated. Also, the large number of elements has made the framework too complex.

Anand and Kodali (2010b)

This framework involves a step-by-step procedure for lean manufacturing implementation. This framework has 10 level steps as shown in figure 4.15:

- Evaluate: Performing an initial appraisal of the organization to understand the amount of wastes and NVA activities with the help of an external consultant.

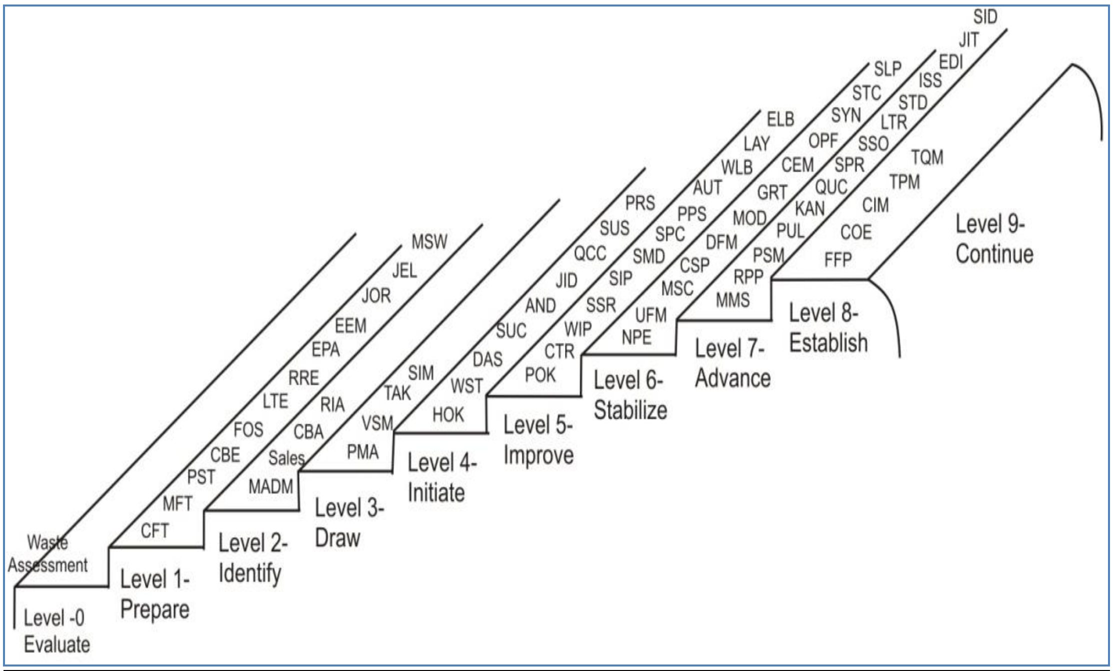


Figure 4.15: Ten step LM implementation framework (Anand and Kodali, 2010b)

- Prepare: Preparing the organization for LM implementation by team formation, training and important structures (like rewards, employee empowerment).
- Identify: Identifying the critical product by evaluating various factors using some decision-making tools.
- Draw: Understanding the manufacturing process of the identified critical product, and its complete flow of materials and information using VSM.
- Initiate: Initiating the actual implementation using 5S, Jidoka, Quality Circles, etc.
- Improve: Implementing elements like *Poke-yoke*, SMED, etc. to achieve a significant reduction in the seven wastes.
- Stabilize: Stabilizing the improvements that happened in the previous stages by increasing the roles of engineers and managers.
- Advance: Implementing advanced elements like kanban, JIT, etc. to aid the pull system.

- Establish: Introduce other management philosophies such as TQM, TPM and Six-Sigma.
- Continue: Focusing on continuous improvement of the existing value stream.

Amin and Karim (2011)

It proposes a systematic process for quantitatively measuring the performance of a manufacturing system in detecting the causes of inefficiencies and selecting appropriate lean strategies.

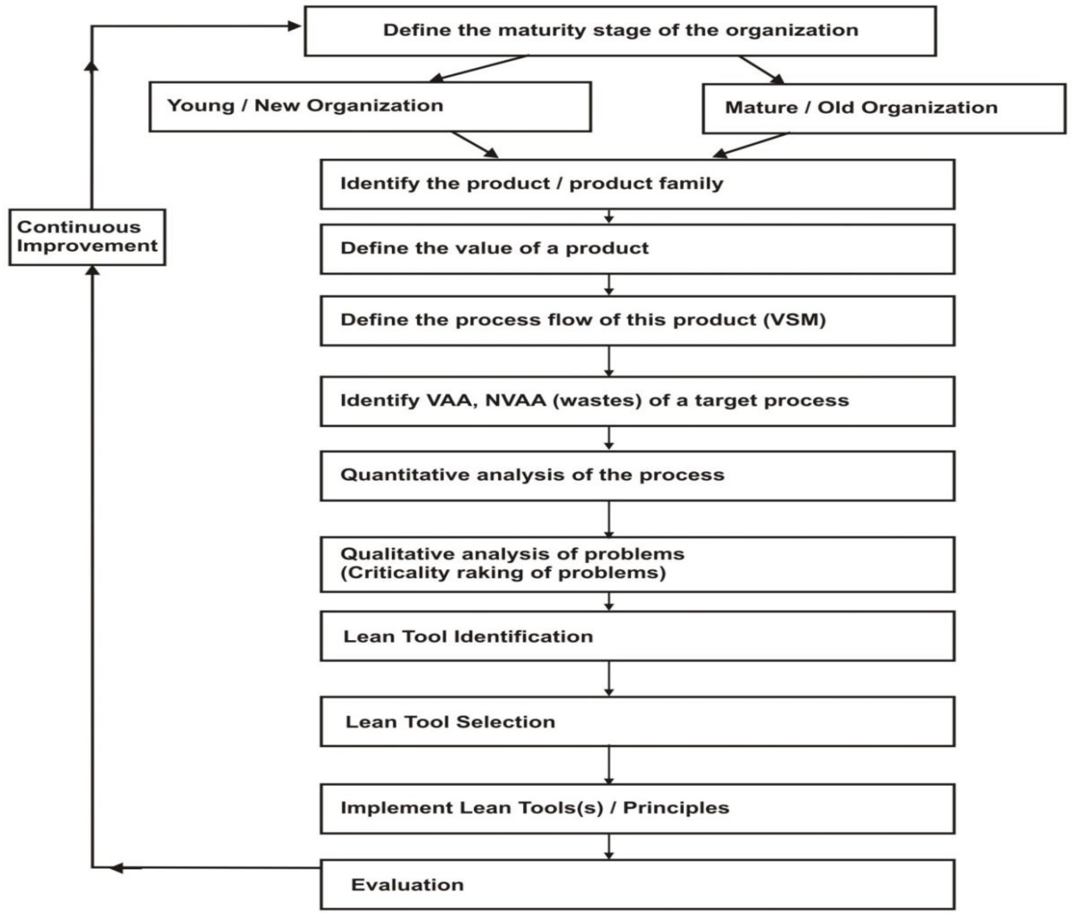


Figure 4.16: LM implementation framework (Amin and Karim, 2011)

The proposed LM implementation framework, has sequential steps: define the maturity stage of an organization, define a product/product family, define the value of a product, identify the process step, measuring value of a product, criticality analysis of a problem, tool identification and selection, and finally, implement and evaluate the implemented lean strategy. After evaluation, improvements are made and the cycle is repeated as shown in figure 4.16. This framework uses life cycle scale to identify the maturity stage of an organization. Value stream mapping is done for quantitative analysis of process related parameters such as lead time, quality, OEE etc. to measure the process performance. A critical analysis is followed by lean implementation team to find the causes of specific problems. A set of tools are suggested for the organization based on their maturity stage to remove the causes of low productivity. Process parameters are evaluated to verify the performance and again the cycle is repeated for continuous improvement.

Aurelio *et al.* (2011)

This framework (Figure 4.17) encompasses a comprehensive view to include strategic and operational dimensions to guide a decision maker through a process to evaluate lean management suitability for an organization.

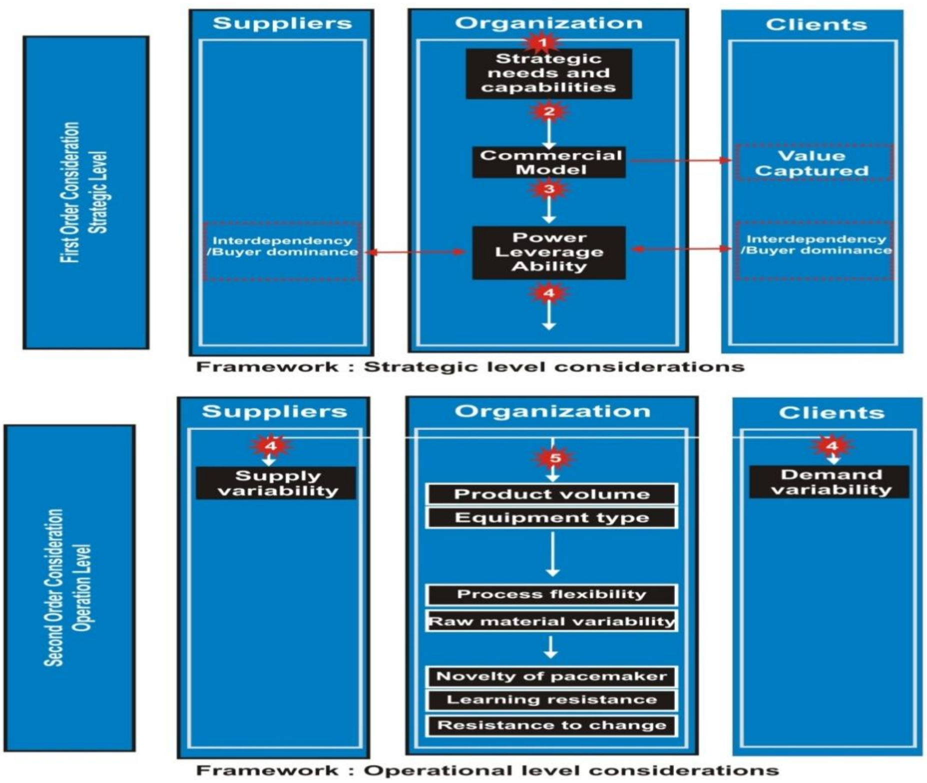


Figure 4.17: Strategic and operational level framework (Aurelio *et al.* 2011)

A total of five key criteria are suggested for evaluation:

- Organization's strategic needs and capabilities.
- Organization's commercial model.
- Company's ability to extend in the future its operational model throughout the supply chain.
- Influence of external factors to operational policies.

A utility function with qualitative descriptors and quantitative rating has been developed for each factor. The final step consists of formatting the framework to a decision model formulation. The framework has been validated through case studies.

Bortolotti and Romano (2012)

Bortolotti and Romano (2011) proposed a lean framework names as '*Lean first, then automate'* as shown in figure 4.18.

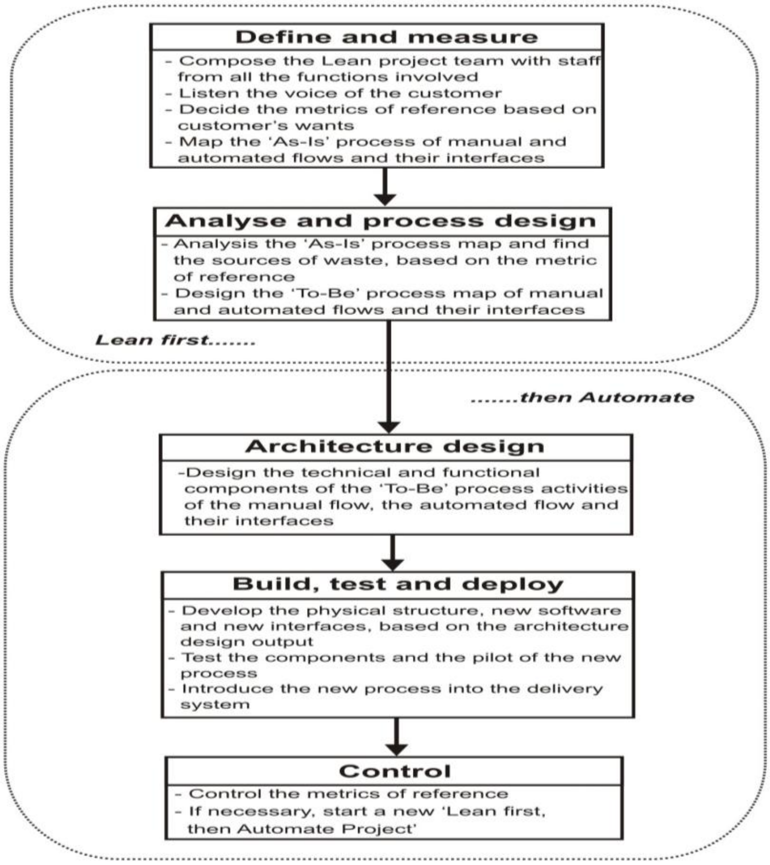


Figure 4.18: '*Lean first, then automate'* framework (Bortolotti and Romano, 2011)

It combines activities to condense and automate processes to improve efficiency and customer satisfaction in a pure service context. The framework comprises of the following phases:

- Define and measure phase: Detailing the customer needs to understand the factors that should be measured, improved and monitored.
- Analyze and process design phase: Identify every waste present through mapping of the process and eliminate its sources.
- Architecture design phase: Describing the sequence of activities that will form the future process.
- Build, test and deploy phase: The future process is implemented and tested.
- Control phase: Constant monitoring using the reference factors.

The framework, based on the empirical investigation, provides a logical sequence to the activities of streamlining and automating processes: first streamline the new process and then automate the value-added activities identified by the final customer. However, the framework doesn't explain the different tools and techniques, involvement of the employees, etc.

Dombrowski and Zahn (2011)

The framework offers an approach to eliminate waste, achieve high quality, and reduce the time-to-market.

It is an enterprise-specific lean development framework consisting of the following four levels – goals, development process, principles and methods and tools as shown in figure 4.19.

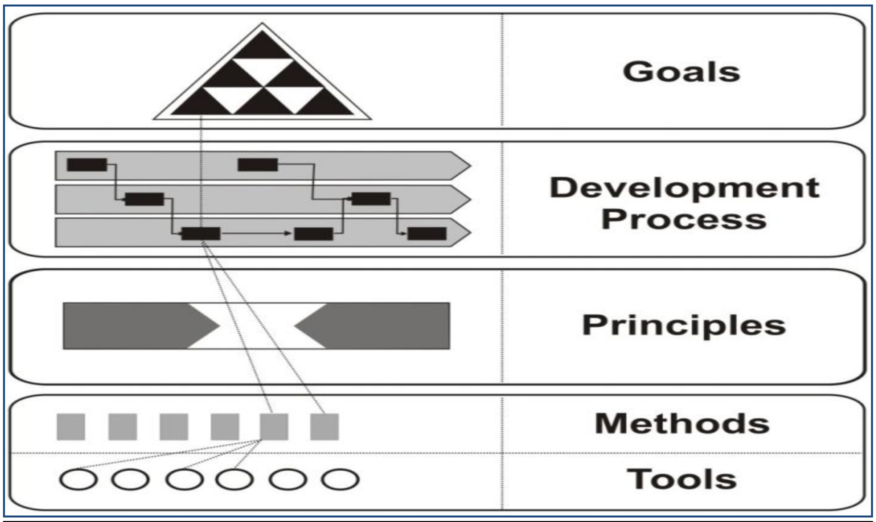


Figure 4.19; Enterprise-specific lean development framework (Dombrowski and Zahn, 2011)

The framework is grouped along following seven principles:

- Kaizen
- Standardization
- Visualization
- Flow and Pull
- Zero-Defects
- Employees and Leadership
- Frontloading

The framework and the detailed description of some methods give the top-management an excellent and structured overview of the concept. On basis of the framework the enterprise developed their enterprise-specific lean development concept. However, the framework doesn't mention the arrangement of planning and controlling of the implementation of lean principles, customer focus, and the use of rewards to motivate the employees.

Gibbons *et al.* (2012)

It identifies a new lean waste defined as a 'wasted opportunity'. It argues the resource based view to a production process and says any of the unused services is a waste. It advocates the focus should shift from external to internal resources.

The framework, as shown in figure 4.20, has the following steps:

- Input- The dynamic resource homogeneity refers to use of a bundle of resources together as an input to a production process, thereby, removing the polarization waste and maintaining flexibility.
- Progress- Refers to the progress of the firm in achieving the desired output.
- Output- This refers to the competitive advantages offered in terms of economies of scope and scale.

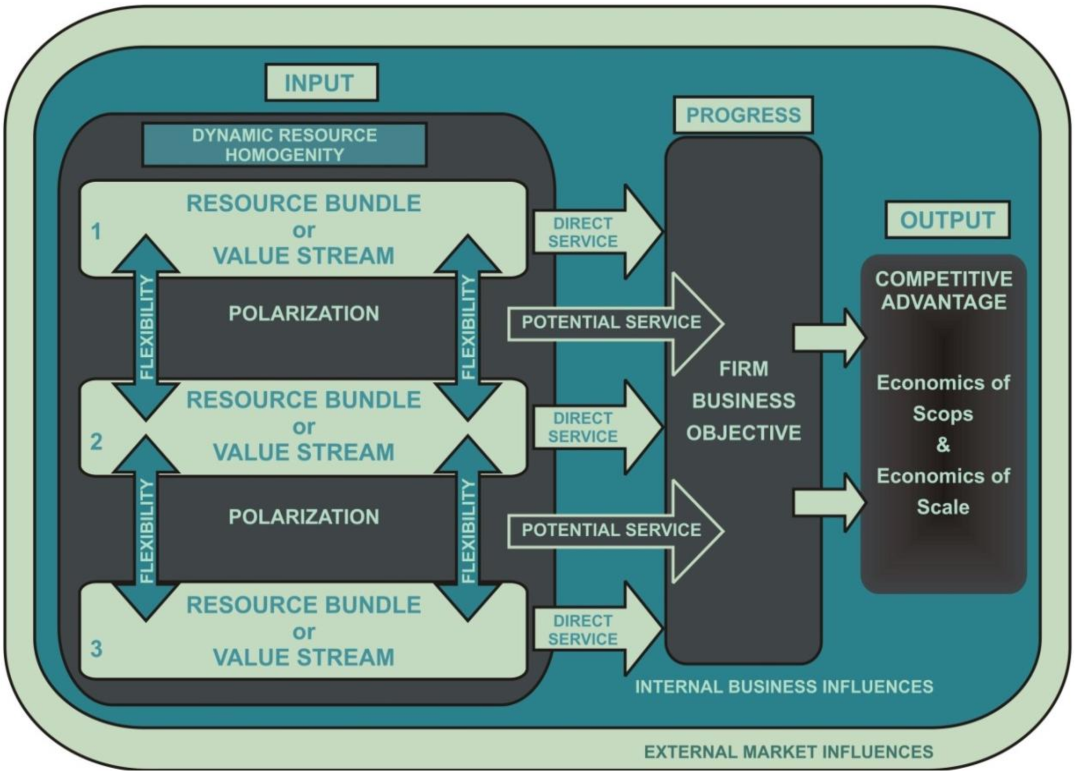


Figure 4.20: Lean resource mapping framework (Gibbons *et al.* 2012)

This framework advocates dynamic homogeneity across process driven value streams, rather than heterogeneity between them. It delivers bundles of potential services to the overall firm business objectives allowing both economies of scale and scope to achieve competitive advantage.

Wanitwattanakosol and Sopadang (2012)

The two phase framework aims to transform SMEs into lean organizations. Phrase one has three interrelated components of:

- Business process management: Re-engineering an organization by using the power of computer simulation combined with business process.
- Value stream management: This is used to create a map of both value and waste in a given process.
- Supplier selection: Integrative supplier relationship is one of the most critical factors to maintain an advantage in the increasing levels of competition.

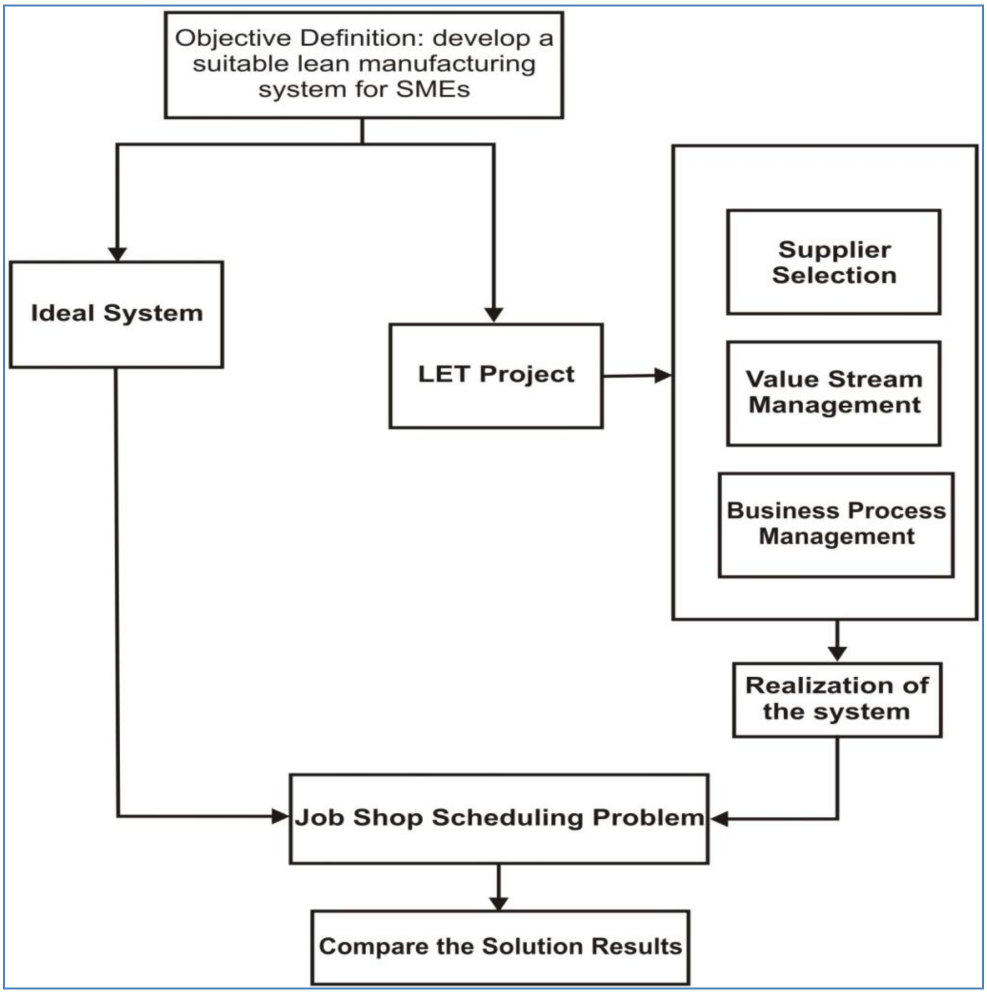


Figure 4.21: Transformation into lean framework for SMEs by two phases (Wanitwattanakosol and Sopadang, 2012)

Second phase performs a JIT production schedule by using ant colony optimization technique combined with a simulation tool. Thus, this framework (Figure 4.21) aims to develop a suitable lean manufacturing system for SMEs and to study the performance of the system for improving effectiveness.

4.3 A Comparative Analysis of Lean Frameworks

All the 21 frameworks reviewed in last section are compared in this section based on eight parameters of comprehensiveness, abstractness, clarity in role definition, complexity, type of framework, level of framework, lean prerequisites incorporation, and performance indicator usage as shown in table 4.1. Based on these parameters the frameworks proposed by James-Moore and Gibbons (1997), Sanchez and Perez (2001), Flinchbaugh (1998), Airbus (2004), were found to have a high degree of comprehensiveness. Except for the frameworks proposed by Karlsson and Åhlström (1996), Cook and Graser (2003), and Lewis (2000) which have a medium degree of clarity in role definition, all the other frameworks were found to have a low degree of clarity. The frameworks proposed by Flinchbaugh (1998), Kobayashi (1990), Davies and Greenough (2001), James-Moore and Gibbons (1997) were found to have a low degree of abstractness. However, the framework proposed by Anand and Kodali (2010 a,b) have high degree of comprehensiveness. These contain 65 elements which may makes it difficult for the firms to comprehend and implement all of them. It has been also found through literature review that some frameworks possess well-organized strategic framework (Flinchbaugh, 1998; Smeds, 1994; Pascal, 2007; Mohanty *et al*., 2007), while some provide a clear explanation of the steps in the model (Anand and Kodali, 2010 a,b; Amin and Karim, 2011; Aurelio *et al.,* 2011; Bortolotti and Romano, 2012; Gibbons *et al.*, 2012; Wanitwattanakosol and Sopadang, 2012). However, the analysis of the frameworks also shows that they suffer from various shortcomings; some frameworks did not list out most of the elements of LM or explain them (Hines *et al*., 2004; Womack and Jones, 1996;

Sanchez and Perez, 2001; Pascal, 2007; Mohanty *et al*., 2007; Amin and Karim, 2011; Aurelio *et al.*, 2011; Bortolotti and and Romano, 2012; Dombrowski and Zahn, 2011; Gibbons *et al.*, 2012; Wanitwattanakosol and Sopadang, 2012), some were highly abstract and conceptual (Flinchbaugh, 2003; Smeds, 1994; Motwani, 2003; Oliver *et al*., 2002; Jina *et al.*, 1997) while some were too comprehensive and complex (Flinchbaugh, 1998; James-Moore and Gibbons, 1997; Anand and Kodali, 2010 a/b). Some of these frameworks are devoid of lean concepts. Unfortunately many of them have large number of elements different to each framework. This is perhaps the most undesirable effect of empirical/exploratory study in lean manufacturing. There is a strong need to converge these divergent views to some standard framework.

Table 4.1: A comparative analysis of research paper on lean frameworks/models

Comparative attributes / Authors	1	2	3	4	5	6	7	8
Smeds (1994)	Low	High	Low	Low	Hypothesis	Strategic	Y	N
Womack and Jones (1996)	Low	High	Low	Low	Conceptual	Operational	N	N
James-Moore and Gibbons (1997)	High	Low	Medium	High	Empirical	Both	Y	Y
Jina *et al.* (1997)	Low	Low	Low	Medium	Conceptual	Strategic	N	N
Ahlstrom (1998)	Low	High	Medium	Low	Empirical	Operational	Y	N
Flinchbaugh (1998)	High	Low	High	High	Empirical	Operational	Y	Y
Sanchez and Perez (2001)	Medium	Low	Low	Medium	Conceptual	Strategic	N	N
Oliver *et al.* (2002)	Low	Medium	Low	Low	Empirical	Operation	N	N
Flinchbaugh (2003)	Medium	Medium	Low	Medium	Hypothesis	Strategic	N	N
Motwani (2003)	Medium	Low	Low	High	Conceptual	Strategic	N	N
Hines *et al.* (2004)	Medium	Medium	Low	Medium	Conceptual	Both	N	N
Pascal (2007)	High	Low	Medium	Medium	Conceptual	Strategic	Y	N
Mohanty *et al.* (2007)	Medium	Low	High	Low	Hypothesis	Strategic	N	N
Anand and Kodali (2010a)	High	Low	High	High	Conceptual	Both	Y	Y
Anand and Kodali (2010b)	High	Low	High	High	Conceptual	Both	Y	N
Amin and Karim (2011)	Medium	High	Medium	Low	Empirical	Operational	N	Y
Aurelio *et al.* (2011)	Low	Medium	Low	Medium	Empirical	Both	Y	Y
Bortolotti and Romano (2012)	Low	Medium	Low	Medium	Conceptual	Both	Y	N
Dombrowski and Zahn (2011)	Low	Low	Low	Low	Conceptual	Strategic	N	N
Gibbons *et al.* (2012)	Low	Medium	Low	Medium	Conceptual	Strategic	N	Y
Wanitwattanakosol and Sopadang (2012)	Low	Medium	Low	Low	Conceptual	Strategic	N	N

Where; *1- Comprehensiveness (Low, Medium, High), 2- Abstractness (Low, Medium, High) , 3- Clarity in role definition (Low, Medium, High) , 4- Complexity (Low, Medium, High), 5- Type of framework (Conceptual/Empirical), 6- Level of framework (Strategic level, Operational level, or Both levels), 7- Incorporates the lean prerequisites (Y/N), 8- Performance indicators of leanness(Y/N).*

4.4 DEVELOPMENT OF AN INTEGRATED LEAN IMPLEMENTATION FRAMEWORK

This section proposes an integrated lean implementation framework taking into account many of the drawbacks of the existing frameworks. The framework is based on a closed loop and cyclical thinking process to achieve the organizational goals. It is a blend of strategic and operational practices consisting of three major phases namely pre-implementation, implementation and post implementation which in turn consist of multiple levels and different lean practices/tools/techniques in a sequential order as shown in figure 4.22. It provides the overall involvement of the manufacturing system starting from supplier to customer. The framework provides an integrated sequential and parallel approach to different associated aspects of lean in a coordinated way. Detailed description of each phases is given next.

4.4.1 Pre-Implementation Phase

The pre-implementation phase is the beginning phase of the lean implementation process. It is basically lean awareness or commitment creation phase among all employees and management. It consists of three levels namely, lean philosophy, lean prerequisites and lean preparation. In this the management and employees comprehend the lean philosophy, demonstrate leadership commitment, involvement, etc. This phase creates a platform for lean implementation and at the same time eliminates the skepticism surrounding its implementation and benefits.

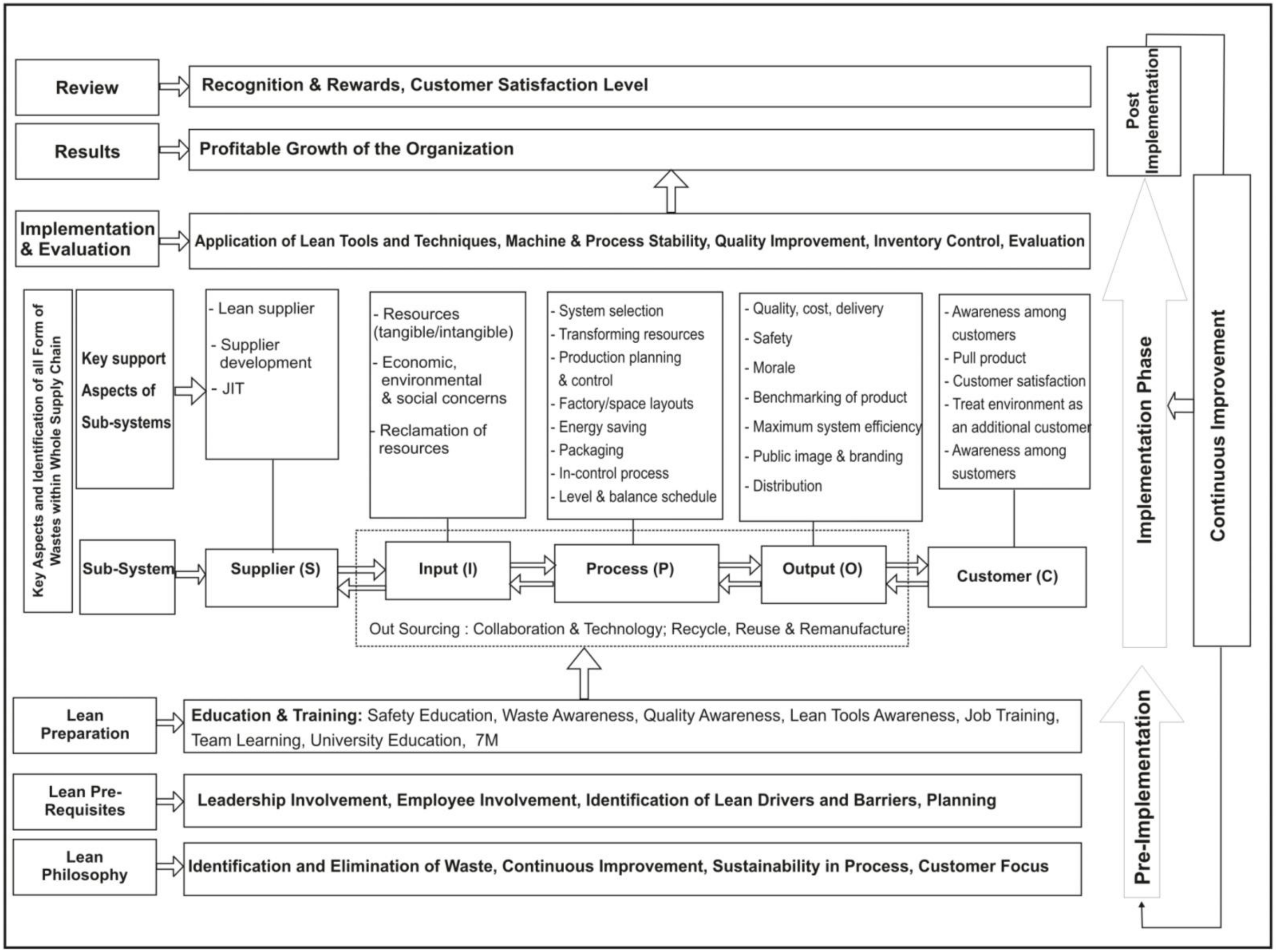


Figure 4.22: Lean implementation framework

4.4.1.1 Lean Philosophy

It consists of the awareness of lean philosophy (identification and elimination of waste, continuous improvement, sustainability in processes and customer focus) among management and employees.

(i) Identification and elimination of waste

Lean is all about creation of value for the end customer by eliminating wastes and non-value added activities from the system. Lean is renowned for its focus on reduction of eight wastes to improve overall customer value. The eight wastes highlighted in LM are overproduction, waiting, conveyance, over processing, excess inventory, movement, defects, and unused employee creativity (Liker, 2004). However, nowadays there is a ninth waste in the form of environmental or energy waste, which implies the unnecessary or excessive usage of resources as well as substances released to air, water, or land that could harm human health or environment (Gehin *et al*., 2008; Millet *et al*., 2007). During this phase, awareness about these wastes and their effect on organization is created. Improving communications among all divisions is the key to reduction in wastes. In order to determine the overall wastes affecting the organization, there is need to take care of the opinions of the various shop managers and section in-charges. Since, it is quite likely that their opinions may be contradictory in nature; there is need a to evolve a technique to cope with such situations. To overcome such problems, multi attribute utility theory has played a key role (Winston, 2004; Malakooti and Raman, 2000) in deciding the tradeoffs between the conflicting factors.

(ii) Continuous improvement

Implementing “lean” within the organization requires a significant ongoing effort so as to improve the quality, productivity, flexibility, etc. It is essential to sustain this effort and realize the benefits of a long term commitment to create a quality culture. If once lean has been implemented, it is not an end in itself, but a means to develop the organization for continuous improvement.

(iii) Sustainability in process

There has been highly varied success in implementing lean into the factories predominantly because of problem in sustainability. Certain practices are implemented and implemented well with management attention, but as management attention is removed or even redirected, performance in the initial success drops. There are two prominent reasons for the difficulty in sustainability; one is the structure, policies, and coaching performance in the factory (the role of plant management). The second one is the support functions such as advance manufacturing engineering or product engineering (Flinchbaugh, 1998). So, to make lean manufacturing successful vertically and horizontally along the time horizon, proper lean management structure be evolved clearly specifying the role of individuals in the structure.

(iv) Customer focus/customer involvement

Customer focus is central to lean philosophy. In this, firms emphasize customer expressed needs and develop solutions to meet these needs. Customer focus revolves around the notion of “defining value from customer perspective”, which requires frequent and regular communication with customers on all aspects involving their experiences with the product. In their book ‘Lean Thinking’, Womack and Jones

(1996) discusses the role of customer focus as "lean thinking must start with a conscious attempt to precisely define value in terms of specific products with specific capabilities offered at specific prices through a dialogue with specific customers". Richards (1996) highlights one of the distinctive principles of lean production is that the consumer and the competition must never be overlooked. The customer must be offered products that are more appealing than the competitive products in the market, otherwise, despite the company being efficient and competent, inventory will grow rapidly.

4.4.1.2 Lean Pre-requisites

The successful lean implementation depends on some concrete foundation such as the pre-requisites (Table 4.2) include leadership commitment, employee involvement, planning, and identification of lean drivers and barriers. Organizations have to take a comprehensive view of these issues before implementing lean. Some of these pre-requisites cannot be taught or forced, but should be developed and nurtured through proper training.

