EFFECTIVE DECISION SUPPORT SYSTEM FOR LEAGILE MANUFACTURING IN SELECT INDIAN INDUSTRIES

THESIS

Submitted in fulfillment of the requirement for the award of the Degree of

Doctor of Philosophy

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CANDIDATE'S DECLARATION

I hereby declare that the thesis entitled **'EFFECTIVE DECISION SUPPORT SYSTEM FOR LEAGILE MANUFACTURING IN SELECT INDIAN INDUSTRIES**', by **Naveen Virmani,** being submitted in fulfillment of the requirements for the degree of Doctor of Philosophy in Department of Mechanical Engineering, under the Faculty of Engineering and Technology, during the academic year 2018-19, is a bona fide record of my original work carried out under guidance and supervision of **DR. RAJEEV SAHA, ASSISTANT PROFESSOR, DEPARTMENT OF MECHANICAL ENGINEERING, YMCAUST, FARIDABAD** and **DR. RAJESHWAR SAHAI, DIRECTOR, RATTAN COLLEGE, FARIDABAD** and has not been presented elsewhere.

I further declare that the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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We, further declare that to the best of our knowledge, the thesis does not contain any part of any work which has been submitted for the award of any degree either in this university or in any other university.

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ABSTRACT

There is intense competition in the market in the recent scenario. The companies are required to adopt advance manufacturing methods like Robotics, PLC'S, AGVS etc. and also required to adopt strategies like Lean manufacturing, Agile manufacturing, Flexible Manufacturing System (FMS), Statistical Process Control (SPC), Six Sigma, Kaizen, Poke Yoke etc. in order to survive in the market. Leagile system is found to be most important strategy to remain competitive by the researchers in last few decades. Leagile manufacturing system which is combination of lean and agile system has been discussed. Leagile manufacturing system has advantages of both, lean as well as agile system.

The major contribution of the research includes:

- In the research work, the attributes affecting leagile manufacturing system have been identified through literature review. A survey has been conducted to validate the attributes. Snowball sampling method is used. Exploratory factor analysis is done to group the attributes in to factors.
- Various Advantages of leagile manufacturing system have been identified.
- The leagile manufacturing tools have been identified which helps in successful implementation of leagile system.
- Various leagile manufacturing barriers have been identified through literature review and in discussion with industry experts. Interpretive Structural Modeling (ISM) technique has been applied to find the driving and dependence power of each barrier. ISM model have been prepared which clearly tells the interrelationship among leagile barriers. This sets the guidelines for overcoming these barriers.
- Various leagile social implications have been identified through literature review and in discussion with industry experts. Total Interpretive Structural Modeling (TISM) technique have been applied to find the driving and dependence power of each social implication. TISM model have been prepared which clearly tells the interrelationship among leagile social implications.

- Critical Success Factors (CSF's) have been identified and modified Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) has been applied to find the ranking of factors.
- Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) technique have also been applied to categorize the critical success factors in to cause and effect categories so that the managers can effectively deal with them.
- Key Performance Indicators (KPI's) have been identified and fuzzy TISM technique have been applied which sets the interrelationship among KPI's under uncertain and complex situations.
- Leagility index have been calculated using Graph Theoretic and Matrix Approach (GTMA) which can be used to compare the performance of organization with similar type of competitive industry.
- Leagile criteria's have been found out and DEMATEL technique has been applied to determine the causal relationship among criteria's.

Keywords: Lean manufacturing, Agile manufacturing, Leagile manufacturing, Interpretive Structural Modeling (ISM), Decision Making Trial and Evaluation Laboratory (DEMATEL), Technique of Order Preference by Similarity to Ideal Solution (TOPSIS), Graph Theoretic and Matrix Approach (GTMA)

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LIST OF ABBREVIATIONS

S.No	TITLE	ABBREVIATIONS
1	Computer aided design	CAD
2	Computer aided manufacturing	CAM
3	Programmable logic controller	PLC
4	Abrasive jet machining	AJM
5	Electro chemical machining	ECM
6	Electric discharge machining	EDM
7	Total quality management	TQM
8	Total preventive maintenance	TPM
9	Exploratory factor analysis	EFA
10	Interpretive structural modeling	ISM
11	Decision making trial and evaluation laboratory	DEMATEL
12	Technique of order preference by similarity to ideal solution	TOPSIS
13	Total Interpretive structural modeling	TISM
14	Critical success factors	CSF
15	Computer numerical control	CNC
16	Quality control	QC
17	Just in time	JIT
18	Quality management	QM
19	Lean manufacturing	LM
20	Statistical process control	SPC
21	Strength, weakness, opportunity, threats	SWOT
22	Lean enterprise research	LER
23	Product development	PD
24	Single minute exchange of dies	SMED
25	Value stream mapping	VSM
26	Plan, do, check and act	PDCA
27	Failure mode and effect analysis	FMEA
28	Defects per million opportunities	DPMO
29	Define, measure, analyze, improve and control	DMAIC
30	Define, measure, analyze, design and verify	DMADV
31	Design for six sigma	DFSS
32	Metal inert gas	MIG
33	Self directed work teams	SDWT
34	Measurement System Analysis	MSA
35	Ultra Sonic machining	USM
36	Flexible manufacturing system	FMS
37	Computer integrated manufacturing	CIM
38	Computer aided process planning	CAPP
39	Electronic data interchange	EDI
40	Automated guided vehicle system	AGVS
41	Enterprise resource planning	ERP
42	Supply chain management	SCM
43	Virtual enterprise	VE
44	Rapid prototyping	RP

45	Laser beam machining	LBM
46	Finite element method	FEM
47	Structural self interaction matrix	SSIM
48	Initial reachability matrix	IRM
49	Final reachability matrix	FRM
50	Positive ideal solution	PIS
51	Negative ideal solution	NIS
52	Analytic hierarchy process	AHP
53	Reachability matrix	RM
54	Human resource management	HRM
55	Basic non fuzzy performance	BNP
56	Key performance indicators	KPI
57	Optimum inventory level	OIL
58	Concurrent engineering	CE
59	Rapid prototyping	RP
60	Agile manufacturing	AM
61	Business process reengineering	BPR
62	Acceptance sampling	AS
63	Analytic network process	ANP
64	Structural equation modeling	SEM
65	Graph theoretic and matrix approach	GTMA
66	Variable characteristic matrix	VCM
67	Leagility Index	LI
68	Research and development	R & D
69	Information technology	IT
70	Group technology	GT
71	Leagile criteria’s	LC
72	Multi attribute decision making	MADM
73	Genetic algorithm	GA
74	Weighted product method	WPM
75	Preference ranking organization method for enrichment of evaluations	PROMETHEE

CHAPTER 1
INTRODUCTION

This chapter explains the concept of leagile manufacturing, its benefits, gaps in literature review so far, motivation of research, objectives and research methods used in the research.

1.1 Introduction

Leagile system is one of the most emerging strategies used in Indian manufacturing industries now days. Leagile system which may be defined as combination of lean and agile systems; are separated by strategic point called de-coupling point. Industries are highly required to use cutting-edge and smart technologies strategies so as to bear the intense competitive pressure. Quality of the product is most important aspect which determines its sale in the market. If the quality is good, the customer will buy the product; the sales will increase and ultimately will result in increased profitability of firm. For this, the industries are using Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Programmable Logic Controller (PLC), SCADA, Robotics, and Advanced Manufacturing Techniques like Abrasive Jet Machining (AJM), Electro Chemical Machining (ECM), Electric Discharge Machining (EDM) etc. and strategies like Virtual Enterprise, Collaborative Planning etc. Customer satisfaction is the main concern for industries nowadays. As in the 20th century, the competition has become more and more intense; the companies started using quality as the strategic weapon. The industries are more and more focusing on quality tools like lean manufacturing, agile manufacturing, Six sigma, Kaizen, Poka yoke, 5S, Total Quality Management (TQM), Total Preventive Maintenance (TPM), Just In Time (JIT) etc. to make their product better and to achieve maximum productivity. Since 1960's, there were fewer sellers and large number of buyers but nowadays, there are large number of sellers in the market. Today, the customers have options to choose from the different alternatives. So Industry has to adopt manufacturing strategy which produces quality products at competitive prices. Lean system was used prominently as most suitable strategy by researchers in last two decades. Lean system was started by Toyota Production System and tries to eliminate all wastes and non value added activities for making product at economic cost. According to Christopher and Towill (2000), lean means “containing little fat” and agile means “nimble”. Nowadays, customers do not want to wait for the product. For example: if a customer wants to buy a car; he has options like Maruti, Toyota, Mahindra, Tata etc. Lean tries to eliminate inventory and focuses on Just in Time (JIT) concept but for system to be agile, there should be optimum level of inventory so that the production can be started as soon as customer order is achieved. Also, for the system to be agile, it should have flexible manufacturing system so that customer demand can be met quickly.

Leagile is combination of both lean and agile system. In the current scenario, make to order or make to stock strategies may not work because make to stock strategy may block the capital and make to order strategy may require more time as shown in figure 1.1. So both lean and agile systems are combined together to make leagile system which focuses on assemble to order strategy.

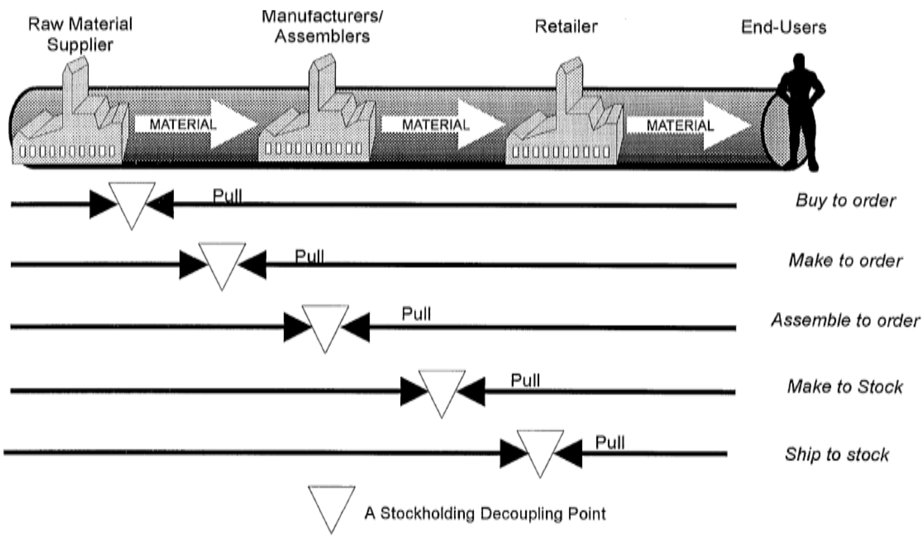


Figure 1.1: Positioning of De-Coupling Point (Naylor, Naim and Berry, 1999)

Naylor, Naim, Berry (1999) gave the concept of leagility by combining lean and agile methodologies in supply chain. Figure 1.1 shows different positions of de-coupling point. Both lean and agile manufacturing system can be incorporated simultaneously in a supply chain; upstream of supply chain, lean system is preferred while downstream agile system is preferred. The level schedule is one with predictable and stable demands of customers; lean system is preferred to minimize waste and non value added activities. Downstream, the customer demand is highly volatile, so the system needs to be flexible and reconfigured quickly to make the customized products within short span of time.

Womack and Jones (1996) have given five principles of lean manufacturing: value, the value stream, flow, pull, and perfection, and are described as:

(1) Value, which is explained by customer

(2) The value stream, which explains the steps required to manufacture the particular product

(3) Flow is concerned with steps which creates value to the product.

(4) Pull explains all about pulling values along the supply chain.

(5) Perfection refers to achieving excellence in particular domain.

1.2 Benefits of leagile manufacturing system

Since both lean and agile systems separately are not sufficient for the industry to compete in market; hybrid system i.e. leagile system can be used which results in increased customer satisfaction, reduced cost per unit etc.

The benefits of leagile manufacturing system are:

- Increased Productivity
- Increased Quality of Products
- Better Customer Satisfaction
- Optimum Inventories
- Increased Sales
- Increased Profitability
- Increased Market Share
- Better Market Reputation
- Increased Employee Morale
- Better Utilization of Resources
- Smooth Flow of Materials
- Reduced Error

1.3 Motivation of Research

Maximizing the profit is the ultimate aim of each and every manufacturing industry and it can be achieved from maximum sales which in turn will be there if product manufactured is of good quality at competitive price. Every activity of industry needs to be well planned and error free so that product can be made with minimum wastage or rather we say no wastage and quickly also. The industry also needs to be aware of latest technologies in the concerned area. In the last few decades, automation has made lot of changes in the manufacturing era. The production of companies has been increased exponentially and losses have become minimum. Many researchers have worked in lean and agile manufacturing alone; but only few literature was available on hybrid system i.e. leagile. So need of exploring the leagile area was identified.

1.4 Gaps in literature

The major things in the leagile literature gap have been identified which is an urgent requirement so that necessary steps can be taken for implementation of leagile system in industries with relative ease.

The major findings were

- Less awareness about quality oriented tools like 5S, kaizen, poka yoke, TQM, TPM, Just in Time etc.
- Tools of leagile system were not identified.
- Lesser number of motivational and training programs organized in the firm.
- Not too much work was done in context of leagile barriers.
- Not much attention was paid for critical success factors of leagile system
- Social Implications was also not identified by past researchers.
- Not much work was done on key performance indicators of leagile manufacturing system.

1.5 Research Objectives

The concept of lean and agile manufacturing directly affects the organization's performance and ultimately the profitability. The profit can be increased by reducing the wastes and on the same time, quick response to customer demand is needed. The purpose of the research is to make effective decision support system for leagile manufacturing in select Indian Industries.The objectives of the research are:

1. To study the scenario of leagile manufacturing within select Indian manufacturing industries.
2. To prepare leagile manufacturing Framework.
3. To identify performance measurement indicators of leagile manufacturing.
4. To develop effective decision support system for implementation of leagile manufacturing.
5. To implement the developed decision support system for leagile manufacturing in select Indian manufacturing industry.

1.6 Organization of the thesis

The thesis will have following 11 chapters:

Chapter 1: Introduction

This chapter discusses the importance of implementing leagile manufacturing system in Indian manufacturing industries, its benefits, research objectives and gaps in literature review.

Chapter 2: Literature review

This chapter discusses the literature of lean manufacturing, agile manufacturing, leagile manufacturing. The lean tools, agile tools and leagile tools are also identified and explained in this chapter.

Chapters 3: Questionnaire Administration and Descriptive Statistics

Different barriers, critical succes factors, key performance indicators, social implications of leagile manufacturing system have been found out through literature review and validated by industry professional and academicians. In total, 950 questionnaires was sent. Out of this, 280 questionnaires were received.

Chapter 4: Barriers of Leagile Manufacturing System

This chapter discusses the barriers in implementing leagile manufacturing system identified by literature review and has been validated by survey. ISM (Interpretive Structural Modeling) technique and MICMAC analysis has been applied to find the hierarchical structure. The barriers are categorized in to categories like autonomous, dependent, independent and linkage. This chapter also discusses the ranking of barriers of leagile manufacturing system by Modified TOPSIS (Technique of Order preference by similarity to ideal situation) technique.

Chapter 5: Social Implications of Leagile Manufacturing System

This chapter discusses the social implications involved while implementing leagile manufacturing system identified by literature review and has been validated by survey. TISM (Total Interpretive Structural Modeling) technique and MICMAC analysis has been applied to find the hierarchical structure. The social implications are categorized into categories like autonomous, dependent, independent and linkage.

Chapter 6: Analyzing Critical Success Factors (CSF's) of Leagile Manufacturing System

This chapter discusses the Critical Success Factors (CSF) involved while implementing leagile manufacturing system identified by literature review and has been validated by survey. Fuzzy DEMATEL (Decision Making Trail and Evaluation Laboratory) technique has been used to categorize critical success factors in to cause and affect categories.

Chapter 7: Key Performance Indicator's (KPI's) of leagile manufacturing system

In this chapter, the key performance indicators have been discussd which were found by literature review. Fuzzy Decision making trial and evaluation laboratory technique have been used to categorize KPI's in to cause and effect categories. This sets the guidelines for managers so that they can successfully implement leagile manufacturing system.

Chapter 8: Ranking of Critical Success Factors of Leagile Manufacturing System

This chapter discusses the Critical Success Factors (CSF) involved while implementing leagile manufacturing system identified by literature review and has been validated by survey. Modified TOPSIS (Technique of Order Preference by Similarity to Ideal Solution) has been used to rank these critical success factors.

Chapter 9: Quantification of Key Factors Affecting Leagile Manufacturing System

This chapter discusses the leagile manufacturing key factors identified by literature has digraph technique has been applied to evaluate interaction among different factors. The leagility index have been defined which can be used for comparing performance of different industries.

Chapter 10: Leagile Criteria Assessment using DEMATEL Approach

This chapter discusses the leagile manufacturing criteria's (LMC'S) identified by literature review involved while implementing leagile manufacturing system and has been validated by survey. The DEMATEL (Decision Making Trail and Evaluation Laboratory) technique has been applied to categorize leagile manufacturing criteria's into cause and effect categories.

Chapter 11: Summary, Key findings, Implications and Scope for future work

Leagile system will help the industries to produce most economical products. Successful implementation of leagile system results in better quality of products, better customer satisfaction, increased productivity, increased sales and ultimately increased turnover and profitability of firm.

1.7 Major Contribution

It is expected that implementing leagile manufacturing system in manufacturing industries will help in increasing the quality of products, increased customer satisfaction, increased sales, better profitability, increased market share, increased employee morale, reduced wastages/defects, better utilization of resources etc. The work is carried out for Indian automobile organizations. Further attempts can be made to verify same results for other industries also.

The steps for the research work is given in figure 1.2

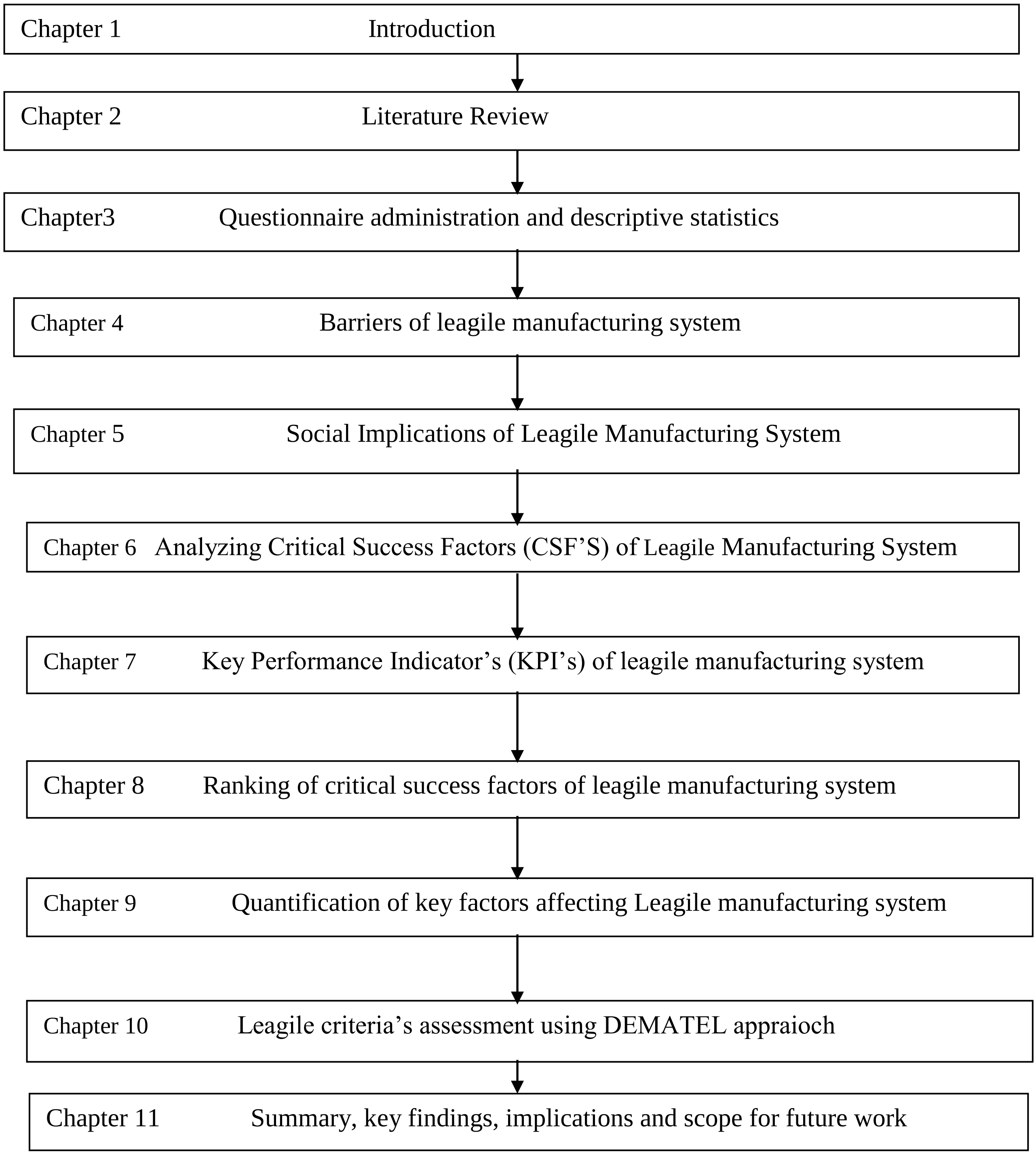


Figure 1.2: Organization of Research Work

CHAPTER 2
LITERATURE REVIEW

This chapter discusses the literature available of lean manufacturing, agile manufacturing and leagile manufacturing. The tools of lean manufacturing, agile manufacturing and leagile manufacturing are also identified and described in this chapter.

2.1 Lean Manufacturing

Taichi Ohno, who was given the task of developing a system that would enhance productivity at Toyota, is generally considered to be a primary force behind the system (Mason, Naylor and Towill, 2000). Womack and Jones (1991), value stream in lean depends on a customer and cost perspective, rather than organization's viewpoint, and a lean manufacturing typically has expected order, low variety of items, longer product life cycles, and price driven customers. Lean is basically concerned with reducing all the activities which does not add value to the product. Lean means less of everything i.e. less manpower, less space, less investment etc. to produce the same output without compromising with the quality. As per Moyano-Fuentes and Sacristán-Díaz (2012), the implementation of lean manufacturing depends on type and size of industry. 'Values' are important personal beliefs that people hold with respect to themselves and the goals for which they strive. Rokeach (1968, 1973); Lean manufacturing includes seven different types of wastes. Mohd. Siddiqui (2013); Kaizen have also shown significant results in improving the quality of product as it is seen in case study of automotive industry. Upadhye, Desmukh and Garg (2010), the need of implementing lean manufacturing and benefits that the companies will get is analyzed by various authors. Vijaykumar and Robinson (2016), described major actions taken by the company to implement lean thinking to improve its efficiency and effectiveness. Various researchers have worked to point out various types of wastages and issues to implement the lean manufacturing systems in MSME. Lean tools like kaizen, JIT, VSM, 5S, SQC, preventive maintenance, total employee involvement, and SMED were used to find and abolish the wastages. Lean focuses on eliminating all those activities which do not participate in enhancing value of the product. Kulhang, Hempen, Sihn and Deuse (2013), Continuous improvement has become the necessity for each and every industry. Value stream mapping is one of the important tool of lean manufacturing. Mohanraj, Sakthivel and Vinodh (2011), Value stream mapping helps to comprehend the steps used to manufacture the product. Devadasan, Sivakumar, Murugesh and Shalij (2012), It also helps in eradicating the problem of excess production and superfluous inventory. The objective of lean manufacturing is to helps employer to maximize their firm's operational efficiency and become competitive through the implementation of various lean tools.

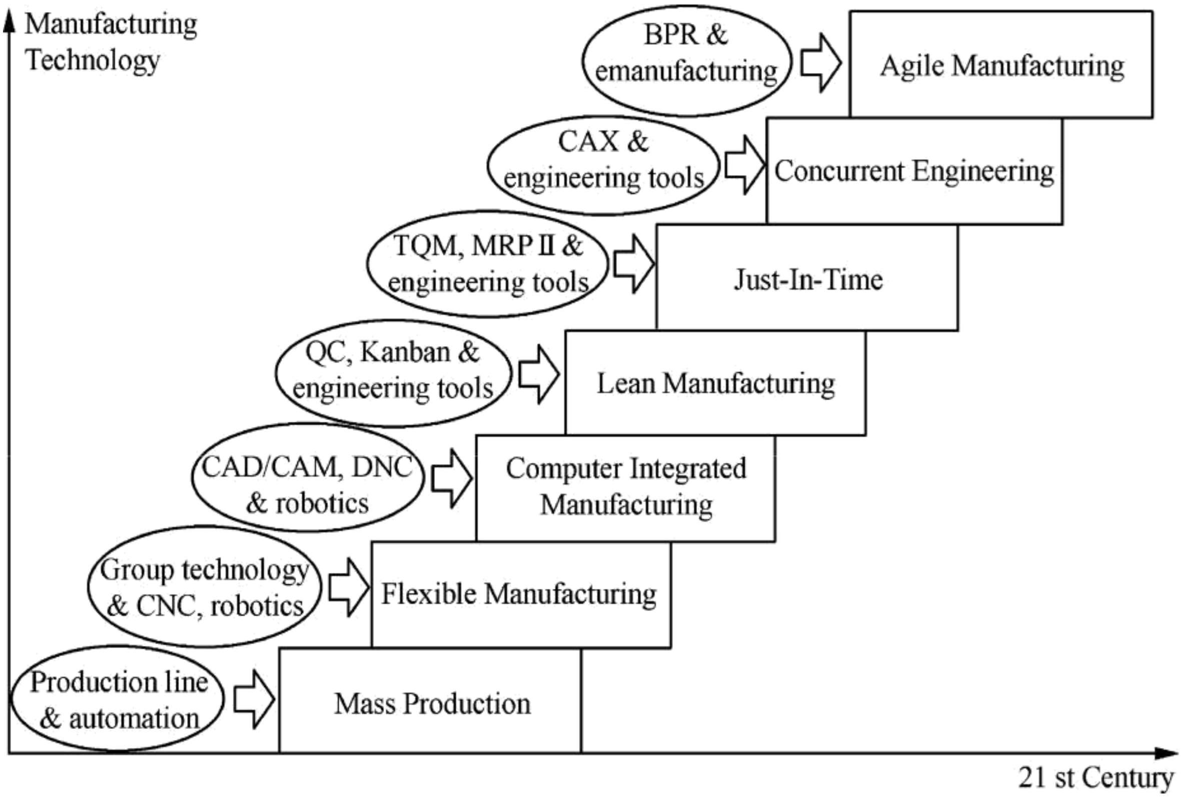


Figure 2.1: Development in manufacturing technology
(Cheng and Bateman, 2008)

The scenario of manufacturing technology is changing at a very fast rate. Few decades earlier, there were fewer producers and large number of buyers or customers; so there was less competition. But with the passage of time, competition grew and today, there is intense competition in the market. The customers have lot and lot of expectation from the producers or manufacturers. The customers want to purchase quality products at economic prices. Also, the customers do not want to wait for the product. So, there is challenge before every industry to well acquaint with latest tools and techniques and recent advancements in the concerned field. The negligence of this will result in loss of reputation in the market and will result in decreased sales and profitability of firm. As shown in figure 2.1, few decades earlier; the industries were concentrated on mass production. Gradually, with the passage of time, the focus was shifted to group technology and then CAD/CAM to Quality control and so on.

Continuous improvement is simple and easy to understand and requires low investment to achieve the goals. There are various ways to increase the competitiveness like kaizen, lean manufacturing, TQM etc. Most of the times, there are difficulties in effectively implementing the concept. This create need to develop different models (Drohomeretski and Gouvea da Costaac, 2014). One of the most effective and suitable model can be leagile manufacturing. Table 2.1 shows the definition of lean manufacturing given by various researchers.

Table 2.1: Some Literature on lean manufacturing

Author	**Year**	**Definition of Lean Manufacturing**
Womack, Jones and Roos	1991	Lean production is a company and manufacturer viewpoint that reduces the time among placement of order and receiving of goods and services by the customer.
Snell and Dean	1992	Lean is a blend of equally strengthen practices, which are grouped into four harmonizing subsystems; Just in Time(JIT) or No Inventory, Quality Management(QM), Total Preventive Maintenance and Human Resource Management activities.
Womack and Jones	1996	The concept of LM is to reduce the amount of resources to the maximum extent without compromising with the quality and quantity.
Czarnicki and Loyd	1998	It is a systematic technique to recognize and abolish waste (non value added activities) by continuous improvement of processes.
Rother and shook	1999	It refers to detection and removing of different wastes like overproduction, inventory, motion, transportation etc. in the value stream to minimize lead time and for making the product economically.

Moutabian	2000	LM concentrates on getting the right products/equipments in the right amount at right time to obtain smooth and continuous production.
Hopp and spearman	2004	The process of production of goods or services in order to minimize costs linked with surplus lead times, inventory or capacity
Liker	2004	It is enhancing value of product by eradicating waste and increasing the quality, and enhancing the efficacy of entire process.
Olson	2004	LM encompasses such practice as employee involvement in worker teams, problem solving, integrated product designs, statistical process control, reengineering setups, cellular manufacturing, pull production, supplier information sharing and partnership, supply base rationalization, in house designed technology, and customer requirements integration.
Shah and Ward	2003	An incorporated Socio methodological structure; main purpose is to remove waste by concomitantly minimizing supplier, buyer and in-house variability.
Alam	2009	LM can be considered as synergistic set of integrated modern manufacturing management practices, commonly classified under subsets of Just in time, total quality management(TQM), total productive maintenance (TPM) and a collection of supportive human resource management practices including teamwork and employee empowerment
Enaghani and Arashpour	2009	It is a culture for quality improvement starting with revolutionizing the minds of employees.
Devadasan, Sivakumar, Murugesh, and Shalij	2012	It eliminates over production and unnecessary inventory
Dora, Kumar,	2013	Ten elements of lean are feedback from supplier; Just in time delivery ; Development of supplier; Involvementof customer ; pull

Goubergen and Molnar		production; Uninteruptted flow; setup reduction of time; total preventive maintenance; statistical process control (SPC) ; employee involvement

Mostafa, Dumrak and Soltan (2013), projected the framework for implementation of lean system in manufacturing industries as shown in figure 2.2. In the conceptual phase, experts of lean system are identified and hired. The organizational features like products manufactured, type of processes involved and quality tools and techniques used are told to them. Afterwards, the review process takes place and training programs are organized for employees. Proper communication and feedback channels are established for better understanding of the lean concept. Potential areas are identified from where the wastages can be significantly reduced. Afterwards, lean metrics are established which sets the guidelines for the managers.