Table 4.2: Lean prerequisites and their constructs/attributes/practices

Leadership	Top Management Commitment	Hoshin Leadership	OMCD	Control Department Concept	Empowerment
Employee Involvement	Culture	Small Group Activity	Kaizen Circle Activity	Practical Kaizen Training	Communication, Tangible Suggestions, Intangible Suggestions, Feed-back
Planning	VSM	SMART Goals	Nemawashi	Catchball	A3 Thinking, PDCA
Drivers/ Barriers	Given in chapter 3				

(i) Leadership commitment

Top management commitment is the first and most important step for the initiation of LM Practices. Top managers need to demonstrate their commitment through their actions rather than words (Dale, 1999; Juran and Gryna, 1993). Just as the commitment of senior management is essential to the implementation of LM, it has also been proven over time that the leadership within the system is a determinant factor in the implementation of lean and its sustainability (Van Dun *et al.*, 2008; Fine *et al.*, 2008). A competent and inspirational leader is required to carry out the company hoshins effectively. According to Womack and Jones (1996), a company needs three types of leaders, to transform itself into a lean organization:

a) Someone who is committed to the business in a long run and can be the anchor providing stability and continuity – an experienced worker with longer history in the company.
b) Someone with deep knowledge about lean techniques – lean specialist.
c) Someone who can be the champion and fight against the organizational barriers as a result of the changes in the organizational operations.

Leaders need to treat company suppliers as partners (Dale, 1999; Deming, 1986). Creation of an Operations Management Consulting Division (OMCD) is the key to controlling the suppliers by setting up joint working groups amongst the most important suppliers of the company. Company leaders focus on areas such as productivity, quality, cost, and safety which can be achieved through the coordinated effort of many groups. The control department coordinates the cross functional activities required to achieve company goals. It is responsible for developing the overall hoshin for the company. Individual departments support it with their own hoshins (Pascal, 2007).

Without any empowerment it becomes difficult for employees to show full commitment towards the organizational goals. Blanchard *et al.*, (2001) identified three keys which managers must use to empower their employees. These keys are:

sharing information with everyone, identifying and creating autonomy through boundaries and replacing the old hierarchy with self-managed teams. These three identified empowerment keys do not just give power to people, but tend to release employees knowledge, experience and motivation in deploying and sustaining lean.

(ii) Employee involvement

Without employee involvement it is almost impossible for the management to implement lean manufacturing. The organizational culture is the base for all involvement activities. Culture is a result as well as an enabler for sustainable and successful lean operations (Liker, 2004). It is important to involve production team members in checking, reporting and if possible correcting hidden failures and minor stoppages. These activities not only help the organization but the employees as well. Once the employees identify the hot spots, strengthen them by involving in Kaizen Circle Activity (KCA), Practical Kaizen Training (PKT) and other small group activity (Pascal, 2007). KCA and PKT are effective and proven involvement activities. These activities boost employee confidence to face future challenges, strengthen an employee’s ability to work in teams, provide opportunities to display leadership skills, and enable to solve problems logically. According to Storch and Lim (1999), effective operation of the lean philosophy requires clear communication, not only among operational units, but also among all segments of the value stream. It is important for the communication to be clear and effective. Tangible suggestions, intangible suggestions and feedback are other useful ways of involving employees in the implementation process.

(iii) Planning

Proper planning is required for successful LM implementation. The best way to start off with the planning process is by creating SMART goals which are clearly defined and provide direction. A tool like VSM helps in identifying the hidden problems and mapping the future state. It carefully draws a visual representation of every process in the material and information flow with all relevant data in the data box. Before implementing lean it is important for everyone to be satisfied with the goals and decisions. The development of targets and means is nemawashi, this is everybody understanding what is going on and agreeing that it is the right thing to do (Miller, 2007). Taking suggestions from managers throughout the management chain can be vital to the organization's success. The term "catch-ball" comes from the concept of throwing the goals, objectives and strategies back and forth throughout the entire hierarchy of the management chain. This process helps to involve all employees in the planning process (Ten Step Supplemental Paper, 2003). The PDCA cycle is also the part of planning which emphasize the prevention of error recurrence by establishing standards. A3 is a way of thinking rooted in PDCA, Nemawashi, and Catchball. A good A3 reflects a sound grasp of the situation and mastery of core lean tools and thinking. But remember, the piece of paper is less important than the process (Pascal, 2007).

4.4.1.3 Lean Preparation

This includes lean preparation in the form of education and training. Any kind of change requires education and training to adopt it and it is no different in case of lean implementation. In a lean production environment, education and training is required to develop multi skilled workers who can perform more than a single job and to create an environment in which workers have the skills and ability to push for continuous improvement. It is commonly admitted that the majority of industrial accidents are caused directly by specific unsafe acts of persons or exposure to specific mechanical or physical hazards. Employers, therefore, realize far more clearly that accident prevention is a profitable combination of humanitarianism and good business policy, and therefore prioritize safety education (Heinrich, 1931). Waste, quality and lean tools awareness forms an important part of education of employees to enhance their performance. As Liker (2004) explained, these wasteful activities lengthen lead times, cause extra movement to get parts or tools, create excess inventory, or result in any type of waiting. Thus, removing these wastes is an essential step to improve efficiency. In most organizations, the top management acts as an introducer (Arawati & Abdullah, 2000) and the quality department acts as a secretariat for monitoring the implementation. Job training and team learning are also required for improving an employee's performance and ultimately contributing towards the growth of the organization. Another important aspect of education and training is the effective and efficient management of 7M (Man, Machine, Material, Motion, Method, Motivation, and Measurement).

Effective and efficient management of 7M

Lean can't be implemented in an organization unless and until there is stability and / or improvement in the attributes like man, machine, motion, method, motivation, measurement, and material. Machine can be improved with the help of 5S and TPM. Redundant motion can be reduced by planning layout more efficiently. Method has to be standardized but should also be continuously improved. Material flow can be made smooth by one piece flow and inventory can be reduced by pull system. Workers are motivated by the remuneration system and rewarding them for their quality suggestions. There are lots of performance parameters which can be measured with appropriate measurement system so that change can be seen in LM implementation. A brief description of 7M is given next.

Man/Human resource (HR): It is the most important resource for any kind of industry no matter how automated it may be since no company can function without this. There is various factors related to human resource that aid in implementing lean philosophy in an organization as shown in table 4.3.

Table 4.3: HR related important factors for successful lean implementation

• Culture (societal and organizational)	• Dealing with Constraints
• Commitment	• Performance Feedback
• Recruiting, Hiring & Training	• Policy Focus & Deployment
• Communication	• Employee Development
• H.R. Systems	• Quality Leadership
• Diffusing Knowledge into Decision Making	• Multifunctional Teams
	• Roles and Responsibilities

Machine: It is not possible to manufacture anything without machine which is an irreplaceable component of manufacturing. As lean emphasizes on just in time production, the inventory levels are always low at every stage. Machine breakdown, set up and adjustment delays, idling and minor stoppages, reduced speed, process defects, reduced yield would lead to a catastrophe in the organization. Lean helps in reducing these wastes to improve machine effectiveness.

Motion: Motion is considered to be a waste as it does not add value to the product. The basic reason of wasted motion is related to poor workplace ergonomics. This in turn causes reduction in productivity, quality of products and safety of workers. Cell based layout reduces the wasted motion to a great extent (Ahlstrom and Karlsson, 1996).

Method: With rapid technological progress, global communication and intensified competition, old methods can neither provide the same results nor can respond to the fast changing situation. Lean can't be successfully implemented unless and until there is stability in method. There are various ways by which improvement in method can be achieved like SMED, standardization, etc. In a lean production system, it is important to move towards a higher degree of process control.

Motivation: Motivated workers are an integral part of lean organization and that can be achieved at certain level with due attention towards the workers by management. Workers are no longer considered as the variable assets which can be fired at any time, rather workers are considered to be fixed assets like the machinery of the organization, and only difference being that machinery depreciates with time whereas the skills and knowledge of the workers increase with time and experience. An important motivational factor is proper remuneration system. This system plays an important role in the lean implementation (Karlsson and Åhlström, 1995). Some of the incentives may be: productivity bonus, if the worker has helped in reducing the standard cycle time of the process; quality bonus, for zero defects in the specified time period; time accuracy bonus, if all orders are delivered on time, etc.

Material: Less inventory levels have their own advantages in terms of lower holding cost and efficient utilization of the storage space. Pull system helps in reduction of inventory and also improves the process efficiency. Lean maximizes the resource utilization including the less usage of material.

Measurement: The lean implementation brings improvements in the performance parameters. To know the improvements, there are guidelines to contemplate for an effective performance measurement system. Frequently, organizations use generic measures with little consideration of their relevance (Bhasin, 2008). If inappropriately planned, the measures can run counter to the strategy and encourage the wrong type of behavior in the lean transformation journey. Table 4.4 is an effective template to evaluate the impact of lean on an organization.

Table 4.4: Performance template (Source: Bhasin, 2008)

Financial	Customer/ market measures	Process	People	Future
Profit after interest and tax Rate of return on capital employed Current ratio Earnings per share	Customer satisfaction index Customer retention rate Service quality Responsiveness (customer defined) On-time delivery (customer defined)	NPD lead time Cycle time Time to market for new products Quality of new product development and project management processes, Quality costs Quality ratings Defects of critical products/components, Material costs Manufacturing costs Labour productivity Space productivity Capital efficiency Raw material inventory WIP inventory Finished goods inventory Stock turnover	Health and safety per employee: Accidents Absenteeism Labour turnover Retention of top employees Quality of professional/ technical development Quality of leadership development	Depth and quality of strategic planning Anticipating future changes New market development New technology development Percentage sales from new products

4.4.2 Implementation Phase

The implementation phase deals in identification and elimination of all forms of wastes throughout supply chain with proper application of lean tools and techniques. It consists of two levels – sub-systems and their various support aspects, and application of appropriate tools/techniques and evaluation as shown in figure 4.22. In lean implementation various aspects of each sub-systems, from supplier to customer are taken care. Outsourcing (maintenance, housekeeping, security, food services, mail, copy services, etc), collaboration (meet the need of doing more with less) and technology (knowledge sharing, idea generation, cost saving information, ERP) to improve the performance of the system are the key aspects in the production process.

4.4.2.1 Sub-system

This level includes the identification of wastes in all sub systems of supply chain and elaboration of key support attributes/aspects of the whole supply chain to enhance the performance of the organization. To improve performance lean should lead to collective improvement in all the activities of supply chain – Supplier (S), Input (I), Process (P), Output (O), and Customer (C) (called SIPOC). The various sub-systems (SIPOC) and their key support aspects are shown in figure 4.22. Some key aspects of SIPOC are presented below:

(i) Suppliers

Effective customer-supplier relationships are widely recognized as crucial to the successful implementation of LM principles to achieve high level of efficiency and effectiveness in the system. On-time delivery by suppliers allows a firm to keep low inventories and shorten response time to customers (Koufteros and Vonderembse, 1998). A company has to establish a relationship with customers and suppliers based on a high degree of motivation to learn and trust to share knowledge freely (MacDuffle and Helper, 1997). Table 4.5 mentions the factors that typically receive consideration during the sourcing process.

Table 4.5: Key factors taken into consideration during sourcing process

• Supplier capability;	• Alternative sources (local and overseas);
• Supplier pricing;	• Lead times; and
• Benchmark pricing;	• Existing problems at the supplier.
• Supplier current quality performance;	

Sourcing teams consisting of employees mainly from purchasing, engineering and supplier development are responsible for the sourcing of components that meet cost and quality criteria. Suppliers should be selected taking care of aspects such as quality, productivity and flexibility of the production system. Consequently, lean supply is associated with level scheduling and optimization to improve quality, service level and lead time (Christopher and Towill, 2000). Empirical evidence shows that suppliers who have adopted lean principles achieve significant improvements in performance of production system, distribution system, quality system, information system, transport system, customer/supplier relations, and delivery times as compared to others who have not yet adopted lean principles (Wu, 2003; Gonza´lez-Benito *et al.*, 2003). The implementation of this system also involves a reduction in the number of suppliers.

(ii) Input

It is important for the organization to keep track of the resources available to meet the customer demand which is dynamic in nature. A lot of factors contribute towards the use of the resources. Economic, environmental and social concern should be taken into consideration while making use of the resources. Reclamation of resources should be given high priority.

(iii) Process

There should be a systematic procedure for performing each process. Transformation of resources from raw materials to end products requires a smooth process. A lot of energy, space, time, and motion could be saved by having effective layouts and planning. It is important to instill autonomation for the profitable growth of the organization but at the same time try to maintain a positive working environment. In the process, schedules should be leveled to reduce workload. In-process control is another aspect that adds to the benefits in terms of better quality products.

(iv) Output

Generally customer and public know the organization through its products. Quality and innovative products delivered on time develop a positive image of any organization to the customer or public. The aspects which decide the nature of the output are productivity, cost, quality, morale, safety, and delivery time. Implementation of benchmarking and a maximum efficiency system could achieve goal of a profitable output. Branding plays a vital role in building the reputation and public image of the organization.

(v) Customer

Customer satisfaction should be the highest priority of any organization. This could be achieved by meeting the customer demand and providing good services. Products should not be produced unless the customer pulls it or asks for it. This way the organization could meet the customer needs as well as avoid overproduction. These days, it is imperative to consider environmental aspect as an additional customer. Creating awareness among customers is also important for increasing the demand.

4.4.2.2 Implementation and Evaluation

This level involves the implementation and evaluation of lean (application of lean tools/techniques, machine & process stability, quality improvement, inventory control and evaluation). The various lean practices at this level are shown in table 4.6:

(i) Application of lean tools and techniques

It has been stated in literature that the biggest challenge in adoption of lean manufacturing is to know which of the tools or principles to use and how to apply them effectively (Browning and Heath, 2009). Another point that is to be noted here is that lean is to be seen as a direction, rather than as a state to be reached after a certain time (Karlsson and Ahlstrom, 1996). Misapplications of LM tools and techniques have also been reported by companies in their pursuit to become lean (Pavnaskar *et al.*, 2003). The misapplication of a LM tool may result in the additional wastage of resources such as time and money. It may also result in reduced industry confidence in the lean manufacturing capabilities and benefits. With the span of time, many LM tools and techniques have been developed and every day new ones are proposed (Feld, 2000; Taylor and Brunt, 2001). Bhamu and Sangwan (2011) critically reviewed a total of 40 papers published during the years 2001-2010 on LM tools and techniques and ranked them according to their frequency of appearance. Observation of the study shows that the five most adopted tools and techniques in lean manufacturing are *kanban*, value stream mapping, *kaizen*, 5S and waste minimization. Many of the tools/techniques are used in conjunction with each other. For example, in order to reduce the takt time, a Kanban is used with VSM to identify and eliminate the non-value added activities and 5S to streamline the system. But the application of LM tools largely depends on the case to case and as such there is no clear sequence of tools to use.

Table 4.6: Constructs/practices in lean implementation and evaluation

Application of LM Tools & Techniques	Description given in section (i)					
Machine& Process Stability	Visual management	VSM	Root cause analysis	5S	TPM	Standardized work, Kaizen
Quality Improvement	Quality function deployment	Jidoka	Poka Yoke	Inspection systems	Six Sigma	TQM
Inventory Control	JIT	Pull system	Kanban	Heijunka	Single piece continuous flow	WIP
Evaluation	Benchmarking	Hoshin evaluation	Evaluation of department performance	Evaluation of employee performance	Employee satisfaction	

(ii) Machine and process stability

Visual management is a management approach that utilizes either one or more of information giving, signaling, limiting or guaranteeing (mistake-proofing/ poka-yoke) visual devices to communicate with "doers", so that places become self-explanatory, self-ordering, self-regulating and self-improving (Galsworth, 1997). To solve a problem, one must first recognize and understand the cause of the problem. There is a root cause for an undesirable condition or problem (Wilson *et al.* 1993). If the real cause of the problem is not identified then one is merely addressing the symptoms and the real problem will continue to exist. Stability can be maintained using 5S and TPM. Imai (2007) mentioned that operational standards demonstrate the best and safest way of performing a job. Freivalds and Niebel (2009) stressed that the information needed to create standards is an outcome of time studies and work measurements. Continuous improvement is possible by standardizing work instructions and creating stable processes.

(iii) Quality improvement

Various tools can be used to improve the quality of the product such as QFD, TQM, Poka-Yoke, Six-Sigma, etc. QFD is a visual connective process that helps teams focus on the needs of the customers throughout the total development cycle. Clausing and Pugh (1991) have mentioned that the use of QFD can reduce the development time by 50 per cent, and start-up and engineering costs by 30 per cent. QFD has become a popular support to the product planning process (Akao and Mazur, 2003; Chan and Wu, 2002). Jidoka enables build-in quality at each process and separates men and machines for more efficient work. A defect exists in either of two states – the defect either has already occurred, calling for defect detection; or is about to occur, calling for defect prediction (Lachajczyk and Dudek-Burlikowska, 2006). The Poka-Yoke is a technique for avoiding human error at work. The inspection systems are the key to identifying defects and the causes that lead to them. Six Sigma and TQM contribute towards improvement of the organization as a whole. Most of the researchers agree that TQM is a useful philosophy to achieve its goals with ease if properly planned and implemented (Black and Porter, 1996; Flynn and Saladin, 2006).

(iv) Inventory control

Inventory control leads to reduction in cost, waste, space, and work. This can be achieved through JIT, pull production system, Kanban, Heijunka, etc. JIT improves return on investment by reducing in-process inventory and associated carrying costs. Pull production is based on actual or consumed demand. Pull production is coordinated by using some sort of signal (or Kanban) represented by a card or sign. Kanban is an effective tool to support the production system. In addition, it proved to be an excellent way for promoting improvements because reducing the number of Kanban in circulation highlights problem areas (Shingo, 1989). Heijunka and kanban are effective tools to maintain stability and WIP control. Heijunka is used to level the release of production kanbans in order to achieve an even production program reducing or eliminating the bullwhip effect. It is important to maintain a single piece continuous flow and keep WIP low.

(v) Evaluation

It is important to evaluate the performance for continuous improvement. Benchmarking is a learning tool designed to reduce uncertainty in the organizational environment by reference to peer experience. Consequently, benchmarking has both cognitive and affective functions (Knuf, 2000). The performance review and planning process should add value, identify organizational barriers, offer the opportunity to explore career aspirations, and provide employees with feedback and honest dialogue. This will ensure that all staff is evaluated in a consistent manner based upon their contribution to the work plans. Employee satisfaction should be measured in order to understand their needs and views.

4.4.3 Post Implementation Phase

The post-implementation phase completes the lean implementation process. This phase involves observing the outcomes and analyzing the entire process. After implementing lean, the organization needs to be patient in order to observe the positive results. The organization should call for review of the entire process in order to create opportunities for continuous improvement.

4.4.3.1 Results

This level emphasizes the outcomes/results of the lean implementation in term of achievement of goals leading to profitable growth of the organization or benefits arising from LM implementation.

Table 4.7: LM implementation benefits

Reduction in all types of wastes	Optimum utilization of resources (space, manpower, material, energy etc.)	Energy consumption reduction
Reduction in customer complaints	Effective and efficient equipment utilization	Increased reliability & OEE of equipment
Improvement in productivity and quality	Imbibe a culture of continuous improvement	Reduction in inventory and WIP inventory
Introduction of innovative practices to improve the overall competitiveness of the organization	Business & livelihood creation	Brand/reputation enhancement
Induction of good management practices	Social relation enhancement	Natural resources protection or restoration
Well managed working place	Improved quality & delivery schedule	Reduction in defects/scraps rejection from the manufacturing process

Fullerton *et al.* (2003) found a positive relationship between company profitability and the degree of implementation of waste reducing production practices. Effective strategy and alignment can only be delivered through strong leadership and positive organizational culture that is receptive to learning and improvement (Hines *et al.*, 2008). Table 4.7 shows most of the reported benefits from LM implementation.

4.4.3.2 Review

This level involves the review of employees for recognition & awards and customer for finding customer satisfaction level as shown in table 4.8.

Table 4.8: Constructs and practices involved in the review process

Recognition & Rewards	Moral award	Position promotion	Salary increment	Bonuses	Recognition by peers	Penalty	Work environment improvement
Customer Satisfaction Level	Customer complaint information	Customer complaint analysis	Customer services	Customer satisfaction	Customer information system		

(i) Recognition and rewards

Every organization strives to achieve a competitive advantage. Managers seek to maximize the company output by motivating employees to raise their performance levels. Hard working individuals, who experience burnout, typically do not feel fulfilled unless recognized or rewarded for their contribution to the organization. Gouldner (1960) mentioned the norm of reciprocity, which focuses on the ability of organization to accommodate the needs of their employees, and reward them for their efforts. With regards to work, adequate salaries serve as an employee reward. Employees should be promoted on the basis of their contribution towards the success of an organization (Siegrist, 1996). Any delay in promotion can result in high level of dissatisfaction and an employee may leave the organization for better opportunities outside the organization. An intuitive approach to reduce the severity of free-riding incentives in teams is to promise relative rewards to the best individual performers in the team (Heneman and Von Hippel, 1995). In practice relative rewards within teams often take the form of bonuses. Team leaders are encouraged to sufficiently differentiate their ratings by making use of the full range of grades (Murphy, 1992). There are other than financial means to reward employees such as praise the employees, provide the opportunity to take on important projects/tasks and proper leadership attention. The latter refers to the treatment of the employees by their managers well so that employees are encouraged to work harder and produce better performance results (Dewhurst *et al*., 2010).

(ii) Customer satisfaction

Customer focus should be the highest priority for any organization. The organization needs to record the multiple complaints from customers and also maintain a central complaint registration system to register various complaints from customers. After customer complaints are received, the firm needs to identify the “vital few” serious complaints that demand in-depth study to discover their basic causes and to remedy these causes (Juran and Gryna, 1993). The strengths and weaknesses of the products and services of a firm and its competitors can be identified. Such information can be used for benchmarking so as to determine the improvement areas. Obtaining useful information through market investigation is important for the success of the firm (Burrill and Ledolter, 1999). In order to improve sales efficiency and customer service quality, it is crucial that the firm computerizes its sales system and establishes its service standards. Service quality is increasingly becoming a more important factor affecting customer satisfaction, customer retention and customer loyalty (Dale, 1999). Regular customer satisfaction surveys can track customer perceptions of the quality of a firm and its competitors. Information about present and future customers is vital to the organization’s success. A customer information system should be established which can be used for several purposes: collecting data on customers, demographics (age, sex, and income level), and preferences; collecting and storing customer feedback, reports, customer satisfaction surveys, customer complaints, customer conferences, etc.; storing customer order information; and recording various customers service activities (Dale, 1999).

4.4.4 Continuous Improvement (CI)

Continuous improvement involves an extended journey, gradually building up skills and capabilities within the organization to find the new problems/wastes in the system and solving them with the help of different tools and techniques. We can say that CI basically involves a cycle of problem finding & solving through brainstorming, check lists, flow diagrams, policy deployment, etc. There is an old saying that goes “once you have arrived, you have already started your descents'. So, there is always room for improvement and looking to improve every day is the spirit of lean teams.

4.5 CONCLUSIONS

This chapter provides the review of 21 lean manufacturing frameworks with respect to comprehensiveness, abstractness, clarity in role definition, complexity, type of framework, level of framework, lean prerequisites incorporation, and performance indicator usage. A new framework has been proposed taking in consideration the strengths and mitigating weaknesses of the existing frameworks as well as the views of industry experts. The proposed framework is in three phases, viz., pre-implementation, implementation and post implementation. The main characteristics of the proposed framework are:

- The framework emphasizes the importance of lean manufacturing philosophy. How and how much lean philosophy will benefit needs to be understood. Understanding of various types of waste, continuous improvement, customer focus, and sustainability in process facilitates lean manufacturing understanding.

- Organization should identify lean drivers and barriers to leverage the drivers and mitigate the barriers before starting implementation. Involvement of all employees from top to bottom should be ensured for effective and sustainable implementation.
- All stakeholders of lean manufacturing implementation should be involved through education and training.
- Lean implementation team should walk and see all supply chain activities (suppliers, input, process, output, and customers) to understand the flow of material and information from supplier to customer. There is a need to identify the areas of improvement.
- There is need to identify appropriate tools and techniques throughout SIPOC (suppliers, input, process, output, and customer) to implement lean throughout the whole supply chain.
- Performance improvement matrices should be reviewed.
- Recognition and reward system for employees should be introduced.
- There should be a review of customer satisfaction.

It is believed that the proposed lean implementation framework will serve as a guide map for the transition from non-lean to lean manufacturing.

CHAPTER 5

LEAN MANUFACTURING IMPLEMENTATION: A CASE STUDY OF CERAMIC INDUSTRY

This chapter reports a case study of lean manufacturing implementation done in the ceramic industry to validate the proposed lean manufacturing implementation framework in the last chapter.

5.1 INTRODUCTION

Literature review in chapter 2 shows that the maximum numbers of publications in lean manufacturing are related to transportation sector (automotive and aerospace industry). Lean manufacturing implementation started in automobile industry and soon its application was adopted by other industries including textile, construction, food, medical, electrical & electronics, services, etc. LM has been adopted by all types of manufacturing systems – product layout, process layout, and fixed layout; batch production and mass productions; discrete production to continuous production. It has found applications from manufacturing to service sector; mass production to high variety and small volumes production; labour-intensive industries to technology intensive industries; construction industry to assembly industry; medical health care to communication industry. However, the implementation of lean manufacturing in the continuous process industry or continuous products industry have been less partly because of certain difficulties in the implementation in these type of industries (Jimenez et al 2011). Application of lean manufacturing in ceramic industry is also challenging as half the process is continuous type and the other half is discrete part manufacturing.

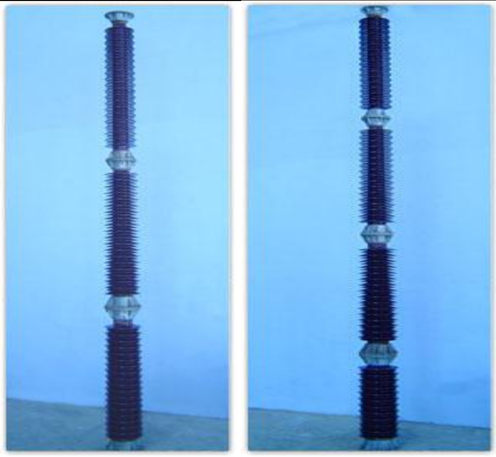
In India, the ceramic industry has witnessed fast growth in demand primarily due to growth in construction and housing sector. This has led to burgeoning demand for sanitary ware, floor and wall tiles. Ongoing reforms in the power sector and expansion of distribution infrastructure has resulted in demand for insulators, especially high tension insulators (for 33kv and above). This is likely to represent a captive market and expected to grow steadily for at least 5-10 years as more and more states get into power sector reform (Rajasthan infrastructure Agenda "2025", Price Water Cooper house report). Rajasthan accounts for 25% of the production of sanitary and electric insulators (http://www.ceramics-india.com/category/ceramic-industry-india/). Despite, being a raw material rich region, the ceramic industry is still largely underdeveloped in this region. There is lot of waste in the production system and this causes a lot of revenue loss to the companies. LM brings improvement in the quality of products and lowers costs which are essential for competing at national and international level.

Two case studies were carried out in automotive sector to understand the finer details of lean manufacturing implementation and to develop our framework. As mentioned earlier, the implementation in ceramic industry is challenging but I choose to take the challenge because of (i) the creation of a ceramic research centre at Government Engineering College, Bikaner; my employer and (ii) easy access to experts and data in the Bikaner and Jaipur ceramic clusters. Moreover, hardly any study has been carried out in the ceramic (insulator) sector.

5.2 SELECTION OF THE ORGANIZATION/CASE COMPANY

After the preliminary discussions with many organizations, the case company, called XXX to maintain confidentiality, was selected primarily because the top management was willing to implement lean manufacturing to improve productivity, quality and flexibility. There were two executives who were aware of lean manufacturing and its benefits. These executives convince the top leadership that organizational challenges can be met by LM implementation easily. The XXX organization is a premier unit in the field of manufacturing high voltage and extra high voltage alumina porcelain insulators;required for transmission lines, distribution lines, sub-station, railway electrification, and electrical switch gear and control equipmentin India.

(a) Hollow insulators



(b) Solid core post insulators

(c) Long rod insulators

(d) Railway insulators

Figure 5.1: Some of the important company products

XXX was set up in 1985 in technical collaboration with Siemens AG, Germany. Presently company is producing 1550MT of insulators with a turnover of INR 300 crores and 2500 employees. It is one of the largest exporters in the country and has been honored with various export awards from ministry of commerce. It manufactures insulators in the range of 33KV to 1200 KV. XXX is renowned for the initiative in its

R&D, product quality and customer satisfaction and an ISO certified company. They have made large investments in infrastructure, manpower training and development practices in line with the best in the world.

The plant is operated by qualified technical personnel, engineers and technicians who have been specially trained in their respective fields. XXX exports its products to countries like USA, Mexico, Canada, Italy, France, Germany, Holland, Spain, UK, South Africa, China, Australia, and other Gulf Countries. The main products of the organization are shown in figure 5.1.

5.3 PRE-IMPLEMENTATION PHASE

The top leadership gave LM implementation responsibility to the quality control department head till there is a separate department of LM implementation is created. The first meeting of top management (All General Managers of the XXX organization) was organized, in which lean implementation strategy was discussed by BITS Pilani team to create awareness of lean philosophy, identification of lean pre-requisites, knowing the customer needs, etc. After initial doubts, all GMs agreed and assured full support to implement lean in whole supply chain. The GMs also agreed to spare employees under in their department for training and also agreed to provide full support to BITS Pilani team in understanding the process and recording the process. The awareness and training programs has been launched from top to bottom level on the lean philosophy. Employees training (see the Figure 5.2) were imparted on waste reduction, safety, and quality particularly for shop floor workers because most of the workers hired by the company are unskilled or partially skilled. Assessing their skill levels and reassigning them to different workstations was a part of our lean initiative. Programs are currently being also devised to help them increase their skill level through workshops/seminars. Table 5.1 shows the plan created at the company level for training. Similarly, other important parameters of this phase were well communicated such as; continuous improvement, customer focus, job training, and sustainability in the improvements made. The outcome of driver and barrier study were shared with GMs. One of the important barriers was resistance to change by employees as there was fear of loss of job due to increased productivity through this study.

Figure 5.2: Training to employees by BITS Pilani team

Table 5.1: Training plans and execution at the company level

S. No	Plan	Position
1.	Awareness programs on lean for all employees [levels L1-L4 (company specific level)]	Completed
2.	Education and training on various aspects of pre-implementation phase	Completed
3.	Assessment of present skill levels	Completed
4.	Identification of skill gaps	Completed
5.	Training to bridge the skill gaps	Continued

5.4 IMPLEMENTATION PHASE

This section elaborates the implementation phase of the study.

5.4.1Formulation of Multifunctional Team

In order to carry out this case study, a cross-functional team was setup with the active support of top management. The members of the team were drawn from various functions at different hierarchy as shown in figure 5.3. The team coined a goal "increase productivity, quality and flexibility to meet fluctuating customer demand".

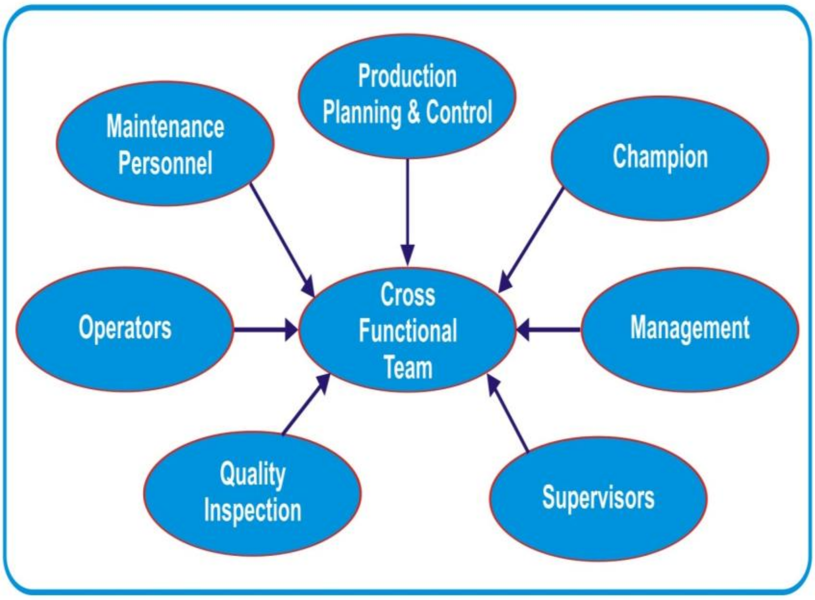


Figure 5.3: Multifunctional team formation

5.4.2 Selection of Critical Product

Next step was the selection of the critical product of the company for the pilot project. Volume of production, cost of poor quality (COPQ) and amount of revenue generated by all four types of insulators (solid core, railways, long rod and hollow) were recorded. Average customer demand was estimated 1550 tons per month, and the distribution by products is as follows:

- 550 tons per month of solid core insulator
- 400 tons per month of long rod insulator
- 450 tons per month of hollow insulator
- 150 tons per month of railway insulator

The in-process average monthly rejections of all types of insulators resulted in COPQ of INR 25.35 Lakhs in the year 2011. The average COPQ for various insulators in the year 2011 is presented in figure 5.4. As seen from table 5.2 and figure 5.4, the solid core insulator has maximum COPQ due to maximum number of rejections, so, this product was chosen for pilot project. Further, operation wise rejection data was obtained for solid core insulator to know the contribution of various defects.

Table 5.2: COPQ of various insulators

S. No.	Name of insulator	Average rejections after post Kiln	Average rejections after post Kiln (MT)	COPQ (INR 115 per Kg)	COPQ in Percentage
1.	Solid Core	2.50% of 550 MT	13.75	INR 15,81,250/-	59.20%
2.	Long Rod	1.75% of 400 MT	07.00	INR 8,05,000/-	30.14%
3.	Hollow	0.50% of 450 MT	02.25	INR 2,58,750/-	09.69%
4.	Railway	0.15% of 150 MT	00.225	INR 25,875/-	00.97%
	Total	………..	23.225	INR 26,70,875/-	100%

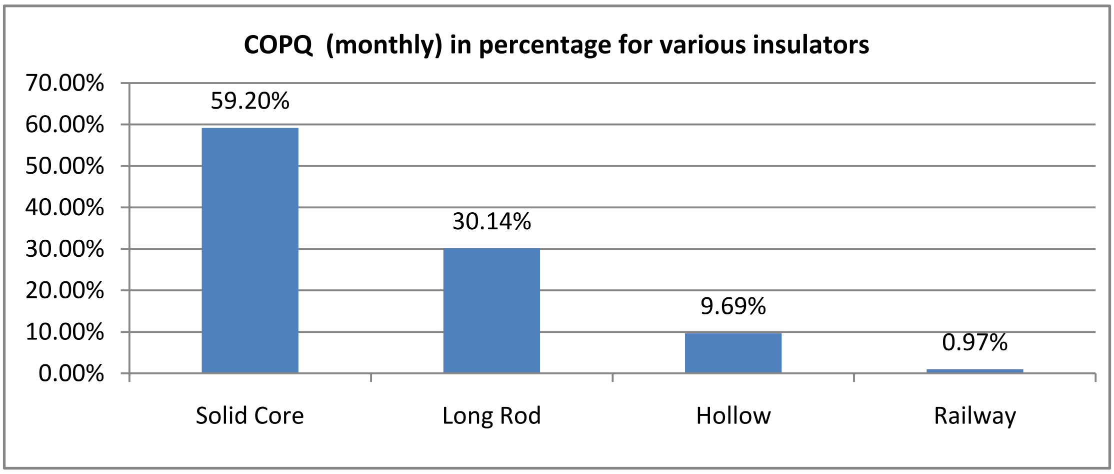


Figure 5.4: COPQ in percentage for various insulators

5.4.3Production Processes and Process Layout

Next, the production process was understood and a process layout was created as shown in figure 5.5. The processes for solid core insulator start with ball milling where two types of mixtures are prepared namely bauxite and non-bauxite by mixing of raw material and water for further processing. The liquid mix product (slurry) from this stage travels in mixing tank for ratio control where semi solid scrap (scrap reuse from downstream activities) is also added. There is separate line to collect the scrap from different processes starting from pug mill to kiln loading. There is one scrap mixing tank at shaper department and through pipes scrap travels back to the fresh mixing tank. For proper pieces of semi-solid scrap insulator one *footer* machine is connected through an underground belt conveyor system to the scrap mixing tank. The slurry then goes to filter pressing after passing through the sieving & ferro-filtration to remove the water. In filter press cakes are prepared by removing water from slurry. And then cakes go in to pug milling, pugs are formed by extrusion.

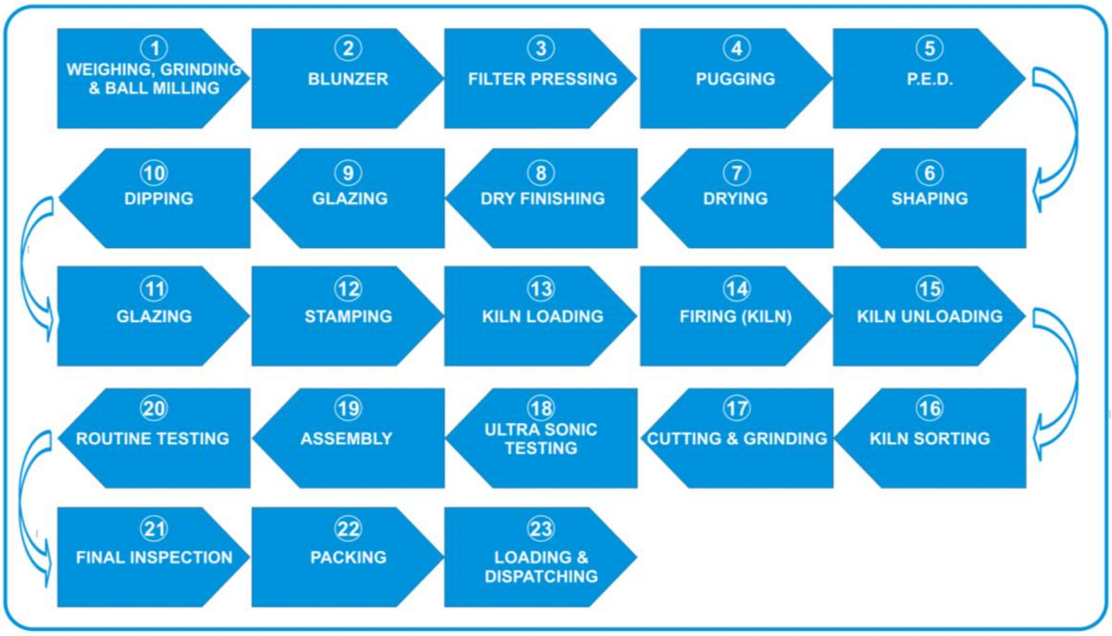


Figure 5.5: Production process for the insulators

PEDs are used to reduce the moisture in the pugs to a particular value before the shaping process. PED is important because if the moisture is too high or too low then proper turning of insulators in the shaping department cannot take place. Next, pugs are turned on vertical lathe machines to give them the required shape. After this process, the insulators are covered with polythene sheets to avoid exposure to foreign materials. Dryers are used to decrease the moisture content of the turned insulators to give them strength. The glazing and gravelling department consists of four processes – dry finishing, dipping, gravelling, and shifting. Dust is removed in dry finishing. Dipping facilitated the coating of glaze material on the insulators. In gravelling, both the ends of the insulators are coated with paint and glue and gravel is blown over. The insulators are stamped with customer identification label and transferred to the kiln department. The last process of the semisolid product or pre-kiln operation is the kiln loading in the cars for heat treatment. Up to semisolid state any scrap can be reused in the *blunzer*.

The first process after pre-kiln is the heating or firing of insulators in the kilns at a particular temperature. The post kiln process constitutes the irreversible solidification of these insulators by heat treatment and transfer to the cutting and grinding department where the ends of the fired insulators are cut to their proper length and grinded for easy manual handling. The grinded insulators then goes to assembly department where the rest of the processes (cement curing, application of fixtures at the ends, and attaching of two or more insulators together according to requirement)are carried out. The second last process in the post kiln is testing and final inspection. Tests like tensile, shear, bending, etc are carried out before final inspection which includes parallelism, eccentricity, visual defects, full dimension, and production specific requirement tests. The quality control passed insulators are packed in break proof wooden packs. The last process is loading and dispatching by the marketing department.

At XXX the marketing department receives demands from domestic and foreign customers. When an order arrives, the production planning and control (PPC) department enters it into the planning system, estimates the date by which it can be completed and make a schedule of delivery on monthly and weekly basis to share it with the production department. Production department breaks this weekly schedule into daily schedule and monitor the production day by day, week by week and month by month. Different types of in-house material handling modes, namely, pallet trucks, battery operated vehicles and manual carts/cars. The plant works on a continuous basis for 24hr a day, 365 days a year (except for major shutdowns) in three shifts (except cutting & grinding, assembly and packaging departments run in two shifts). Each shift is 8hr long with 45 minute break.

5.4.4 Preparation and Analysis of Current Value Stream Map (CVSM)

A CVSM serves as a starting point to help every person in the manufacturing system to identify waste. Value stream perspective means working on a big picture and trying to improve the whole process, not just individual processes. It helps in visualizing future state when improvements/changes are incorporated in the system. After selecting the critical product, current state of value stream was mapped as follows:

- An A3 size (or 11×17 inch) ledger size paper was taken and icons were drawn representing customer, supplier and production control.
- Shipping and receiving data were entered along with the icons for trucks using directional arrows for the movement
- Entries were made to prepare a data box below the icons to capture the monthly/daily requirements of each product after understanding the general flow and processes.
- Both electronic and manual information flow arrows were drawn between the parties concerned.
- Next, inventory icons were drawn along with the quantities.
- The last major step was drawing of timeline at the bottom of the value stream map and sum up all the processing time and note them at the end of the timeline. Similarly, waiting time was summed up and noted on the timeline scale. Time

study was carried out to capture the individual process activities and timings for the same.

The current value stream map is shown in figure 5.6. Further, the CVSM was developed by showing the collected data according to the approach as recommended by Rother and Shook (1999). Data collection for the material flow started at the shipping department, and worked backward all the way to the ball mill process, gathering snapshot data such as cycle time of each process, number of workers and number of shifts. There are two inventories mentioned below the inventory triangle in the current state map in which top data represent the inventory of solid core and below one indicates the inventories of all types of insulators.

The following observations and analyses can be made from the current state of the organization:

- The processing time is approximately 13 days (18702.07 minutes), while the waiting time is about 24.84 days. Apart from this, there is lot of inventory piled up before drying, kiln sorting, cutting & grinding, assembly and final inspection processes/workstations.

- There is excess inventory in the whole supply chain. This includes the inventory of 90 days locked at incoming material stores for the fear of unavailability of raw material.

- There is a large WIP before major processes/workstations due to fear of unavailability of right quantity of finished goods. This also causes excess waiting time (24.84 days) and results increased lead time. This can be reduced by making special emphasis to reduce various defects, especially after kiln operation.

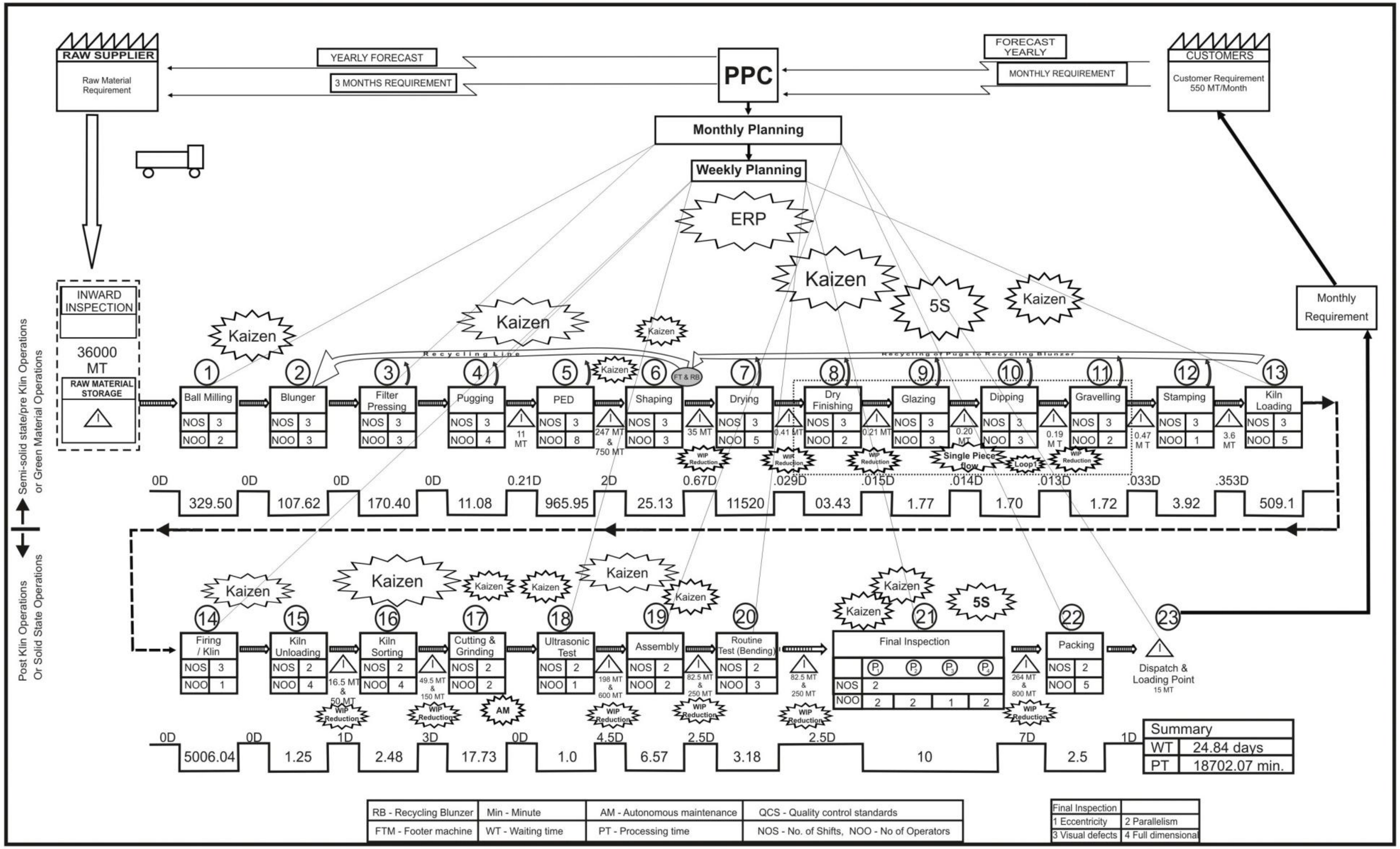


Figure 5.6: Current value stream map

5.4.5 Waste Analysis

During the analysis of the current value state map, the wastes of lean were identified in each process/workstation. Root cause analysis was carried out for each waste as shown in figures 5.7-5.12.The processes/workstations are color coded for our convenience. The summary of wastes and their root causes are given in table 5.3. It is worthwhile to mention that the help of the shop floor employees was of great value.

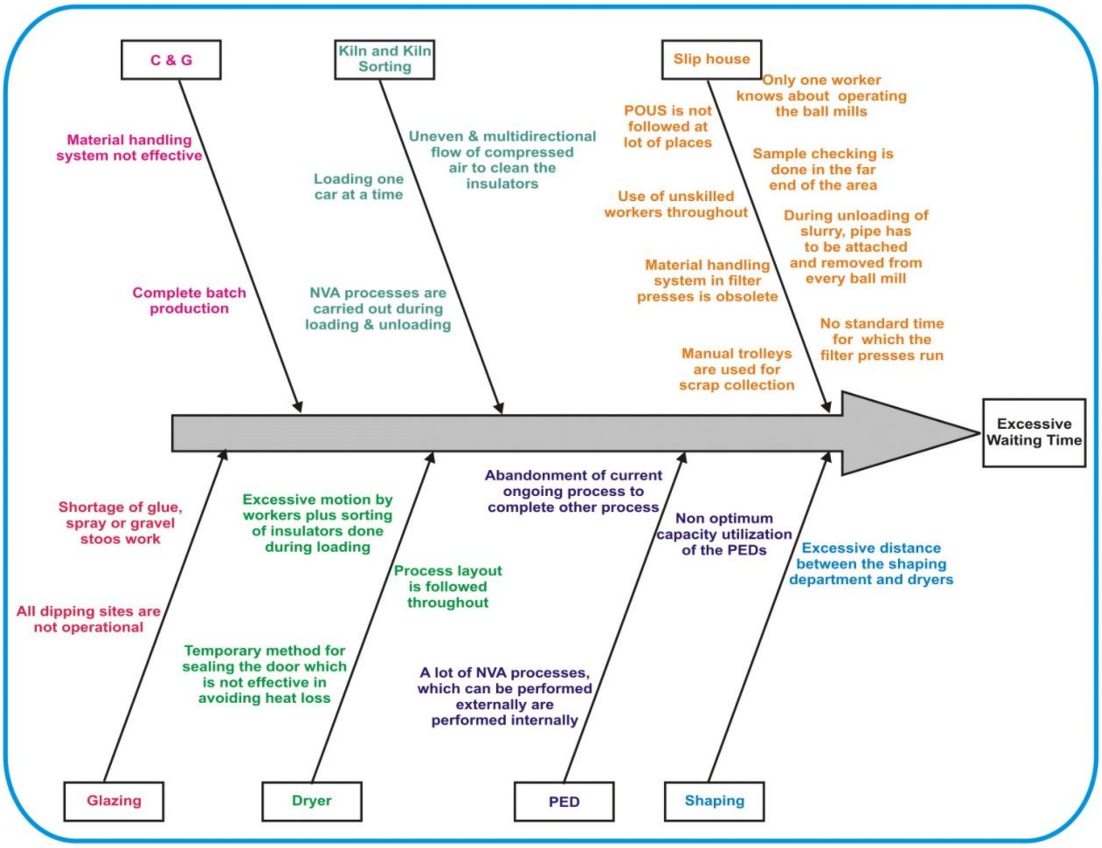


Figure 5.7: Ishikawa diagram of waiting time

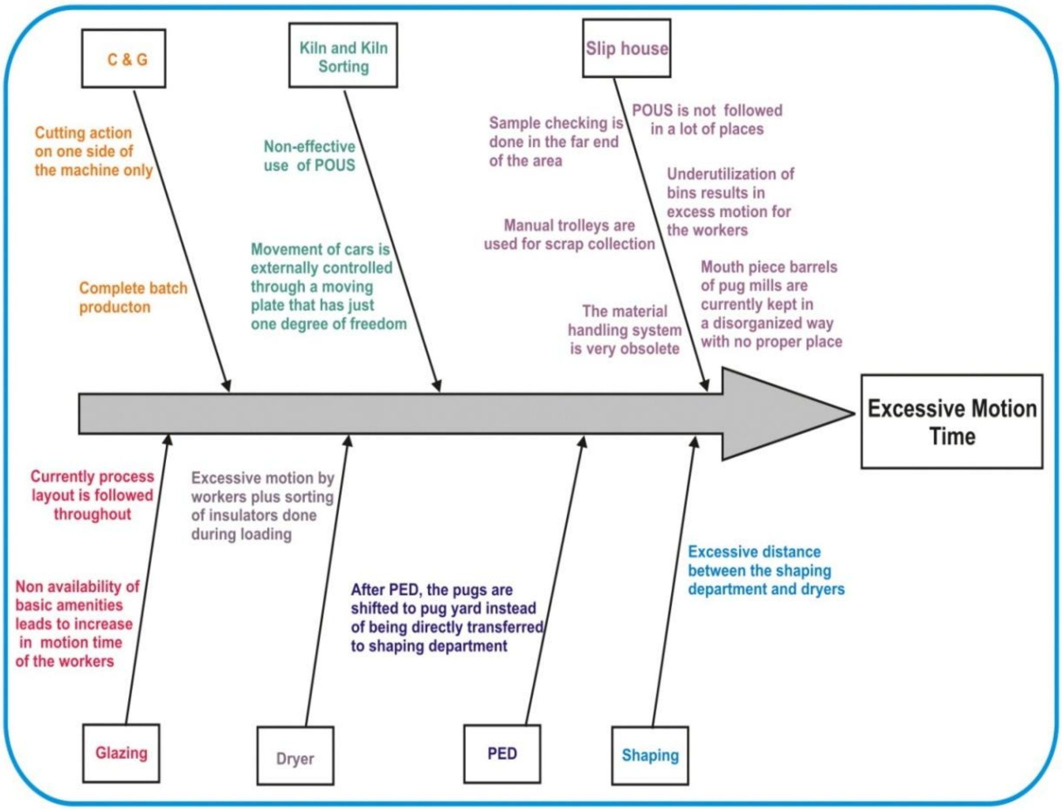


Figure 5.8: Ishikawa diagram of motion time

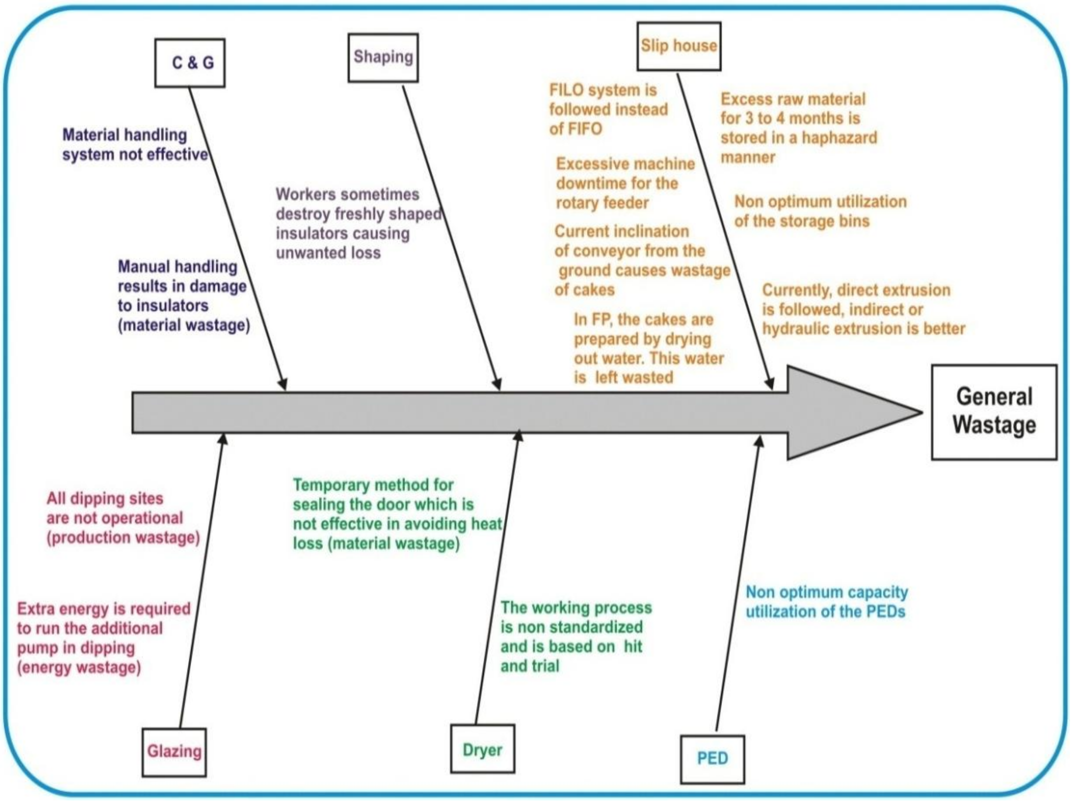


Figure 5.9: Ishikawa diagram of general waste

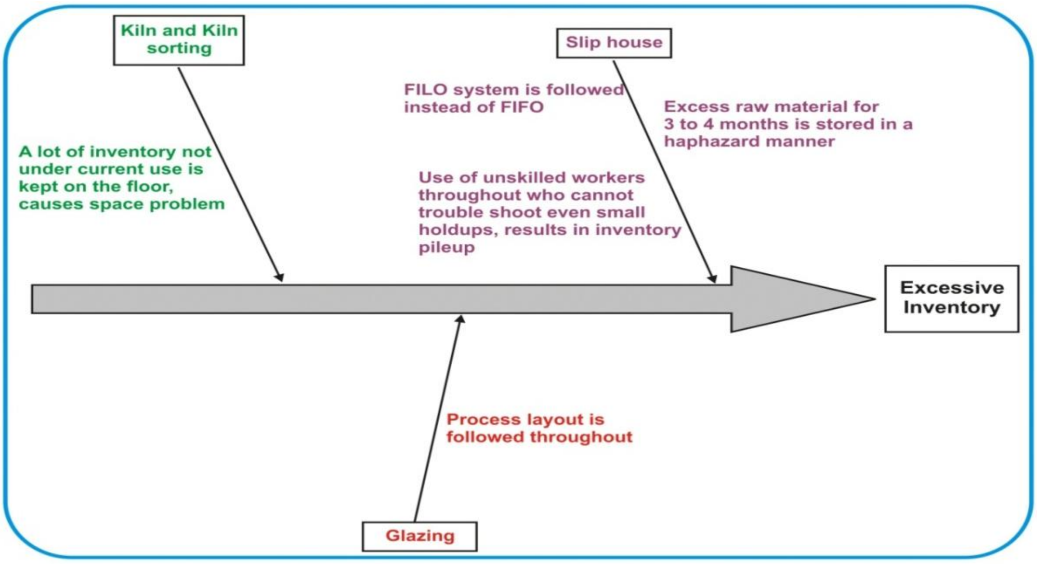


Figure 5.10: Ishikawa diagram of excessive inventory

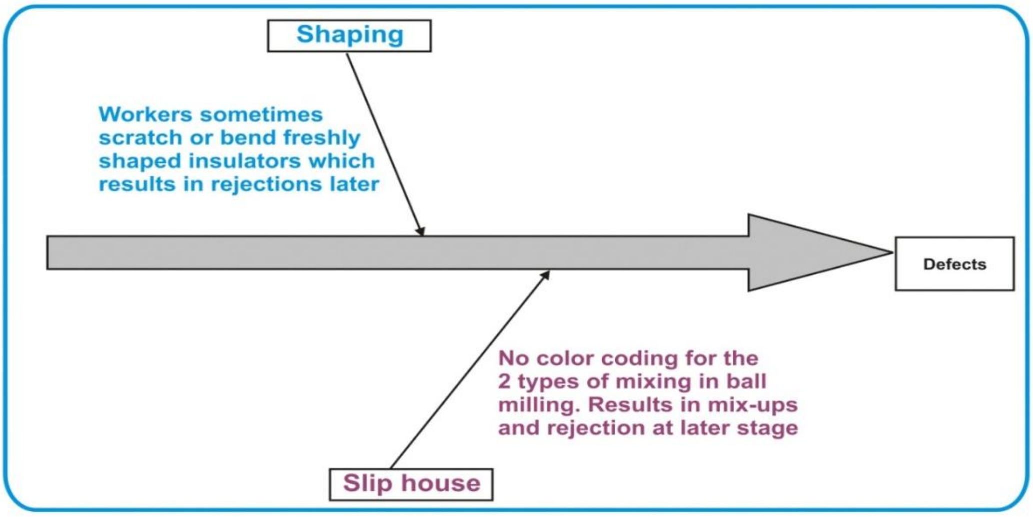


Figure 5.21: Ishikawa diagram of defects*

**Detail discussion of the same has been given in next section*

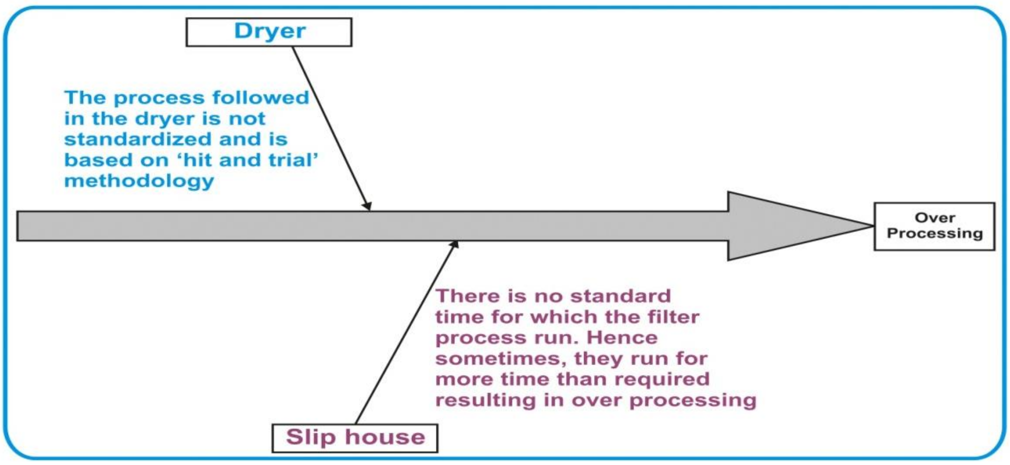


Figure 5.12: Ishikawa diagram of over processing

Table 5.3: Wastes and their root causes at different processes/workstations

S. No	Waste/ Process/workstation	Root cause(s)
	Slip house	
1	Inventory	• First in, last out system followed in the storage area as the storage bins are open from only one side • Excess raw material for 3 to 4 months is stored in a haphazard fashion
2	Defects	• No colour coding for the 2 types of mixing in ball milling. Results in mix-ups and rejection at later stage
3	Motion time and general wastage†	• Underutilization of bins. Results in more number of bins and hence movement of workers
4	Motion time and waiting time	• POUS (point of use system) is not followed. All ball mills are used for normal as well as bauxite mixing. Results in a huge spread of raw materials. • For sample checking, the sample is taken to the far end of the area by a worker on foot. • Manual trolleys are used for scrap collection • The location of oil tanks is very random. They are not kept at their point of use • The mouth piece barrels of pug mills are currently kept in a disorganized way with no proper place
5	Inventory and waiting time	• Use of unskilled workers throughout the plant. They perform just one job mindlessly and can't troubleshoot even little problems. Results in inventory pileup and increase in waiting time
6	Waiting time	• Charging of ball mill with water and RM is done separately and the cap of the ball mill is tightened using nuts and bolts which wastes a lot of time. • During unloading of slurry, the pipe has to be attached and removed from every ball mill • Path of movement of racks of pugs is currently very cluttered and haphazard. A lot of times, wastage of time is there due to collisions
7	Waiting time and untapped human talent	• Only one worker knows how to work the ball mills. This increases the waiting time for the ball mills when the worker is busy with some other job.
8	Motion time	• Before the ball mill can start to work, the worker has to travel a lot of times between the ground floor and first floor
9	Water wastage†	• In filter press, the cakes are prepared by drying out water. This water is left wasted.
10	Wastage and untapped human talent	• Cycle time of filter press is around 2.5 hours while rotary feeder is a continuous process
11	Waiting time or over processing	• There is no standard time for which the filter presses run
12	Energy wastage†	• Currently the process followed for extrusion is direct extrusion. This requires a much higher power input and energy compared to indirect or hydraulic extrusion • The machine downtime of the rotary feeder is much because the workers just sit idle a lot of the time
13	Defects and waiting time	• The current inclination of the conveyor from the ground is large due to which a lot of cakes keep falling and the workers have a hard time putting the cakes up

S. No	Waste/ Process/workstation	Root cause(s)
14	Low space utilization†	• A lot of area which can be used otherwise for other purposes is used by the workers to put their personal belongings
	PED	
1	Waiting time	• A lot of processes internal in nature are performed which wastes a lot of time. These are processes which can be performed before the main process starts • Sometimes during the process of loading or unloading the work is left in the middle because the workers need to tend to some processes elsewhere
2	Underutilization of resources and waiting time	• The PED's are not being used to their optimum capacity. Most of the PED's are at least 25 to 50 percent empty
3	Motion time	• After PED, the pugs are kept in the pug yard for a certain interval of time
	Shaping Department	
1	Defects	• Workers sometimes destroy freshly shaped insulators causing unwanted loss for the company
2	Motion time and waiting time	• The distance between shaping and dryer is much more than required. This causes a lot of time wastage.
	Dryer	
1	Motion time, waiting time and transportation time	• For loading the workers have to move around a lot plus they have to sort through the racks to find out which insulators are to be taken.
2	Energy wastage† and waiting time	• The application of mitti on the door for sealing purposes is very old, wasteful and temporary. Plus it is not very effective to avoid heat loss.
3	Energy wastage† and over processing	• The process followed in the dryer is not standardized and is based on 'hit and trial' methodology. This gives rise to non-value added activities. Also lot of wastages of energy due to not fully loading of dryers.
	Glazing	
1	Waiting time	• Only one or two dipping sites are used at a particular time
2	Energy wastage†	• Currently the liquid glaze is cleaned by using a pump and pumping the glaze out of the tank through a sieve. Then a pump is again used to transfer the liquid back into the tank.
3	Waiting time	• Work is sometimes stopped due to shortage of glue, spray or gravel.
4	Motion time, waiting time and inventory	• Currently process layout is followed.
5	Motion time	• Because of non-availability of basic amenities in the department itself the workers feel free to roam about the premises when they need a drink of water or need to relieve themselves
	Kiln and Kiln Sorting	
1	Waiting time	• Currently the insulators are loaded one at a time in the car • Stones, laying bricks and rods are sometimes fetched in the middle of the loading process which causes loss of time • While cleaning the insulators with compressed air, the air is blown from different sides. This basically increases cleaning time as the dust keeps moving to and fro between insulators

S. No	Waste/ Process/workstation	Root cause(s)
2	Motion time	• When transferring into the kiln, all the movement is facilitated by one moving plate which has only one degree of freedom and that also is limited. Also the cars are pushed inside with the help of pipes. • When the insulators are transferred to the cutting and grinding department, they are not actually taken to the point of use but are left near the walking area for the cutting and grinding people. This creates excess motion and wastes time
3	Inventory	• The kiln department has a major space problem. A lot of inventory that is not under use lies around and gets in the way of all the workers. It increases the operating cost as well.
	Cutting and Grinding	
1	Motion time	• Cutting action on this machine is only on one side. Therefore for cutting both sides the insulator has to be rotated which takes up a lot of time
2	Defects and waiting time	• Material handling system is not very effective or efficient. Many a times the workers have to resort to unconventional ways ('jugaad') to get things done
3	Defects	• Manual handling of such large insulators may result in damage to insulators
4	Waiting time and motion time	• Currently complete batch flow is followed.

† These are not one of the eight wastes of lean manufacturing, but to show importance of energy consumption and other resources it is shown here for top management attention.

5.4.6 Pareto charts analysis of defects in each process

In each process Pareto chart analysis has been done to know the monthly average rejection trends for different types of defects in pre kiln and post kiln operations as shown in tables 5.4 to 5.11 and also drawn in figures 5.13 to 5.20. After root cause analysis improvement initiative has been taken to reduce the same as discussed in the next section (section 5.4.7).

(a) Slip house rejections

Table 5.4: Analysis of defects in slip house

Defects Reason	Monthly average rejection (MT)	Percentage	Cumulative percentage
Round Crack	0.099	65.13	65.13
Damaged Pug	0.026	17.10	82.23
Bore Crack	0.010	06.58	88.81
Fallen	0.007	04.60	93.41
Ovality	0.007	04.60	98.01
Bend	0.003	01.99	100.00
Total	0.152	100.00	

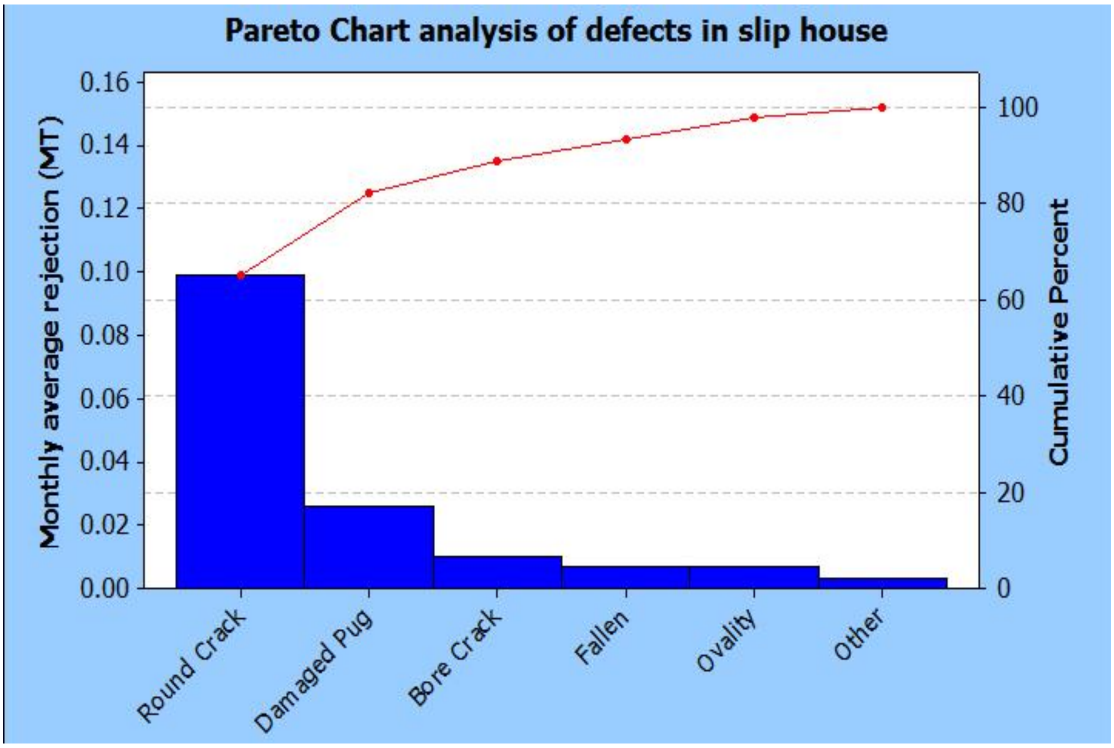


Figure 5.13: Pareto chart analysis of defects in slip house

(b) PED loading rejections

Table 5.5: Defects analysis of PED loading

Defects Reason	Monthly average rejection (MT)	Percentage	Cumulative percentage
Fallen	0.050	47.17	47.17
Damaged Pug	0.036	33.96	81.13
Round Crack	0.010	09.44	90.57
Accident	0.007	06.60	97.17
Hard Pug	0.003	02.83	100
Total	0.106	100	

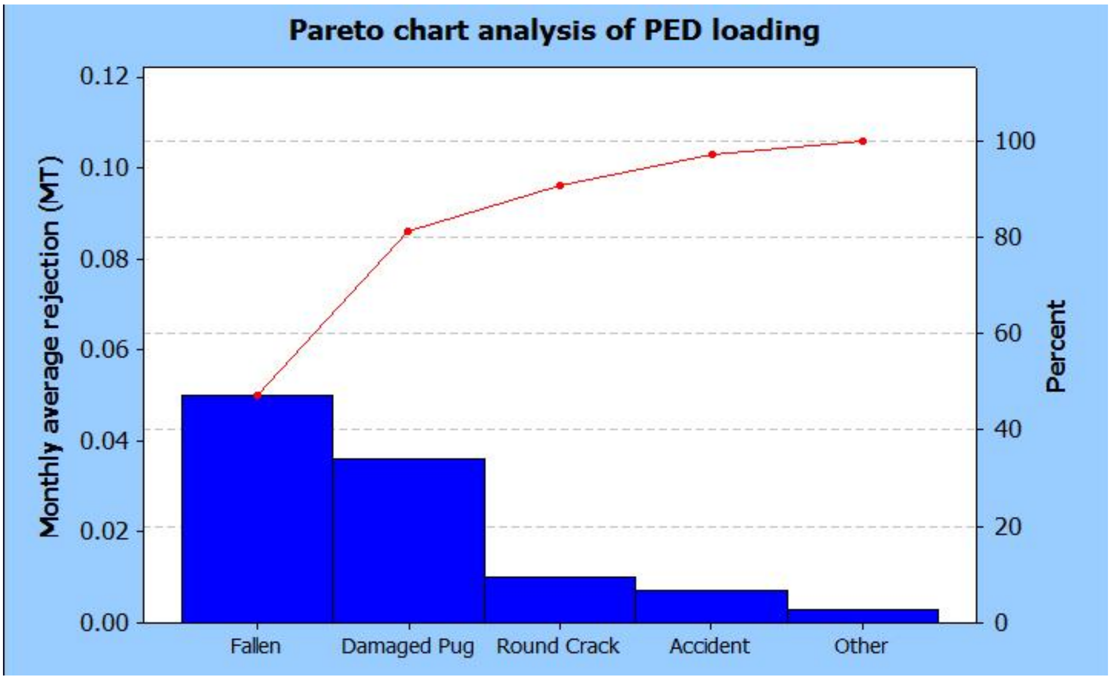


Figure 5.14: Pareto chart analysis of PED loading

(c) PED unloading rejections

Table 5.6: Analysis of defects in PED unloading

Defects Reason	Monthly average rejection (MT)	Percentage	Cumulative percentage
Damaged Pug	0.099	40.74	40.74
Fallen	0.073	30.04	70.78
Round Crack	0.049	20.17	90.95
Soft Pug	0.010	04.13	95.08
Bore Crack	0.003	01.23	96.31
Blank Rejection	0.003	01.23	97.54
Accident	0.003	01.23	98.77
Hard Pug	0.003	01.23	100
Total	0.243	100	