In the implementation design phase, questionnaire of implementation of lean manufacturing system is analyzed and work sampling is also done. In work sampling, the time spent by workers in different activities like setup time of tool, assembling, welding, painting etc. is recorded and analyzed. It is compared with standard time; which is combination of normal time and allowances. A set of observations are taken and mode method is used to get the final reading. The observation, which occurred maximum number of times, is selected for further analysis. Current process sequence is analyzed using value stream mapping. Different types of wastes like overproduction, motion, transportation, inventory etc. are analyzed and corresponding amount is identified and analyzed. SWOT (Strength, weakness, opportunity and threats) analysis is done in context of lean system. Afterwards, the process is improved upon by eradicating the wastes and activities which are redundant and have no role in increasing the value of product and future state value stream mapping is set and lean transformation plan is ready to implement.

In the implementation and evaluation phase, the employees of organization are trained and motivated so that they become well acquainted with lean concept and implementation can be done with relative ease. Pilot study is done in order to determine and identify the feasibility, time required to accomplish it etc.

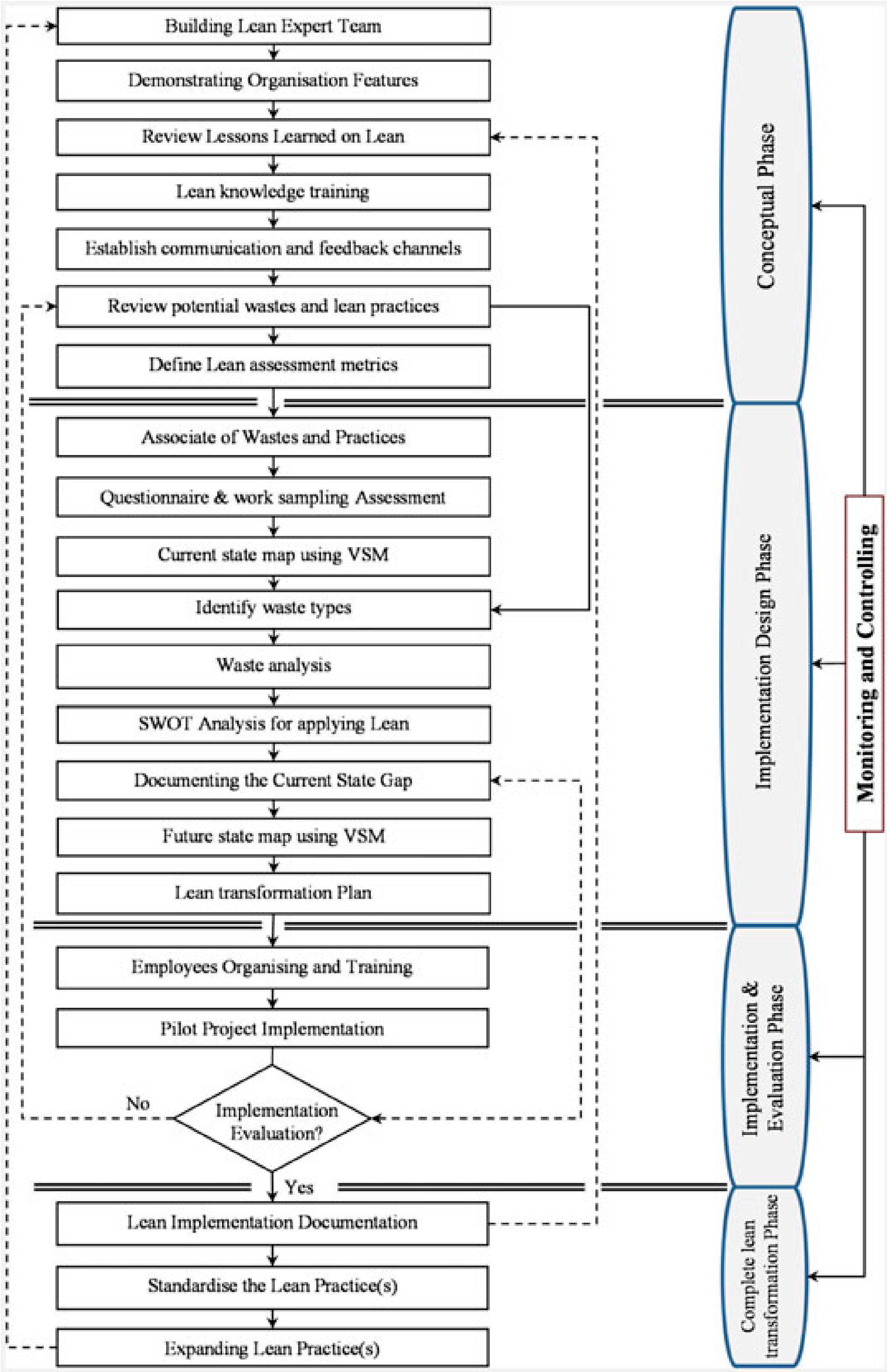


Figure 2.2: A framework for implementation of lean manufacturing

(Mostafa, Dumrak and Soltan, 2013)

In complete lean transformation phase, lean practice procedures and techniques are documented and standardization of process, equipment or machineries used is done so that the products made are of high quality at economic cost. In the last step, lean practices are expanded and continuously improved to make the system better.

Lean manufacturing includes seven different types of wastes

1. Transport
2. Defects
3. Overproduction
4. Over-processing
5. Inventory
6. Waiting
7. Motion

The Lean Enterprise Research (LER, 2004) at Cardiff Business School, highlighted that for most production operations:-

- 5% of the activities add value
- 35% are essential non-value activities
- 60% are of no significance in enhancing value.

Lean not only means reducing all types of wastes but it also means that products should be assembled only and only when customer's demand is there.

2.1.1 Lean manufacturing benefits

1. Reduced inventory
2. Wastage reduction
3. Reduced lead time
4. Better understanding of process
5. Financial savings
6. Less rework
7. Improved quality of products
8. Increased customer satisfaction
9. Increased productivity
10. Increased market share
11. Increased resource utilization

2.1.2 Roadblock in implementing Lean Manufacturing

1. Reluctance of the workers and staff members to change

2. It requires training to be given to the workers and the staff members, meanwhile production may be stopped.
3. Time shall be given for training to employees.

2.1.3 Principles of Lean

The five-step thought process for guiding the implementation of lean techniques is easy to remember, but not always easy to achieve. The principles of lean manufacturing are shown in figure 2.3

1. Defining the concept of value as per the perception of customer.
2. Recognizing the steps required in the value-stream.
3. Ensuring the smooth functioning of value-stream.

Figure 2.3: Lean Principles

Source: http://www.lean.org/WhatsLean/Principles.cfm

4. Ensuring the flow of value to the customer in proper and orderly manner.
5. Necessray steps are taken to attain perfection in the system.

Product development process plays a significant role in deciding the efficiency and effectiveness of lean process as shown in figure 2.4. Lean manufacturing involves several significant steps and eradicate all insignificant and illogical costs and tries to save each and every resources. It helps to make the product by using less of every resource like material, time, man power etc. There are some pre requirements for the system to be lean product development (PD).

No process is 100 % perfect; so employees should strive for perfection and tries to minimize the losses associated with the processes involved to manufacture the product. Quality of the products can be improved continuously by focusing on production system. By doing so, the losses can be minimized and quality of products can be improved. Product development is a pivotal subject in context with lean manufacturing and involves planning, design and development, production and sales of novel products.

Lean production was started from Toyota production system. By adopting systematic procedures and set of tools and techniques, lean system can be successfully implemented in to the manufacturing system. Employees are required to get training on latest techniques like 3D printing, LASER welding, robotics, automation, CNC's etc. Now days, there are many software like PRIMVERA available in market which calculate the project completion time, total float etc. Since total float indicates the time duration by which any activity can be delayed without effecting the project completion time. So the mangers can act accordingly and may focus the manpower where there is any delay of completion of particular activity. Table 2.2 shows the tools of lean manufacturing system.

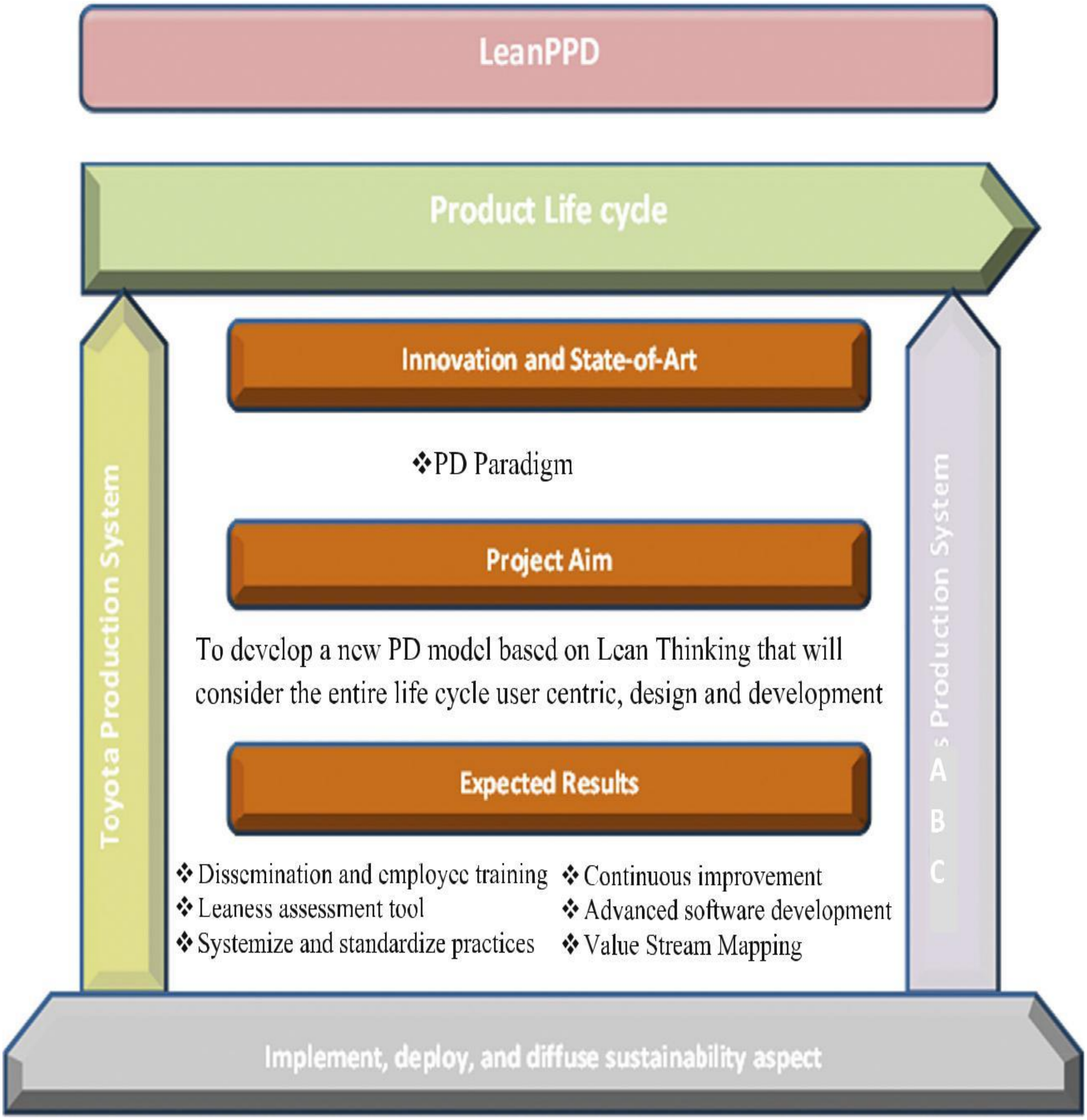


Figure 2.4: Summary of Lean Product development PD model

(Shehab et. al., 2010)

Table 2.2: Lean Manufacturing Tools

S.No	Lean Tool	Authors	Total No.
1	Just in Time	Abdulmalek, Rajgopal and Needy (2006), Ahlstrom (1998), Worley and Doolen (2006), Achanga, Shehab, Roy and Nelder (2006), Irani, Chavalier and Cohen (1993), Kulatilaka, (1988), , Behrouzi and Wong (2011) , Bamber and Dale (2000) , Don-Taylor (1997), Marvel and Standridge (2009), Davies and Greenough (2001), Backhouse and Burns (1999)	12
2	Kaizen	Wafa and Yasin (1998), Crabill, Harmon and Meadows (2000), Achanga, Shehab and Nelder (2006), Worley and Doolen (2006), Kulatilaka (1988), Behrouzi and Wong (2011) , Bamber and Dale (2000) , Marvel and Standridge (2009), Davies and Greenough (2001), Backhouse and Burns (1999)	10
3	Poka Yoke or Mistake Proofing	Anvari et. al. (2011), Crabill, Harmon and Meadows (2000), Worley and Doolen (2006), Irani, Chavalier and Cohen (1993), Kulatilaka (1988), Behrouzi and Wong (2011) , Bamber and Dale (2000) , Don-Taylor (1997), Davies and Greenough (2001)	9
4	TQM	Wafa and Yasin (1998), Anvari et. al. (2011), Worley and Doolen (2006), Behrouzi and Wong (2011) , Bamber and Dale (2000) , Marvel and Standridge (2009), Davies and Greenough (2001), Backhouse and Burns (1999)	8
5	TPM	Bhatia (2004), Mccullen and Towill (2001), Anvari et. al. (2011), Worley and Doolen (2006), Irani, Chavalier and Cohen (1993), Kulatilaka (1988) , Behrouzi and Wong (2011) , Marvel and Standridge (2009), Hoyt (1995)	9

6	SMED or Quick Changeover	Ahlstrom (1998) , Mccullen and Towilland Towill (2001), Achanga, Shehab, Roy and Nelder (2006), Baker (2002), Lasi et. al. (2014) , Behrouzi and Wong(2011) , Herrmann and Minis (1996), Song and Nagi (1997)	8
7	SIX Sigma	Le, Gunn and Nahavandi (2004) , Martínez-Jurado and Moyano-Fuentes(2014), Worley and Doolen (2006), Irani, Chavalier and Cohen (1993), Kulatilaka (1988) , Behrouzi and Wong (2011) , Marvel and Standridge (2009), Hoyt (1995), Davies and Greenough (2001)	9
8	5S	Anand and Kodali (2010) , Mccullen and Towill (2001), Irani, Chavalier and Cohen (1993), Kulatilaka (1988) , Don-Taylor (1997), Hoyt (1995)	6
9	Group Problem Solving	Baker (2002), Anvari et. al. (2011), Kulatilaka (1988) , Behrouzi and Wong (2011), Hoyt (1995)	5
10	Takt Time	Baker (2002) ,Mccullen and Towill (2001), Achanga, Shehab, Roy and Nelder (2006) , Behrouzi and Wong(2011) , Bamber and Dale (2000), Hoyt (1995)	6
11	Kanban	Bamber and Dale and Dale (2000), Davies and Greenough (2001), Dombrowski, Miekke and Engel (2012), Motwani (2003), Bhasin and Burcher and Burcher (2006), Bicheno (2004), Doolen and Hacker (2005), Anvari et. al. (2011), Achanga, Shehab, Roy and Nelder (2006), Worley and Doolen (2006), Kulatilaka (1988) , Behrouzi and Wong (2011) , Don-Taylor (1997) , Marvel and Standridge (2009), Huang and Li (2010)	15
12	Autonomation or Jidoka	Barker (1998), Crute, Ward, Brown and Graves (2003) , Bhasin and Burcher (2006), Achanga, Shehaboy, R and Nelder (2006), Dombrowski, Miekke and Schulze (2012), Kulatilaka (1988) , Behrouzi and Wong (2011), Davies and Greenough (2001)	8