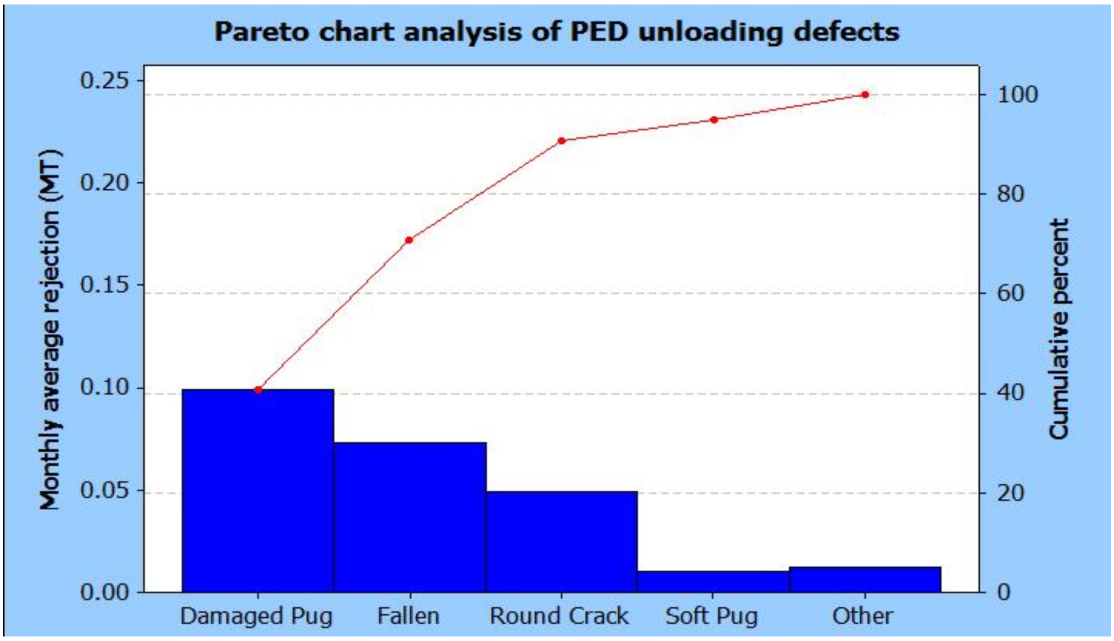


Figure 5.15: Pareto chart analysis of PED unloading defects

(d) Dryer loading rejection

Table 5.7: Defects analysis in dryer loading

Defects Reason	Monthly average rejection (MT)	Percentage	Cumulative percentage
Shed Band	0.379	37.75	37.75
Shed Cut	0.205	20.42	58.17
Shaping Handling	0.175	17.43	75.60
Others	0.083	08.27	83.87
Bad Shaping	0.066	06.57	90.44
Handling	0.049	04.90	95.34
Shed Cut	0.030	02.98	98.32
Chipping	0.010	01.00	99.32
Accident	0.007	00.68	100
Total	1.004	100	

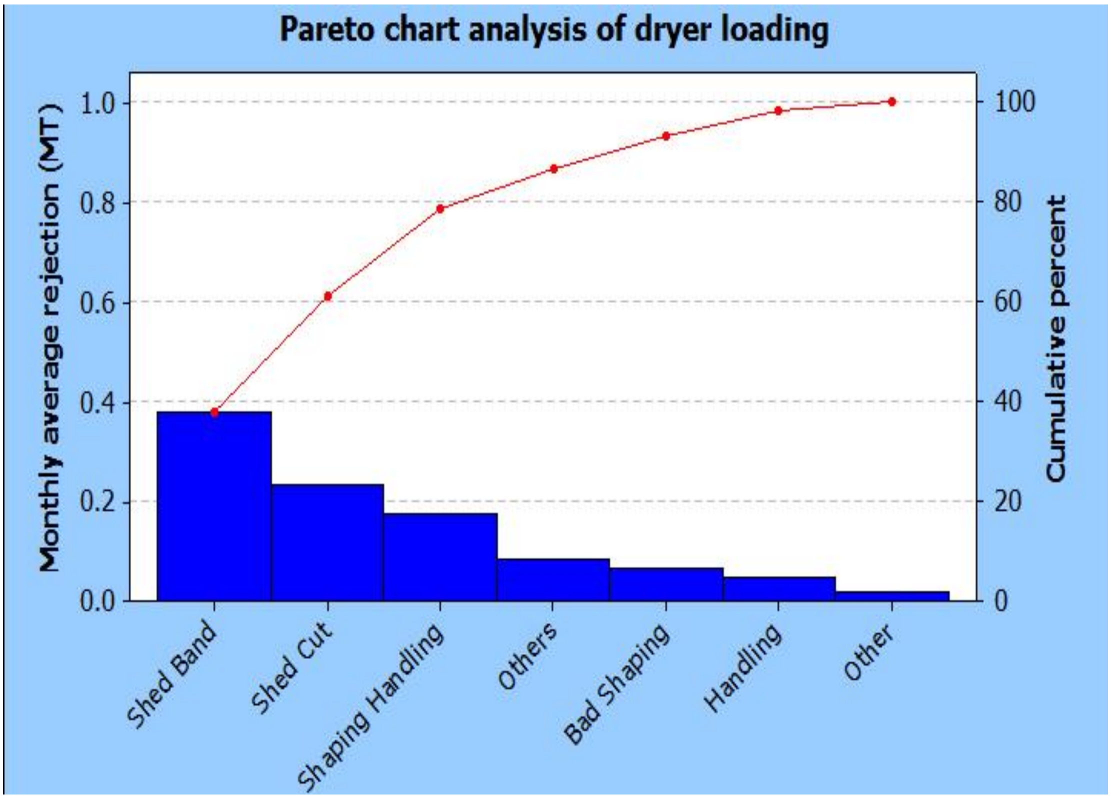


Figure 5.16: Pareto chart analysis of dryer loading

(e) Dryer sorting rejections

Table 5.8: Defects analysis in dryer sorting

Defects Reason	Monthly average rejection (MT)	Percentage	Cumulative percentage
Peticot Crack	1.287	75.31	75.31
Shed Bend- SB	0.356	20.83	96.14
Shed Cut	0.066	03.86	100
	1.709	100	

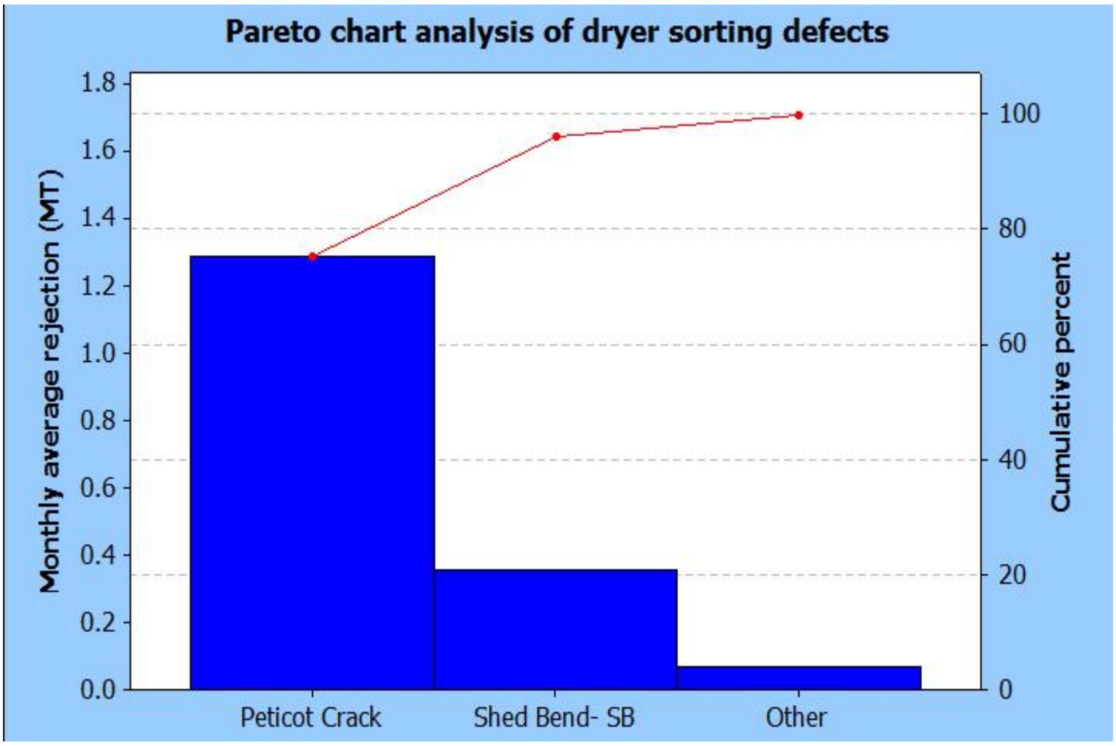


Figure 5.37: Pareto chart analysis of dryer sorting defects

(f) Kiln rejection

Table 5.9: Defects analysis in kiln

Defects Reason	Monthly average rejection (MT)	Percentage	Cumulative %
Round Crack	0.270	33.75	33.75
Chipping	0.247	30.87	64.62
Peticot Crack	0.125	15.63	80.25
Accident	0.056	07.00	87.25
Handling	0.056	07.00	94.25
Shed Crack Rejection	0.046	05.75	100
Total	0.800	100	

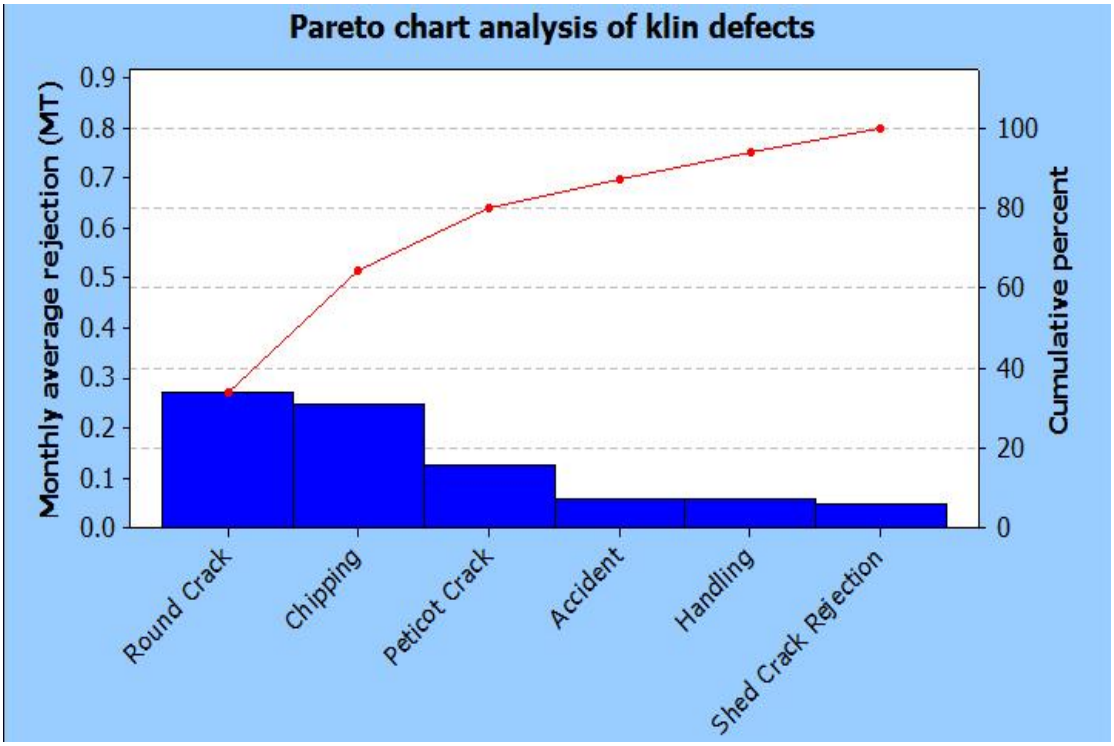


Figure 5.18: Pareto chart analysis of kiln defects

(g) Kiln sorting rejections

Table 5.10: Defects analysis in kiln sorting

Rejection reason	Monthly average rejection (MT)	Percentage	Cumulative percentage
Peticot Crack	1.61	85.19	85.19
Shed Cut	0.28	14.81	100
Total	1.89	100	

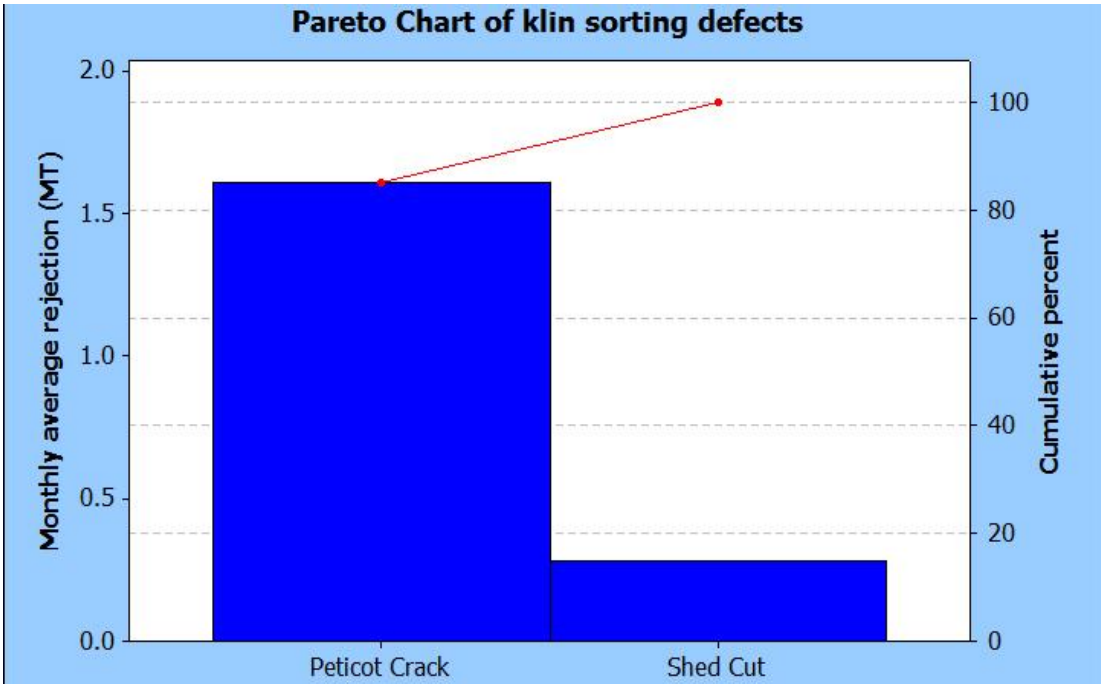


Figure 5.19: Pareto chart of kiln sorting defects

(h) Other post kiln rejections

Table 5.11: Defects analysis in other post kiln rejections

Rejection reason	Monthly average rejection (MT)	Percentage	Cumulative %
Handling/Chipping	0.234	41.20	41.20
ERP stock adjustment at packing/RTST	0.139	24.47	65.67
Inside Bottom/Inside Top	0.073	12.85	78.52
Broken	0.046	08.10	86.62
Inside Crack/Surface Crack	0.043	07.57	94.19
Cavity/CMV	0.033	05.81	100
Total	0.568	100	

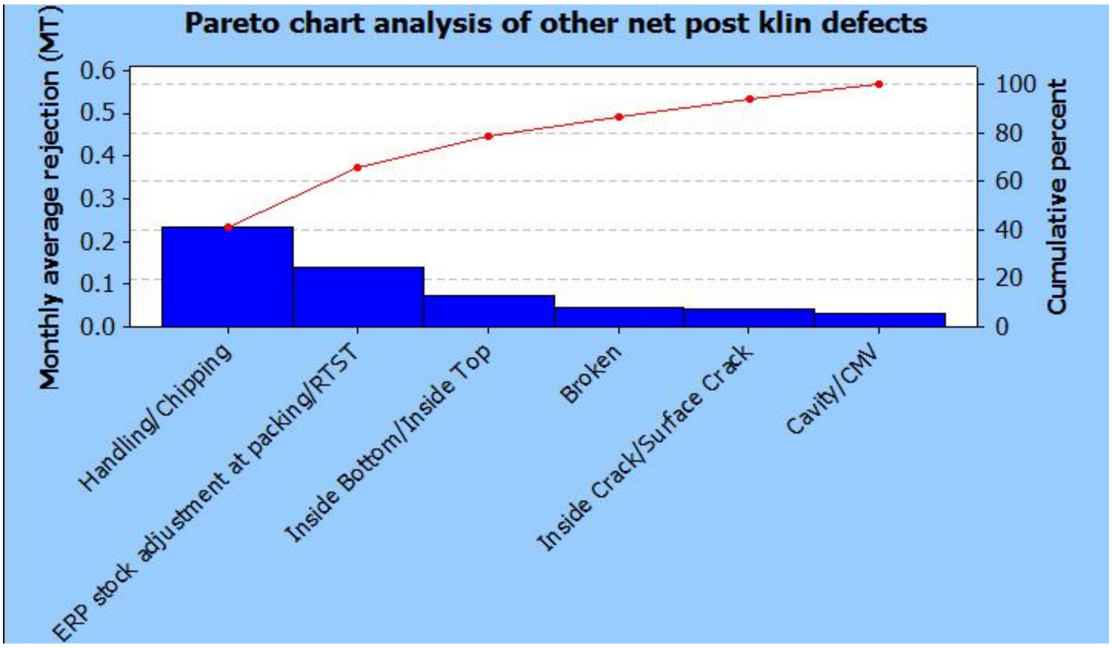


Figure 5.20: Pareto chart analysis of other post kiln defects

5.4.7 Recommendations for Defect Reduction

(I) Pre kiln defect reductions

It can be seen in the Pareto analysis that major defects/green rejections are in the category of Shed Bend, Shed Cut, Round Crack, Damaged Pug, Peticot Crack (PC), Shaping and handling rejections. The following (Table 5.12, 5.13 and 5.14) actions were taken to reduce these defects;

Table 5.12: Corrective/Preventive Actions Planned for various rejections

Type of rejection	**Possible causes**	**Corrective/ Preventive actions**
SDC (SHED CUT)	Blank Bend	Blank must be free from bend.
		Nozzle / Table setting
		While loading uniform pushing
		While transferring for PED loading should not be shake
		Bend, damage, short length wooden plank should not use
	Blank Damage	Storage due to more rack stock in pug yard / pugging yard.
		Keep the rack in a fashion which does not damaged the blank in pug yard / pugging yard.
		FIFO to be followed in pug yard.
	Pug alignment while loading on machine.	Pug to be loaded in centre of machine.
		Avoid turning of damaged pug.
	Taper cutting	Alignment of pug cutter (P.M.) should be in one plane.
		Cutting wire should be tight.
		Cutting speed should be fast.
	Less gap between shed OD to blank OD	Study was done and set the proper diameter of blank for different size of insulators
	Sticking of blank during Drying process in PED	Separator (made of plastic) was provided between two or more blank.
QC (QC Cutting)	QC cutting of all mandrill items in every shift	For WTV cutting use the Pistol caliper
	QC cutting of boring items in every setting of taper items	Check the top & bottom boring dimension and taper length if only doubt then only cut the material.
	Flat surface on the blank	Table nozzle setting
	Small lot size of tapper boring item	One item should be extruded continuously as per planning on one time as per shaping machine requirement.
Failing	Blank Condition	Blank of correct PMR to be used for turning.
	Centre out of machine	Between centre of machine should be inline
	Toper cutting	Pug cutter should be in alignment. Cutting wire should be tightened. Cutting speed should be fast
NC (Neck Crack)	Improper support in "C" clamp	"V" frame made for large solid core insulators
	Improper rack setting while dryer pushing	Proper rack down to be done at the time dryer pushing
	Neck crack due to taper cutting from bottom	Turned with single footer at shaping
	Rack down time cone get damage due to less stem length	Stem length increased by 25mm

	Improper rack setting while dryer pushing	Proper rack down to be done at the time dryer pushing
DP (Damaged Pug)	Increasing pug stock	Pug stock to be maintained 250 MT to 300 MT in shaping pug yard to avoid over stock which causes defects
	Improper rack placement	Racks to be kept with proper gap
	Unskilled men power	Required 50% skilled men and remaining 50% unskilled men to go on regular training so they learn job
	Angle touching while loading in racks	Proper packing must be there if not then, to be fix at both sides of pugs
	Space constraint	Proper 5S implementation for some space creation
	Manpower shortage	Joint affords of dept and personnel dept is required
RC (Round Crack)	Table setting with mouth piece	Should be proper
	De-airing	To be check after set up
	Moisture variation of cake	Avoid hard or soft cakes
	Smaller wet pug length	Planks to be use as per size
	Smaller pug lifting hook	To use required size lifting hook
	Tripping while extrusion	Power tripping to be avoided as far as possible by electrical department
	Oil application on pugs	Proper oil application with gauge
	Improper application of stopper mass	Stopper to be loose after PED loading especially for solid core insulators.
BC (Bore Crack)	Soft pugging	Soft cakes if any to be separate & scrap it
FL (Fallen)	Loose stopper mass	Before loading/unloading in PED check stopper mass tightening
	Floor condition	Floor condition be improve, floor repairing is must
	Unskilled men power	Provide training then give the tasks

Table 5.13: Corrective/preventive actions planned for some minor rejections

Shed Bend defects rejection

- Shaping yard stock to be maintained zero approximately as there is no restriction of retention period for dryer.
- First come first out system to be preferred i.e. first turning insulators racks to be kept front side of dryer to avoid multiple handling.
- Chanel was provided inside the dryer to avoid wall touching.
- No covering of turned ware system to be introduced by establishing 140,165,187 hrs cycle.
- Area specified and rack keeping arrangement done by providing railing.
- Application for manual ladder during uncovering in front of dryer.
- To avoid shed sabotaging which happened 2 to 3 times it is proposed to fix camera.
- Binding for niwar/painting/galvanization of planks

Overall kiln loading rejections

- Floor condition is improved at kiln and glazing area
- Congestion at floor due to empty racks and sorted goods in kiln area is improved
- Facility was provided to glazing department to shift the material in K-8 side area

BDC rejections

- Removed centre out & jerking through TPM
- Insulator to be kept direct in rack after unloading from machine
- PMR to be increased by 0.1 i.e. 1.3 – 1.5 instead of 1.2-1.4 (depend upon design)

PC rejections

- Indication of damper opening to be operated by modified system.
- Immediate loading after turning to maintain wares uniformity.
- Introduction of fresh air damper before rise to maintain uniformity of humidity inside the dryer.
- Good finishing for Bauxite body so that it could be dipped directly without finishing to prevent delay in PC.

Cake rejections

- Soft filter pressing to be avoided
- Change the filter cloths after 800 cycles
- Cakes falling while cake releasing to be avoided
- Avoid cake hardening
- Cake falling white feeding to rotor feeder to be avoided
- Body mass leakages from rotor feeder to be minimize. This is a major problem

Some general suggestions to reduce the pre kiln defects

- Controlling of both the dampers through 4-20mA controlled linear servo motors for fine control of damper opening and SCADA will show us exact opening of dampers at PC. This will help in controlling of unwanted opening of fresh air damper similarly condensation of water inside the dryer will be avoided. Do opening of fresh air from initial stage along with exhaust.
- Bigger size exhaust dampers have been provided in some of the dryers to drain out the humidity as per requirement to avoid condensation.

- Use “V” groove plank for large solid core insulators. Gunny thread should be tight properly in shaping itself. Proper rack setting should be done immediate after shaping.
- Loose booms/rings from the top of insulators should be removed immediate after taken out from dryer.
- Automatic closing of dampers immediate after power failure.

(II) Post kiln defects: root cause analysis and actions to reduce the major Defects

Post kiln rejections were very important, as in pre kiln stage all the insulators were in a semi solid phase and any waste or defected insulator can be thrown back into the system for reuse. It can be seen in the Pareto chart analysis of pre-kiln stage that most of the defects are due to improper handling, improper storage and disorganized workplace. All the major green/semisolid defects can be reduced through proper implementation of 5S and making improvements in material handling system. After the kiln operation the insulators take a complete solid form and any waste after this goes into the dumpster resulting in a direct loss for the company. It has been also observed that in kiln operation approximately 60% of overall manufacturing cost is associated so post kiln defects analysis has given highest priority due to huge cost involvement.

Ishikawa diagrams have been drawn for rejections in each process after post kiln as shown in figures 5.21 to 5.24. Rejections reasons and actions were taken accordingly which were listed in the tables 5.14 to 5.17. The major rejection was; an INBT/INST & cement cavity rejection, PC and Shed bends in the post kiln.

(a) INBT/INST &cement cavity rejections

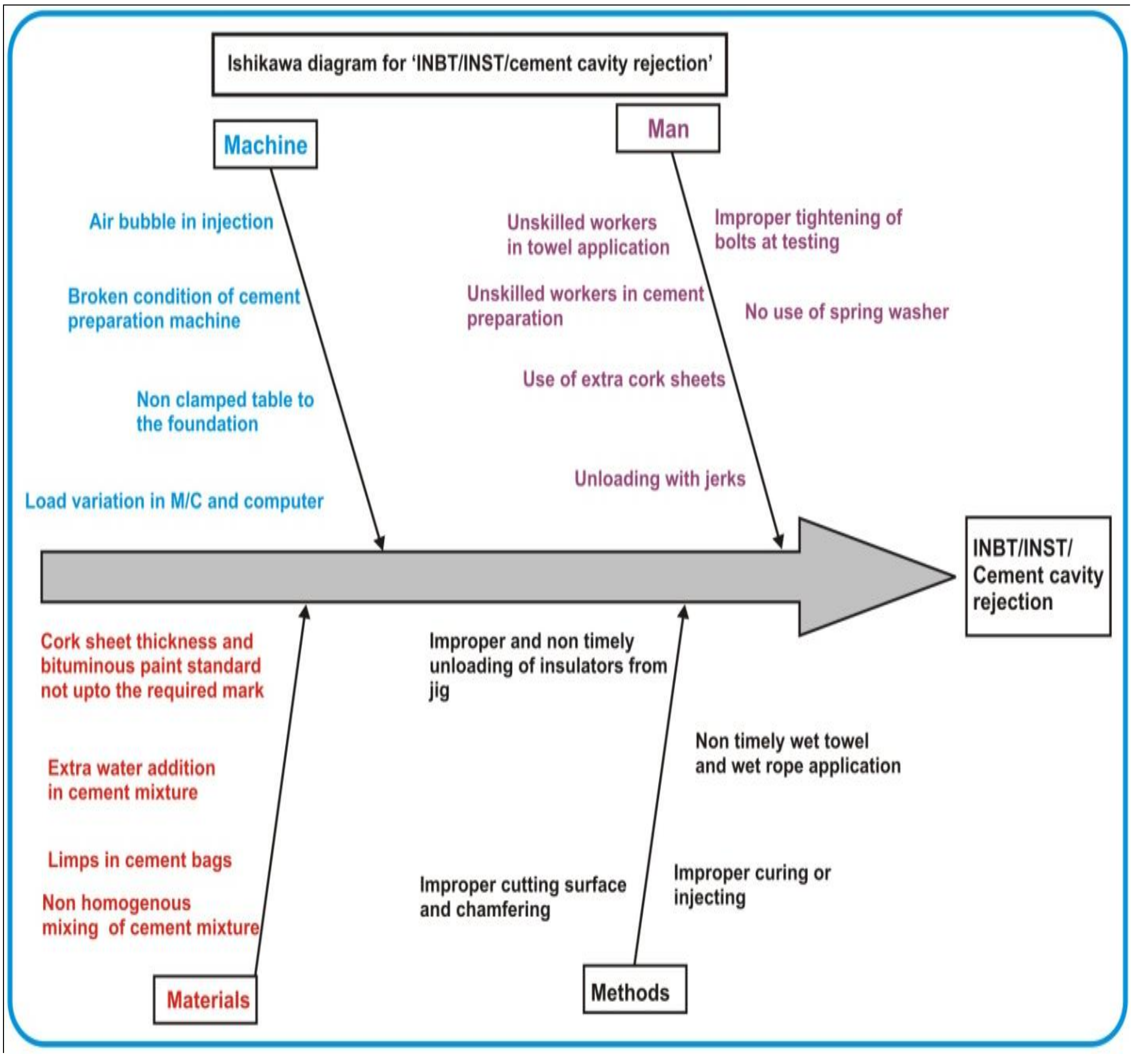


Figure 5.21: Ishikawa diagram for INBT/INST/Cement cavity rejections

Table 5.14: Action plans to remove INBT/INST rejections

	Reasons	Actions
Man	1. Improper tightening of bolts at testing 2. No use of spring washer 3. Unskilled men in towel application. 4. Unskilled men in cement preparation. 5. Use of extra cork sheets. 6. Unloading with Jerk.	1. Awareness given to testing and assembly workers for testing procedure, injection process. 2. Witnesses in critical processes. 3. Rejection follow up and analysis. 4. Monitoring of critical process. 5. Unloading on rubber sheet
Machine	1. Table is not clamped to the foundation. 2. Load variation in M/C and computer. 3. Air bubble in injection M/C. 4. Condition of cement preparation M/C and bowl.	1. Checking of M/C before starting the shift. 2. Testing procedure awareness. 3. Regular maintenance schedule has been started for cement preparation M/C and bowl.

	Reasons	Actions
Method	1. Testing before due date 2. Proper spring washer is not used. 3. No proper air curing 4. No properly timely of unloading of insulator's from jig. 5. No proper injecting. 6. Before injecting, wet rope not properly tied. 7. Proper and timely wet towel covering is not there. 8. Cutting surface and chamfering is not proper.	1. Information of correct process to be displayed in concerned departments. 2. Spring washers to be changed at regular interval. 3. PRC is also implemented. 4. Work instruction has been displayed at shop floor. 5. Injecting from lower hole. 6. Awareness given to the all contractors as well as worker about wet towel covering & proper rope tightening before injecting.
Materials	1. No homogenous mixing of Cement mixture. 2. Lumps in cement bags. 3. Extra water addition in cement mixture. 4. Cork sheet thickness and Bituminous paint quality.	1. Min. 10 min. for mixing of cement and witness it by QC 2. Continuous stirring of cement by wooden plank at the time of injection. 3. 100% incoming inspection.

(b) PC rejections

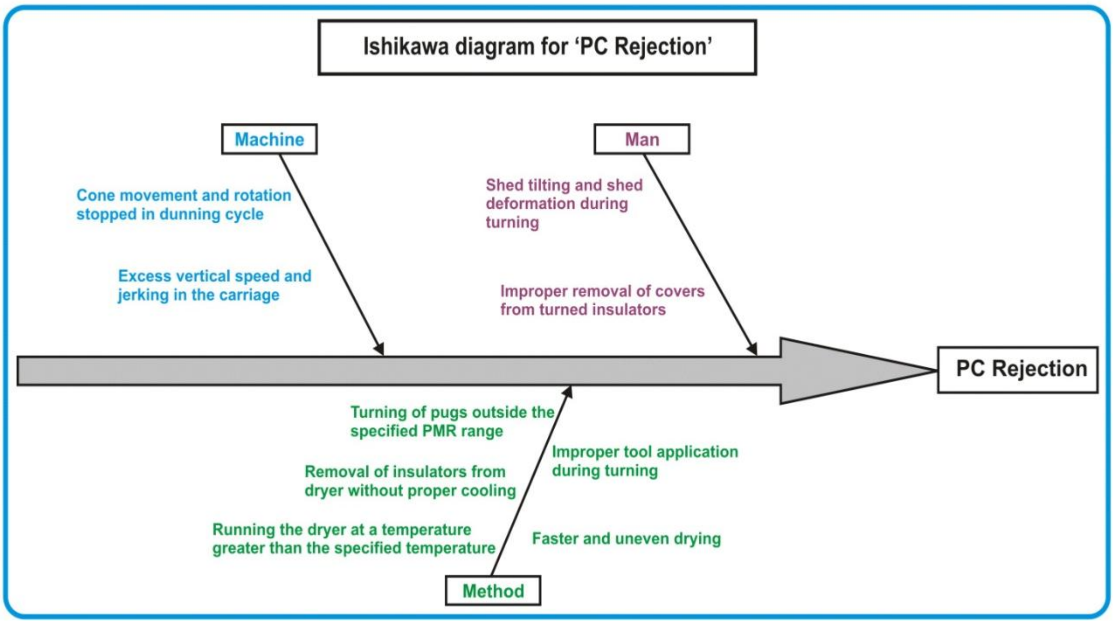


Figure 5.22: Ishikawa diagram for 'PC rejections'

Table 5.15: Action plans to remove PC rejections

	Reasons	Actions
Man	1. Shed tilting and Shed deformation during turning.	1. No correction of bend and tilted shed during turning.
Machine	1. Cone movement and rotation is stopped in running cycle. 2. Excess vertical speed and jerks in the carriage.	1. Implementation of inter locking system in between cyclo-gear motor and cone fan motor. 2. Detection of problematic machine to remove jerking.
Method	1. Turning of pugs outside the specified PMR range. 2. Improper tool application during turning. 3. Removal of insulators from dryer without proper cooling. 4. Fast and uneven drying. 5. Running the dryer at a temperature more than the specified temperature.	1. Tool application as per drawing. 2. Removal of insulators from dryer after cooling at 90 to 100 degree Celsius. 3.Turning of pugs within specified PMR range

(c) Shed bend rejections

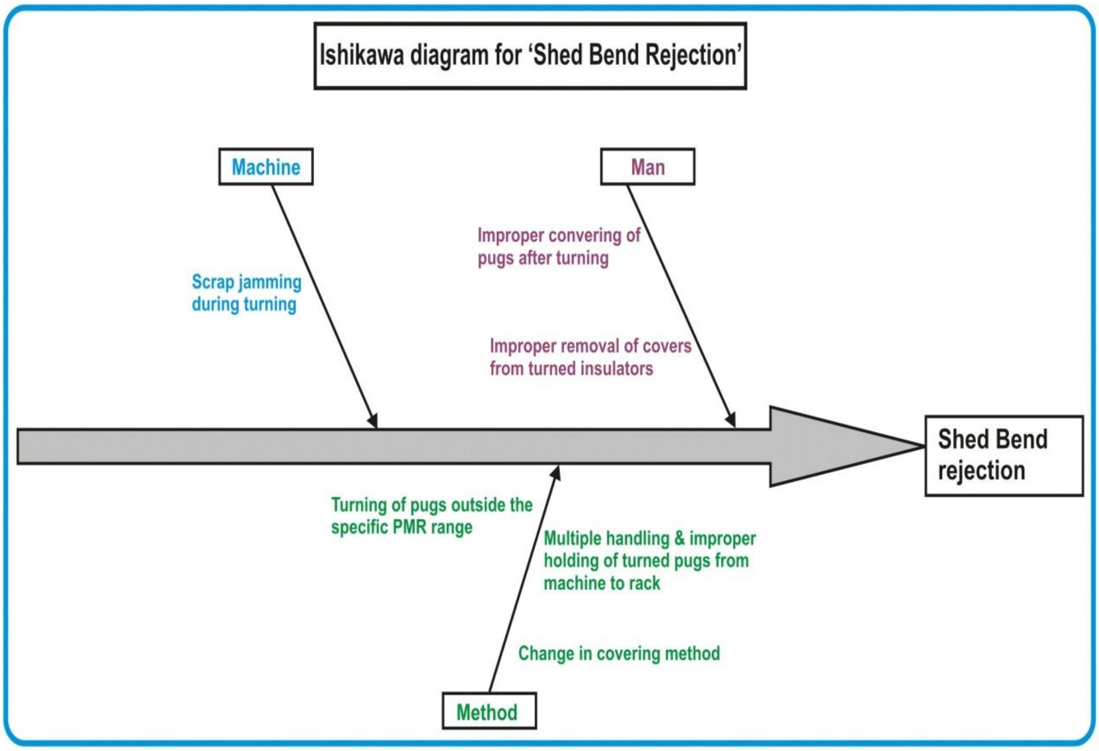


Figure 5.23: Ishikawa diagram for 'Shed Bend Rejection'

Table 5.16: Action plans to remove Shed bends rejections

	Reasons	Actions
Man	1. Improper covering of pugs after turning. 2. Improper removal of covers from turned insulators.	1. Specific skilled man power to be deployed.
Machine	1. Scrap jamming during turning	1. Tool application as per drawing.
Method	1. Turning of pugs outside the specified PMR range. 2. Change in covering method. 3. Multiple handling and improper holding of turned pugs from racks.	1. Turning of pugs within specified PMR range. 2. Turned wares not to be kept on the floor.

(d) Other post kiln rejections: method category only

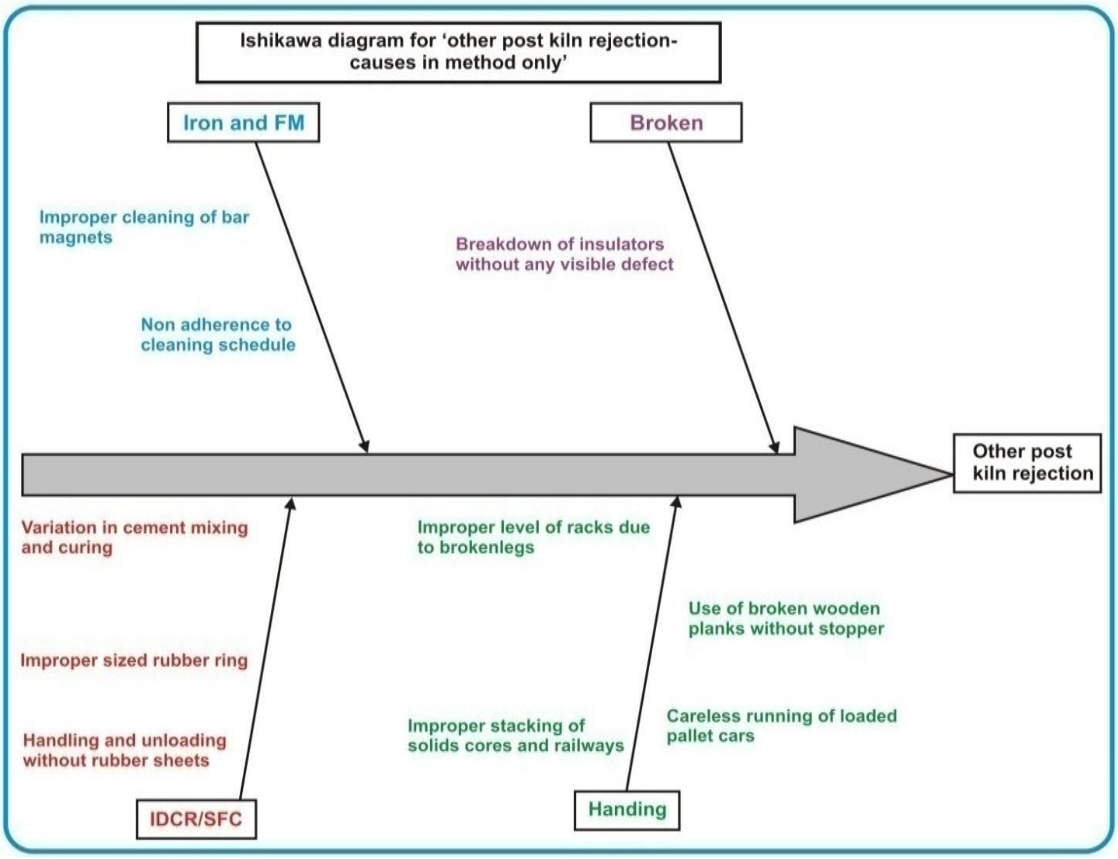


Figure 5.24: Ishikawa diagram of other post kiln rejections

Table 5.17: Action plans to remove other post kiln rejections

	Reasons	Actions
Broken rejection		
Method	1. Variation in cementing process. 2. Invisible porcelain defect.	1. Plan to take trials with different process conditions and MP.
Iron and FM rejection		
Method	1. No proper cleaning of bar magnets 3.Cleaning frequency not adhered to schedule	1. Water jet pressure should be increased. 2. Witness of magnet cleaning. 3. Checking of magnet cleaning after every shift instead of once a day.
Handling rejection		
Method	1. Improper stacking of 33kV solid cores and railway insulators. 2. Broken wooden planks (without stopper) 3. Improper level of racks (due to broken legs). 4. Careless running of loaded pallet cars.	1. Stacking of small items individually on racks, instead of pyramid stacking. 2. Removing all improper wooden planks from kiln sorting, C&G and assembly. 3. Broken racks are to be identified and repaired. 4. Shifting of semi-finished / finished goods in supervision and training to contractor. 5. Segregation in sorting and C&G.
IDCR/SFC rejection		
Method	1. Proper size rubber ring not used. 2. Improper \`O' ring placement. 3.Cement thickness variation 4. Cement curing not proper. 5. Handling/ Unloading without rubber sheet.	1. \`O' ring inspection before testing and awareness to all testing workers. 2. Careful assembly of critical items and timely towel application. 3. Use of proper size rubber ring before assembly. 4. WI displayed at shop floor. 5. Handling/unloading on rubber sheet

5.4.8Performance Improvement Initiatives

Table 5.18 shows the actions taken to improve the performance of the manufacturing system other than mentioned in the previous section.

Table 5.18: Improvement implemented in the processes

S. No.	Improvements	Performance parameter improvements
1.	A rack with hook, knife, spanner, hopper and drainage pipe was placed combined near to 2-3 ball mills instead of one kept for 6 ball mills.	PT saved 30 sec (0.5 min)
2.	The charging process has been improved by charging the ball mill simultaneously with raw materials and water (combining two activities).	18 min saved in PT, energy also saved
3.	The filter presses are kept on for random times, from 3 hrs to 3.5 hrs. It was suggested to have a digital clock and a siren was installed on each filter press to ensure it does not over-run. The floor repaired at some places to make it uniform for making movement of pallet trucks smooth.	Saved average 20Min. in PT, Defects reduction
4.	There were 4 workers in PM-2 and 3 workers in PM-1 with 1 machine operator each. The operator was engaged in starting/ stopping the belt after extrusion and in marking the pugs after the rack is completely loaded. Hence he was working in only 10% (approximately) of the time. Rest of the time he overlooked the process. Hence providing 1 operator for 2 machines was experimented successfully.	1 Manpower reduction
5.	The tools were not in place while fixing the extrusion head due to which the operator had to get it from other pug mill. Some mouth piece did not have hooks to lift. Hence it was very difficult to lift it. Usually it takes 14-15 sec to place a plank on platform but in Pug Mill due to non-availability of space the workers takes around 32 sec to place the plank. Moreover they have to travel 50-60m more which constitutes waste of motion.	Saving in PT 15sec (.25min.)
6.	After PED, the pugs were kept in the pug yard for a certain interval of time with proper covering of insulators by Polythene. Now this step was removed and pugs directly transfer to the dryer after shaping.	Waiting time 0.67D reduced and also WIP removed up to zero level.
7.	One loop was created which consist workstations 8-9-10-11 to make one piece flow of product. Here the processing time of dry-finishing (W/S 8) was 206 sec. but in case of other three stations it is almost same (vary between102 to 106 sec.), so one more station of dry-finishing was created to make one piece flow. No new workers was assigned the job at new w/s 8 but two persons who are working for batch shifting in previous layout was used to do the processing at new dry-finishing workstation. This helps in better handling of materials, reduction in motion time, waiting time and drastic reduction in floor inventory.	Reduction in WIP, Reduction in WT after workstations 8, 9 and 10, Handling defects reduction
8.	Previously the liquid glaze was cleaned by using a pump and pumping the glaze out of the tank through a sieve. Then a pump was again used to transfer the liquid back into the tank. Instead of following this, the liquid glaze is allowed to fall by gravity through a sieve, and then a pump is used to transfer the glaze back to the tank. This helped in reduction of one of the pumps and hence save the power used by it.	Energy saving

S. No.	Improvements	Performance parameter improvements
9.	More green rejection was at dryer sorting stage due to PC & BDC. Action: All critical designs which were prone to PC were identified & accordingly trial plan was implemented. Bauxite body insulators showed heavy 'S' crack tendency, which was discontinued.	Defects rejection reduction
10.	The kiln department in general was facing with a lesser available space problem. Effort was made to reduce the inventory on the floor. A lot of inventory that was not under use lies around and gets in the way of all the workers. Plus it increases the operating cost as well. The worker also needs to be careful during handling of material. Working hastily increases the chances of damage to the product and at this stage i.e. after the kiln operation it is a direct loss for the company. It was observed that inventory was high in the post kiln operations. Previously XXX was holding 7 days' inventory in the warehouse because of poor communication and a play-safe tendency. Electronic information flow was started for the suppliers of XXX. Now it was reduced for 6 days. It helped in reducing order quantity and inventory at raw material stores in the company also. Now instead of 4 month order to supplier, this is now two month raw material inventory in store. So inventory was reduced in pre and post kiln operations.	Reduction in WIP, Reduction in WT after W/S 16, 18, and 21
11.	Material handling system was not very effective or efficient. Many a times the workers had to resort to unconventional ways ('jugaad') to get things done. Lot of Kaizens in material handling was started as shown in figures 5.30 to 5.34.	Material handling rejections reduced
12.	Bolting and tightening is most important activity in Bending test also it takes most of the time of overall cycle time. By installing of electric powered bolt tightner on every bending machine, PT time was saved overall process.	Saved in PT 0.81 min
13.	At the time of loading, operator was standing idle and helpers were loading insulators on machine during bending test. During loading operator started to help helper to load insulators so that other helper was withdrawing from machine.	One man power reduction
14.	The location of oil tanks was very random. They were not kept at their point of used (POUS) place for oiling one end of pugs for PED operations. Location was changed of the same to follow POUS.	Saved in PT 10 Min.
15.	The process for starting the ball mill was not standardized. The operator has to travel between the first floor and the ground floor a lot of times before he can set everything in order. This ambiguity was minimized through placing the ON/OFF switch of ball mill near to loading point.	Saved in PT 15 Min.
16.	During unloading of slurry, the pipe had to be attached and removed from every ball mill. A permanent attachment line was installed for the same.	Saved in PT 13 Min.
17.	The inclination of the conveyor from the ground was large due to which a lot of cakes keep falling down and the workers had a hard time putting the cakes up. Present conveyor system was replaced with a hydraulic operated lift system which requires lesser energy and processing time, also one operator was reduced from this.	Saved in PT 5 Min. and one manpower at one rotary feeder
18.	As far as possible, converted internal processes to external processes. For example, processes like application of wire mass jaali and covering both the sides of the insulator with polythene was started to do before the pugs were loaded in the PED. This helped save time during the actual loading.	Saved in PT 1hr

S. No.	Improvements	Performance parameter improvements
19.	While cleaning the insulators using compressed air, the direction of air were kept constant and the worker moves from one particular end to the other. Previously the process of cleaning were from both the sides , that increases the cleaning time as the dust kept on moving to and fro between adjacent insulators.	Saved in PT 30 Min.
20.	Stones, laying bricks and rods were sometimes fetched in the middle of the loading process which causes loss of time. Proper layout was done so that kiln loading time was saved along with effective 5S implementation.	Saved in PT 16Min.
21.	When transferring from the kiln, the cars were pushed with the aid of rope. Many times this rope gets brake results is damage of insulators. This was replaced with wire ropes as shown in Figure 5.34.	Defects reduction
22.	When the insulators were transferred to the C&G process, they were not actually taken to the point of use but were left near the walking area for the cutting and grinding people. This creates excess motion and wastes time. C&G time reduced due to implementing proper layouts (5S).	Saved in PT 3 Min.
23.	Space Creation through 5S in different shops as shown in figures 5.25-29.	Space creation 719 m2

Figure 5.25: Space creation through 5S in store

Figure 5.26: Space creation through 5S in store

Figure 5.27: Space creation through 5S in slip house

Figure 5.28: Space creation through 5S at slip house

Figure 5.29: Space creation through 5S in the shaper area

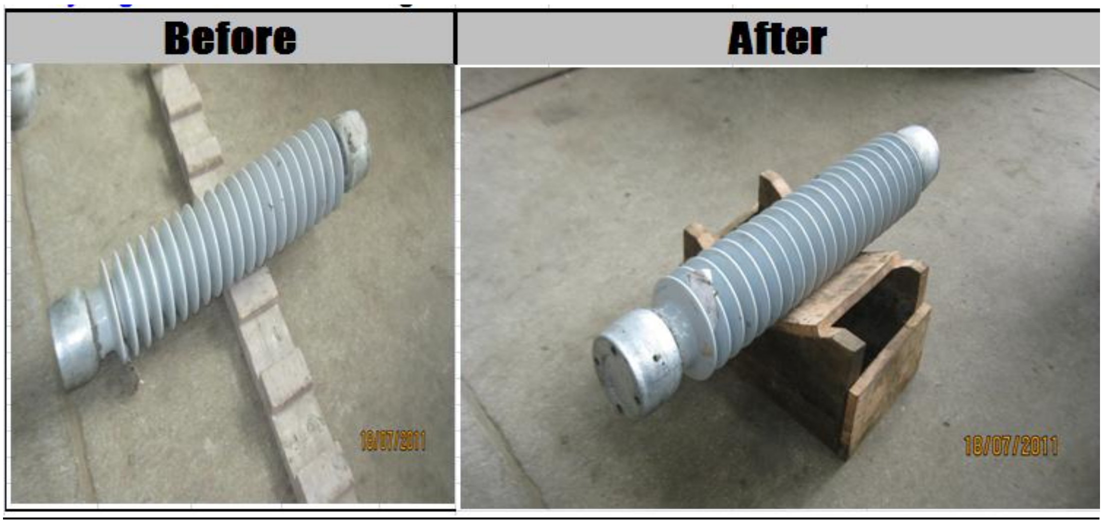


Figure 5.30: Kaizen in material handling

Figure 5.31: Kaizen in material handling

Figure 5.32: Kaizen in material handling

Figure 5.33: Kaizen in material handling

Figure 5.34: Kaizen in kiln unloading

5.4.9 Other General Improvements Initiatives

- Autonomous maintenance was started which is basically maintenance performed by the machine operator rather than the maintenance staff. It includes the seven steps -initial cleaning, preventive cleaning measure, development of lubrication and cleaning standards, general inspection, autonomous inspection, Process discipline, and independent autonomous maintenance(Source: http://elsmar.com/ Planned Maintenance/sld033).Autonomous maintenance was done in three workstations as per first schedule up to 18th Nov. 2011 were; the machines C&G

section (C.G. M/C 1 to 7, T.C. M/C 1 to 7, and Lapping M/C 1 and 2), the machines in the shaping section (Machine – 1 to 26, ZEIDLER-2 and 4, CNC-1 and 2, TI-1 and 2, VACKS and MIM-9), and the machines in the testing section(bending testing machine, shear testing machine, compression testing machine, computerized chemical balancing machine and programmable precision universal testing machine).

- As a part of our lean initiative, with the help of the company staff all the functions of ERP software was implemented well within the company. ERP reduced the amount of information between processes like transferring multiple entries of the products in hard copies at each process. This system was helped in downsizing the inventory levels and better interdepartmental coordination. It also helped to improve delivery schedules and bottlenecks during the production processes. Other benefits includes; reports have been presented on time, a lot of paper saving was done, considerable reduction in manpower and motion time
- The importance of human resources in the lean implementation is very crucial. In particular, involvement of workers in the continuous quality improvement programs, expansion of their autonomy and responsibility, the presence of multifunctional workers have all, been crucial for improvements in the firms' performances. So in order to promote employee contributions and to increase their empowerment and responsibility, company moderately invested in employee training, as a means to impart them multitasking capabilities. In turn, it also helped to boost the morale of the employees by providing them a sense of autonomy and responsibility. In the XXX, shop floor supervisors were extensively trained to identify bottlenecks and take corrective actions to reduce the scrap and rework.

- The rack comes with excessive planks. Instead of normal planks, it was proposed to have V- shape planks to carry pugs. In this way the rolling of the small pug pieces from planks was eliminated to a certain extent.
- The machine downtime of the rotary feeder was checked. A lot of the time it has been noticed that the workers just sit idle a lot of the time. So TPM was used here to decrease the downtime. Basic facilities such as drinking water and toilet should be provided within the workstation area as workers take this as an excuse to loiter around.
- Workers angry with their supervisors sometimes vent out their frustration by slyly destroying a freshly shaped insulator. This causes unwanted loss for the company. Installation of CCTV throughout helped to avoid this problem plus it instills fear in the workers minds that they are being watched.
- Improved communication among employees through seminars/workshops/ meetings.
- Some of the quality control standards (Table 5.19) for C&G, assembly and testing processes were setup. Some Kaizens (Table 5.20) are still going on or partially implemented.

Table 5.19: Quality control standards Developed

S. No.	KPM	Standard
Cutting & Grinding		
1	Carriage condition	Carriage should be free from shake, play and vibration
2	Mandrill preparation for Hollow	1. Rubber bush hardness should be proper 2. Bush size should be as per ID of insulators 3. Proper placement of bush.
3	Cutting of sorted insulator as per specified cutting drawing	Cutting surface should be flat, parallel, and free from pits and projection. Proper gravel length and cutting length in S/C.
		Cutting surface should be flat, parallel, and free from pits and projection. Proper cutting of length and cone radius should be maintained in Railway and long road.
4	Chamfer of cutting edge	Chamfering should be as per specified drawing.

S. No.	KPM	Standard
Assembly		
1	Bituminous paint application on gravel portion	Uniform and proper coating of bituminous paint on Gravel portion, and then on surface also of solid core and dry it completely.
2	Selection of metal part	Uniform and proper coating of bituminous paint inside metal part, dry completely and do Greasing on all aluminum M/P before injecting.
3	Selection of shell (insulator)	Shell OD, Height and T/B gravel should be as per specified Drawing
4	Checking of jig/dowel pin/bolts	Dowel pin should be spaced as per PCD. Bolts should be properly tightened
5	Wet rope tightening	Cotton rope should be sufficient wet and tight it before injecting.
6	Concentricity	Shell OD should be in center to maintain equal cement gap
7	Injecting process	Injecting should be done from lower hole (injecting hole) and puts the finger on upper hole to remove air pocket. Ensure no leakage of cement from wet rope.
8	Cement mixture	Homogeneous mixing and no more % of water added
9	Injecting time	Check the cement injecting time.
10	Cleaning, leveling, cavity and concentricity checking	Cement should be properly leveled and cleaned by sponge, and check cement cavity and cement concentricity.
11	Unloading on Rubber sheet	Hollow insulators should be unloading on rubber-sheet to avoid surface chipping and M/P damage.
		Solid-core insulators should be unloading on rubber-sheet to avoid cement rejection (CR)
12	Wet towel tightening	Wet towel should be applied properly on cementing portion and plastic covering to be done for proper curing within half an hour after injecting
13	Curing chamber temp.	55 to 65 *Cg.
14	Curing chamber (including loading and unloading)	Min. 48 Hrs.
Testing		
1	Before due date testing	Testing schedule (procedure) display on shop floor.
2	Air curing	Testing schedule (procedure) display on shop floor.
3	Sticker	Assy. Date and shift sticker available for all insulators.
4	Load	Routine load applying on insulators as per Drawing/Customer requirement

Table 5.20: Kaizens partially implemented

S. No	Kaizens/Improvements	Process/Division
1.	Template hanging stand should be portable for easy search and prevention of bending	Shaping
2.	Partition in beam trolley to keep individual size beam safely	KILN
3.	More gap in line track (transfer trolley alignment with track) to avoid defects	KILN
4.	Cost saving by fixing additional adopter in pug mills	Maintenance
5.	Cost saving by removing 1 HP cooling pump motor from feed pump Hydraulic power pack of filter press	Maintenance
6.	Rejected Pilot truck has been converted to hollow shifting truck in such a manner that the handling rejection has been minimized to half	Assembly
7.	Providing extra beam guider in the top of the extra large hollow epoxy assembly area in such a manner that it arrests vibration during Crane movement and hence reduces chipping of extra large insulators results increases workers confidence and satisfaction	Assembly
8.	Applied polythene sheet during bituminous painting between insulators and there by arrested the extra spillage of paint.	C&G
9.	Pallet truck painted with a unique number to detect the breakdown frequency	C&G
10.	Given the color code to tools for easy identification and keep in a tool box to reduce the wrong tool implementation	Shaping
11.	To reduce the sieving time/wastage due to over flow. Use 60 in place of 48 inch screen in a bauxite body.	Slip house
12.	Reduced roller attachment length to avoid radius cut and tool marks problem under shed	Quality

5.4.10 Development of the Future Value Stream Map (FVSM)

Finally, the future value stream map is constructed as shown in figure (5.35), which reported a considerable reduction in defects, inventories, processing time, waiting time, and manpower reduction as discussed in next section.

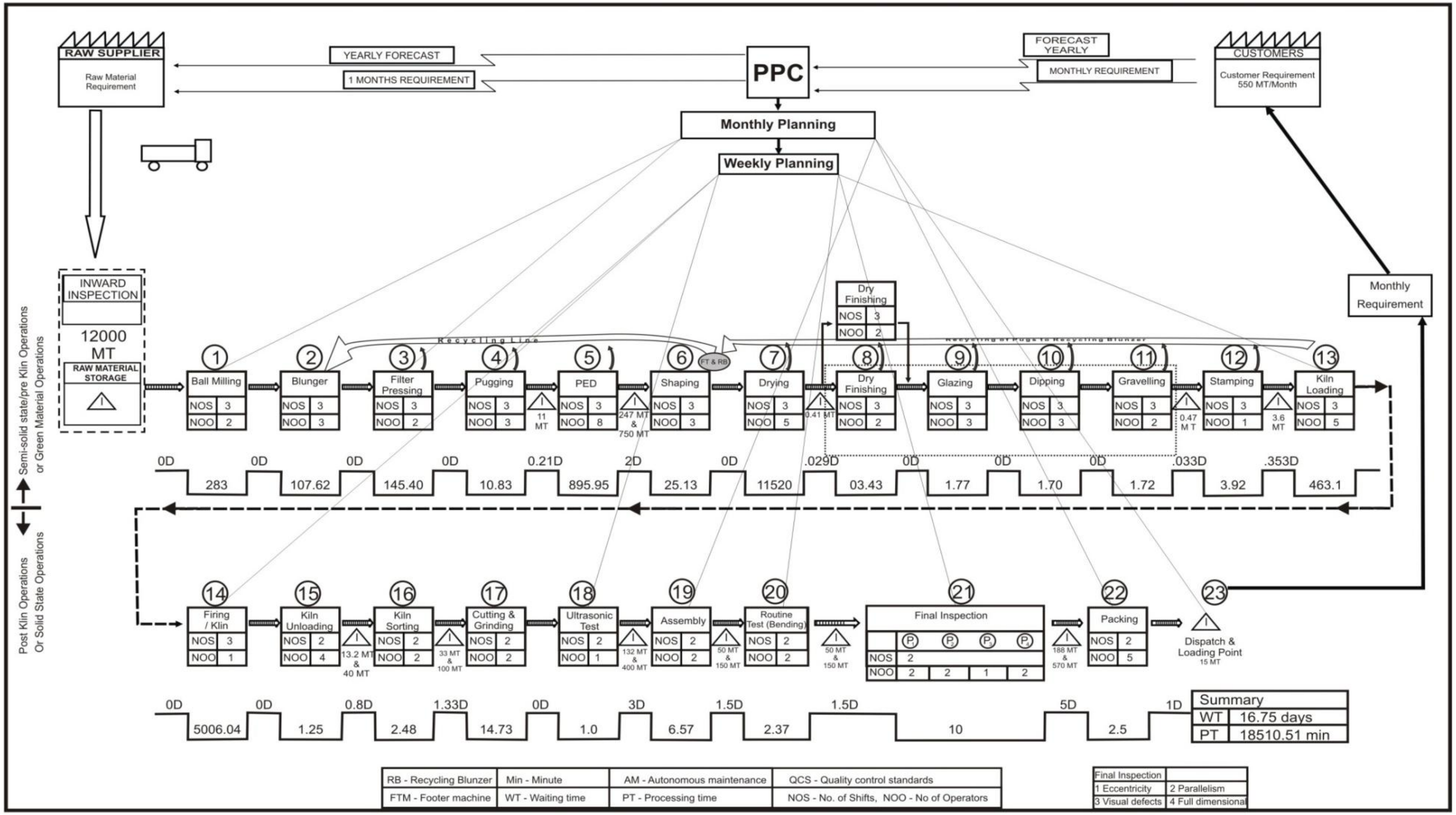


Figure 5.35: Future Value Stream Map

5.5POST IMPLEMENTATION PHASE

This phase basically consist two important levels namely, results and review which are discussed as follows:

5.5.1Results

The information collected before and after lean manufacturing implementation is compared to show improvements in performance parameters. This section also shows the improvements and net financial savings to the company due to lean manufacturing. Some of the performance parameter improvements are given below:

(I) Processing time (PT)

The implementation of the proposed kaizens and reduction in wastes has resulted in decreasing the processing time from 18,702.07 minutes to 18,510.51minutes i.e., a reduction of 191.56 minutes as shown in figure 5.36.

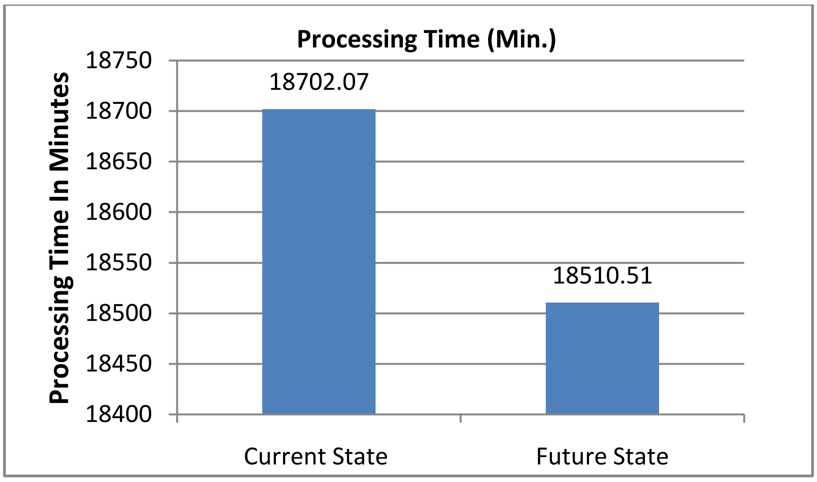


Figure 5.36: Processing time

(II) Waiting time (WT)

Reduction in defects resulted in reduction of raw material inventory and WIP inventory at many workstations. The introduction of one piece flow from workstation 8 (dry Finishing) to 11 (gravelling) brought down the waiting time. Overall waiting time is reduced from 24.84 days to 16.75 days, i.e. improvement of 8.09 days (32.56%) which is very significant as shown in the figure 5.37.

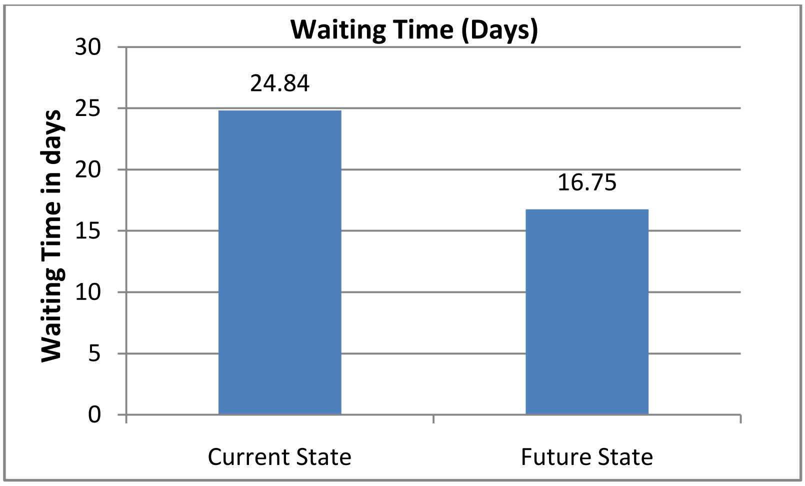


Figure 5.37: Waiting time

(III) Financial savings

(A) Savings through autonomous maintenance (AM)

This represents the comparison of the machine spares cost before and after autonomous maintenance was applied to a few workstations (Shaping, C&G and Testing) as shown in tables 5.21, 5.22 and 5.23.

Table 5.21: Autonomous maintenance savings in shaping

S. No.	Name of machines	Maintenance date	Before AM machine spares cost (3 months)	Average maintenance cost/month	After AM machine spares cost (3 months)	Average maintenance cost/month
1	Zedler No. 2	31-Dec-11	142610.08	47536.69	94972.98	31657.65
2	Zeidler No. 4	10-Feb-12	55454.62	18484.87	10332.87	3444.29
3	CNC No. 1	03-Jan-12	139908.54	46636.18	15107.3	5035.66
4	CNC No. 2	01-Jan-12	23831.73	7943.91	17138	5712.66
5	MIM No. 9	29-Jan-12	13135.55	4378.51	1620.55	540
6	TI No. 2	7-Dec-11	5667.04	1889.01	2296.46	765.48
	Total		380607.56	126869.17	141468.16	47155.74

- **Actual savings: INR 239,139.4**

Table 5.22: Autonomous maintenance savings in testing

S. No.	Name of Machines	AM done date	Before AM machine spares cost (3 months)	Average maintenance cost/month	After AM machine spares cost
1	Bending M/C No. 2	11-Jan-12	4555.59	1518.53	Nil
2	Bending M/C No. 3	19-Jan-12	3775.35	1258.45	Nil
3	Bending M/C No. 4	24-Jan-12	506	168.66	Nil
4	IBP Testing M/C No. 1	14-Jan-12	1868.7	622.9	Nil
	Total		10705.64		Nil

- **Actual savings: INR 10705.64**

Table 5.23: Autonomous maintenance savings C&G

S. No.	Name of machines	Maintenance date	Before AM machine spares cost (3 months)	Average maintenance cost/month	After AM machine spares cost (3 months)	Average maintenance cost/month
1	C & G No. 1	12-Jan-12	8289.59	2763.19	6428.74	2142.91
2	C & G No. 2	10-Jan-12	23452.47	7817.49	5609.6	1869.86
3	C & G No. 3	21-Jan-12	16037.41	5345.8	2915.15	971.71
6	C & G No. 6	27-Jan-12	9684.02	3228	290.21	96.73
7	C & G No. 9	25-Jan-12	202.39	67.46	Nil	Nil
8	TC No. 2	10-Feb-12	34423.58	11474.52	10411.29	3470.43
9	TC No. 3	18-Jan-12	54618.87	18206.29	3430.35	1143.45
10	TC No. 4	30-Jan-12	30063.02	10021	10323.17	3441.05
11	TC No. 5	15-Jan-12	116469.05	38823.01	5006.74	1668.66
12	TC No. 6	20-Jan-12	2723.68	907	698.45	232.81
13	TC No. 7	7-Jan-12	69701.77	23233.92	12539.31	4179.77
	Total		365665.85	121887.68	57653.01	19217.38

- **Actual savings: INR 308,012.84**

(B) Defects reduction and saving through improvement initiatives

The percentage reduction in defects and the financial savings gained through the improvement initiatives discussed in section 5.5.8 and 5.5.10 are shown in table 5.24.

Table 5.24: Defects reduction and financial saving through improvementinitiatives

Project Name	Area	% defects (March 2011)	% defects (March 2012)	Actual saving April'11 to Mar'12 (lacs)
To reduce PC rejection	Dryer sorting	6.10%	2.41%	4.13
To reduce Shed bend rejection	Dryer sorting	1.50%	0.88%	15.56
To reduce Shed crack rejection	Dryer sorting	0.40%	0.12%	3.65
To reduce SDC rejection	Dryer sorting	0.70%	0.22%	3.65
To reduce VC rejection	Dryer sorting	1.20%	0.49%	20.42
To reduce Chipping(CP) rejection	Dryer sorting	0.70%	0.51%	1.94
To reduce ACC rejection	Dryer sorting	1.10%	0.65%	0.97
To reduce WF rejection	Dryer sorting	1.40%	1.11%	0.73
To reduce BDC rejection	Kiln sorting	1.82%	0.55%	14.47
To reduce Falling rejection	Kiln sorting	1.73%	0.24%	99.35
To reduce Post Kiln rejection	Post kiln	6.81%	1.11%	150.4
Total				315.24

(C) Overall financial benefits reaped from improvement initiatives

Table 5.25 below shows the overall financial gain of INR 344.27 lacs in the financial year 2011-2012. The overall gain is the sum of savings in section (A) and (B) above plus gains through 5S and kaizens.

Table 5.25: Overall financial benefits from improvement initiatives

S. No	Improvement Initiative	Actual saving in the financial year 2011-12
1	Kaizen in Kiln sorting (To reduce BDC at kiln sorting stage, colour dye applied in core and then insulators are dry finished till the colour disappeared)	022.90
2.	5S	000.55
2	Saving through QIP initiatives (Defects reduction)	315.24
3	Autonomous Maintenance	005.58
	Total Saving (Rs lacs)	344.27

(IV) Space creation

Lean initiatives (5S implementation) allowed a better use of the physical space and machinery at XXX, and created 719 square meter space from the project as shown in figures 5.25 - 5.29.

(V) Breakdown analysis of machines

The gain in break down time in shaping, C&G and testing processes/workstations after autonomous maintenance implementation is shown in tables 5.26, 5.27 and 5.28.

Table 5.26: Average breakdown in the shaping workstation

S. No.	Name of machines	AM done date	Before AM average breakdown 3 months (hours)	After AM average breakdown 3 months (hours)
1	Zedler No.2	31-Dec-11	14	2.5
2	Zeidler No.4	10-Feb-12	6	4
3	CNC No. 1	03-Jan-12	3.5	3.6
4	CNC No. 2	01-Jan-12	4	4
5	MIM No. 9	29-Jan-12	7.83	3.5
6	TI No. 2	7-Dec-11	1.5	3.5
	Monthly average breakdown		6.14 hours	3.52 Ours

Table 5.27: Average breakdown in the C&G workstation

S. No.	**Name of machines**	**AM done date**	**Before AM average breakdown 3 months (hours)**	**After AM average breakdown 3 months (hours)**
1	C & G No. 1	12-Jan-12	5.5	1.8
2	C & G No. 2	10-Jan-12	3.7	1.36
3	C & G No. 3	21-Jan-12	8	4.16
4	C & G No. 4	30-Jan-12	3	2
5	C & G No. 5	8-Feb-12	9.3	2.16
6	C & G No. 6	27-Jan-12	8.6	1.83
7	C & G No. 9	25-Jan-12	3.6	0.6
8	TC No. 2	10-Feb-12	10.5	6.3
9	TC No. 3	18-Jan-12	10.16	4.83
10	TC No. 4	30-Jan-12	8	4
11	TC No. 5	15-Jan-12	9.16	2.5
12	TC No. 6	20-Jan-12	12.3	8.5
13	TC No. 7	7-Jan-12	7	10.6
	Monthly average breakdown		7.60 hours	3.90 hours

Table 5.28: Average breakdown in the testing workstation

S. No.	**Name of machines**	**AM done date**	**Before AM average breakdown 3 months (hours)**	**After AM average breakdown 3 months (hours)**
1	Bending M/C No. 2	11-Jan-12	8.16	2.6
2	Bending M/C No. 3	19-Jan-12	9.6	5.5
3	Bending M/C No. 4	24-Jan-12	8.6	4.6
4	IBP Testing M/C No. 1	14-Jan-12	9.16	2.83
	Monthly average breakdown		8.88 hours	3.88 hours

(VI) Defects reduction analysis in kiln and post kiln processes

A number of action/improvement initiatives have been taken as discussed in the section 5.4.7and 5.4.9 to reduce the defect rejection rates. The improvements of these initiatives are shown in tables 5.29 - 5.31 and figures 5.38 - 5.40.