13	Right First Time	Behrouzi and Wong (2011), Anvari et. al. (2011) , Bhasin and Burcher (2006), Crabill (2000), Achanga, Shehab and Nelder (2006), Irani, Chavalier and Cohen (1993), Kulatilaka (1988), Davies and Greenough (2001)	8
14	Value Stream Mapping	Bhasin and Burcher (2006), Doolen and Hacker (2005), Crabill, Harmon and Meadows (2000), Achanga, Shehab, Roy and Nelder (2006), Worley and Doolen (2006), Huang and Li(2010), Jung, Chung and Cho (1996)	7
15	Bottleneck Analysis	Bicheno(2004), Crabill, Harmon and Meadows (2000), Achanga, Shehab, Roy and Nelder (2006), Davies and Greenough (2010), Jung, Chung and Cho (1996)	5
16	Standardized work	Crabill, Harmon and Meadows (2000), Feld(2001), Worley and Doolen (2006) , Don-Taylor and Nagi (1996), Huang and Li (2010)	6
17	Visual Management	Flinchbaugh (1998), Worley and Doolen (2006) , Don-Taylor(1997) , Marvel and Standridge (2009), Huang and Li (2010), Jung, Chung and Cho (1996)	6
18	Andon	Green, Johnson and Adams (2006), Hobbs(2004), Jina, Bhattacharya and Walton (1997), Karim and Arif-Uz-Zaman (2013), Bhasin and Burcher (2006), Worley and Doolen (2006) , Don-Taylor(1997), Jung, Chung and Cho (1996)	8
19	One Piece Flow	Bhasin and Burcher (2006), Huang and Li (2010), Irani, Chavalier and Cohen (1993) , Marvel and Standridge (2009), Davies and Greenough (2001), Jung, Chung and Cho (1996)	6
20	PDCA	Crute, Ward, Brown and Graves (2003), Huang and Li (2010) , Marvel and Standridge (2009)	3
21	Heijunka or Leveling the	Karlsson and Ahlstrom(1996), Motwani (2003) ,Wafa and Yasin (1998) , Bhasin and Burcher (2006),	7

	workload	Worley and Doolen (2006), Kulatilaka (1988), Backhouse and Burns(1999)	
22	Cellular Manufacturing	Krafcik (1988), Mostafa (2011) , Ahlstrom (1998) ,Richards (1996), Crabill, Harmon and Meadows (2000), Worley and Doolen (2006), Jung, Chung and Cho (1996), Backhouse and Burns (1999)	8
23	Continuous Flow	Kumar and Phrommathed (2006) , Rother and Shook (1999), Crabill, Harmon and Meadows (2000), Worley and Doolen (2006) , Bamber and Dale (2000), Jung, Chung and Cho (1996)	6
24	SPC	Lozano and valles (2007) , Soni and Kodali (2009) , Rother and Shook (1999), Worley and Doolen (2006), Irani, Chavalier and Cohen (1993), Kulatilaka (1988), Backhouse and Burns (1999)	7
25	Team Development	Marvel and Standridge (2009) , Soni and Kodali (2009), Crabill, Harmon and Meadows (2000), Kulatilaka (1988) , Bamber and Dale (2000) , Don-Taylor (1997) , Macduffie (1995), Jung, Chung and Cho (1996)	8
26	Work Simplification	Mohanty, Yadav and Jain (2007), Monden (1998), Powell, Alfnes and Strandhagen (2013) , Ahlstrom(1998) , Richards(1996), Crabill, Harmon and Meadows (2000), Achanga, Shehab, Roy and Nelder (2006), Irani, Chavalier and Cohen (1993), Huang and Li (2010), Jung, Chung and Cho (1996)	10
27	Visual Management	Shingo (1989) , Wafa anYasin (1998) , Rother and Shook (1999) ,Richards (1996), Huang and Li (2010), Crabill, Harmon and Meadows (2000), Achanga, Shehab, Roy and Nelder (2006) , Bamber and Dale and Dale (2000), Backhouse and Burns (1999)	9
28	Supplier Development	Wan and Chen (2009) , Bhasin and Burcher (2006), Bamber and Dale (2000), Huang and Li (2010), Jung, Chung and Cho (1996)	

29	Work Balancing	Rother and Shook (1999), Wafa and Yasin (1998), Bhasin and Burcher (2006), Richards (1996), Crabill, Harmon and Meadows (2000), Achanga, Shehab, Roy and Nelder (2006), Bamber and Dale (2000), Marvel and Standridge (2009), Jung, Chung and Cho (1996), Backhouse and Burns (1999)	10
30	Socio Technical Systems	Smeds (1994) , Bhasin and Burcher (2006), Melton (2005), Crabill, Harmon and Meadows (2000), Achanga, Shehab, Roy and Nelder (2006), Worley and Doolen (2006) , Bamber and Dale (2000), Pavnaskar, Gershenson, and Jambekar (2003), Jung, Chung and Cho (1996), Backhouse and Burns (1999)	10
31	Self Directed Work Teams	Smeds (1994), Soni and Kodali (2009), Melton (2005), Huang and Li (2010), Jung, Chung and Cho (1996)	5
32	Point-of-Use storage	Pavnaskar, Gershenson, and Jambekar (2003), PMI (2008) ,Wafa and Yasin (1998), Worley and Doolen (2006), Reid, Rogers and Liles (1996), Jung, Chung and Cho (1996)	6
33	Lean Accounting	Shah and Ward (2007), Olson and Saetre (1997) , Soni and Kodali (2009) , Ahlstrom (1998) , Bhasin and Burcher (2006), Melton (2005), Huang and Li (2010), Achanga, Shehab, Roy and Nelder (2006), Kulatilaka (1988), Pavnaskar, Gershenson, and Jambekar (2003), Ramasesh, Kulkarni and Jaykumar (2001)	11
34	Lean Suppliers	PMI (2013), Sanchez and Perez (2001) , Rother and Shook (1999) , Richards (1996) , Melton (2005), Kulatilaka (1988) , Bamber and Dale (2000), Pavnaskar, Gershenson, and Jambekar (2003), Huang and Li (2010), Backhouse and Burns (1999)	10
35	Zero Defects	Teleghani (2010) , Bhasin and Burcher (2006) , Melton (2005), Pavnaskar, Gershenson, and	4

		Jambekarn (2003)	
36	FMEA(Failure mode and effect analysis)	Politte (2006), Scherrer, Boyle and Deflorin (2009) , Soni and Kodali (2009) , Ahlstrom (1998) , Bhasin and Burcher (2006), Richards (1996), Worley and Doolen (2006), Irani, Chavalier and Cohen (1993), Kulatilaka (1988) , Bamber and Dale (2000), Pavnaskar, Gershenson, and Jambekar (2003), Backhouse and Burns (1999)	12
37	Brain Storming	Wafa and Yasin (1998) , Ahlstrom (1998) , Melton (2005), Pavnaskar, Gershenson, and Jambekar (2003)	4
38	Pareto chart	Worley and Doolen (2006) , Soni and Kodali (2009) , Bhasin and Burcher (2006) , Melton (2005), Achanga, Shehab, Roy and Nelder (2006), Pavnaskar, Gershenson, and Jambekar(2003), Jung, Chung and Cho (1996)	7
39	Fishbone(Ishikawa) Diagram	Monden (1998) , Wafa and Yasin (1998) , Bhasin and Burcher (2006) , Melton (2005), Huang and Li (2010), Achanga, Shehab and Nelder (2006), Irani, Chavalier and Cohen (1993) , Bamber and Dale (2000), Huang and Li (2010), Backhouse and Burns(1999)	10
40	Measurement System Analysis (MSA)	Nightingale and Mize (2003), Puvanasvaran, Megat, Hong and Razali (2009) , Wafa and Yasin (1998) , Ahlstrom (1998) , Rother and Shook (1999), Huang and Li (2010), Achanga, Shehab, Roy and Nelder (2006), Irani, Chavalier and Cohen (1993), Jung, Chung and Cho (1996), Backhouse and Burns (1999)	10
41	System Diagrams	Nordin, Deros and Wahab (2012), Rivera and Frank chen (2007) , Wafa and Yasin (1998), Achanga, Shehab, Roy and Nelder (2006), Worley and Doolen (2006), Pavnaskar, Gershenson, and Jambekar (2003), Huang and Li (2010)	7
42	A3 Report	https://www.moresteam.com/lean/a3-report.cfm	

		accessed on	
43	Regression Analysis	https://www.moresteam.com/toolbox/regression-analysis.cfm	
44	Project Priority Calculator	https://www.moresteam.com/toolbox/project-priority-calculator.cfm	
45	Histogram	https://www.moresteam.com/toolbox/	
46	Trend Chart or Run Chart	https://www.moresteam.com/toolbox/	
47	Modern Manufacturing Practices	Womack, Jones and Roos (1991), Wong and Wong (2011) , Wafa and Yasin (1998) , Richards (1996) , Melton (2005), Worley and Doolen (2006), Jung, Chung and Cho (1996)	7
48	Cellular Manufacturing	Wafa and Yasin (1998) , Rother and Shook (1999) , Bhasin and Burcher (2006), Pavnaskar, Gershenson, and Jambekar (2003)	4
49	Risk assessment	Melton (2005) , Wafa and Yasin (1998) , Bhasin and Burcher (2006), Richards (1996) , Melton (2005), Worley and Doolen (2006), Pavnaskar, Gershenson, and Jambekar (2003), Hoyt (1995)	8
50	Time Value Mapping	Melton (2005) ,Rother and Shook (1999) , Wafa and Yasin (1998) , Richards (1996), Worley and Doolen (2006), Kulatilaka (1988) ,Bamber and Dale (2000), Pavnaskar, Gershenson, and Jambekar (2003), Hoyt (1995)	9
51	Spaghetti diagramming	Melton (2005) , Wafa (1998) , Richards (1996), Worley and Doolen (2006), Kulatilaka (1988), Pavnaskar, Gershenson, and Jambekar (2003), Jung, Chung and Cho (1996)	7

- **Just in Time**: It was originated in Japan in 1960's. In 1990's JIT term was converted into new term called lean manufacturing. Mostly in industries, inventory results in huge carrying cost and results in blockage of capital. So inventory needs to be eliminated as maximum as possible. So now days, industries focus on Just in

Time(JIT), which implies that the materials should enter in the firm as and when required in production system.

- **Kaizen:** This term was first introduced in Japan after the Second World War. It consists of two terms i.e. kai means change and zen means for betterment. No process or activity is 100% perfect; there is also some scope of improvement. This results in increased quality and productivity. Hammer et al. (1993) explains Kaizen as procedure leaning thinking.
- **Poka Yoke:** Defects causes a prominent loss. So, the production system is required to make error proof. It was first applied by Shigeo Shingo in 1960's. It mainly focuses on removing the human errors so that the products manufactured are free from defects.
- **Total Quality Management (TQM):** According to International Organization for Standardization (ISO): TQM is a management approach for an organization, centered on quality, based on the participation of all its members and aiming at long-term success through customer satisfaction, and benefits to all members of the organization and to society.
- **Total Preventive Maintenance (TPM):** TPM focuses on proper and timely maintenance of machines, so that the frequency of breakdowns or defects can be reduced to minimum. It also concentrates the standardized equipments so that the production can be there with relative ease.
- **Single Minute Exchange of Dies (SMED):** It tries to lessen the equipment changeover time as minimum as possible. Normally, a lot of time is wasted in changeover and machinery is halted which results in lower productivity of firm. So, changeover time should be decreased so that production can be increased significantly and customers get the products in minimum time.
- **Six Sigma**: It tries to reduce the variation in products or processes. It is the quality level which is achieved by Motorola, Honeywell, General electric etc. It says there can be 3.4 defects per million opportunities (DPMO) or 99.99966% of all opportunities are defect free. It results in increased sales and profitability as quality of product is increased. Two approaches commonly used are DMAIC (Define, Measure, Analyze, Improve, Control) and DMADV (Define, Measure, Analyze, Design, Verify) or DFSS (Design for Six Sigma).

- **5S:** It implies the sorting out important items and removing unnecessary items or things from the workplace. There is systematic process or steps to produce the product. The workplace needs to be clean and properly maintained. Also, the process or method needs to be standardized, so that the chances of error can be minimized. The sustainability is another important aspect which implies the maintaining all above things properly controlled**.** 5S consists of list of 5 Japanese words

    ■SEIRI – Sort out

    ■SEITON – Systemize

    ■SEISO – Shining

    ■SEIKETSU – Standardize

    ■SHITSUKE - Sustain

- **Group Problem Solving**: No single person is expertise in all the fields. Whenever any problem arises in company, the managers calls meeting of experts/managers so as to get ideas about different alternative or solutions possible for the problem.
- **Kanban**: In this components are supplied through an instruction card send along production line. It was used to limit the flow of work on the production line i.e. work in process should be minimum to avoid any disruptions and continuous flow of materials should be achieved.
- **Autonomation:** It is defined as automation with human touch. It consists of following principles.
    - ➢ Detect the abnormality.
    - ➢ Stop the process.
    - ➢ Rectify the problem.
    - ➢ Analyze the root cause and correct it.
- **Right First Time:** It is the strategy used by industry people to do the things correctly in the first attempt. Lot of money, time, and resources are wasted in correcting the things. So, it is better to do the things with dedication and sincerity so that number of defects produced is minimum.