(a) Kiln rejection

Table 5.29: Monthly average rejections in kiln

Defects reason	Monthly average rejection before lean implementation (MT)	Monthly average rejection after lean implementation (MT)
Round Crack	0.270	0.205
Chipping	0.247	0.116
Peticot Crack	0.125	0.059
Accident	0.056	0.020
Handling	0.056	0.030
Shed Crack Rejection	0.046	0.036
Total	0.800	0.466

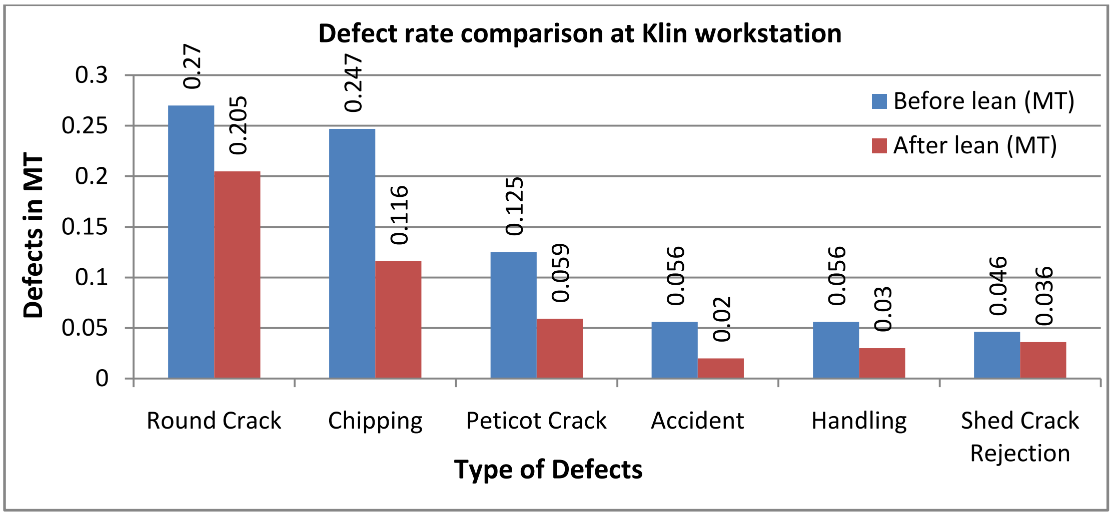


Figure 5.38: Defect rate comparison at kiln workstation

(b) Kiln sorting

Table 5.30: Monthly average rejections in kiln sorting

Rejection reason	Monthly average rejection before lean implementation (MT)	Monthly average rejection after lean implementation (MT)
Peticot Crack	1.61	0.924
Shed Cut	0.28	0.215
Total	1.89	1.139

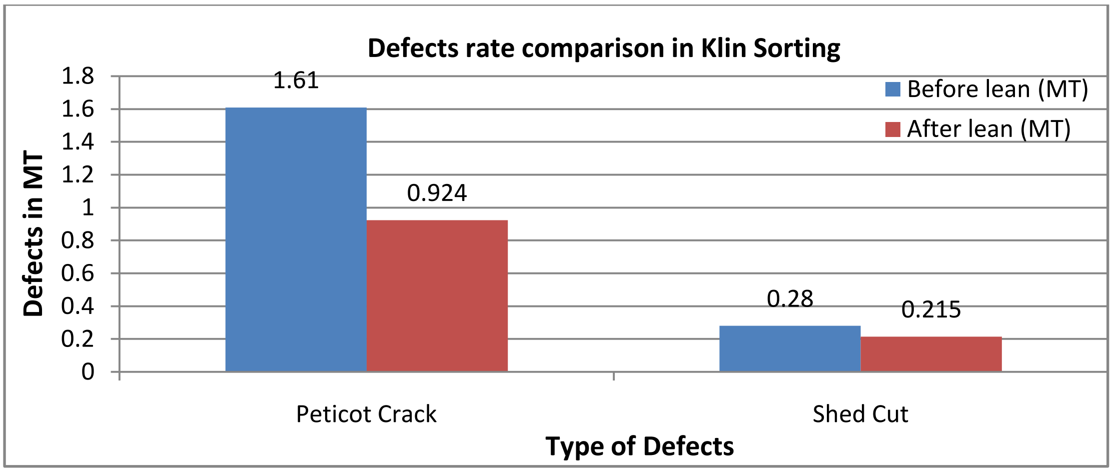


Figure 5.39: Defects rate comparison in kiln sorting

(c) Post kiln rejections

Table 5.31: Monthly average rejections in post kiln processes

Rejection reason	**Monthly average rejection before lean implementation (MT)**	**Monthly average rejection after lean implementation (MT)**
Handling/Chipping	0.234	0.116
ERP stock adjustment at packing/RTST	0.139	0.099
Inside Bottom/Inside Top	0.073	0.049
Broken	0.046	0.020
Inside Crack/Surface Crack	0.043	0.026
Cavity/CMV	0.033	0.023
Total	0.568	0.333

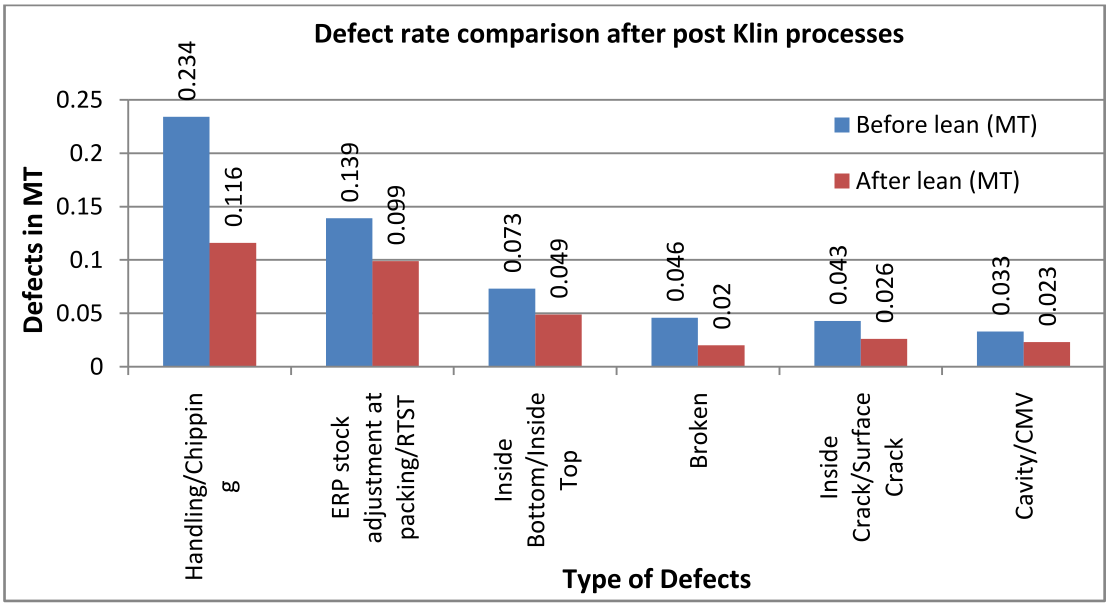


Figure 5.40: Defect rate comparison after post kiln processes

(d) Material handling rejection

Table 5.32 shows the handling rejections. It can be observed that handling rejections have been reduced.

Table 5.32: Material handling rejections

Stages	**Status for the period from 01/010/2011 To 15/01/2012 (%)**	**Status for the period from 16/01/2012 To 30/04/2012 (%)**	**Difference**
Dryer Sorting	1.66	1.45	0.21
Glazing	0.37	0.29	0.08
Kiln Loading	0.39	0.36	0.03
Kiln Sorting	0.59	0.29	0.30
Cutting & Grinding	0.04	0.03	0.01
Assembly	0.13	0.03	0.10
Testing	0.30	0.14	0.16

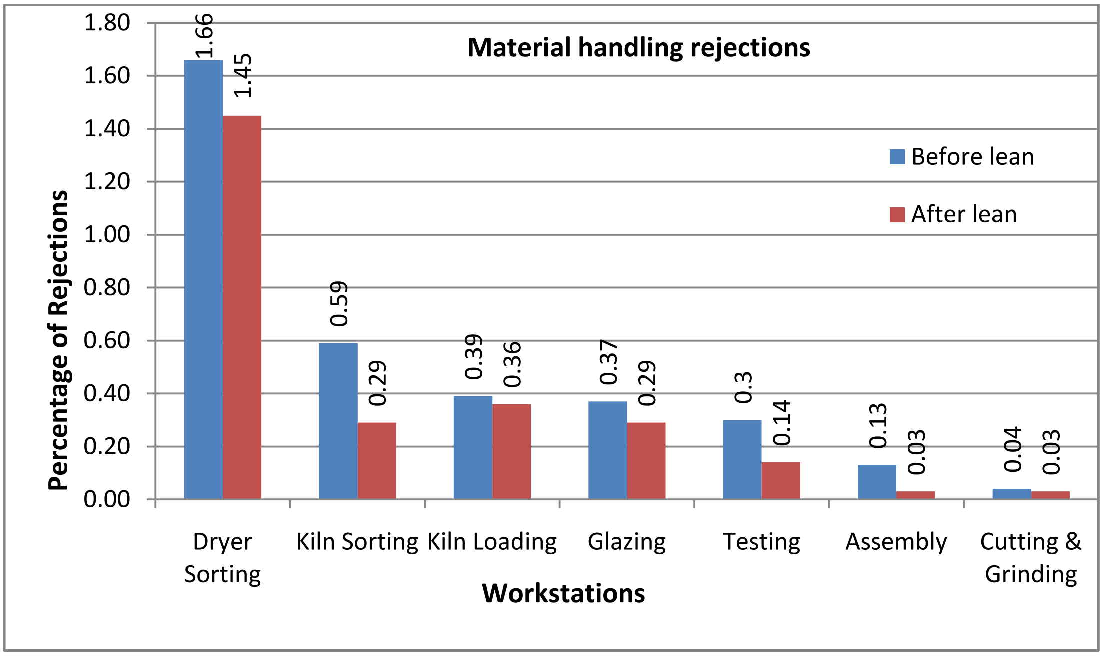


Figure 5.41: Material handling rejections

Before lean manufacturing implementation, overall monthly post kiln rejections were 3.258 MT and after LM implementation it is 1.938 MT, i.e. an improvement of 40.51%. These calculations are based on monthly average defects in the tables 5.30-5.32.

(VII) WIP reduction at different processes/workstations

WIP has been reduced in the organization by reducing various defects. Table 5.33 shows the WIP reduction at various processes/workstations.

Table 5.33: WIP at different processes/workstations

S. No.	WIP Before Workstation	WIP Before Lean (MT)	WIP After Lean (MT)
1	Dryer	35.00	00.00
2	Glazing	00.21	00.00
3	Dipping	00.20	00.00
4	Gravelling	00.19	00.00
5	Kiln Sorting	16.50	13.20
6	Cutting & Grinding	49.50	33.00
7	Assembly	198.0	132.0
8	Routine Testing	82.50	50.00
9	Final Inspection	82.50	50.00
10	Packing	264.0	188.0
	Total	728.60	466.20

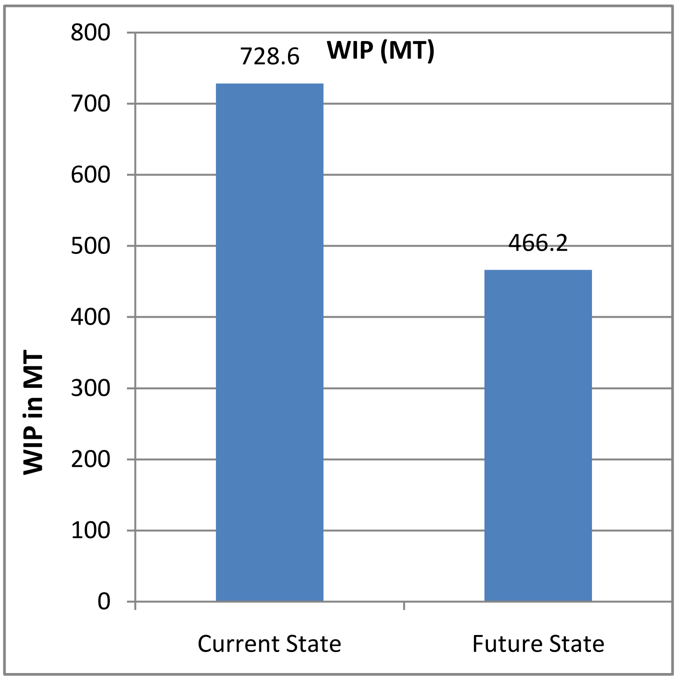


Figure 5.42: WIP reduction

Overall WIP is reduced by 36% starting from ball milling to packaging as shown in figure 5.42.

(VIII) Reduction in manpower

One piece flow in dry finishing, glazing, dipping and gravelling reduced manpower in transferring of products. Also, kaizens in testing and changing the position of tools in pugging, kiln etc., resulted in reduction of manpower. The total reduction in manpower is 6.85% as shown in figure 5.43. It is possible to reduce manpower further by adopting leveled and balanced workloads at different workstations.

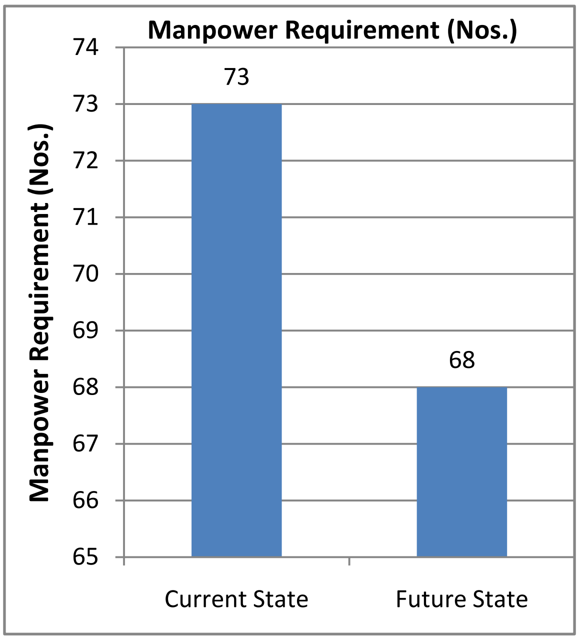


Figure 5.43: Manpower reduction

5.5.2 Review (recognition & awards, and customer satisfaction)

'Kaizen awards' was introduced for employee(s) suggesting kaizen for the improvement. The award is in term of cash/bonus/salary increments depending upon the importance of the kaizen and the employees involved in suggestion. Recognition of good work is also done through annual certificates/mementoes to motivate the employees which are the ultimate strategy to combat burnouts. Pay revision system has been linked with the performance of the workers.

The organization has started recording multiple complaints from customers and also maintains a central complaint registration system. After customer complaints are received, the “vital few” complaints are studied in-depth to discover their basic causes by marketing/quality control department. Regular customer satisfaction surveys was started to track customer perceptions of the quality of the firm and its competitors. This information will be used to improve the quality of products and services in future.

5.6 CONTINUOUS IMPROVEMENT

It is the continuous improvement concept in the system which involves an extended journey, gradually building up skills and capabilities within the organization to find the new problems/wastes in the system and solving them with the help of different tools and techniques. There is always room for improvement and looking to improve every day is the spirit of lean teams.

5.7 CONCLUSIONS

The case study in this chapter shows the validation of the lean manufacturing implementation framework proposed in chapter 4. The execution of the case study has been divided into pre implementation, implementation and post implementation phases as per proposed framework. It has shown that the external lean consultants/facilitators are more effective in removing the resistance of the employees to change. The study has shown the importance of value stream mapping, 5S, kaizen, and TPM in lean manufacturing implementation in ceramic industry. The productivity and quality of the case organization has improved. The organization has also become flexible by eliminating wastes at various processes/workstations and responds to fluctuating customer demands quickly and efficiently. The important tools used for the case study in implementation phase are VSM, TPM, 5S, and *kaizens*.

The pre implementation and post implementation performance measure validate the lean manufacturing benefits. The various quantitative benefits of lean manufacturing implementation for the case organization are:

- Waiting time reduction by 32%
- Processing time reduction by 191.56 min. (1.02%)
- Reduction in inventory/WIP by 36%
- Defects reduction (average) by 40.51%
- Space creation for further use is 719 square meters
- Reduction in manpower by 6.85%
- Cost saving of Rs 344.27 lacs in the financial year 2011-12

Qualitative benefits have also been observed in term of skill up gradation, team work, multi skilling and improved morale of the employees.

CHAPTER 6

CONCLUSIONS

Nowadays, to sustain in the dynamic business scenario, companies are adopting new manufacturing philosophies/tools/practices. Among them, lean manufacturing is widely accepted philosophy which brings significant benefits/improvements in the performance parameters. But it is not an easy task to implement the LM as there are lots of issues associated with the lean manufacturing implementation like, organizational culture, top management commitment, employee involvement, methodology adopted to implement, etc. Any organization must know all the aspects of lean manufacturing before implementing it.

Chapter 2 presents a review of research papers on lean manufacturing/lean production. The review focuses on research contribution, research methodologies, type of industry, and author profile. Following conclusions are drawn from the review:

- There are many lean manufacturing definitions with divergent objectives and scope.
- Theory verification through empirical and exploratory studies has been the focus of research in LM. More research is based on exploratory longitudinal studies rather than exploratory cross-section studies. Research on LM is conducted across the globe. There are papers from the developed, emerging and under developed countries. However, USA and UK lead the research with more publications.
- The research in LM has picked up since the beginning of the 21st century. Automotive industry has been the focus of LM research but LM has been adopted by other type of

industries also. However, the adoption of LM in SMEs is not widespread because of the fear of high implementation cost and uncertain future benefits. Some sort of external support is required to enhance adoption of LM in SMEs. Success of LM depends largely on the cultural and work practices prevalent in organizations.

- LM has been adopted by all types of manufacturing systems – product layout, process layout, and fixed layout; batch production and mass productions; discrete production and continuous production. LM has found applications from manufacturing to service sector; mass production to high variety and small volumes production; labour-intensive industries to technology intensive industries; construction industry to assembly industry; medical health care to communication industry.
- One of the critical implementation factors of LM is simultaneous adoption of leanness in supply chain. One of the reasons for the slow adoption of LM under variable demand scenario is to link the production pull signal to the variable demand.
- LM adoption led has to more stress at managerial level rather than the shop floor level people.
- There is no standard LM implementation process/framework. LM has become an integrated system composed of highly integrated elements and a wide variety of management practices.

Some of the research issues identified from literature review are:

- The research on LM through empirical and exploratory studies has led to many frameworks with divergent views. Use of a wide variety of management practices has led to different views, devoid of concepts. There is a strong and urgent need to converge these divergent views to some standard framework/process. Development of stepwise guidelines/process for LM implementation, like existing TPM, TQM or six-sigma implementation guidelines, is strongly needed.

- The use of wide variety of management practices in LM implementation has led to a wide range of generic performance indicators. There is a need to develop LM standard/critical metrics for its evaluation before implementation, during implementation, and after implementation.
- Various researchers in LM have used more than 18 tools/techniques/methodologies. Most of these tools/techniques/methodologies are standalone methods, developed and used previously. Further research is required to distinguish the standard tools/techniques/methodologies for LM. Similarly, there are other systems like six sigma, agile manufacturing and green manufacturing which have some elements of lean manufacturing. More research is required to distinguish the common and different elements of LM, agile manufacturing, six sigma and green manufacturing.
- Lean manufacturing has not been adopted by a large number of SMEs due to the fear of implementation cost and benefits. External support from government, suppliers, customers and outside consultants could enhance the successful implementation of lean manufacturing in SMEs. More focused research is required for LM implementation in SMEs.
- A large number of organizational practices have been reported in the literature for the successful implementation of LM. These are standardization, discipline and control, continuous training and learning, team-based organization, participation and

empowerment, multi-skilling and adaptability, common values, compensation and reward system to support lean production, belief, commitment, communication, work methods, management support, remuneration system, accounting system, etc. It may be worthwhile to prioritize these practices to help managers in decision making.

- The genesis of divergent views on LM perhaps lies in its divergent definitions, objectives and scopes. The researchers have developed LM as a way, process, set of principles, approach, concept, philosophy, system, program, and paradigm. The urgent needs are to standardize the LM definition, converge LM scopes and synthesize the LM objectives to a few critical objectives.

Chapter 3 develops statistically reliable and valid models for drivers and barriers of lean manufacturing implementation based on a survey of the ceramic industries. Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) techniques have been used for modeling. The drivers and barriers to lean manufacturing, developed on the basis of literature review and discussions held with relevant academicians and industry experts are divided into groups using SPSS statistical tool. Drivers are divided into three groups - internal drivers (low manpower productivity, high scraps/reworks/rejection, poor skills/ capabilities of workers, unavailability of skilled workers), policy drivers (weak process control, unbalanced workload on different workstations, poor workplace organization/ housekeeping, lack of standard operating procedures) and external drivers (fluctuating customer orders, low quality material by suppliers, suppliers take a long time to deliver, high product variety/customer specific product). Barriers are divided into two groups - policy & economic barriers (lack of top management commitment, high cost of consultant fee for training, misconception of high investment to implement lean, inadequate training opportunity, not an industry norm like ISO) and operational barriers (resistance to change and adopt innovations, too much time and effort required to implement lean, too general and not industry specific procedures, low awareness of lean manufacturing). Structural equation modeling technique has been used to test these models. Hypotheses testing affirm that external drivers are positively related to policy drivers, and policy drivers are positively related to internal drivers. Also, policy and economic barriers are positively related to operational barriers and hence these should be mitigated first.

Chapter 4 provides the review of 21 lean manufacturing frameworks with respect to comprehensiveness, abstractness, clarity in role definition, complexity, type of framework, level of framework, lean prerequisites incorporation, and performance indicator usage. A new framework has been proposed taking in consideration the strengths and mitigating weaknesses of the existing frameworks as well as the views of industry experts. The proposed framework is in three phases, viz., pre-implementation, implementation and post implementation. The main characteristics of the proposed framework are:

- The framework emphasizes the importance of lean manufacturing philosophy. How and how much lean philosophy will benefit needs to be understood. Understanding of various types of waste, continuous improvement, customer focus, and sustainability in process facilitates lean manufacturing understanding.

- Organization should identify lean drivers and barriers to leverage the drivers and mitigate the barriers before starting implementation. Involvement of all employees from top to bottom should be ensured for effective and sustainable implementation.
- All stakeholders of lean manufacturing implementation should be involved through education and training.
- Lean implementation team should walk and see all supply chain activities (suppliers, input, process, output, and customers) to understand the flow of material and information from supplier to customer. There is a need to identify the areas of improvement.
- There is need to identify appropriate tools and techniques throughout SIPOC (suppliers, input, process, output, and customer) to implement lean throughout the whole supply chain.
- Performance improvement matrices should be reviewed.
- Recognition and reward system for employees should be introduced.
- There should be a review of customer satisfaction.

It is believed that the proposed lean implementation framework will serve as a guide map for the transition from non-lean to lean manufacturing.

A case study is presented in chapter 5 to validate the lean manufacturing implementation framework proposed in chapter 4. The execution of the case study has been divided into pre implementation, implementation and post implementation phases as per proposed framework. It has shown that the external lean consultants/facilitators are more effective in removing the resistance of the employees to change. The study has shown the importance of value stream mapping, 5S, kaizen, and TPM in lean manufacturing implementation in ceramic industry. The productivity and quality of the case organization has improved. The organization has also become flexible by eliminating wastes at various processes/workstations and responds to fluctuating customer demands quickly and efficiently. The important tools used for the case study in implementation phase are VSM, TPM, 5S, and *kaizens*.

The pre implementation and post implementation performance measure validate the lean manufacturing benefits. The various quantitative benefits of lean manufacturing implementation for the case organization are:

- Waiting time reduction by 32%
- Processing time reduction by 191.56 min. (1.02%)
- Reduction in inventory/WIP by 36%
- Defects reduction (average) by 40.51%
- Space creation for further use is 719 square meters
- Reduction in manpower by 6.85%
- Cost saving of Rs 344.27 lacs in the financial year 2011-12

Qualitative benefits have also been observed in term of skill up gradation, team work, multi skilling and improved morale of the employees.

Some specific research contributions of the study:

- The extensive review of literature reveals that lean manufacturing may be adopted, irrespective of the type of the organization.

- Drivers and barriers of lean manufacturing implementation are developed based on an exhaustive review of literature and discussions with the practitioners.
- A survey instrument is developed to collect the data for drivers and barriers of lean implementation.
- Reliability and validity of the lean manufacturing drivers and barriers were assessed by using SPSS® 17 for MS Windows®.
- Development of a lean manufacturing implementation framework based on a critical review of the existing frameworks and discussion with industry experts.
- In this research the use of lean manufacturing tools and techniques in the process industry are addressed and in particular the ceramic industry as represented by MIL, to show the productivity and quality improvement in this sector. The primary idea of this research is to help the ceramic industries to take new initiatives such as lean manufacturing in order to become cost-competitive in today's global market. This research can be readily extended to other similar industries of Rajasthan like textile, metal etc, which play a significant role in the state's economy.

Limitations and scope for future research:

First, the sampling technique used in the survey is not a probability sampling method which delimits the generalizability of the conclusions. The sample size for the validation of drivers and barriers is small. The questionnaire may be tested on a large sample. The items in the questionnaire are subjective in nature. Respondents were asked to rate items based on their perception, to gauze the extent to which the items are applicable in their respective companies. Hence, the lack of objective measures might have introduced certain amount of bias into the data collected. The influence of demographic traits on performance may also be assessed.

The present study has concentrated on ceramic industry of Rajasthan only. To test the wider validity of the instrument, the work can be extended to other types of industries, different size of industries and at different places. One specific limitation of the study is also non-homogeneous sample. Research may be also carried out to correlate overall change with employee and customer satisfaction.

REFERENCES

Aalbregtse, R. J., Hejka, J. A. and McNeley P.K. (1991), "TQM: How do you do it?" *Automation*, Vol. 38, No. 8, pp. 30-32.

Abdulmalek, F.A. and Rajgopal, J. (2007), "Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study", *International Journal of Production Economics*, Vol. 107, No. 1, pp. 223-236.

Achanga, P., Shehab, E., Roy, R. and Nelder, G. (2005), "Critical success factors for lean implementation within SMEs", *Journal of Manufacturing Technology Management*, Vol. 17, No. 4, pp. 460-471.

Achanga, P., Shehab, E., Roy, R. and Nelder, G. (2006), "Critical success factors for lean implementation within SMEs", *Journal of Manufacturing Technology Management*, Vol. 17, No. 4, pp. 460-471.

Achanga, P., Shehab, E., Roy, R. and Nelder, G. (2012), "A fuzzy-logic advisory system for lean manufacturing within SMEs", *International Journal of Computer Integrated Manufacturing*, DOI 10.1080/0951192X.2012.665180, published online on 19th March, 2012.

Agrawal, R.K. and Hurriyet, H. (2004), "The advent of manufacturing technology and its implications for the development of the value chain", *International Journal of Physical Distribution & Logistics Management*, Vol. 34, No. 3/4, pp. 319-339.

Agus, A. and Hajinoor, M.S. (2012), "Lean production supply chain management as driver towards enhancing product quality and business performance: Case study of manufacturing companies in Malaysia", *International Journal of Quality & Reliability Management*, Vol. 29, No. 1, pp. 92-121.

Ahlstrom, P. (1998), "Sequences in the implementation of lean production", *European Management Journal*, Vol. 16, No. 3, pp. 327-334.

Åhlström, P. and Karlsson, C. (1996), "Change processes towards lean production-The role of the management accounting system", *International Journal of Operations & Production Management*, Vol. 16, No. 11, pp. 42-56.

Ahlstrom, P. and Karlsson, C. (2000), "Sequences of manufacturing improvement initiatives: The case of delayering", *International Journal of Operations & Production Management*, Vol. 20, No. 11, pp. 1259–1277.

Airbus, (2004), “Six steps to implementing lean”, *White Paper*, available at: www.manufacturingfoundation.org.uk/PriorResearch.pdf (Cited on 20th Sep. 2012).

Aitken, Dr. J., Christopher, M. and Towill, D. (2002), “Understanding, Implementing and Exploiting Agility and Leanness”, *International Journal of Logistics: Research & Applications*, Vol. 5, No. 1, pp. 59-74.

Akao, Y. and Mazur, G.H. (2003), “The leading edge in QFD: Past, present and future”, *International Journal of Quality & Reliability Management*, Vol. 20, No. 1, pp. 20-35.

Alhourani, F. and Seifoddin, H. (2007), “Machine cell formation for production management in cellular manufacturing systems”, *International Journal of Production Research*, Vol. 45, No. 4, pp. 913-934.

Al-Tahat, M.D. (2010), “Effective Design and Analysis of Pattern Making Process Using Value Stream Mapping”, *Journal of Applied Sciences*, Vol. 10, No. 11, pp. 878-886.

Alukal, G. (2003), “Create a Lean, Mean Machine”, *Quality Progress*, Vol. 36, No. 4, pp. 29-34.

Álvarez, R., Calvo, R., Peña, M.M. and Domingo, R. (2009), “Redesigning an assembly line through lean manufacturing tools”, *International Journal of Advanced Manufacturing Technology*, Vol. 43, No. 1, pp. 949-958.

Amin, M. A. and Karim, M. A. (2011), “A systematic approach to evaluate the process improvement in lean manufacturing organizations”, *The 9th Global Conference on Sustainable Manufacturing*, 28-30 September 2011, LENEXPO Exhibition Center, St. Petersburg.

Anand, G. and Kodali, R. (2009a), “Selection of lean manufacturing systems using the analytic network process: a case study”, *Journal of Manufacturing Technology Management*, Vol. 20, No. 2, pp. 258-289.

Anand, G. and Kodali, R. (2009b), “Application of Value stream mapping and simulation for the design of lean manufacturing systems: a case study”, *International Journal of Simulation and Process Modeling*, Vol. 15, No. 2, pp. 192-204.

Anand, G. and Kodali, R. (2010 a), “Development of a framework for implementation of lean manufacturing systems”, *International Journal of Management Practice*, Vol. 4, No. 1, pp. 95–116.

Anand, G. and Kodali, R. (2010 b), "Analysis of Lean Manufacturing Frameworks", *Journal of Advanced Manufacturing Systems,* Vol. 9, No. 1, pp. 1–30.

Anand, G. and Kodali, R. (2011), "Design of lean manufacturing systems using value stream mapping with simulation", *Journal of Manufacturing Technology Management,* Vol. 22, No. 4, pp. 44-473.

Anderson, S. (2002), *Poka-Yoke: Mistake-Proofing as a Preventive Action,* The Informed Outlook (Special Reprint March 2002), Newsletter, pp. 1-4.

Andersson, R., Eriksson, H. and Torstensson, H. (2006), "Similarities and differences between TQM, six sigma and lean", *The TQM Magazine*, Vol. 18, No. 3, pp. 282-296.

Anon (2001a), *Daimler Chrysler Corporation's New Toledo North Assembly plant represents worldwide best practices for lean, flexible, high-quality manufacturing*, Reprint from Gale Group.

Antony, J. (2011), "REFELECTIVE PRACTICE: Six Sigma v/s Lean, Some perspectives from leading academician and practitioners", *International Journal of Productivity and Performance Management*, Vol. 60, No. 2, pp. 185-190.

Antony, J., Kumar, M., Madu, C.N. (2005), "Six sigma in small and medium sized UK manufacturing enterprises: some empirical observations", *International Journal of Quality & Reliability Management*, Vol. 22 No.8, pp.860-74.

Arawati, A. and Abdullah, M. (2000), "Total quality management practices in manufacturing companies in Malaysia: An exploratory analysis", *Total Quality Management*, Vol. 11, No. 8, pp. 1041-1051.

Arkader, R. (2001), "The perspective of suppliers on lean supply in a developing country context", *Integrated Manufacturing Systems*, Vol. 12, No. 2, pp. 87-93.

Arnheiter, E.D. and Maleyeff, J. (2005), "The integration of lean management and Six Sigma", *The TQM Magazine,* Vol. 17, No. 1, pp. 5-18.

Assarlind, M., Gremyr, I. and Backman, K. (2012), " Multi- faceted views on a Lean Six Sigma application", *International Journal of Quality & Reliability Management,* Vol. 29, No. 1, pp. 21-30.

Atkinson, P. and Mukaetova- Ladinska, E.B. (2012), "Nurse-led liaison mental health service for older adults: Service development using lean thinking methodology", *Journal of Psychosomatic Research,* Vol. 72, No. 1, pp. 328-331.

Aurelio D., Grilo A. and Cruz-Machado, V. (2011), "A Framework for Evaluating Lean Implementation Appropriateness", *2011 IEEE International Conference on Industrial Engineering and Engineering Management*, 6-9 December 2011, Singapore, pp. 779-783.

Bamber, L. and Dale, B. G. (2000), "Lean production: a study of application in a traditional manufacturing environment", *Production Planning and Control*, Vol. 11, No. 3, pp. 291-298.

Barker, R.C. (1994), "The Design of Lean Manufacturing Systems Using Time-based Analysis", *International Journal of Operations & Production Management*, Vol. 14, No. 11, pp. 86-96.

Bartholomew, D. J., Steele, F., Galbraith, J. and Moustaki, I. (2008), *Analysis of Multivariate Social Science Data*, Statistics in the Social and Behavioral Sciences (2nd Ed), Taylor & Francis.

Bayo- Moriones, A., Bello-Pintado, A. and Merino-Diaz-de-Cerio, J. (2008), "The role of organizational context and infrastructure practices in JIT implementation", *International Journal of Operations & Production management*, Vol. 28, No. 11, pp. 1042-1066.

Behrouzi, F. and Wong, K.Y. (2011), "Lean performance evaluation of manufacturing systems: a dynamic and innovative approach", *Procedia Computer Science,* Vol. 3, No. 1, pp. 388-395.

Bendell, T. (2006), "A review and comparison of six sigma and the lean organizations", *The TQM Magazine*, Vol. 18, No. 3, pp. 255-262.

Bentler, P. M. (1989), *EQS: Structural equations program manual, version 3.0. Los Angeles: BMDP Statistical Software Inc.*

Bergmiller, G.G. and McCright, P.R. (2009), "Parallel Models for Lean and Green Operations", *Proceedings of the 2009 Industrial Engineering Research Conference*, Miami, FL, May 2009.

Berry, W.L., Christiansen, T., Bruun, P. and Ward, P. (2003), "Lean Manufacturing: A Mapping of Competitive Priorities, Initiatives, Practices, and Operational Performance in Danish Manufacturers", *International Journal of Operations & Production Management*, Vol. 23, No. 11, pp. 16-29.

Bhamu, J. and Sangwan K S (2011), “Lean manufacturing tools and techniques: a review of literature during 2001-2010”, *In: Proc. of the International Congress on Productivity, Quality, Reliability, Optimization and Modeling,* ISI New Delhi, India, February 7-8, 2011, pp 979-990.

Bhamu, J.P., Kumar, J.V.S and Sangwan, K.S. (2012), “Productivity and quality improvement through value stream mapping: a case study of Indian automotive industry”, *International Journal of Productivity and Quality Management*, Vol. 10, No. 3, pp. 288-306.

Bhasin, S. (2008), “Lean and Performance Measurement”, *Journal of Manufacturing Technology Management*, Vol. 19, No. 5, pp. 670–684.

Bhasin, S. (2012), “Prominent obstacles to Lean”, *International Journal of Productivity and Performance Management*, Vol. 61, No. 4, pp. 403-425.

Bhasin, S. and Burcher, P. (2006), “Lean viewed as a philosophy”, *Journal of Manufacturing Technology Management*, Vol. 17, No. 1, pp. 56-72.

Biazzo, S. and Panizzolo, R. (2000), “The assessment of work organization in lean production: the relevance of the worker’s perspective”, *Integrated Manufacturing Systems,* Vol. 11, No. 1, pp. 6-15.

Black, J.T. (2007), “Design rules for implementing the Toyota Production System”, *International Journal of Production Research*, Vol. 45, No. 16, pp. 3639-3664.

Black, S. and Porter, L. (1996), “Identification of critical factors of TQM”, *Decision Sciences*, Vol. 27, No. 1, pp. 1-21.

Blanchard, K., Carlos, J. P. and Randolph, A., (2001), *Empowerment Takes More Than A Minute*, 2nd ed., Berrett-Koehler Publishers, SanFrancisco.

Bollbach, M. (2010), “Implementing Lean Manufacturing Techniques in China**:** A consideration of country-specific barriers to implementing lean manufacturing in China”, *Conference Global Economic recovery,* University of Oxford.

Bonavia, T. and Marin, J.A. (2006), “An empirical study of lean production in the ceramic tile industry in Spain”, *International Journal of Operations & Production Management*, Vol. 26, No. 5, pp. 505-531.

Booth, R. (1996). “Agile Manufacturing”, *Engineering Management Journal*, Vol. 6, No. 2, pp. 105-112.

Bortolotti, T. and Romano P. (2012), "Lean first, then automate: a framework for process improvement in pure service companies. A case study", *Production Planning & Control: The Management of Operations*, Vol. 23, No. 7, pp. 513-522.

Bowen, E.D. and Youngdahl, E.W. (1998), "Lean" service: in defense of a production-line approach", *International Journal of Service Industry Management*, Vol. 9, No. 3, pp. 207-225.

Boyer, K.K. (1996), "An assessment of managerial commitment to lean production", *International Journal of Operations & Production Management*, Vol. 16, No. 9, pp. 48-59.

Boyle, T.A. and Scherrer-Rathje, M. (2009), "An empirical examination of the best practices to ensure manufacturing flexibility Lean alignment", *Journal of Manufacturing Technology Management*, Vol. 20, No. 3, pp. 348-366.

Braglia, M., Carmignani, G. and Zammori, F. (2006), "A new value stream mapping approach for complex production systems", *International Journal of Production Research*, Vol. 44, No. 18-19, pp. 3929-3952.

Braglia, M., Frosolini, M. and Zammori, F. (2009), "Uncertainty in value stream mapping analysis", *International Journal of Logistics: Research and Applications*, Vol. 12, No. 6, pp. 435-453.

Brown, A., Eatock, J., Dixon, D., Meenan, B.J. and Anderson, J. (2008), "Quality and continuous improvement in medical device manufacturing", *The TQM Magazine*, Vol. 20, No. 6, pp. 541-555.

Browning, T. and Heath, R. (2009), "Reconceptualizing the effects of lean on production costs with evidence from the F-22 Program", *Journal of Operations Management*, Vol. 27, No. 1, pp. 23-44.

Bruce, M., Daly, L. and Towers, N. (2004), "Lean or agile, A solution for supply chain management in the textiles and clothing industry?" *International Journal of Operations & Production Management*, Vol. 24, No. 2, pp. 151-170.

Burcher, P., Dupernex, S. and Relph, G. (1996), "The road to lean repetitive batch manufacturing -Modeling planning system performance", *International Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 210-220.

Burrill, C. and Ledolter, J. (1999), *Achieving quality through continual improvement*, 1st ed., John Wiley & Sons, Inc.

Byrne, B.M. (2001), *Structural Equation Modeling with AMOS: Basic concepts, applications, and programming,* Mahwah, N.J.: Lawrence Erlbaum Associates.

Chan, L. and Wu, M. (2002), "Quality function deployment: A literature review", *European Journal of Operational Research,* Vol. 143, No. 3, pp. 463-497.

Chen, H., Wyrick, D.A. and Lindeke, R.R. (2010), "Lean automated manufacturing: avoiding the pitfalls to embrace the opportunities", *Assembly Automation,* Vol. 30, No. 2, pp. 117-123.

Chen, L. and Meng, B. (2010a), "Why most Chinese enterprises fail in deploying lean production", *Asian Social Science,* Vol. 6, No. 3, pp. 52-57.

Chen, L. and Meng, B. (2010b), "The Application of Value Stream Mapping Based Lean Production System", *International Journal of Business and Management,* Vol. 5, No. 6, pp. 203-209.

Christopher, M. (2000), "The Agile Supply Chain-Competing in Volatile Markets", *Industrial Marketing Management*, Vol. 29, No. 1, pp. 37-44.

Christopher, M. and Towill, D.R. (2000), "Supply chain migration from lean and functional to agile and customized", *Supply Chain Management: An International Journal,* Vol. 5, No. 4, pp. 206-213.

Christopher, M., Towill, D.R., Aitken, J. and Childerhouse, P. (2009), "Value stream classification", *Journal of Manufacturing Technology Management*, Vol. 20, No. 4, pp. 460-474.

Clausing, D. and Pugh, S. (1991), "Enhanced quality function deployment", *Proceedings of the Design Productivity International Conference,* February 6-8, Honolulu, HI, pp. 15-25.

Claycomb, C., Germain, R. and Droge, C. (1999), "Total system JIT outcomes: inventory, organization and financial effects", *International Journal of Physical Distribution & Logistics Management,* Vol. 29, No. 10, pp. 612-630.

Comm, C.L. and Mathaisel, D.F.X. (2000), "A paradigm for benchmarking lean initiatives for quality improvement", *Benchmarking: An International Journal*, Vol. 7, No. 2, pp. 118-128.

Comm, C.L. and Mathaisel, D.F.X. (2005), "An Exploratory Analysis in Applying Lean Manufacturing to a Labor-Intensive Industry in China", *Asia Pacific Journal of Marketing and Logistics*, Vol. 17, No. 4, pp. 63-80.

Conti, R., Angelis, J., Cooper, C., Faragher, B. and Gill, C. (2006), "The effects of lean production on worker job stress", *International Journal of Operations & Production Management*, Vol. 26, No. 9, pp. 1013-1038.

Cook, C. R. and Graser, J.C. (2003), "The effect of lean manufacturing", *Research Monograph*, http://rand.org/pubs/monographreports/MR1325/ MR 1325.ch2.pdf (Cited on 20th Sep. 2012).

Cooney, R. (2002), "Is "lean" a universal production system? Batch Production in the automotive industry", *International Journal of Operations & Production Management*, Vol. 22, No. 10, pp. 1130-1147.

Cooper (Jr.), J.J. (2009), "The integration of lean manufacturing competency-based training course into university curriculum", *Online Journal of Workforce Education and Development,* Vol. 4, No. 1, pp. 1-12.

Cooper, R. (1996), "Lean enterprises and the confrontation strategy", *The Academy of Management Executive*, Vol. 10, No. 3, pp. 28-39.

Cottyn, J. H., Landeghem, V., Stockman, k. and Derammelaere, S. (2011), "A method to align a manufacturing execution system with Lean objectives", *International Journal of Production Research*, Vol. 49, No. 14, pp. 4397-4413.

Cox, J.F. and Blackstone, J.H. (Eds) (1998), *APICS Dictionary, 9th ed., APICS–The Educational Society for Resource Management*, Falls Church, VA.

Cua, K., McKone, K. and Schroeder, R.G. (2001), "Relationships between implementation of TQM, JIT, and TPM and manufacturing performance", *Journal of Operations Management*, Vol. 19, No. 6, pp. 675-94.

Dale, B.G. (1999), *Managing Quality*, Blackwell Publishers, Oxford.

Dankbaar, B. (1997), "Lean production: denial, confirmation or extension of Socio-technical systems design*?", Human Relations*, Vol. 50, No. 5, pp. 567-583.

Davies, C. and Greenough, R. M. (2001), "Maintenance survey- identification of lean thinking within maintenance", in Proceedings of the *17th National Conference on Manufacturing Research*, Cardiff, UK, pp. 37–42.

Davy, J. A., White, R. E., Merritt, N. J. and Gritzmacher, K. (1992), "A derivation of the underlying constructs of just-in-time management systems", *Academy of Management Journal*, Vol. 35, No. 1, pp. 653-70.

Dawes, J., Faulkner, M. and Sharp, B. (1998), "Business orientation scales: development and psychometric assessment" *In proc. of 27th EMAC Conference Stockholm*, Vol. 5, pp. 461-478.

De Treville, S. and Antonakis, J. (2006), “Could lean production job design be intrinsically motivating? Contextual, configurational, and levels-of-analysis issues”, *Journal of Operations Management*, Vol. 24, No. 2, pp. 99-123.

Delgado, C., Ferreira, M. and Branco, M.C. (2010), “The implementation of lean six sigma in financial services organizations”, *Journal of Manufacturing Technology Management*, Vol. 21, No. 4, pp. 512-523.

Demeter, K. and Matyusz, Z. (2010), “The impact of lean practices on inventory turnover”, *International Journal of Production Economics*, Vol. 133, No.1, pp.154-163.

Deming, W. E. (1986), *Out of the crisis: quality, productivity and competitive position*, Cambridge University Press.

Dentz, J., Nahmens, I. and Mullens, M. (2009), “Applying lean production in factory home building”, *City space: A Journal of Policy Development and Research,* Vol. 11, No. 1, pp. 81-104.

Dettmer, H. W. (2001), *Beyond Lean manufacturing: Combining Lean and the Theory of Constraints for higher performance*, Port Angeles, US.

Dewhurst, M., Guthridge, M. and Mohr, E. (2010), *Motivating people: getting beyond money, Business Source Complete.* Available at: http://samedayessay.com, (Cited on 20th Sep. 2012).

Dombrowski, U. and Zahn, T. (2011), “Design of a Lean Development Framework”, *2011 IEEE International Conference on Industrial Engineering and Engineering Management*, 6 – 9 December 2011, Singapore, pp. 1917.

Doolen, T.L. and Hacker, M.E. (2005), “A review of lean assessment in organizations: an exploratory study of lean practices by Electronics manufacturers”, *Journal of Manufacturing Systems,* Vol. 24, No. 1, pp. 55-67.

Dowlatshahi, S. and Taham, F. (2009), “The development of a conceptual framework for Just-In-Time implementation in SMEs”, *Production Planning & Control*, Vol.20, No.7, pp. 611-621.

Drickhamer, D. (2000), *Manufacturer of automotive climate-control systems follows lean manufacturing map*, Reprint from Gale Group.

Emiliani, M.L. (2000), “Supporting small businesses in their transition to lean production”, *Supply Chain Management: An International Journal*, Vol. 5, No. 2, pp. 66-71.

Emiliani, M.L. (2006), "Origins of lean management in America-The role of Connecticut businesses", *Journal of Management History*, Vol. 12, No. 2, pp. 167-184.

Emiliani, M.L. and Stec, D.J. (2004), "Using Value – Stream maps to improve leadership", *The Leadership & Organization Development Journal*, Vol. 25, No. 8, pp. 622-645.

Eroglu, C. and Hofer, C. (2011), "Lean, leaner, too lean? The inventory- performance link revisited", *Journal of Operations Management*, Vol. 29, No. 1, pp. 356-369.

Eswaramoorthi, M., Kathiresan, G. R., Prasad, P. S. S. and Mohanram, P. V. (2011), "A survey on lean practices in Indian machine tool industries", *International Journal of Advanced Manufacturing Technology*, Vol. 52, No.1, pp. 1091-1101.

Feld, W. (2000), *Lean manufacturing: Tools, techniques, and how to use them*, Boca Raton, FL: St. Lucie Press.

Feld, W.M. (2001), *Lean Manufacturing Tools & Techniques and How to Use Them,* APICS Series on Resource Management, The St Luis Press.

Fine, D., Hansen, M. A. and Roggenhofer, S. (2008), *From Lean to lasting: Making operational improvements stick*, The McKinsey Quarterly.

Flinchbaugh, J.W. (1998), "Implementing lean manufacturing through factory design", *Unpublished Master's Thesis*, Massachusetts Institute of Technology.

Flinchbaugh, J.W. (2003), "Beyond lean: building sustainable business and people success through new ways of thinking", *Center for Quality of Management Journal*, Vol. 10, No. 2, pp. 37-50.

Flynn, B. B., Schroeder, R. G. and Sakakibara, S. (1994), "A framework for quality management research and an associated measurement instrument", *Journal of Operations Management*, Vol. 11, No. 4, pp. 339-366.

Flynn, B.B. and Saladin, B. (2006), "Relevance of Baldrige constructs in an international context: A study of national culture", *Journal of Operations Management*, Vol. 24, No. 5, pp. 583.

Forza, C. (1996), "Work organization in lean production and traditional plants-What are the differences?", *International Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 42-62.

Fraser, K., Harris, H. and Luong, L. (2007), “Improving the implementation effectiveness of cellular manufacturing: a comprehensive framework for practitioners”, *International Journal of Production Research*, Vol. 45, No. 24, pp. 5835-5856.

Freivalds, A. and Niebel, B. W. (2009), *Niebel's Methods, standards and work design*, McGraw-Hill, New York, United States of America.

Fullerton R.R., McWatters, C.S. and Fawson, C. (2003), “An Examination of the Relationship between JIT and Financial Performance”, *Journal of Operations Management*, Vol. 21, No 4. pp. 383–404.

Fullerton, R.R. and Wempe, W.F. (2009), “Lean manufacturing, non-financial performance measures, and financial performance”, *International Journal of Operations & Production Management*, Vol. 23, No. 3, pp. 214-240.

Furterer, S. and Elshennawy, A.K. (2005), “Implementation of TQM and Lean Six Sigma Tools in Local Government: a Framework and a Case Study”, *Total Quality Management*, Vol. 16, No. 10, pp. 1179-1191.

Galsworth, G. D. (1997), *Visual Systems: Harnessing the Power of Visual Workplace*, AMACOM, New York, USA.

Gapp, R., Fisher, R. and Kobayashi, K. (2008), “Implementing 5S within a Japanese context: an integrated management system”, *Management Decision*, Vol. 46, No. 4, pp. 565-579.

Gebauer, H., Friedli, T., Fleisch, E. (2006), "Success factors for achieving high service revenues in manufacturing companies", *Benchmarking: An International Journal*, Vol. 13, No. 3, pp. 374-386

Gehin, A., Zwolinski, P. and Brissaud, D. (2008), “A tool to implement sustainable end-of life strategies in the product development phase”, *Journal of Cleaner Production*, Vol. 16, No. 5, pp. 566–576.

George M.L. (2003), *Lean Six Sigma for Service*, McGraw-Hill, New York, NY.

George, M. L. (2002), *Lean Six Sigma: Combining Six Sigma Quality with Lean Speed*, New York: McGraw-Hill.

Ghosh, M. (2012), “Lean Manufacturing Performance in Indian Manufacturing Plants”, *Journal of Manufacturing Technology Management*, Vol. 24, No.1, pp. 1-12.

Gibbons, P. M., Kennedy, C., Burgess, S. C. and Godfrey, P. (2012),"The development of a lean resource mapping framework: introducing an 8th waste", *International Journal of Lean Six Sigma*, Vol. 3, No. 1, pp. 4–27

Gnanaraj, S.M., Devadasan, S.R., Murugesh, R. and Sreenivasa, C.G. (2011), “Sensitisation of SMEs towards the implementation of Lean Six Sigma – an initialisation in a cylinder frames manufacturing Indian SME”, *Production Planning & Control*, Vol. 23, No. 8, pp. 599-608.

Gomes, R. and Mentzer, J. T. (1998), “A systems approach to the investigation of just-in-time”, *Journal of Business Logistics*, Vol. 9, No. 2, pp. 71-88.

Gonza´lez-Benito, J., Martı´nez-Lorente, A.R. and Dale, B.G. (2003), “A study of the purchasing management system with respect to TQM”, *Industrial Marketing Management*, Vol. 32, No. 6, pp. 443-54.

Gouldner, A., W. (1960), “The norm of reciprocity: A preliminary statement”, *American Sociological Review*, Vol. 25, No. 2, pp. 161-178.

Green, M. and Dick, M. (2001), *“*Baseline analysis diagnoses manufacturing”, *Lean Directions: The e-Newsletter of Lean Manufacturing (Society of Manufacturing Engineers), http://www.sme.org/cgi-bin/get-newsletter.pl?LEAN&20010709&1& (25 June, 2012).*

Grewal, C. (2008), “An initiative to implement lean manufacturing using value stream mapping in a small company”, *International Journal of Manufacturing Technology and Management*, Vol. 15, No. 3/4, pp. 404-417.

Grove, A.L., Meredith, J.O., Macintyre, M., Angellis, J. and Neailey, K. (2011), “Lean implementation in primary care health visiting services in National Health Service UK”, *Quality Safety Health Care*, Vol. 19, No. 1, pp. 1-5.

Gulyani, S. (2001), “Effects of Poor Transportation on Lean Production and Industrial Clustering: Evidence from the Indian Auto Industry”, *World Development*, Vol. 29, No. 7, pp. 1157-1177.

Gunasekaran, A., Forker, L. and Kobu, B. (2000), “Improving operations performance in a small company: a case study”, *International Journal of Operations & Production Management*, Vol. 20, No. 3, pp. 316–335.

Gunasekaran, J. Lyu Implementing JIT in a small company: A case study Production Planning and Control, 8 (4) (1997).

Gupta, M. and Snyder, D. (2009), “Comparing TOC with MRP and JIT: a literature review”, *International Journal of Production Research*, Vol. 47, No. 13, pp. 3705-3739.

Gupta, S.M. and Brennan, L. (1995), “Implementation of just-in-time methodology in a small company”, *Production Planning and Control*, Vol. 6, No. 4, pp. 358–364.

Gupta, T. and Chakrabarty, S. (1984), “Looping in a multi-stage production system”, *International Journal of Production Research*, Vol. 22, No. 2, pp. 299-311.

Gupta, V., Acharya, P. and Patwardhan, M. (2012), “Monitoring quality goals through lean Six-Sigma insure competitiveness”, *International Journal of Productivity and Performance Management*, Vol. 61, No. 2, pp. 194-203.

Haig, B.D. (2005), “Exploratory Factor Analysis, Theory Generation, and Scientific Method”, *Multivariate Behavioral Research*, Vol. 40, No. 3, pp. 303-329.

Hair, J.F., Anderson, R., Tatham, R. and Black, W. (1995), *Multivariate Data Analysis* (4^{th} Ed.), Prentice-Hall, Englewood Cliffs, NJ.

Hair, J.F., Black, W., Babin, B. and Anderson, R.E. (2006), *Multivariate data analysis*, Pearson Education INC., Upper Saddle River, NJ.

Hall, R.W. (1983), *Zero Inventories*. Dow JonesIrwin, Homewood, IL.

Hakes C. (1991), *Total Quality Management: The Key to Business Improvement, 1st ed.*, Chapman and Hall, London.

Hallgren, M. and Olhager, J. (2009), “Lean and agile manufacturing: external and internal drivers and performance outcomes”, *International Journal of Operations & Production Management*, Vol. 29, No. 10, pp. 976-999.

Haque, B. and Moore, M.J. (2004), “Measures of performance for lean product introduction in the aerospace industry”, *Proceedings of the Institution of Mechanical Engineers Part B-Journal of Engineering Manufacture*, Vol. 218, No. 10, pp. 1387-1398.

Harbour, H. (2001a), *It’s not easy being lean*, Reprint from Gale Group.

Harbour, H. (2001b), *Getting lean is an endless journey*, Reprint from Gale Group.

Harbour, H. (2001c), *Lean tools must be used properly*, Reprint from Gale Group.

Harrison, A. and Storey, J. (1996), “New wave manufacturing strategies, operational, organizational & human dimensions”, *International Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 66-76.

Hayes, R.H. and Pisano, G.P. (1994), “Beyond world-class–the new manufacturing strategy”, *Harvard Business Review*, Vol. 72 No. 1, pp. 77-86.

Heinrich, H.W. (1931), *Industrial accident prevention*, NewYork, McGraw-Hill.

Heneman, R. L. and Von Hippel, C. (1995), “Balancing Group and Individual Rewards: Rewarding Individual Contributions to the Team”, *Compensation and Benefits Review,* Vol. 27, No. 4, pp. 63-68.

Herbert, S. (1953), *Causal ordering and identifiability,* In Hood, W. C., Koopmans, T.C., *Studies in Econometric Method,* New York: Wiley, pp. 49-74.

Herron, C. and Braiden, P.M. (2006), “A methodology for developing sustainable quantifiable productivity improvement in manufacturing companies”, *International Journal of Production Economics,* Vol. 104, No. 1, pp. 143-153.

Hilton, R. J. and Sohal, A. (2012), “A conceptual model for the successful deployment of Lean Six Sigma”, *International Journal of Quality & Reliability Management,* Vol. 29, No. 1, pp. 54-70.

Hines, P. and Rich, N. (1997), “The seven value stream mapping tools”, *International Journal of Production & Operations Management,* Vol. 17, No. 1, pp. 46-64.

Hines, P., Holweg, M. and Rich, N. (2004), “Learning to evolve -A review of contemporary lean thinking”, *International Journal of Operations & Production Management,* Vol. 24, No. 10, pp. 994-1011.

Hines, P., Francis, M. and Found, P. (2006), “Towards lean product life cycle management: A framework for new product development”, *Journal of Manufacturing Technology Management,* Vol. 17, No. 7, pp. 866-887.

Hines, P., Martins, A.L. and Beale, J. (2008a), “Testing the boundaries of lean thinking: observations from the legal public sector”, *Public Money & Management,* Vol. 28, No. 1, pp. 35-40.

Hines, P., Rich, N. and Esain, A. (1999), “Value stream mapping: A distribution industry application”, *Benchmarking: An International Journal,* Vol. 6, No. 1, pp. 60-77.

Hines, P., Rich, N., Bicheno, J., Brunt, D., Taylor, D., Butterworth, C. and Sullivan, J. (1998), “Value Stream Management”, *The International Journal of Logistics Management,* Vol. 9, No. 1, pp. 25-42.

Ho, S.K.M. (2010), “Integrated lean TQM model for global sustainability and competitiveness”, *The TQM Journal,* Vol. 22, No. 2, pp. 143-158.

Hodge, G.L., Ross, K.G., Joines, J.A. and Thoney, K. (2011), “Adapting lean manufacturing principles to the textile industry”, *Production Planning & Control,* Vol. 22, No. 3, pp. 237–247.

Holweg, M. (2007), "The genealogy of lean production", *Journal of Operations Management*, Vol. 25, No. 2, pp. 420-37.

Hopp, W. J. and Spearman, M.L. (2004), "To Pull or Not to Pull: What Is the Question?" *Manufacturing & Service Operations Management*, Vol. 6, No. 2, pp. 133-148.

Howell, G.A. (1999), "What is lean construction-1999?" *Proceedings Seventh Annual Conference of the International Group for Lean Construction*. 26-28 July 1999, University of California, Berkeley, CA, USA.

Hsu, C., Chang, A. and Kuo, H. (2012), "Integrating Grey Theory into Kano's QFD Based on Data Mining to Enhance Supply Market Survey with Purchasing", *WSEAS Transactions on Information Science and Applications*, Vol. 9, No. 2, PP. 37-47.

http://blogs.sch.gr/wpcontent/blogs.dir/1/files/groupdocuments/135/1312096172/Working Together Using Catch-Ball-EL.pdf (Cited on 20th Oct. 2012).

http://www.ceramics-india.com/category/ceramic-industry-india/ (Cited on 20th Oct. 2012).

Hu, L. and Bentler, P.M. (1999), "Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives" *Structural Equation Modeling*, Vol. 6, No. 1, pp. 1-55.

Huang, C.C. and Liu, S.H. (2005), "A novel approach to lean control for Taiwan-funded enterprises in mainland China", *International Journal of Production Research*, Vol. 43, No. 12, pp. 2553-2575.

Huang, S.H., Dismukes, J.P., Shi, J., Su, Q., Wang, G., Razzak, M.A. and Robinson, D.E. (2002), "Manufacturing System Modeling for Productivity Improvement", *Journal of Manufacturing Systems*, Vol. 21, No. 4, pp. 249-259.

Imai, M. (2007), *Gemba kaizen: a commonsense, low-cost approach to management*, McGraw-Hill, New York, United States of America.

James-Moore, S.M. and Gibbons, A. (1997), "Is lean manufacture universally relevant? An investigative methodology", *International Journal of Operations & Production Management*, Vol. 17, No. 9, pp. 899–911.

Jayaram, J., Vickery, S. and Droge, C. (2008), "Relationship building, lean strategy and firm performance: an exploratory study in the automotive supplier industry", *International Journal of Production Research*, Vol. 46, No. 20, pp. 5633-5649.

Jensen, S.H. and Jensen, K.H. (2007), “Implementing of Lean manufacturing in SME Companies”, *International Conference on Economic Engineering and Manufacturing Systems Brasov*, 25 – 26 October 2007, RECENT, Vol. 8, nr. 3a (21a), pp. 305-308.

Jiménez, E., Tejeda, A., Pérez, M., Blanco, J. and Martínez, E. (2011), “Applicability of lean production with VSM to the Rioja wine sector”, *International Journal of Production Research,* Vol. 50, No. 7, pp. 1890-1904.

Jina, J., Bhattacharya, A.K. and Walton, A.D. (1997), “Applying lean principles for high product variety and low volumes: some issues and propositions”, *Logistics Information Management*, Vol. 10, No. 1, pp. 5–13.

Johansen, E. and Walter, L. (2007), “Lean construction: Prospects for the German construction industry”, *Lean Construction Journal*, Vol. 3, No. 1, pp. 19-32.

Jones, D. and Womack J. (2000), *Seeing the Whole: Mapping the Extended Value Stream*, Lean Institute, Cambridge, MA.

Jorgensen, B. and Emmitt, S. (2008), “Lost in transition: the transfer of lean manufacturing to construction”, Engineering”, *Construction and Architectural Management*, Vol. 15, No. 4, pp. 383-398.

Juran, J.M. and Gryna, F.M. (1993), *Quality Planning and Analysis*, 3rd ed., McGraw-Hill, New York.

Kainuma, Y. and Tawara, N. (2006), “A multiple attribute utility theory approach to lean and green supply chain management”, *International Journal of Production Economics*, Vol. 101, No. 1, pp. 99-108.

Kalsaas, B.T. (2002), “Value Steam Mapping: An adequate method for going lean?”, *Paper presented at NOFOMA 2002, the 14th international conference Trondheim,* June 13-14, 2002.

Kannan, V.R. and Ghosh, S. (1996), “Cellular manufacturing using virtual cells”, *International Journal of Operations & Production Management*, Vol. 16, No. 5, pp. 99-112.

Karlsson, C. and Åhlström, P. (1995), “Change processes towards lean production: the role of the remuneration system”, *International Journal of Operations & Production Management*, Vol. 15, No. 11, pp. 80-99.

Karlsson, C. and Ahlstrom, P. (1996), “Assessing changes towards lean production”, *International Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 24–41.

Katayama, H. and Bennett, D. (1996), “Lean production in a changing competitive world: a Japanese perspective”, *International Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 8-23.

Kemper, B., Mast, J.D. and Mandjes, M. (2010), “Modeling process flow using diagrams”, *Quality and Reliability Engineering International Journal*, Vol. 26, No. 1, pp. 341-349.

Kettinger, W. and Grover, V. (1995), “Toward a theory of business process change management”, *Journal of Management Information Systems*, Vol. 12, No. 1, pp. 9–30.

Knuf, J. (2000), “Benchmarking The Lean Enterprise: Organizational Learning At Work”, *Journal of Management in Engineering*, Vol. 16, No. 4, pp. 58-71.

Kobayashi, I. (1990), *20 Keys to Workplace Improvement, 1st ed.*, Productivity Press, Cambridge, MA.

Koeske, G. F. (1994), “Some recommendations for improving measurement validation in social work research”, *Journal of Social Service Research*, Sec. 18, pp. 43-72.

Koufteros, X.A. (1999), “Testing a model of pull production: a paradigm for manufacturing research using structural equation modeling”, *Journal of Operations Management*, Vol. 17, No. 4, pp. 467-488.

Koufteros, X.A. and Vonderembse, M.A. (1998), “The impact of organizational structure on the level of JIT attainment: towards theory development”, *International Journal of Production Research*, Vol. 36, No. 10, pp. 2863–2878.

Krafcik, J.F. (1988), “Triumph of the lean production system”, *Sloan Management Review*, Vol. 30, No. 1, pp. 41-52.

Krishnamurthy, R. and Yauch, C.A (2007), “Leagile manufacturing a proposed corporate infrastructure”, *International Journal of Operations & Production Management*, Vol. 27, No. 6, pp. 588-604.

Kumar, M. and Antony, J. (2008), “Comparing the quality management practices in UK SMEs”, *Industrial Management & Data Systems*, Vol. 108, No. 9, pp. 1153-1166.

Kumar, M., Antony, J., Singh, R.K., Tiwari, M.K. and Perry, D. (2006), “Implementing the lean Sigma framework in an Indian SME: a case study”, *Production Planning & Control*, Vol. 17, No. 4, pp. 407–423.

Lachajczyk, H. and Dudek-Burlikowska, M. (2006), Quality continuous improvement of company with usage the Poka-Yoke methods, *PSKN 7/2006*, pp. 57-64, (in Polish).

Lander, E. and Liker, J.K. (2007), “The Toyota Production System and art: making highly customized and creative products the Toyota way”, *International Journal of Production Research*, Vol. 45, No. 16, pp. 3681-3698.

Landy, F. J., Barnes, J.L. and Murphy, K.R. (1978), “Correlates of Perceived Fairness and Accuracy of Performance Evaluation”, *Journal of Applied Psychology*, Vol. 63, No. 6, pp. 751-754.

Lasa, I.S., De-Castro, R. and Laburu, C.O. (2009), “Extent of the use of Lean concepts proposed for a value stream mapping application” *Production Planning & Control*, Vol. 20, No. 1, pp. 82-98.

Lasa, I.S., Laburu, C.O. and Vila, R.D.C. (2008) “An evaluation of the value stream mapping tool”, *Business Process Management Journal*, Vol. 14, No. 1, pp. 39-52.

Lee, B.H. and Jo, H.J. (2007), “The mutation of the Toyota Production System: adapting the TPS at Hyundai Motor Company”, *International Journal of Production Research*, Vol. 45, No. 16, pp. 3665-3679.

Lee, I. (2007), “Evaluating artificial intelligence heuristics for a flexible Kanban system: simultaneous Kanban controlling and scheduling”, *International Journal of Production Research*, Vol. 45, No. 13, pp. 2859-2873.

Lewis, M. A. (2000), “Lean Production and Sustainable Competitive Advantage”, *International Journal of Operations & Production Management*, Vol. 20, No. 8, pp. 959-978.

Lian, Y.H. and Van Landeghem, H. (2007), “Analyzing the effects of lean manufacturing using a value stream mapping-based simulation generator”, *International Journal of Production Research*, Vol. 45, No. 13, pp. 3037–3058.

Liker, J. K. (1996), *Becoming Lean*, Portland, OR: Productivity Press.

Liker, J.K. (2004), *The Toyota Way: 14 Management Principles from the World’s Greatest Manufacturer*, McGraw-Hill.

Liker, J.K. and Wu, Y.C. (2000), “Japanese automakers, US suppliers and supply-chain superiority”, *Sloan Management Review*, Vol. 42, No. 1, pp. 81-93.

Ljungberg, O. (1998), “Measurement of overall equipment effectiveness as a basis for TPM activities”, *International Journal of Operation and Production Management*, Vol. 18, No. 5, pp. 495–507.

Losonci, D., Demeter, K. and Jenei, I. (2011), “Factors influencing employee perceptions in lean transformations”, *International Journal of Production Economics*, Vol. 131, No. 1, pp. 30-43.

MacDuffle, J.P. and Helper, S. (1997), “Creating lean suppliers: diffusing lean production through the supply chain”, *California Management Review*, Vol. 39, No. 4, pp. 118-51.

Mackelprang, A. W. and Nair, A. (2010), “Relationship between Just-in-Time Manufacturing Practices and Performance: A Meta-Analytic Investigation”, *Journal of Operations Management,* Vol. 28, No. 4, pp. 283-302.

Maguad, B.A. (2006), “The modern quality movement: Origins, development and trends”, *Total Quality Management*, Vol. 17, No. 2, pp. 179-203.

Mahapatra, S.S. and Mohanty, S.R. (2007), “Lean manufacturing in continuous process industry: an empirical study”, *Journal of Scientific and Industrial Research*, Vol. 66, No. 1, pp. 19-27.

Malakooti, B. and Raman, V. (2000), “Clustering and selecting multiple criteria alternatives using unsupervised and supervised neural networks”, *Journal of Intelligent Manufacturing*, Vol. 11, No. 5, pp. 435–451.

Marsch, H.W. and Hocevar, D. (1985), “Applications of confirmatory factor analysis to the study of self concept: first and higher order factor models and their invariance across groups”, *Psychological Bulletin*, Vol. 97, No. 3, pp. 562-582.

Mason-Jones, R., Naylor, B. and Towill, D.R. (2000), “Lean, agile or leagile? Matching your supply chain to the marketplace”, *International Journal of Production Research,* Vol. 38, No. 17, pp. 4061-4070.

Mathaisel, D.F.X. and Comm, C.L. (2000), “Developing, implementing and transferring lean quality initiatives from the aerospace industry to all industries”, *Managing Service Quality*, Vol. 10, No. 4, pp. 248-256.

McCarthy, I. and Tsinopoulos, C. (2003), “Strategies for agility-an evolutionary and configurationally approach”, *Integrated Manufacturing Systems,* Vol. 14, No. 2, pp. 103-113.

McCullen, P. and Towill, D. (2001), “Achieving lean supply through agile manufacturing”, *Integrated Manufacturing Systems*, Vol. 12, No. 7, pp. 524-533.

McDonald, T., Van-Aken, E.M. and Rentes, A.F. (2002), “Utilizing Simulation to Enhance Value Stream Mapping: A Manufacturing Case Application”, *International Journal of Logistics: Research and Applications*, Vol. 5, No. 2, pp. 213-232.

Meiling, J., Backlund F. and Johnsson, H. (2011), “Managing for Continuous Improvement in Off-Site Construction: Evaluation of lean management principles”, *Engineering Construction and Architectural Management*, Vol. 19, No. 2, pp. 141-158.

Miller, G., Pawloski, J. and Standridge, C.(2010), “A case study of lean, sustainable manufacturing”, *Journal of Industrial Engineering and Management*, Vol. 3, No. 1, pp. 11-32.

Miller, J. (2007), available at: http://www.gembapantarei.com (Cited on 20th Sep. 2012).

Millet, D., Bistagnino, L., Lanzavecchia, C., Camous R. and Poldma, T. (2007), “Does the potential of the use of LCA match the design team needs?” *Journal of Cleaner Production*, Vol. 15, No. 4, pp. 335–346.

Miltenburg, J. (2007), “Level schedules for mixed-model JIT production lines: characteristics of the largest instances that can be solved optimally”, *International Journal of Production Research*, Vol. 45, No. 16, pp. 3555-3577.

Ming-Te, L., Kuo-Chung, M.A. and Pan, W.T. (2012), “Using data mining technique to perform the performance assessment of lean service”, *Neural Computing and Application, DOI: 10.1007/s00521-012-0848-y.*

MIT (2000), *Transitioning to a Lean Enterprise*: A Guide for Leaders, 1/2/3, available at: http://lean.mit.edu/Products/TTL/TTL-vol1.pdf

Modarress, B., Ansari, A. and Lockwood, D.L. (2005), “Kaizen costing for lean manufacturing: a case study”, *International Journal of Production Research*, Vol. 43, No. 9, pp. 1751-1760.

Mohanty, R.P. and Deshmukh, S.G. (1998), “Managing green productivity: some strategic directions”, *Production Planning & Control*, Vol. 9, No. 7, pp. 624-633.

Mohanty, R.P., Yadav, O.P. and Jain, R. (2007), "Implementation of lean manufacturing principles in auto industry", *Vilakshan - XIMB Journal of Management*, pp. 1–32, available at: www.ximb.ac.in/ximb_journal/Publications/Article-01.pdf (accessed 10 April 2008).

Mollenkop, D., Stolze, H., Tate, W.L. and Ueltschy, M. (2010), "Green, Lean, and Global Supply Chains", *International Journal of Physical Distribution & Logistics Management*, Vol. 40, No. 1-2, pp. 14-41.

Monden, Y. (1981a), "What makes the Toyota production system really ticks?" *Industrial Engineering*, Vol. 1, No. 1, pp.13-16.

Monden, Y. (1989), *JIT Production System for Auto Industry (in Japanese).* Tokyo: Japan Productivity Center, 1989.

Monden, Y. (1983), *Toyota production system: An integrated approach to just-in-time.* Norcross, GA: Industrial Engineering and Management Press.

Motwani, J. (2003), "A business process change framework for examining lean manufacturing- A case study", *Industrial Management & Data Systems*, Vol. 103, No. 5, pp. 339-346.

Moyano-Fuentes, J. and Sacristan-Diaz, M. (2012), "Learning on lean: a review of thinking and research", *International Journal of Operations & Production management*, Vol. 32, No. 5, pp. 551-582.

Murphy, K. (1992), "Performance Measurement and Appraisal: Motivating Managers to Identify and Reward Performance", William J. Bruns, Jr. (ed.): *Performance Measurement, Evaluation, and Incentives*, Harvard Business School Press, Boston, pp. 37-62.

Muttar, K. (1985), "An investigation of the validity of objective and subjective measures of organizational climate", *University Microfilms International, Ann Arbor*, MI.

Narasimhan, R., Swink, M. and Kim, S.W. (2006), "Disentangling leanness and agility: An empirical investigation", *Journal of Operations Management*, Vol. 24, No. 1, pp. 440-457.

Naslund, D. (2008), "Lean, Six Sigma and Lean Sigma: fads or real process improvement methods?", *Business Process Management Journal*, Vol. 14, No. 3, pp. 269-287.

National Manufacturing Competitiveness Programme (NMCP) under XI Plan, Lean Manufacturing Competitiveness Scheme for MSMEs, Govt. of India Report, 2005 (cited 2010 March 20), Available from: http://www.dcmsme.gov.in/schemes/nmcp_scm.htm.

Naumann, E. and Giel, K. (1995), *Customer satisfaction measurement and management: using the voice of the customer*, Thomson Executive Press, Cincinnati, OH.

Naylor, J.B., Naim, M.M. and Berry, D. (1999), "Leagility: integrating the lean and agile manufacturing paradigms in the total supply chain", *International Journal of Production Economics*, Vol. 62, No. 1, pp. 107-18.

Niepce, W. and Molleman, E. (1996), "A case study, Characteristics of work organization in lean production and sociotechnical systems", *International Journal of Operations & Production management*, Vol. 16, No. 2, pp. 77-90.

NIST (2000), *Principles of Lean Manufacturing with Live Simulation, Manufacturing Extension Partnership*, National Institute of Standards and Technology, Gaithersburg, MD.

Nordin, N., Md Deros, B. and Abd Wahab, D. (2010), "A Survey on Lean Manufacturing Implementation in Malaysian Automotive Industry", *International Journal of Innovation, Management and Technology*, Vol. 1, No. 4, pp. 374-380.