- **Value Stream Mapping:** It implies the steps required to manufacture the product. Value is added at each and every step. It tries to remove all non value added activities.
- **Bottleneck Analysis:** The problems are analyzed and conditions are identified in which it occurs. The engineer's works upon it and make changes in the present design and improves the system.
- **Standardized Work:** This is done to remove the causes or error possibilities. So, the process needs to be standardized. For example: In a MIG (Metal inert gas) welding, the set of parameters like current, voltage have predefined values; so that the quality of weld produced is better.
- **Visual Management**: It is management strategy in which communication of information takes place by means of visual signals instead of texts for more clarity and understanding of things.
- **Andon**: It is used to notify senior staff/management**,** maintenance people of a quality or process problem by means of signboard. This is done so that the problem encountered can be rectified immediately and production can be started again.
- **One Piece Flow:** This refers to movement of on work piece between workstations so that the work in process should be minimum
- **Plan, Do, Check and Act (PDCA):** It is also known as Deming cycle.
  - Plan : Establish targets or goals
  - Do: Execute the plan.
  - Check: Verify whether the results obtained matches with predetermined standards
  - Act: If there is any deviation between planned and actual results, then take corrective action.
- **Heijunka or Leveling the workload:** This refers to make the product in right quantity by volume and product mix as per the customer demand. It balances the use of operator and machine and reduces risk of unsold goods.
- **Continuous flow:** Continuous flow is needed so that maximum production can be made and equipment halt time is minimized.
- **Statistical Process Control (SPC):** It contains seven tools:
  - Pareto chart
  - Histogram
  - Fishbone or Ishikawa diagram or cause and effect diagram

- Control charts
- Scatter diagram
- Flow chart or run chart
- Check sheet

- **Team Development:** There is no single person in industry which can solve all the problems. So it is necessary to build a team. Meetings and get together held time to time to make strong relationship among each others.
- **Work Simplification:** It is the way of finding easiest, simplest, reliable way of doing the job. For example, if the clothes are rinsed before some time and then washed, the process takes less time.
- **Visual Management:** In this, causes of problems are visualized manually and solutions are found out without using any testing equipment.
- **Supplier Development:** Supplier development is necessary as no single supplier can provide all the supplies. Sometimes, there are problems in the manufacturing processes which the suppliers can easily rectify.
- **Workload Balancing**: It is used to balance the work between various substations so that it can match with customer demands. The main focus is to eliminate the idle time of machines.
- **Socio-technical system:** It is used to develop interrelationship between technical systems and social aspects. It is the joint optimization process which tries to improve both technical and social aspects.
- **Self Directed Work Teams (SDWT):** It is a group of people from different departments in organization which work for common objective or goal.
- **Point-of use usage:** It means that the raw materials or components are stored at the point where production is happened. It minimizes the material handling time.
- **Lean Accounting:** This refers to applying lean system in accounts domain. It concentrates on removing wastages form accounts processes while maintaining financial control.
- **Lean suppliers:** It implies the suppliers which supplies the product of highest quality at minimum cost. Sales after service, reliability, speed, quality etc. are the some important criteria's while selecting a supplier.
- **Zero defects:** The defects are desired to be as minimum as possible as it results in loss to the company and also have a ill effect on goodwill with customers. The

industries are required to make standardized operating procedures so that the products are manufactured are of good quality.

- **Failure Mode and Effect Analysis (FMEA):** It is a method of identifying all possible failures in design, production or assembly and their effects.
- **Brainstorming:** Brainstorming is used in broader sense than group problem solving i.e. there can be many different groups to get the ideas/suggestions about the same common problem.
- **Pareto Chart:** It is also called 80-20 rule. It signifies that 80 % problems are caused by 20 % of causes. It tries to focus on that 20 % causes so that the problem can be reduced significantly.
- **Fishbone diagram:** It is also called ishikava diagram or cause and effect diagram. As the name implies cause and effect diagram, the different causes or factors affecting the particular strategy is determined and analyzed**.**
- **Measurement System Analysis (MSA):** It is a mathematical procedure of determining that how much variations within measurement contribute to overall process variation. The parameters used are: bias, linearity, stability, repeatability, reproducibility.
- **System Diagram:** It is a way of finding the interaction of system with its environment and its components. The interactions can be better analyzed and problems faced can be reduced easily.
- **A3 report:** In this technique, a large paper of size A3 usually is taken. The problem is drawn graphically and effort is made to find the solution.
- **Regression analysis:** In this technique, the association between two variables is identified and analyzed. For example: while designing the diesel engine, the relation between cut-off ratio and efficiency can be determined using regression analysis.
- **Project Priority calculator:** In this method, different proposed projects are evaluated in terms of investment and profitability. The project which gives highest gains are selected.
- **Histogram:** It is a simple way of analyzing the information. For example, the sales of product can be analyzed by making histogram over a period of time.

- **Modern Manufacturing Processes:** Now days, many modern manufacturing processes are used like AJM (Abrasive Jet Machining), USM (Ultra Sonic Machining) etc. which produces products of high quality in less time.
- **Cellular manufacturing:** In this, cells are designed to produce particular part or product. It facilitates continuous production by set-up time reduction and eliminating unneeded activities.
- **Risk assessment:** The risks associated with various processes are identified and quantitative and qualitative analysis is done so that necessary steps can be taken, if such problems are faced.
- **Time Value Mapping:** It is tracking of time taken by item at various work stations. Standard time is set initially and if there is more time taken then cause is identified and necessary steps are taken.
- **Spaghetti diagramming**: It is used to reduce the wastatges like transportation, motion and waiting time. The flow of materials, waiting time, walking of people is shown by different colors.

2.2 Agile Manufacturing System

Companies are also required to make their manufacturing system agile which can respond to quick changes in customer's demand. For this the manufacturing system need to be flexible to make variety of products, which can meet with fluctuating customer's demands.

There is a necessity to eliminate gap between the customer demand and the production of goods by industries. Various researchers have worked in agile manufacturing domain.

Agility requires the use of Flexible Manufacturing System (FMS), Computer Aided Design (CAD), Computer Integrated Manufacturing (CIM), multifunctional team etc. to meet the changing demands of the customers as shown in figure 2.6

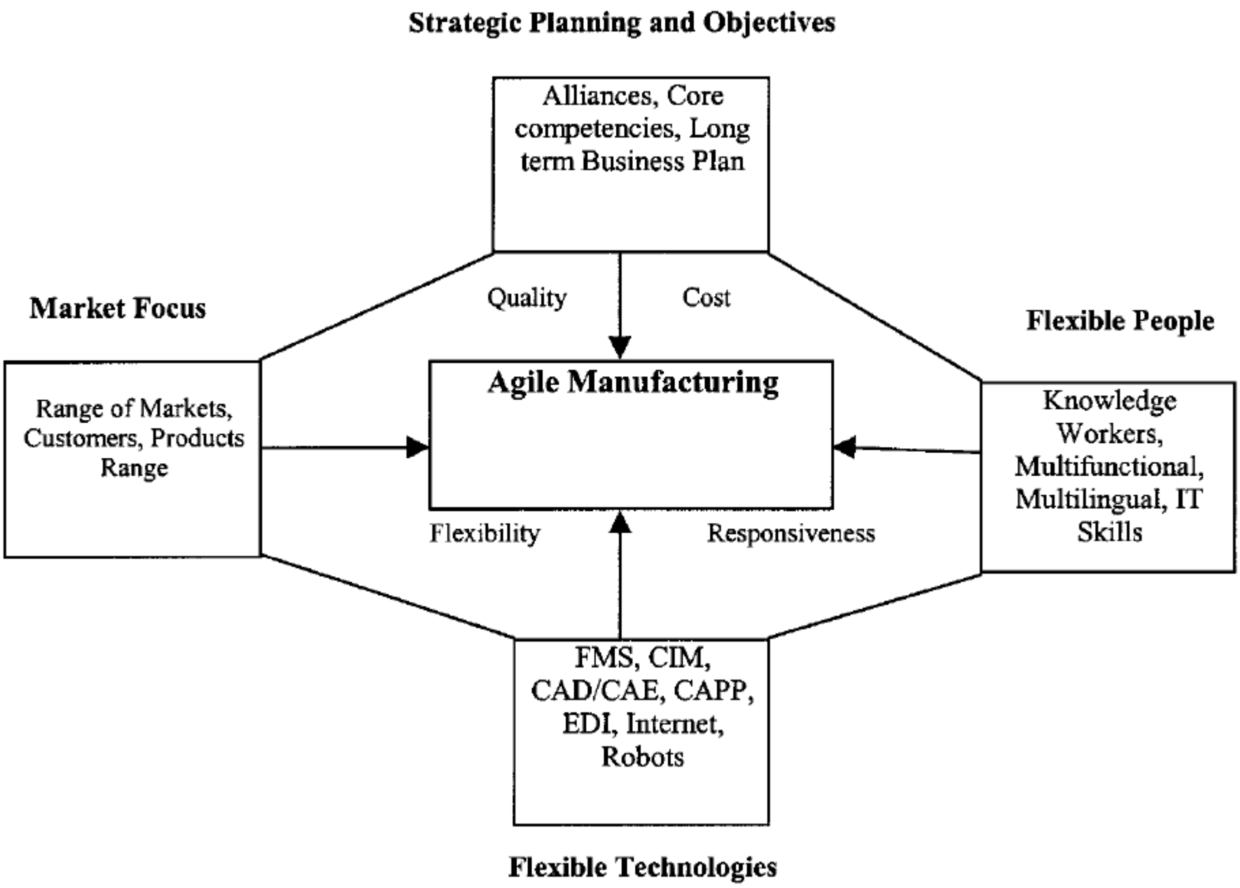


Figure 2.5: Agile Manufacturing Paradigm (Gunasekaran and Yusuf, 2002)

It is necessary for the industries to make the variety of products within minimum time possible. Figure 2.5, shows the agile manufacturing paradigm. For example, if a person is willing to buy a cell phone, he has so many options available with him like Samsung, Sony, Nokia etc. Also, there are so many models of cell phones of these companies which are available in the market. This implies there is excess competition in the market. So, if the particular company's cell phones are out of stock, in general, customer selects the other manufacturer's cell phone. Also, the company is required to have manufacturing system flexible enough so that products can be customized and manufacturing system can be reconfigured quickly as per the needs of clients. Computer Aided Process Planning (CAPP) helps in deciding the optimal sequence of manufacturing the product and minimizing lead time.

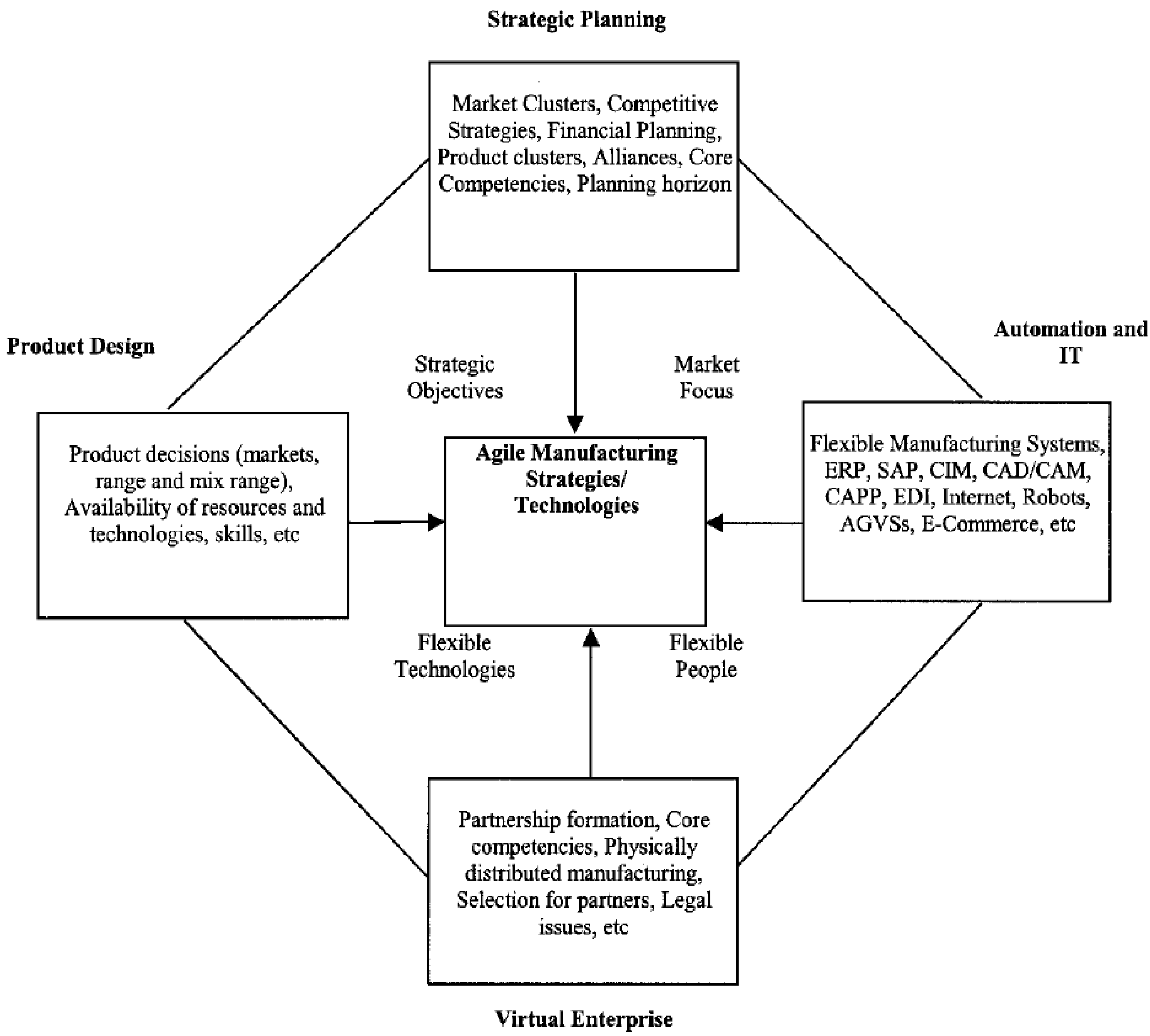


Figure 2.6: Agile manufacturing strategies/techniques (Gunasekaran and Yusuf, 2002)

The figure 2.6 explains various strategies or techniques required for the system to be agile. These are virtual enterprise, automation and IT, product design and strategic planning. Virtual enterprise includes Partnership formation, Core competencies, physically distributed manufacturing, selection for partners, legal issues etc. Automation and IT includes Flexible manufacturing systems, ERP, CIM, CAD/CAM, CAPP, EDI, Robotics, AGVS, E-commerce etc. Product design includes mix flexibility, availability of resources and technologies, skills etc. and strategic planning includes Market clusters, competitive strategies, financial planning, product clusters, Alliances, core competencies, Planning Horizon (Gunasekaran and Yususf, 2002).

Agility is defined as methodology which integrates managerial structure, production systems, and logistics and Supply Chain Management (SCM) and employees mindsets. Christopher and Towill, (2000) and Brown and Bessant(2000) defined agility as ability to fast response to fluctuating needs of customers in terms of cost, value, capacity, and speed. Naylor, Naim and Berry, (1999), agility means increasing the profitability and sales by using knowledge of market and virtual enterprise by quickly providing customized products. Mccullen and Towill (2001) have emphasized capacity requirements to fulfill customer requirements quickly. In lean production, customers buy specific products, whereas in agile reserves capacity that may additionally need to be made available at very short notice. Gould (1997) and Moore (1996), companies are required to incorporate flexible system in organizations so as to meet customer's demand well on time. Cho, Jung and kim (1996), agility means ability to endure and flourish in volatile market by responding rapidly. According to Gupta and Mittal (1996), Agile Manufacturing (AM), is a organization concept that combines employees and resources into a meaningful unit by means of modern and latest information technologies and resources. Devor, Graves and Mills (1997), agility is the capability to flourish in a market full of competition by continuous and quickly change and by providing quality products and services to the customers.

Gunasekaran (1998), Agile manufacturing enablers are : (i) virtual enterprise (ii) physically distributed manufacturing group (iii) quick partnership (iv) synchronized manufacturing; (v) incorporated production system; (vi) quick prototyping; and (vii) e commerce

These are shown in figure 2.7

2.2.1 Benefits of Agile Manufacturing System

a. Better Customer Relations
b. Larger variety of products, so customers have more options
c. Customized products can be made with more accuracy due to flexible manufacturing system
d. Increased Turnover of companies

e. Better supplier relations

2.2.2 Disadvantages of Agile Manufacturing System

1. Due to Fluctuating demand of customer, there may be shortage of new product. Due to this some people may use some other means of earning i.e. selling the required item in black also.
2. Skilled and trained operators are needed.

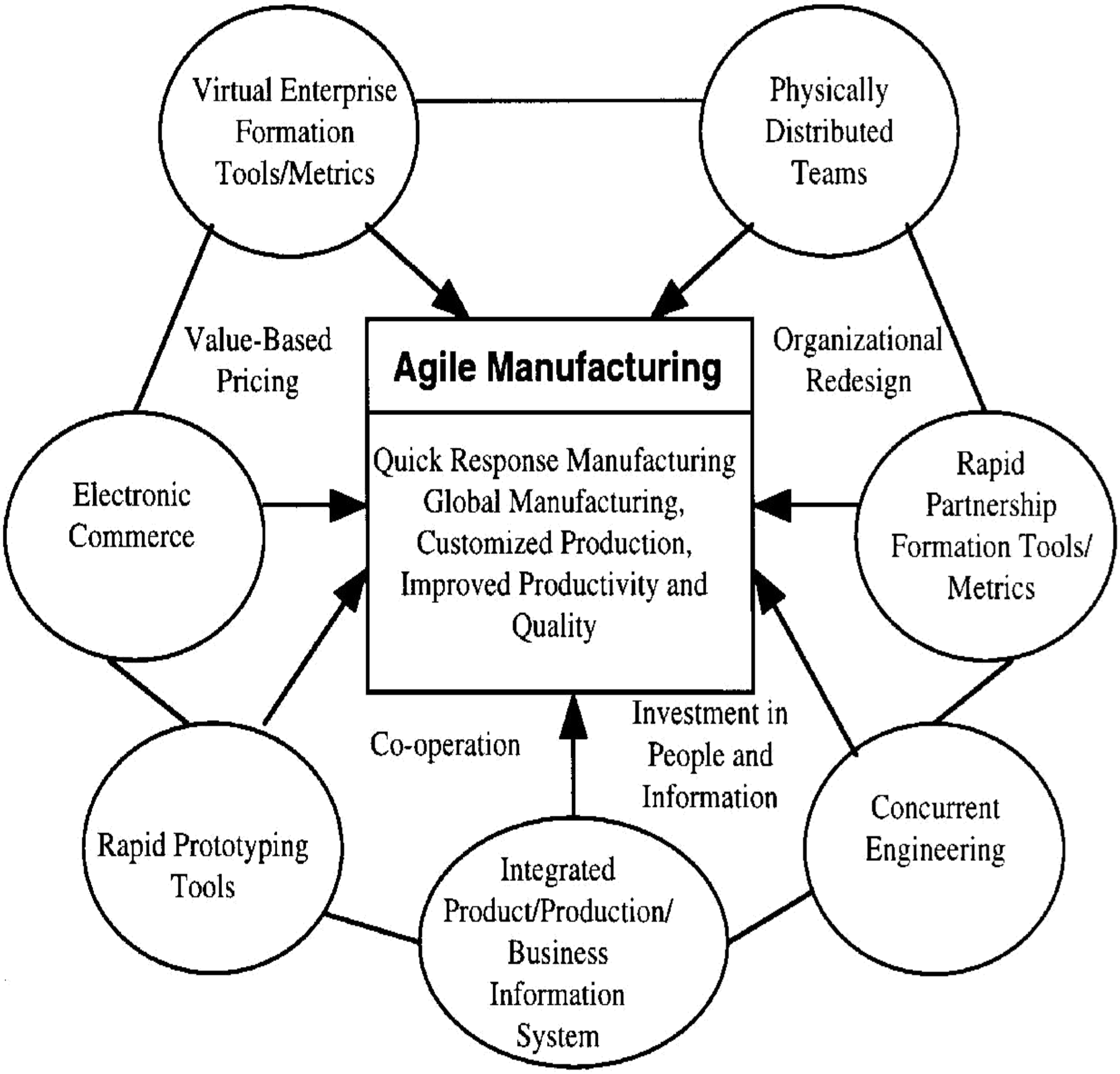


Figure 2.7: Model for enablers of agile manufacturing

(Gunasekaran, 1998)

3. High Investments in procuring latest available machines.
4. Greater maintenance of operating machines.

Table 2.3 shows the definition of agile manufacturing given by various researchers and Table 2.4 shows tools of agile manufacturing system.

Table 2.3: Some literature on Agile Manufacturing

Author	**Year**	**Definition of Agile Manufacturing**
Goldman, Nagel and and Priess	1995	Ability of working and prospering in a market which requires changes as per needs and demands of customers.
Adamides	1996	Responsibility-based manufacturing
Booth	1996	More flexibility and responsiveness
Cho, Jung, Kim	1996	Capability to compete in market place and prospering by responding effectively and efficiently in market.
Gupta and Mittal	1996	The main objective of agile system is to respond rapidly as per changing demand patterns of customers
Hoyt, Huq and Liles	1997	Flexibility and rapid response to market demands
Devor, Graves and Mills	1997	Capability to flourish in a atmosphere full of competition by continuous improvement in procedures required to produce goods or services.
Gunasekaran	1998	Ability to grow and thrive in cutthroat surroundings and provide customized products to the customers on time.
Backhouse	1999	The capability of an firm to become accustomed with sudden

and Burns		changes in customer demand.
Christopher and Towill	2000	It is a organization performance that consists of managerial structures, information systems, supply chain management and employees cooperation
Lummus, Duclos and Vokurka	2003	It is capability of firm to provide economic products and services to the customers without compromising with both quality as well as quantity.
Debra, Ningjian and Jeffrey	2003	Agile machining system is a machining system that can change quickly and easily to produce a planned range of product models in a product class, and be rapidly and cost-effectively reconfigured to respond to new model introductions.
Ching, Lin, Te and Cheng	2004	An organizational strategy to launch new products in to quickly varying markets.

Table 2.4: Agile Manufacturing Tools

S.No	Agile Tool	Authors	Total No.
1	Concurrent Engineering	Prince and kay (2003), Shahin and Janatyan (2010), Tsai and Lee (2006), Chutima and Kaewin (2007), Vinodh, Sundaraj and Devadasan (2010), Francisco and Mauela (2010), Misra, Kumar and Kumar (2010), Assen, Hans and Welde (2000), Macduffie (1995), Schroeder, Bates and Junttila (2002), Li, Sian and Li (2002), Jacobs, Droge, Vickery and Calantone (2011) , Soni and Kodali (2009), Irani, Chavalier and Cohen (1993), Pavnaskar, Gershenson, and Jambekar (2003), Backhouse and Burns (1999)	16
2	Rapid Prototyping	Moore et. al. (2003), Vinodh, Sundaraj and Devadasan (2010), Yusuf and Adeleye (2003), Shamsuzzoha (2011), Yan and Jiang (1999), Gunasekaran (2001),	10

		Paul (2000), Al-Tahat, Dalalah and Barghash (2009) , Soni and Kodali (2009), Goranson (1998)	
3	Electronic commerce	Charles, Cochran and Dobbs (1999), McCullen and Towill (2001), Devor, Graves and Mills (1997), Fine and Fruend (1990), Giachetti, Martinez, Saenz and Chen (2003),Goldman, Nagel and Priess (1995), Goranson (1998), Gunasekaran (1998), Gunnasekaran (1999a), Gunasekaran (1999 b) , Soni and Kodali (2009) , Bamber and Dale (2000) , Don-Taylor (1997), Pavnaskar, Gershenson, and Jambekar (2003), Backhouse and Burns (1999)	15
4	Virtual Enterprise	Gunasekaran (2001), Gupta and Buzacott (1993), Gupta and Goyal (1989), Hallman (2003), Katayama and Benette (1999), Kulatika (1988), Lee (1999), Morgan and Daniels (2001), Nagel, Dove, Goldman and Priess (1991), Newnan, Podgurski, Quinn and Merat (2000), Ordobaddi and Mulvaney (2001), Prince and kay (2003) , Mccullen and Towill(2001) , Bamber and Dale (2000) , Don-Taylor (1997), Jung, Chung and Cho (1996)	16
5	Integrated Product/Business Information System	Aoyama (1998), Olson (1997), Candadai, Herrmann and Minis (1995), Mccullen and Towill(2001) , Melton (2005), Worley and Doolen (2006), Kulatilaka (1988) , Houshmand and Jamshidnezhad (2006), Pavnaskar, Gershenson, and Jambekar (2003), Jung, Chung and Cho (1996), Chiarini (2014)	11
6	Physically Distributed Teams	Candadai, Herrmann and Minis (1995), Pant, Rattner and Hsu (1994), Prince and kay (2003) , Mccullen and Towill(2001) , Melton (2005), Worley and Doolen (2006), Kulatilaka (1988) , Bamber and Dale (2000), Don-Taylor (1997), Brauner and Ziefle (2015), Jung, Chung and Cho (1996), Backhouse and Burns(1999)	12
7	Rapid	Canel and Khumawala (1997), Perry, Sohal and	8

	Partnership Formation	Rumpf (1999) , Soni and Kodali (2009) , Mccullen and Towill(2001) , Melton (2005), Worley and Doolen (2006) , Bamber and Dale (2000), Backhouse and Burns(1999)	
8	FMS	Cheng , Harison and Pan (1998), Plonka (1997) , Vokurka and O' Leary-Kelly (2000) , Melton, (2005), Kulatilaka (1988) , Bamber and Dale (2000), Jung, Chung and Cho (1996)	7
9	Mass Customization	Cho, Jung and Kim (1996), Pradhan and Huang (1998), Goldsby, Griffith and Roath (2006) , Soni and Kodali (2009) ,Vokurka and O' Leary-Kelly (2000), Worley and Doolen and (2006) , Bamber and Dale (2000)	7
10	Teamwork	Don-Taylor(1997), Quinn, Causey and Kim (1997), Goldsby, Griffith and Roath (2006) , Vokurka and O' Leary-Kelly(2000)	4
11	Multidisciplinary Workforce	Don-Taylor (1996), Reid (1996), Goldsby, Griffith and Roath (2006) , Dove (1995) , Soni and Kodali (2009) ,Vokurka and O' Leary-Kelly (2000) , Richards (1996) , Melton (2005), Jung, Chung and Cho(1996)	9
12	Empowering Employees	Dove (1995), Prince and kay (2003), Goldsby, Griffith and Roath (2006) , Soni and Kodali (2009), Jung, Chung and Cho(1996)	5
13	Focus on Innovation	Feng and Zang (1998), Richards (1996) , Soni and Kodali (2009) , Melton (2005), Baratt, Choi and Li (2010)	5
14	Modern Manufacturing Processes	Forsythe and Ashby (1997) , Ordobaddi and Mulvaney (2001) ,Vokurka and O' Leary-Kelly (2000) , Mohd. Hasan, Sarkis and Shankar (2011), Worley and Doolen (2006), Kulatilaka (1988), Piercy and Rich (2015), Posada et. al. (2015)	
15	Group Technology	Goldman, Nagel and Priess (1994), Sarmiento (2000), Sarmiento (1998), Sarmiento and Nagi (1999), Prince and kay (2003), Candadai, Herrmann and Minis (1995)	12

		,Richards (1996), Misra, Kumar and Kumar (2010), Rajgopalan (2001), Baratt, Choi and Li (2010), Hoyt (1995)	
16	Production Process Reengineering	Govindaraj (1997), Sharp, Irani and Desai (1999), Sheridan (1993), Candadai, Herrmann and Minis (1995) , Soni and Kodali (2009) , Richards (1996), Worley and Doolen (2006), Baratt, Choi and Li (2010), Backhouse and Burns(1999)	9
17	Robotics and PLC'S	Gupta and Nagi (1995), Smith and Wolfe (1995), Goldsby, Griffith and Roath (2006) , Bhasin and Burcher (2006), Vokurka and O' Leary-Kelly (2000) , Richards (1996), Baratt, Choi and Li (2010)	7
18	CAD/CAM, CAPP and CIM	Herrmann and Minis (1995), Song and Nagi (1996) , Soni and Kodali (2009) , Bhasin and Burcher (2006), Vokurka and O' Leary-Kelly (2000), Richards (1996), Fiano, K.M (2013)	7
19	Rapid Machine set-ups and Changeovers or SMED	Herrmann and Minis (1996), Song and Nagi (1997) , Dove (1995) , Fliedner and Vokurka (1997), Baratt, Choi and Li (2010), Hoyt (1995), Backhouse and Burns(1999)	7
20	Standardized Operating Procedures	Hoyt (1995), Strader, Lin and Shaw (1998) , Dove (1995) , Bhasin and Burcher (2006), Kulatilaka (1988), Baratt, Choi and Li (2010)	6
21	Reconfigurable and continuously changeable system	Hoyt, Huq and Liles (1997), Struebing (1995), Candadai, Herrmann and Minis (1995), Goldsby, Griffith and Roath (2006) , Bhasin and Burcher (2006), Hoek (2000), Singh, Singh and Yadav (2012), Vijaykumar and Robinson (2016), Baratt, Choi and Li (2010), Jung, Chung and Cho (1996), Xiaobo , Jiancai and Zhenbi (2000)	11
22	E-Manufacturing	Sarkis (1997), Saha and grover (2012), Syam (1997), Candadai, Herrmann and Minis (1995) ,Dove (1995),	8

		Baratt, Choi and Li (2010), Jung, Chung and Cho (1996), Backhouse and Burns(1999)	
23	Machine Vision Capabilities	Irani, Chavalier and Cohen (1993), Talluri, Baker and Sarkis (1999), Candadai, Herrmann and Minis (1995) , Vinodh, Devdasan and Shankar(2010) , Vinodh and Arvindraj (2012), Baratt, Choi and Li (2010)	6
24	Make to order strategy	Iyer and Nagi (1997), Tu (1997), Dove (1995), Richards (1996), Melton (2005), Worley and Doolen (2006), Kulatilaka (1988) , Baratt, Choi and Li (2010)	8
25	Effective Information system	Jain (1995), Veeramani and Joshi (1997), Venkatadri, Rardin and Montreuil (1997), Wang, Rajurkar and Kapoor (1996) , Richards (1996) , Melton (2005), Pavnaskar, Gershenson, and Jambekar (2003), Baratt, Choi and Li (2010), Jung, Chung and Cho (1996)	9
26	Modular Production Facilities	Johnson and Reid (1997), Prince and kay (2003), Goldsby, Griffith and Roath (2006) ,Richards (1996) , Melton (2005), Kulatilaka (1988), Baratt, Choi and Li (2010), Jung, Chung and Cho (1996), Backhouse and Burns(1999)	9
27	Fast Production cycle times	Jung, Chung and Cho (1996), Monteruil, Venkatadri and Lefrancois (1991),Weng (1999),Weston (1998), Prince and kay (2003), Kulatilaka (1988), Baratt, Choi and Li (2010), Jung, Chung and Cho (1996)	8
28	General Purpose Equipments	Katayama (1999), Wiebe (1997),Wong and Veeramani (1996), Goldsby, Griffith and Roath (2006) , Melton (2005), Backhouse and Burns (1999)	6
29	Effective communication Technology	Kidd (1994), Zhou and Besant (1999), Zhou, Besant and Souben (1998), Prince and kay (2003) , Dove (1995), Jung, Chung and Cho (1996), Backhouse and Burns(1999)	7
30	Competitive Unit cost	Koonce, Dhamija and Judd (1997), Mills (1995), Minis, Hermann, Lam and Lin (1999), Prince and kay	6

		(2003) , Bhasin and Burcher (2006), Jung, Chung and Cho (1996)	
31	Intelligent Workers	Merton-Allen (1997), Prince and kay (2003), Goldsby, Griffith and Roath (2006) , Dove (1995) , Melton (2005), Kulatilaka (1988), Pavnaskar, Gershenson and Jambekar (2003), Jung, Chung and Cho(1996)	8
32	Focus on Emerging Trends	Assen, Hans and Welde (2000), Prince and kay (2003) , Dove (1995) , Bhasin and Burcher (2006), Melton (2005), Pavnaskar, Gershenson and Jambekar (2003), Backhouse and Burns (1999)	7
33	Collaborative product design	Backhouse and Burns (1999) , Dove (1995) , Bhasin and Burcher (2006), Melton (2005)	4
34	Listening to customers	Goldsby, Griffith and Roath (2006) ,Dove (1995) , Bhasin and Burcher (2006), Richards (1996) , Melton, T. (2005), Kulatilaka (1988), Pavnaskar, Gershenson and Jambekar (2003), Jung, Chung and Cho (1996)	8

- **Concurrent Engineering:** It is a process in which different stages occurs simultaneously instead of consecutively. It reduces product development time. It also results in improved productivity and efficiency of firm.
- **Rapid Prototyping:** It is a method to quickly fabricate the scale or physical model using three dimensional computer aided design (CAD) data. It is usually done by 3D printer which uses additive layer manufacturing technology.
- **Electronic commerce:** It is the buying and selling of goods and services, or the transmitting of funds or data, over an electronic network, primarily the internet. These business transactions occur either as business-to-business, business-to-consumer, consumer-to-consumer or consumer-to-business.
- **Virtual Enterprise:** A Virtual Enterprise (VE) is defined as association of different firms that approach each other to share latest technologies and strategies in order to better respond to the customers by means of computer networks.
- **Modular production facilities**: Since customer demands are changing very rapidly in the current scenario. So, the industries need to have various

production facilities in the system, so that the customer's demands can be met with in less time.