Norusis, M. (1994), "SPSS professional statistics 6.1", *SPSS Inc.*, Chicago II.

Ohno, T. (1988), *Toyota production system: Beyond large-scale production*, Cambridge, MA: Productivity Press.

Olivella, J., Cuatrecasas, L. and Gavilan, N. (2008), "Work organization practices for lean production", *Journal of Manufacturing Technology Management*, Vol. 19, No. 7, pp. 798-811.

Oliver, N., Delbridge, R. and Barton, H. (2002), "Lean production and manufacturing performance improvement in Japan, the UK And US 1994–2001", *Working Paper No. 232, ESRC Centre for Business Research*, University of Cambridge.

Oliver, N., Schab, L. and Holweg, M. (2007), "Lean principles and premium brands: conflicts or complement?", *International Journal of Production Research*, Vol. 45, No. 16, pp. 3723-3739.

Panizzolo, R., Garengo, P., Sharma, M. L. and Gore, A. (2012), "Lean manufacturing in developing countries: evidence from Indian SMEs', *Production Planning & Control: The Management of Operations,* DOI:10.1080/09537287.2011.642155.

Papadopoulou, T.C. and Ozbayrak, M. (2005), "Leanness: experiences from the journey to date", *Journal of Manufacturing Technology Management*, Vol. 16, No. 7, pp. 784-807.

Parry, G.C. and Turner, C.E. (2006), "Application of lean visual process management tools", *Production Planning & Control*, Vol. 17, No. 1, pp. 77-86.

Pascal, D. (2007), *Lean Production Simplified,* 1st ed., Taylor & Francis Group.

Pavnaskar, S.J., Gershenson, J.K. and Jambekar, A.B. (2003), "Classification scheme for lean manufacturing tools", *International Journal Production Research*, Vol. 41, No. 13, pp. 3075-3090.

Pearl, J. (1998), "Graphs, Causality, and Structural Equation Models", *Sociological Methods and Research*, Vol. 27, No. 2, pp. 226-284.

Pepper, M.P.J. and Spedding, T.A. (2010), "The evolution of Lean Six Sigma", *International Journal of Quality Reliability Management*, Vol. 27, No. 2, pp. 138-155.

Perez, C., De-Castro, R., Simons, D. and Gimenez, G. (2010), "Development of lean supply chains: a case study of the Catalan pork sector", *Supply Chain Management: An International Journal*, Vol. 15, No. 1, pp. 55-68.

Pettersen, J. (2009), "Defining lean production: some conceptual and practical issues", *The TQM Journal*, Vol. 21, No. 2, pp. 127-142.

Pham, D.T., Pham, P.T.N. and Thomas, A. (2008), "Integrated production machines and systems- beyond lean manufacturing", *Journal of Manufacturing Technology Management*, Vol. 19, No. 6, pp. 695-711.

Pheng, L.S. and Chuan, C.J. (2001), "Just- in- time Management in precast concrete construction: a survey of the readiness of main contractors in Singapore", *Integrated Manufacturing Systems*, Vol. 12, No. 6, pp. 416-429.

Phillips, T. (2000), "Building the lean machine", *Advanced Manufacturing*, January, pp. 1-21.

Piercy, N. and Rich, N. (2009), "Lean transformation in the pure service environment: the case of the call service centre", *International Journal of Operations & Production Management*, Vol. 29, No. 1, pp. 54-76.

Pingale, A. and Vani, D. (2010), "Implementation of lean manufacturing to improve competitiveness", *SAE International*, 2010-01-2025, Published on 10/05/2010.

Pingyu, Y. and Yu, Y., (2010), "The barriers to SMEs implementation of lean production and countermeasures – based on SMS in Wenzhou", *International Journal of Innovation, Management and Technology*, Vol. 1, No. 2, pp. 220-225.

Pool, A., Wijingaard, J. and Zee, D.J. (2011), "Lean planning in the semi-process industry: a case study", *International Journal of Production Economics*, Vol. 1, No. 1, pp. 1-10.

Powell, D., Riezebos, J. and Strandhagen J.O. (2012), "Lean production and ERP systems in small- and medium-sized enterprises: ERP support for pull production", *International Journal of Production Research*, DOI:10.1080/00207543.2011.645954.

Prickett, P. (1994), "Cell-based Manufacturing Systems: Design and Implementation", *International Journal of Operations & Production Management*, Vol. 14, No. 2, pp. 4-17.

Psychogios A.G. and Tsironis, L. K. (2012), "Towards an integrated framework for Lean Six Sigma application: Lessons from the airline industry", *Total Quality Management & Business Excellence*, Vol. 23, No. 3, pp 397-415..

Psychogios, A.G., Atanasovski, J. and Tsironis, L. K. (2012), "Lean Six Sigma in a service context: A multi- factor application approach in the telecommunications industry", *International Journal of Quality & Reliability Management*, Vol. 29, No. 1, pp. 122-139.

Puvanasvaran, P., Megat, H., Hong, T.S. and Razali, M. (2009), "The roles of communication process for an effective lean manufacturing implementation", *Journal of Industrial Engineering Management*, Vol. 2, No. 1, pp. 128-152.

Rajasthan Infrastructure Agenda "2025", Project Profiles-Manufacturing Vision 2025, Key Deliverable 4 (Volume IV), September 2003 (Cited 2010 March 20), Available from: http://ppp.rajasthan.gov.in/PWC report/KD4/manufacturing/manu-vol-I.pdf.

Ramarapu, N.K., Mehra, S. and Frolick, M.N. (1995), "A comparative analysis and review of JIT implementation", *International Journal of Operations & Production Management*, Vol. 15, No. 1, pp. 38-49.

Ramesh, V. and Kodali, R. (2011), "A decision framework for maximising lean manufacturing performance", *International Journal of Production Research*, Vol. 50, No. 8, pp. 2234-2251.

Ranganathan, C. and Kannabiran, J. (2004), "Effective management of information systems function: An exploratory study of Indian organizations", *International Journal of Information Management*, Vol. 25, No. 3, pp. 247–266.

Rasheed, A. M. A. and Prescott, J. E. (1992), "Towards an Objective Classification Scheme for Organizational Task Environments", *British Journal of Management*, Vol. 3, No. 1, pp. 197-206.

Rashid, A.H.A., Shaari, M.F., Zakwan, N.M.Z. and Basri, N.F.H. (2010), "Lean manufacturing assessment in Malaysia small medium enterprise: a case study", *World Engineering Congress 2010, 2nd to 5th August 2010*, Kuching, Sarawak, Malaysia, *Conference on Manufacturing Technology Management.*

Ravi, V. and Shankar, R. (2005), "Analysis of interactions among the barriers of reverselogistics", *Technological Forecasting and Social Change*, Vol. 72, pp. 1011-29.

Reichhart, A. and Holweg, M. (2007), "Lean distribution: concepts, contributions, conflicts", *International Journal of Production Research*, Vol. 45, No. 16, pp. 3699-3722.

Richards, C. W. (1996), "Agile manufacturing: beyond lean?" *Production and Inventory Management Journal*, 2nd Quarter, Vol. 37, No. 2, pp. 60-64.

Riezebos, J., Klingenberg, W. and Hicks, C. (2009), "Lean Production and information technology: Connection or contradiction?" *Computers in Industry*, Vol. 60, No. 1, pp. 237-247.

Riveraa, L. and Chen, F.F. (2007), "Measuring the impact of Lean tools on the cost–time investment of a product using cost–time profiles", *Robotics and Computer-Integrated Manufacturing*, Vol. 23, No. 1, pp. 684–689.

Robertson, M. and Jones, C. (1999), "Application of lean production and agile manufacturing concepts in a telecommunications environment" *International Journal of Agile Management Systems*, Vol. 1, No. 1, pp. 14-16.

Robinson S., Radnor Z.J., Burgess, N. and Worthington, C. (2012), "Simlean: Utilising simulation in the implementation of lean in healthcare", *European Journal of Operational Research*, Vol. 219, No. 1, pp. 188-197.

Rose, A.M.N., Deros, B.Md. and Rahman, M.N.Ab. (2010), "Development of framework for lean manufacturing implementation in SMEs", *The 11th Asia Pacific Industrial Engineering and Management Systems Conference , The 14th Asia Pacific Regional Meeting of International Foundation for Production Research,* Melaka, 7 – 10 December 2010.

Rother M, and Shook J. (1999), *Learning to see: Value stream mapping to add value and eliminate MUDA,* The Lean Enterprise Institute, Brookline, MA.

Rothstein, J.S., (2004), "Creating lean industrial relations: General Motors in Silao, Mexico", *Competition and Change,* Vol. 8, No. 3, pp. 203-221.

Roy, S. (2011), "Transforming SMEs through lean manufacturing clusters", *Indian Foundry Journal,* Vol. 57, No. 2, pp. 35-40.

Sahoo, A.K., Singh, N. K., Shankar, R. and Tiwari, M. K. (2008), "Lean philosophy: implementation in a forging company", *International Journal of Advanced Manufacturing Technology*, Vol. 36, No. 1, pp. 451-462.

Sakakibara S., Flynn, B.B., Schroeder, R. G. and Morris, W. T. (1997), "The Impact of Just-in-Time Manufacturing and Its Infrastructure on Manufacturing Performance", *Management Science,* Vol. 43, No. 9, pp. 1246-1257.

Salem, O., Solomon, J., Genaidy, A. and Luegring, M. (2005), "Site Implementation and Assessment of Lean Construction Techniques", *Lean Construction Journal,* Vol. 2, No. 2, pp. 1-21.

Sanchez, A.M. and Perez, M.P. (2001), "Lean indicators and manufacturing strategies", *International Journal of Operations & Production Management,* Vol. 21, No. 11, pp. 1433–1451.

Saurin, T.A., Marodin, G.A. and Ribeiro, J.L.D. (2011), "A framework for assessing the use of lean production practices in manufacturing cells", *International Journal of Production Research,* Vol. 49, No. 11, pp. 3211-3230.

Schonberger, R. J. (1982), *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity,* New York: The Free Press.

Schonberger, R. J. (1984), "Just-In-Time Production Systems: Replacing Complexity With Simplicity in Manufacturing", *Management of Industrial Engineering,* Vol. 16, No. 10, pp. 52-63.

Schonberger, R. J. (1986), *World Class Manufacturing: The Lessons of Simplicity Applied,* New York: The Free Press.

Schonberger, R. J. (2007), "Japanese Production Management: An Evolution—With Mixed Success", *Journal of Operations Management,* Vol. 25, No. 1, pp. 403-419.

Serrano, I., Ochoa, C. and Castro, R.D. (2008), "Evaluation of value stream mapping in manufacturing system redesign", *International Journal of Production Research*, Vol. 46, No. 16, pp. 4409-4430.

Seth, D. and Gupta, V. (2005), "Application of value stream mapping for lean operations and cycle time reduction: an Indian case study", *Production Planning & Control*, Vol. 16, No. 1, pp. 44-59.

Seth, D., Seth, N. and Goel, D. (2008), "Application of value stream mapping (VSM) for minimization of waste in the processing side of supply chain of cottonseed oil industry in Indian context", *Journal of Manufacturing Technology Management*, Vol. 19, No. 4, pp. 529-550.

Shah, R. and Goldstein, S.M. (2006), "Use of structural equation modeling in operations management research: looking back and forward", *Journal of Operations Management*, Vol. 24, No. 1, pp. 148–169.

Shah, R. and Ward, P.T. (2003), "Lean manufacturing: context, practice bundles, and Performance", *Journal of Operations Management*, Vol. 21 No. 2, pp. 129-49.

Shah, R. and Ward, P.T. (2007), "Defining and developing measures of lean production", *Journal of Operations Management*, Vol. 25, No. 1, pp. 785-805.

Shah, R., Chandrasekaran, A. and Linderman, K. (2008), "In pursuit of implementation patterns: the context of Lean and Six Sigma", *International Journal of Production Research*, Vol. 46, No. 23, pp. 6679-6699.

Shahin, A. (2011), "A conceptual model of group technology and lean production for productivity enhancement", *European Journal of Business and Management*, Vol. 1, No. 1, pp. 42-54.

Shen, S.X. and Han, C.F. (2006), "China electrical manufacturing services industry value stream mapping collaboration", *International Journal of Flexible Manufacturing Systems*, Vol. 18, No. 1, pp. 285-303.

Shingo, S. (1989), *A study of the Toyota Production System*, Productivity Press.

Siegrist, J. (1996), "Adverse health effects of high-effort/low-reward conditions", *Journal of Occupational Health Psychology*, Vol. 1, No. 1, pp. 27-41.

Silva, I.B., Batalha, G.F., Filho, M.S., Ceccarelli, F.Z., Anjos, J.B. and Fesz, M. (2009), "Integrated product and process system with continuous improvement in the auto parts industry", *Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 34, No. 2, pp. 204-210.

Simons, D. and Zokaei, K. (2005), "Application of lean paradigm in red meat processing", *British Food Journal,* Vol. 107, No. 4, pp. 192-211.

Simpson, D.F. and Power, D.J. (2005), "Use the supply relationship to develop lean and green suppliers", *Supply Chain Management: An International Journal*, Vol. 10, No. 1, pp. 60-68.

Singh, B. and Sharma, S.K. (2009), "Value stream mapping as a versatile tool for lean implementation: an Indian case study of a manufacturing firm", *Measuring Business Excellence,* Vol. 13, No. 3, pp. 58-68.

Singh, B. Garg, S.K. and Sharma, S.K. (2010), "Scope for lean implementation: a survey of 127 Indian industries", *International Journal of Rapid Manufacturing*, Vol. 1, No. 3, pp 323-333.

Singh, B., Garg, S.K. and Sharma, S.K. (2009), "Lean can be a survival strategy during recessionary times", *International Journal of Productivity and Performance Management,* Vol. 58, No. 8, pp. 803-808.

Singh, B., Garg, S.K. and Sharma, S.K. (2010), "Development of index for measuring leanness: study of an Indian auto component industry", *Measuring Business Excellence*, Vol. 14, No. 2, pp. 46-53.

Singh, B., Garg, S.K. and Sharma, S.K. (2011) 'Value stream mapping: literature review and implications for Indian industry', *International Journal of Advanced Manufacturing Technology,* Vol. 53, No. 1, pp. 799–809.

Singh, R. (1998), "Lean Manufacturing: Changing Paradigms in Product Manufacturing, Design & Supply", *The Third International Conference on Quality Management* www.qmconf.com/Docs/singh98.pdf , available on line on 20 Jan. 2012.

Singh, R. K., Garg, S. K. and Deshmukh, S.G. (2008), "Strategy Development by SMEs for competitiveness: a review", *Benchmarking: An International Journal*, Vol. 15 No. 5, pp. 525-547.

Smeds, R. (1994) "Managing change towards lean enterprises", *International Journal of Operations & Production Management*, Vol. 14, No. 3, pp. 66–82.

Snee, R.D. (2010), “Lean Six Sigma- getting better all time”, *International Journal of Lean Six Sigma*, Vol. 1, No. 1, pp. 9-29.

Soderquist, K. and Motwani, J. (1999), “Quality issues in lean production implementation: a case study of a French automotive supplier”, *Total Quality Management*, Vol. 10, No. 8, pp. 1107-1122.

Sohal, A.S. (1996), “Developing a lean production organization: an Australian case study”, *International Journal of Operations & Production Management*, Vol. 16, No. 2, pp. 91-102.

Sohal, A.S. and Egglestone, A. (1994), “Lean Production: Experience among Australian Organizations”, *International Journal of Operations & Production Management*, Vol. 14, No. 11, pp. 35-51.

Soni, G. and Kodali, R. (2012), “Evaluating reliability and validity of lean, agile and leagile supply chain constructs in Indian manufacturing industry”, *Production Planning & Control: The Management of Operations*, DOI:10.1080/09537287.2011.642207.

Staats, B.R., Brunner, D.J. and Upton, D.M. (2011), “Lean principles, learning, and knowledge work: evidence from a software service provider”, *Journal of Operations Management*, Vol. 29, No. 1, pp. 376-390.

Storch, R.L. and Lim, S. (1999), “Improving flow to achieve lean manufacturing in shipbuilding”, *Production Planning & Control*, Vol. 10, No. 2, pp. 127-137.

Storhagen, N. G. (1993), *Management ochflödeseffektivitet i Japan ochSverige. (Management and Flow Efficiency in Japan and Sweden),* Swedish, Linköping, Linköping University.

Stump, B. and Badurdeen, F. (2009), “Integrating lean and other strategies for mass customization manufacturing: a case study”, *Journal of Intelligent Manufacturing*, Vol. 23, No. 1, pp. 109-124.

Suarez-Barraza, M.F., Smith, T. and Dahlgaard-Park, S.M. (2012), “Lean Service: A literature analysis and classification”, *Total Quality Management & Business excellence*, Vol. 23, No. ¾, pp. 359-380.

Subha, M.V. and Jaisankar, S. (2012), “Balanced adoption of lean manufacturing practices in engineering goods manufacturing firms”, *European Journal of Social Sciences*, Vol. 28, No. 2, pp. 273-279.

Suehiro, K., (1992), *Eliminating Minor Stoppages on Automated Lines,* Productivity Press, Cambridge, MA.

Sugimori, Y., Kusunoki, K., Cho, F. and Uchikawa, S. (1977), "Toyota Production System and Kanban system: materialization of just-in time and respect-for-human system", *International Journal of Production Research,* Vol. 15, No. 6, pp. 553–564.

Sullivan, J., Hines, P., Rich, N., Bicheno, J., Brunt, D., Taylor, D. and Butterworth, C. (1998), "Value stream management", *International Journal of Logistics Management*, Vol. 9, No. 1, pp. 25-42.

Swamidass, P.M. (2007), "The effect of TPS on US manufacturing during 1981–1998: inventory increased or decreased as a function of plant performance", *International Journal of Production Research,* Vol. 45, No. 16, pp. 3763-3778.

Taj, S. (2005), "Applying lean assessment tools in Chinese hi-tech industries", *Management Decision,* Vol. 43, No. 4, pp. 628-643.

Taj, S. and Berro, L. (2006), "Application of constrained management and lean manufacturing in developing best practice for productivity improvement in an auto-assembly plant", *International Journal of Productivity and Performance Management*, Vol. 55, No. 4, pp. 332-345.

Taj, S. and Morosan, C. (2011), "The impact of lean operations on the Chinese manufacturing performance", *Journal of Manufacturing Technology Management*, Vol. 22, No. 2, pp. 223-240.

Takahashi, K., Morikawa, K. and Chen, Y.C. (2007), "Comparing Kanban control with the theory of constraints using Markov chains", *International Journal of Production Research*, Vol. 45, No. 16, pp. 3599-3617.

Tan, K.H., Denton, P., Rae R. and Chung, L. (2012), "Managing lean capabilities through flexible workforce development: a process and framework", *Production Planning & Control: The Management of Operations,* DOI:10.1080/09537287.2011.646013.

Tapping, D. and Shuker, T. (2003), *Value stream management for the Lean office,* Productivity Press, New York, NY.

Taylor, D. and Brunt, D. (2001), *Manufacturing Operations,* Thompson, London.

Taylor, D.H. (2005), "Value chain analysis: an approach to supply chain improvement in agro-food chains", *International Journal of Physical Distribution & Logistics Management*, Vol. 35, No. 10, pp. 744-761.

Ten Step, Inc. and C & K Management Ltd. (2003), "Get Everyone Working Together Using Hoshin Kanri 'CatchBall"', *Ten step Supplemental Paper*. September 1, available at:

Tenko Raykov & George A. Marcoulides (2006), "On Multilevel Model Reliability Estimation From the Perspective of Structural Equation Modeling", *Structural Equation Modeling: A Multidisciplinary Journal*, Vol. 13, No. 1, pp. 130-141.

Towill, D.R. (2007), "Exploiting the DNA of the Toyota Production System", *International Journal of Production Research*, Vol. 45, No. 16, pp. 3619-3637.

Valentinova, A. K. (2010), *Challenges in Lean implementation: Successful transformation towards Lean enterprises*, Master thesis, University of Aarhus.

Van Dun, D. H., Hicks, J. N., Wilderom, C. P. M. and Van Lieshout, A. J. P. (2008), "Work Values and Behaviors of Middle Managers in Lean Organizations: A New Research Approach Towards Lean Leadership", paper presented at the *11th Bi-annual 12 Conference of the International Society of the Study of Work and Organizational Values*, Singapore.

Van-Hoek, R.I. (2000), "The thesis of leagility revisited", *International Journal of Agile Management Systems*, Vol. 2, No. 3, pp. 196-201.

Villa, D. (2010), "Automation, Lean, Six Sigma: Synergies for improving laboratory efficiency", *Journal of Medical Biochemistry*, Vol. 29, No. 4, pp. 339-348.

Vimal, K.E.K. and Vinodh, S. (2012), "Leanness evaluation using IF-THEN rules', *International Journal of Advance Manufacturing Technology*', DOI 10.1007/s00170-012-3919-4.

Vinodh, S. and Joy, D. (2011), "Structural Equation Modelling of lean manufacturing practices", *International Journal of Production Research*, Vol. 50, No. 6, pp. 1598-1607.

Vinodh, S., Arvind, K.R. and Somanaathan, M. (2010), "Application of value stream mapping in an Indian camshaft manufacturing organization", *Journal of Manufacturing Technology Management*, Vol. 21, No. 7, pp. 888-900.

Wanitwattanakosol, J. and Sopadang, A. (2012), "A Framework For Implementing Lean Manufacturing System In Small And Medium Enterprises", *Applied Mechanics and Materials*, pp. 110-116.

Wee, H.M. and Wu, S. (2009), "Lean supply chain and its effect on product cost and quality: A case study on Ford Motor Company", *Supply Chain Management: An International Journal*, Vol. 14, No. 5, pp. 335-341.

Weller, H.N., Nirschl, D.S., Petrillo, E.W., Poss, M.A., Andres, C. J., Cavallaro, C.L., Echols, M.M., Grant-Young, K.A., Houston, J.G., Miller, A.V. and Swann, R.T. (2006), "Application of Lean Manufacturing Concepts to Drug Discovery: Rapid Analogue Library Synthesis", *Journal of Combinatorial Chemistry*, Vol. 8, No. 5, pp. 664-669.

White, R.E. and Prybutok, V. (2001), "The relationship between JIT practices and type of production system", *Journal of Omega*, Vol. 29, No. 2, pp. 113-24.

Wilson, P. F., Dell, L. D. and Anderson, G. F. (1993), *Root Cause Analysis: A Tool for Total Quality Management,* Milwaukee: ASQC Quality Press.

Winata, L. and Mia, L. (2004), "Linking just in time, information technology for communication and management accounting information: an exploratory study", *DSS Conference Proceedings.*

Winston, W.L. (2004), *Operations Research: Applications and Algorithms*, 4th ed., Thomson Brooks/Cole.

Womack J.P., Jones D. and Roos D. (1990), *The Machine That Changed the World,* Rawson Associates, New York, NY.

Womack, J. P. and Jones, D.T. (1994), "From Lean Production to the Lean Enterprise", *Harvard Business Review,* Vol. 72, No. 2, pp. 93-103.

Womack, J., Jones, D. and Roos, D. (1991), *The Machine that Changed the World: The Story of Lean Production,* Harper Perennial Publishers, NY.

Womack, J.P. and Jones, D.T. (1996), *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, 1st ed., Simon & Schuster, New York.

Won, J., Cochran, D., Johnson, H.T., Bouzekouk, S. and Masha, B. (2001), "Rationalizing the Design of the Toyata Production System: A comparison of two approaches," *Proceeding of CIRP International Design Seminar,* Stockholm, Sweden, 2001.

Wong, Y.C. and Wong, K.Y. (2011), "Approaches and practices of lean manufacturing: the case of electrical and electronics companies", *African Journal of Business Management,* Vol. 5, No. 6, pp. 2164-2174.

Wong, Y.C., Wong, K.Y. and Ali, A. (2009), "A study on lean manufacturing implementation in the Malaysian electrical and electronics industry", *European Journal of Scientific Research,* Vol. 38, No. 4, pp. 521-535.

Worley, J. (2004), "The role of socio-cultural factors in a lean manufacturing implementation", *Unpublished Master Thesis*, Oregon State University, Corvallis, OH.

Worley, J.M. and Doolen, T.L. (2006), "The role of communication and management support in a lean manufacturing implementation", *Management Decision*, Vol. 44, No. 2, pp. 228-245.

Wu, Y.C. (2003), "Lean manufacturing: a perspective of lean suppliers", *International Journal of Operations & Production Management*, Vol. 23, No. 11/12, pp. 1349-76.

Yang, T. and Lu, J.C. (2011), "The use of a multiple attribute decision-making method and value stream mapping in solving the pacemaker location problem", *International Journal of Production Research*, Vol. 49, No. 10, pp. 2793-2817.

Yavuz, M. and Akcali, E. (2007), "Production smoothing in just-in-time manufacturing systems: a review of the models and solution approaches", *International Journal of Production Research*, Vol. 45, No. 16, pp. 3579-3597.

Yu, H., Tweed, T., Al-Hussein, M. and Nasseri, R. (2009), "Development of Lean Model for House Construction Using Value Stream Mapping", *Journal of Construction Engineering and Management*, Vol. 135, No. 8, pp. 782-790.

Yusuf S. M. and Aspinwall E. (2000), "Total quality management implementation frameworks: Comparison and review", *Total Quality* Management, Vol. 11, No. 3, pp. 281–294.

Yusuf, Y.Y. and Adeleye, E.O. (2002), "A comparative study of lean and agile manufacturing with a related survey of current practices in the UK", *International Journal of Production Research*, Vol. 40, No. 17, pp. 4545-4562.

Zayko, M.J., Broughman, D.J. and Hancock, W.M. (1997), "Lean manufacturing yields world-class improvements for small manufacturer", *IIE Solution*, April, pp. 36-40.

Zhang, Z., Lee, M.K.O., Huanga, P., Zhang, L. and Huang, X. (2005), "A framework of ERP systems implementation success in China: an empirical study", *International Journal of Production Economics,* Vol. 98, No. 1, pp. 56-80.

Zhou, B. (2012), "Lean principles, practices, and impacts: a study on small and medium-sized enterprises (SMEs)", *Annals of Operations Research*, DOI 10.1007/s10479-012-1177-3, published on line 6th July, 2012.

Birla Institute of Technology & Science, Pilani
Pilani Campus
Jaiprakash Bhamu, Research Scholar of Mechanical Engineering Department

To Date:

____

____

____

Dear Sir/Madam

I am Jaiprakash Bhamu working as an Assistant Professor at Government Engineering College, Bikaner and pursuing my doctoral thesis on the topic of lean manufacturing at Birla Institute of Technology and Science, Pilani . It gives me immense pleasure to interact with you on this topic.

The goal of Lean Manufacturing (LM) is to become highly responsive to customer demand by reducing the waste in human effort, inventory, time to market, and manufacturing space while producing quality products efficiently and economically. Various authors have documented benefits of lean implementation such as improvement in production lead time, processing time, cycle time, set up time, change-over time, inventory, defects & scrap, overall equipment effectiveness, etc. I am sure each of you would wish to implement lean manufacturing to get above mentioned benefits. However, all organizations were not equally successful in implementing lean. I am doing a research to find factors which drive or hinder lean manufacturing implementation

In this context, I request you to kindly fill the attached questionnaire, which is one of the important components of my research work. Your judicious response will assure substantial help to carry out the same successfully. I will be happy to acknowledge the same.

Please make it convenient to spare your valuable time to fill in and return the attached questionnaire. **The collected information will be kept confidential and utilized for research purpose only. If you wish, you need not disclose you or your company identity.** I welcome your suggestions. Should you require any additional information, please do not hesitate to contact me.

If you are not associated with this subject then forwarding this letter to the concerned person will be of a great help.

Thanking you.

Yours truly,

Jaiprakash Bhamu

Address for Correspondence:

Mr Jaiprakash Bhamu c/o Prof K S Sangwan
Department of Mechanical Engineering
Birla Institute of Technology and Science, Pilani
Rajasthan 333031

innovate achieve lead

Birla Institute of Technology & Science, Pilani
Pilani Campus, Vidya Vihar
Pilani 333031, Rajasthan, India

Tel: +91 9414202822
Mail: bhamujp@gmail.com

PART I: GENERAL INFORMATION OF PARTICIPATING ORGANIZATION AND RESPONDING PERSON

Name and address of the organization ______________________________

____

Type of the organization : Micro ☐ SSI ☐ Medium-Scale ☐ Large- Scale ☐

Primary products of the organization : ______________________________

Management type : Independently managed ☐ Limited ☐ Owner managed ☐

No. of employees : Less than 50 ☐ 50-200 ☐ 200-500 ☐ Above 500 ☐

Sales turnover : Up to 1 crore ☐ 1-5 crore ☐ 5-25 crore ☐ Above 25 ☐

Year of establishment ______________________________

Exports : 0% ☐ Partial export ☐ 100% ☐

Primary export market : ______________________________

Name of responding person : ______________________________

Designation : ______________________________

Department : ______________________________

Experience (Years) : ______________________________

E-mail : ______________________________

Ph. No./Mobile No. : ______________________________

Would you like to be contacted for any further information or a personnel interview? YES/NO

Can I acknowledge you in my research work/thesis? YES/NO

Can I acknowledge your organization in my research work/thesis? YES/NO

1	What is the average age (in years) of shop floor employees?			
	Under 30	30-40	40-50	Over 50
2	Average stay (in years) of workers in the plant?			
	0-1	1-3	3-10	Over 10

Part II- *Drivers and Barriers* of lean manufacturing (give the importance on the scale of 1 to 5, where:

(1 – Very Low, 2 – Low, 3 – Medium, 4 –High, 5 –Very High)

OR

(1 –Completely Disagree, 2 –Rarely Agree, 3 –Partly agree, 4 –Rather Agree, 5 – Completely Agree)

A typical example is shown below:

	Completely Disagree	Rarely Agree	Partly agree	Rather Agree	Completely Agree
Low manpower productivity	1	2	3	4	(5)

(A) DRIVERS

(Factors which you perceive are forcing or has forced the organization to implement lean manufacturing)

1	High level of stock/inventory	1	2	3	4	5
2	Low manpower productivity	1	2	3	4	5
3	Poor skills/capabilities of workers	1	2	3	4	5
4	Unavailability of skilled workers	1	2	3	4	5
5	High Labour Cost	1	2	3	4	5
6	High scrap/rework/rejection	1	2	3	4	5
7	Poor commitment of employees	1	2	3	4	5
8	Customer wants reliable and prompt deliveries	1	2	3	4	5
9	Fluctuating customer orders	1	2	3	4	5
10	High product variety or customer specific products	1	2	3	4	5
11	Unbalanced workload on different workstations	1	2	3	4	5
12	Poor workplace organization and housekeeping	1	2	3	4	5
13	High cost of energy (Electricity or Fuel Cost)	1	2	3	4	5
14	Weak process control	1	2	3	4	5
15	Low capacity to fulfil the regular demand of customers	1	2	3	4	5
16	Lack of standard operating procedures	1	2	3	4	5
17	Short time to fulfil customer orders	1	2	3	4	5
18	Low quality material or parts by suppliers	1	2	3	4	5
19	Suppliers take long time to deliver	1	2	3	4	5
20	Frequent changes in supply schedule by customers	1	2	3	4	5

(B) BARRIERS

(Factors which you perceive are forcing or has forced the organization not to implement lean manufacturing)

1	High cost of consultant fee for training	1	2	3	4	5
2	Low awareness of lean manufacturing	1	2	3	4	5
3	Misconception of high investment	1	2	3	4	5
4	No immediate results or low perceived benefits	1	2	3	4	5
5	Low System Flexibility to Change or Poor Organizational Culture	1	2	3	4	5
6	Lack of top management commitment	1	2	3	4	5
7	Lack of change management agents or lack of Human resources	1	2	3	4	5
8	Inadequate training opportunity	1	2	3	4	5
9	Procedures are too generic and not industry specific	1	2	3	4	5
10	Resistance to change and adopt innovations	1	2	3	4	5
11	Too much Time & effort required to implement lean	1	2	3	4	5
12	Not an industry norm like ISO	1	2	3	4	5

Publications

Journals

1) Bhamu, J., Shailendra Kumar, J. V. and Sangwan, K. S. (2012), "Productivity and quality improvement through value stream mapping: a case study of Indian automotive industry", *International Journal of Productivity and Quality Management*, Vol. 10, No. 3, pp. 2012.
2) Bhamu, J., Khandelwal, A. and Sangwan, K. S. (2012), "Lean manufacturing implementation in an automated production line: a case study", *International Journal of Services and Operations Management*, Vol. xx, No. xx, pp xxx. In press
3) Bhamu, J. and Sangwan, K.S., "Lean Manufacturing: Literature review and research issues", *International Journal of Operations and Production Management,* revision submitted.
4) Bhamu, J. and Sangwan, K.S., "Development and validation of lean manufacturing implementation framework". Communicated.
5) Bhamu, J., Mehta, D. and Sangwan, K.S., "Development of drivers and barriers of lean manufacturing implementation in ceramic industry using structural equation modelling**".** Communicated.
6) Bhamu, J. and Sangwan, K.S., **"**Application of lean manufacturing in Rajasthan ceramic sector: a case study". Working paper.
7) Bhamu, J. and Sangwan, K.S., "Development of interpretive structural model of drivers of lean manufacturing implementation". Working paper.

Conferences

1) Bhamu, J., Choudhary, D., Tayal, S. and Sangwan, K.S. (2012), Development of interpretive structural model of barriers of lean manufacturing implementation in Small and Medium Enterprises (SMEs), *XVI Annual International Conference of the Society of Operations Management, 21st-23rd December, 2012, at IIT, Delhi (India).*

2) Bhamu, J., Choudhary, D., Gaddam, S. and Sangwan, K.S. (2012), A strategic and operational framework for implementation of lean manufacturing practices, *XVI Annual International Conference of the Society of Operations Management, 21st-23rd December, 2012, at Indian Institute of Technology (IIT), Delhi (India).*

3) Bhamu, J., Bhakar, V. and Sangwan, K.S. (2011), Integrated lean management system for sustainable development: a conceptual model, *Proc. of the International Conference on Sustainable Manufacturing: Issues, Trends and Practices, 10-12 November, 2011, BITS Pilani, pp. 235-238.*

4) Bhamu, J. and Sangwan, K.S. (2011), Lean manufacturing tools, techniques and methodology, *In: Proc. of 26th national Convention of Production Engineers, 7-8 May 2011, IEI Jaipur, pp 21-26.*

5) Bhamu, J., Shailendra Kumar J V and Sangwan K S (2011), Application of value stream mapping in lean manufacturing: a case study, *In: Proc. Of 26th national Convention of Production Engineers, 7-8 May 2011, IEI Jaipur, pp 27-33.*

6) Bhamu, J. and Sangwan K S (2011), Lean manufacturing tools and techniques: a review of literature during 2001-2010, *In: Proc. of the International Congress on Productivity, Quality, Reliability, Optimization and Modeling, ISI New Delhi, India, February 7-8, 2011, pp 979-990.*

BRIEF BIOGRAPHY OF THE CANDIDATE

JAIPRAKASH BHAMU received his B.E. in Mechanical Engineering from MBM Engineering College, Jodhpur (Rajasthan) and M. Tech. in Manufacturing System Engineering from Malaviya National Institute of Technology, Jaipur (Raj.) India. Mr Bhamu is employed with Government Engineering College, Bikaner as an Associate Professor. He is pursuing his PhD as a research scholar in the Department of Mechanical Engineering, BITS, Pilani and has over 10 years teaching experience at under graduate and post-graduate levels. His areas of interest are lean manufacturing, total quality management and sustainable manufacturing. He has published papers in National/International Conferences and International Journals. He is member of Society of Automotive Engineering (SAE) India.

BRIEF BIOGRAPHY OF THE SUPERVISOR

KULDIP SINGH SANGWAN did his B.E. and M.E. from Punjab Engineering College, Chandigarh, and PhD from BITS, Pilani. He has also obtained PG Diploma in Operations Management. He is presently working as Head of the Mechanical Engineering Department at BITS, Pilani and has over 20 years teaching experience at under graduate and graduate levels. He has published a monogram on concurrent engineering and many research papers in national and international journals. His areas of research interest are CMS, Green Manufacturing, World-class Manufacturing, TPM, Concurrent Engineering, Operations Management, and application of Fuzzy Mathematics, Genetic Algorithms, Simulated Annealing, and Neural Networks in design of manufacturing system. Prof. Sangwan is life member of Institution of Engineers (India), Society of Operations Management and Indian Society of Technical Education. Prof. Sangwan has developed research collaborations with German and Spanish universities in the area of Titanium alloy machining, automotive life cycle engineering, and lean and green manufacturing. He has also developed many courses related to the manufacturing management, engineering design and design engineering for the working professionals.