- **Integrated Product/Business Information System:** Group of interrelated components that work collectively to carry out input, processing, output, storage and control actions in order to convert data into information products that can be used to support forecasting, planning, control, coordination, decision making and operational activities in an organization.
- **Physically distributed teams:** Physical teams are distributed in the market regarding data collection for determining the changing and fluctuating demands of the customers.
- **Rapid partnership formation:** The partnerships or joint ventures needs to be made with suitable firms so that the problems can be solved with best possible way.
- **Flexible Manufacturing System (FMS):** It is a system in which machines are capable to produce variety of parts as per changing needs of customers and there is automatic material handling between the sub-stations.
- **Mass Customization:** It is a marketing and manufacturing technique that combines the flexibility and personalization of custom-made products with the low unit costs associated with mass production.
- **Team work:** There is no single person in industry which can solve all the problems. So it is necessary to build a team. Meetings and get together needs to be held time to time to make strong relationship among each others.
- **Multidisciplinary workforce:** The workforce is hired and team is made of different specialization so that each and every problem can be solved with relative ease.
- **Empowering Employees:** Employees needs to be empowered so that they can take the decisions in urgent situations. Also, it creates a feeling of belongings with the firm.
- **Focus on innovation:** The industries need to innovate new methods of production, new materials, and new technologies so that better and better quality products can be produced at minimum cost.

- **Modern Manufacturing Processes:** Now days, many modern manufacturing processes are used like Abrasive Jet Machining (AJM), Ultra Sonic machining (USM) etc. which produces products of high quality in less time.
- **Group Technology:** It is a manufacturing technique in which parts having similarities in geometry, manufacturing process and/or functions are manufactured in groups.
- **Production process reengineering:** The production process needs to be analyzed carefully and efforts must be made to continuously improve the process.
- **Robotics and Automation:** The automation has brought a revolution in manufacturing industries. Automation have resulted in increased productivity, better quality of products, reduced error etc.
- **CAD/CAM, CAPP and CIM:** Computer aided design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Process Planning (CAPP) and Computer Integrated Manufacturing (CIM) are the advancements in recent manufacturing era. These technologies results in close dimensional tolerance of products, efficient utilization of resources and better productivity.
- **Reconfigurable system:** The production should have sufficient flexibility in the production system so that it can be reconfigured quickly as per the needs and demands of the customers.
- **E-Manufacturing**: **It is the use of internet which** covers the range of online manufacturing activities for products and services, including product design, production control, supply chain management, maintenance and sale services through the Internet.
- **Machine Vision Capabilities:** This is required so that if there is any error on particular machine, it should not go to next step.
- **Make to order strategy:** Make to order strategy helps in blockage of finished products. The processing of assembly should start immediately after receipt of customer order.
- **Effective Information system:** The information system needs to be very effective in industries. If the customer's demand changes; the information should be reached within less time and proper action or steps must be taken accordingly immediately.

- **Modular Production Facilities:** In the modern scenario, customer demands changes frequently. So, this is required so as to meet the changing needs of customers.
- **Fast production cycle time:** The time required to manufacture the product needs to be minimized as the product out of stock will change customer's interest towards product of other company
- **General Purpose Equipments:** The general purpose equipments serve many purposes and able to produce variety of parts which fulfills the different types of customers.
- **Effective communication Technology:** Proper and effective communication is required within the departments so that the product can be manufactured quickly and delivered to the customers without any delay.
- **Competitive unit cost:** The products are required to be manufactured at competitive cost. If the cost of product is higher, less number of customers will buy it. On the other hand, if the cost of the products is too low, it may cause loss to the organization. In that case, instead of making profit; which is primary objective of industries, it will undergo losses. So, the cost of the product needs to be optimum.
- **Intelligent workers:** If the workers act smartly or dedicatedly, the quality of the products, production will automatically increase. For this, the workers are required to get motivated and trained time to time.
- **Collaborative product design**: It refers to business strategy, work processes and collection of software's that facilitates different companies in removing the problems which are faced while development of product.
- **Standardized operating procedures:** Standard procedures reduce the chances of error, complexities from the process. It helps the workers to make their task easier and hence results in better quality of the products produced.
- **Listening to customers:** listening to the problems/feedback decides the sales of product to large extent. It is the customer only who may face the problems in product while using it. Also, the customers can suggest better features/characteristics which can be incorporated in the product.

The figure 2.8 shows the gradually developments occurs in the agile manufacturing domain. It includes co-operation, organizational changes, value based pricing strategies and investments in people and information. For system to be agile, it should have multimedia and internet facilities so that information regarding any fluctuation in customer demand can be received with in less time. Also, the employees are trained and motivated enough so that they feel confident and work efficiently while dealing with any production problem. Also, employees must be empowered so that they also feel sense of belongings with the firm and consider the industry as their own. This attitude will help the employees to work enthusiastically and with full energy level. Various strategies like Total Quality Management (TQM), Just In Time (JIT) also plays a pivotal role in agile manufacturing implementation.

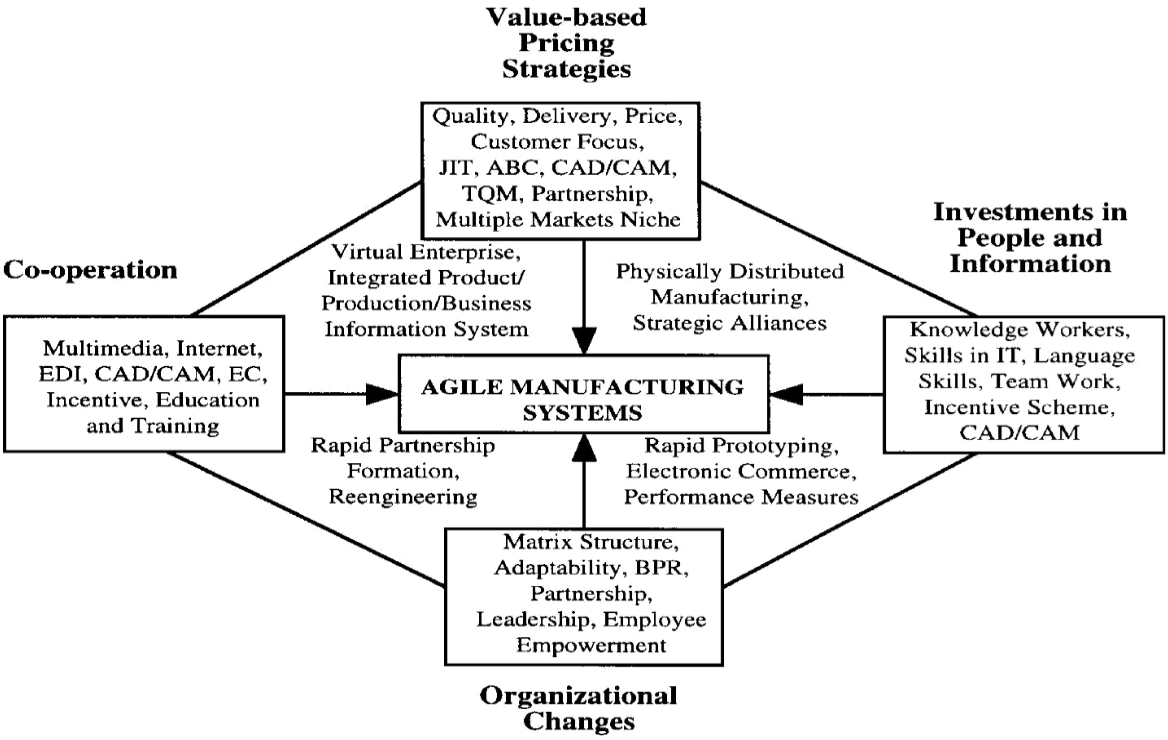


Figure 2.8: A framework for agile manufacturing development (Gunasekaran, 1998)

2.3 Leagile Manufacturing System

Leagile manufacturing system has attributes of both lean as well as agile manufacturing system. Lean and agile manufacturing systems are separated by a de-coupling point.

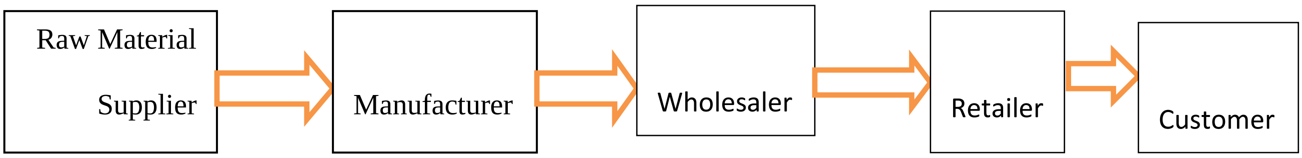


Figure 2.9: Typical Supply Chain

For Example, in this figure 2.9 as shown, the customer pulls value from the retailer, which in turn results in pulling the value by the retailer from the wholesaler and so on. Leagile manufacturing concept acts as a vital function in deciding the profitability of companies. Upstream of this supply chain, there is a stable demand , so lean manufacturing is to be adopted but downstream it have fluctuating demand, so supply chain should be agile. Lean manufacturing focusses on reducing the inventories as maximum as possible i.e. cutting down inventory costs. But if there will be no inventory then how the system can be agile. So for fulfilling the fluctuating demand of customers, there should be some optimum level of inventory and system must be leagile.

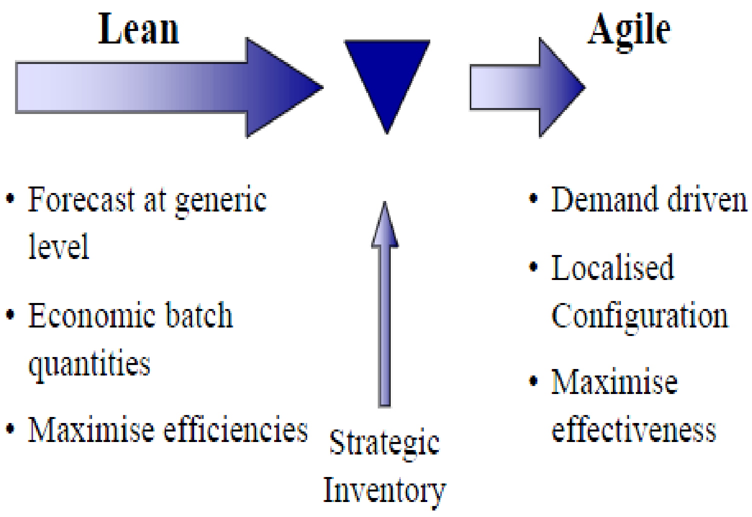


Figure 2.10: The de-coupling point approach

(Christopher and Towill, 2001)

Figure 2.10 shows the position of de-coupling. A more stable demand will lead to movement of de-coupling point downstream and fluctuating demand of customer will lead to movement of de-coupling point up`stream. The decision of quantity of inventory to be kept is taken by mangers based on their knowledge and past experiences. The managers use different forecasting techniques and experience for sales forecasting. Hoek (2000) discusses the basis concept of leagility using postponement as one of the central principles. Postponement is delaying of operational activities in a system until customer orders are received rather than completing activities in advance and then waiting for orders. Fadaki, M. (2015), has discussed that leagile supply chanin deals better with market uncertainity and is more responsive towards the customers.

This principle is different from lean and agile systems because lean concentrates on fixed level of inventory produced in advance, whereas agile manufacturers would be able to produce for orders varying in demand and product mix. Thus de-coupling point differentiated lean and agile manufacturing system (Gupta, 1996). A leagile system has characteristics of both lean and agile systems in order to exploit market opportunities in cost effective manner (Krishnamurthy and Yauch, 2007).

Table 2.5 shows the definition of leagile manufacturing given by various researchers.

Table 2.5: Some literature on Leagile manufacturing

Author	**Year**	**Definition of Leagile Manufacturing**
Naylor , Naim and Berry	1999	The lean and agile strategy can be combined by positioning the decoupling point in supply chain. A leagile system has characteristics of both lean and agile systems, acting together in order to exploit market opportunities in a cost effective manner
Krishnamurthy and Yauch	2007	Leagile system operates at different points in a manufacturing supply chain. A key element is de-coupling point. The lean processes are on upstream side of de-coupling point and agile processes exist on downstream side.

Table 2.6: Leagile Manufacturing Tools

S.No	Tool	Authors	Total No.
1	Flexible Set ups	Bernardes and Hanna (2009), Prince and kay (2003), Goldsby, Griffith and Roath (2006) , Soni and Kodali (2009), Bhasin and Burcher (2006), Baratt, Choi and Li (2010), Narsimham, Swink and Kim (2006), Dove (1995), Lummus, Duclos and Vokurka (2003), Lummus, Duclos and Vokurka (2005), Lu, Olofsson and Stehn (2011)	11
2	Set-up time minimization	Baratt, Choi and Li (2010), Prince and kay (2003), McDonlad, Van Aken and Rentes (2000) , Dove (1995), Lummus, Duclos and Vokurka (2003), Lummus, Duclos and Vokurka (2005), Lu, Olofsson and Stehn (2011)	7
3	Cross-trained employees	Bamber and Dale (2000), Prince and kay (2003) ,Dove (1995), Bhasin and Burcher (2006), Lummus, Duclos and Vokurka (2003), Lummus, Duclos and Vokurka (2005)	6
4	Relationship with suppliers	Barker (1998). Prince and kay (2003), Hoek (2000) , Bhasin and Burcher (2006), Kulatilaka (1988), Pavnaskar, Gershenson and Jambekar (2003), Baratt, Choi and Li (2010), Lu, Olofsson and Stehn (2011)	8
5	Quality Assurance	Iyer and Nagi (1994), McDonlad, Van Aken and Rentes (2000) , Bhasin and Burcher (2006), Behrouzi and Wong (2011), Bergenwall, Chen and White	9

		(2012), Baratt, Choi and Li (2010), Lummus, Duclos and Vokurka (2003), Lummus, Duclos and Vokurka (2005), Lu, Olofsson and Stehn (2011)	
6	Reduced Lead time	Kisperska-Moron and De Hann (2010), Oliver, Delbridge and Barton (2002), Prince and kay (2003), Candadai, Herrmann and Minis (1995) , Dove (1995), Bhasin and Burcher (2006), Kulatilaka (1988), Pavnaskar, Gershenson and Jambekar (2003), Baratt, Choi and Li (2010)	9
8	Information driven virtual supply chain	Zheng (2010), Oliver, Delbridge and Barton (2002), Shah and Ward (2007), Yusuf, Adeleye and Gunasekaran (2004), Candadai, Herrmann and Minis (1995), McDonlad, Van Aken and Rentes (2000) , Dove (1995) , Bhasin and Burcher (2006) , Behrouzi and Wong (2011), Lu, Olofsson and Stehn (2011)	10
9	Total Preventive Maintenance	Zheng (2010), Cox and Chicksand (2005), Cua, Mckone and Schroeder (2001), Inman, Sale, Green and Whitten (2010), McDonlad, Van Aken and Rentes (2000), Naim and Gosling (2010), Narsimham, Swink and Kim (2006), Kulatilaka (1988), Baratt, Choi and Li (2010), Lu, Olofsson and Stehn (2011)	10
10	Process Integration and Performance Measurement	Zheng(2010), Christopher and Towill (1998), Dal, Furlan and Vineli (2008), Kisperska and De- Hann (2010) , McDonlad, Van Aken and Rentes (2000),	9

		Pavnaskar, Gershenson and Jambekar(2003), Baratt, Choi and Li (2010), Lummus, Duclos and Vokurka (2003),Lummus, Duclos and Vokurka (2005)	
11	Centralized and collaborative planning	Zheng (2010), Bruce, Daly and Towers (2004), Goldsby, Griffith and Roath (2006), Harrison and Van Hoek (2005), Holweg (2007), Mason-Jones, Naylor and Towill (2000), Prince and kay (2003) , Soni and Kodali (2009), Pavnaskar, Gershenson and Jambekar (2003), Dove (1995), Lummus, Duclos and Vokurka (2003), Lummus, Duclos and Vokurka (2005)	12
12	Market sensitiveness and responsiveness	Zheng (2010), Yusuf, Adeleye and Gunasekaran (2004), Prince and kay (2003) , Dove (1995) ,Soni and Kodali (2009), McDonlad, Van Aken and Rentes (2000) , Behrouzi and Wong (2011), Baratt, Choi and Li (2010), Dove (1995), Lu, Olofsson and Stehn (2011)	10
13	EDI(Electronic data Interchange)	Zheng (2010), Agarwal, Shankar and Tiwari (2006), Krishnamurthy and Yauch (2007), Agarwal, Shankar and Tiwari (2007), Bhatia (2004), Dove (1995) , Soni and Kodali (2009) , McDonlad, Van Aken and Rentes (2000) , Behrouzi and Wong (2011), Baratt, Choi and Li (2010)	10
14	ERP(Enterprise resource planning)	De Toni and Tonchia (1998), McDonlad, Van Aken and Rentes (2000) , Dove (1995) , Soni and Kodali (2009) , Behrouzi	9

		and Wong (2011), Pavnaskar, Gershenson and Jambekar (2003), Baratt, Choi and Li (2010), Lummus, Duclos and Vokurka (2003), Lummus, Duclos and Vokurka (2005)	
15	Kaizen	Fernie and Azuma (2004), D'Souza and Williams (2000) , Vokurka and O' Leary-Kelly (2000), Pavnaskar, Gershenson and Jambekar (2003), Dove (1995), De Toni (1998), McDonlad, Van Aken and Rentes (2000)	7
16	TQM	Da Silveira, Giovani and Caglaino (2006) , Soni and Kodali (2009), McDonlad, Van Aken and Rentes (2000), Pavnaskar, Gershenson and Jambekar (2003), Dove (1995), Lummus, Duclos and Vokurka (2003),Lummus, Duclos and Vokurka (2005)	7
17	Customer support	Duclos and Lummus (2003), McDonlad, Van Aken and Rentes (2000) , Soni and Kodali (2009), Pavnaskar, Gershenson and Jambekar (2003), Dove (1995)	5
18	Relations with supplier	Huang and Li (2010), Canel and Khumawala (1997), Prince and kay (2003), Goldsby, Griffith and Roath (2006) , Soni and Kodali (2009), Baratt, Choi and Li (2010)	6
19	Location of suppliers	Prince and kay (2003), Harrison (1997), Hines (1998), Goldsby, Griffith and Roath (2006) , Soni and Kodali (2009), McDonlad, Van Aken and Rentes (2000), Baratt, Choi and Li (2010), Dove (1995)	8

20	Design Attributes	Sanchez and Perez (2001), McDonlad, Van Aken and Rentes (2000), Goldsby, Griffith and Roath (2006) , Soni and Kodali (2009), Pavnaskar, Gershenson and Jambekar (2003), Fadaki (2015)	5
21	Six Sigma	Vokurka and O' Leary-Kelly (2000), Sharifi and Zhang (2001), Masson, Iosif, Mackerron and Fernie (2007) , Behrouzi and Wong (2011), Pavnaskar, Gershenson and Jambekar (2003), Baratt, Choi and Li (2010), Dove (1995)	7
22	Poka Yoke	McDonlad, Van Aken and Rentes (2000), Goldsby, Griffith and Roath (2006), Kulatilaka (1988), Baratt, Choi and Li (2010), Narasimhan, Swink and Kim (2006)	5
23	5S	Lummus, Duclos and Vokurka (2003), Lummus, Duclos and Vokurka (2005), Goldman, Nagel and Priess (1995), McDonlad, Van Aken and Rentes (2000), Kulatilaka (1988)	5
24	SMED (Single Minute Exchange of Dies)	Yusuf and Adeleye (2003),Yusuf, Adeleye and Gunasekaran (2004), Goldsby, Griffith and Roath (2006), Prince and kay (2003), McDonlad, Van Aken and Rentes (2000) , Soni and Kodali (2009), Kulatilaka (1988), Baratt, Choi and Li (2010), Fadaki (2015)	8
25	Modern Manufacturing Techniques used	Narasimhan, Swink and Kim (2006), Naim and Gosling (2011), Mccullen and Towill (2001), Prince and kay (2003), Goldsby,	8

		Griffith and Roath (2006), Soni and Kodali (2009), Kulatilaka (1988), Baratt, Choi and Li (2010)	
26	Robotics and Automation	Lu, Olofsson and Stehn (2011), Prince and kay (2003), Goldsby, Griffith and Roath (2006) , Soni and Kodali (2009), Pavnaskar, Gershenson and Jambekar (2003), McDonlad, Van Aken and Rentes (2011), Krishnamurthy and Yauch (2007)	7
27	Administration Policy	Krishnamurthy and Yauch (2007), Gunasekaran, Lai and Cheng (2008), Gosling, Purvis and Naim (2010) , Soni and Kodali (2009), Pavnaskar, Gershenson and Jambekar (2003)	5
28	Experience and skills of Employees	Halldorson and Aastrup (2003), Prince and kay (2003), Goldsby, Griffith and Roath (2006) , Dove (1995) , Soni and Kodali (2009), Pavnaskar, Gershenson and Jambekar (2003), Baratt, Choi and Li (2010)	7
29	Group Technology	Bruce, Daly and Towers (2004), Christopher and Towill (2000), Stratton and Warburton (2003), Goldsby, Griffith and Roath (2006) , Dove (1995), Sherehiy, Karwowski and Layer (2007), Behrouzi and Wong (2011), Pavnaskar, Gershenson and Jambekar (2003), Baratt, Choi and Li (2010), Lu, Olofsson and Stehn (2011), Krishnamurthy and Yauch (2007)	11
30	Innovation and R&D	Agarwal and Shankar (2002 a), Agarwal and Shankar (2002 b), Shehab et. al. (2010), McDonlad, Van Aken and Rentes	9

		(2000) ,Dove (1995), Sarmiento and Nagi (1998), Kulatilaka (1988), Pavnaskar, Gershenson and Jambekar (2003), Baratt, Choi and Li (2010)	
31	Organizational Culture	Sarmiento and Nagi (1999), Vinodh and Devadasan (2012), Chen and Chen (2006), Chen and Chen (2008), Prince and kay (2003), Kulatilaka (1988) , Behrouzi and Wong (2011), Pavnaskar, Gershenson and Jambekar (2003), Scheer (2012)	9
32	Management Leadership	Hong and Lee (2002), Vinodh, Kumar and Girubha (2012), McDonlad, Van Aken and Rentes (2000) , Dove (1995) , Soni and Kodali (2009), Kulatilaka (1988), Behrouzi and Wong(2011), Pavnaskar, Gershenson and Jambekar (2003), Lu, Olofsson and Stehn (2011), Krishnamurthy and Yauch (2007)	10

- **Flexible set-ups:** Since customers expects more varieties of the products. Flexibility is required in the manufacturing system so that large number of product varieties can be made.
- **Set-up time reduction:** The set-up time needs to be reduced to the minimum extent possible so that the finished products can be supplied to customers in less time.
- **Cross Trained Employees:** In this employees hired to do one job get trained to do other jobs also. It helps in reducing the costs, save productivity even in absence of some employees.
- **Relations with suppliers:** The relations with suppliers should be so good that in case of financial scarcity or any problem, the suppliers supply the components or raw materials for the sake of good-will.

- **Quality assurance:** Quality is what every customer wants. Assuring the quality to the customers raise their trust towards the companies and boost up the sales of product.

- **Reduced lead time:** This will reduce the takt time i.e. time between placement of order by customer and receiving of goods and helps in increased customer satisfaction.
- **Information driven virtual supply chain:** This will help the industries to be well acquainted with changing demand patterns of customers and act accordingly so that customers get the product of their choice within time.
- **Total Preventive Maintenance (TPM):** The employees are required to give special attention towards maintenance of machineries/ equipments. Proper maintenance results in better equipment life, reduced machine downtime etc.
- **Process Integration and performance measurement:** The process needs to be integrated so the products can be manufactured with in minimum time possible. Also, the performance should be measured time to time and corrective measures should be taken if the performance level falls.
- **Centralized and collaborative planning:** This involves the proper planning of various activities collectively of all the plants situated at different locations all over the globe.
- **Market sensitiveness and responsiveness:** It refers to sensitiveness of market i.e. how frequently the customer demands changes and ease and pace with which changes can be made in the production system to meet fluctuating demand patterns.
- **Enterprise Resource Planning (ERP):** It is business software used by management people which permits it to run the business smoothly and mechanize many back office activities. The activities regarding selection of raw material suppliers, raw material availability and production report generation etc. is done electronically.
- **Electronic Data Interchange (EDI):** It can be defined as electronic exchange of business information using a consistent procedure with another company and thus reducing the usage of paper work.

- **TQM:** TQM is Total quality management. It involves everybody i.e. customer, supplier, employer and employee for improving the quality of product**.**
- **Customer support:** It involves the support from customers for improving the quality of product. The customers also assist in improving the quality of product by providing proper feedback and valuable suggestions.
- **Location of suppliers**: Location of suppliers should be nearby manufacturing plant so that on receipt of customer order, the order of bought out parts or raw materials can be provided immediately by supplier.
- **Design Attributes:** Design attributes affects a lot in the quality of product produced. For example: A good design of car model will have features like better aesthetics, better mileage, less maintenance, better comfort and better performance.
- **Poka-Yoke:** The process needs to be error proof. This capability in system reduces the number of defects and hence reduces the need of inspecting finished products also.
- **Modern manufacturing techniques used:** Today, there are so many latest techniques like Rapid Prototyping (RP), 3D printing, Abrasive Jet Machining (AJM) and Laser Beam Machining (LBM) etc. They have profound effect on the quality of products.
- **Administration policies:** Administrative policies affect a lot and can help in changing the mindset of employees. If administration and HR (Human Resource) policies are good, the employees treat the industries as their own and work whole heartedly and dedicatedly.
- **Experience and skills of employees:** Experience and skills of employees matters a lot in deciding the efficiency of industry. Experienced and dexterous employees can solve almost all problems with in less time and production can be relatively increased.
- **Group Technology:** In group technologies, parts/components which have similar characteristics are placed under one group and are processed in groups. This leads to save of time, high productivity, better quality and increased profitability.
- **Innovation and R&D:** There is lots of development since last few decades and it is still going on. So, the companies are required to adopt latest technologies

and focus on innovation and R&D activities like use of CAD/CAM and analysis packages like hyper mesh, Nastran, Finite Element Method (FEM) etc. so that quality of product can be improved more and more.

- **Organization Culture:** The organization should plan motivation and training programs for the employees so that they perform their work efficiently and effectively.
- **Management Leadership:** Managers are the persons which manage whole organization. For effective leadership, the managers are required to act smartly and provide better solution for the problem encountered.

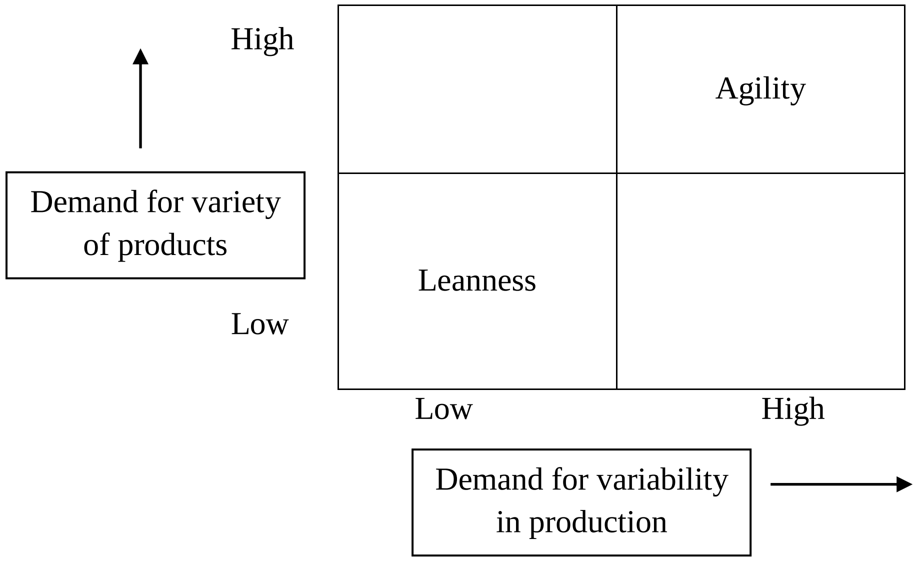


Figure 2.11: Applications based on demand for variety of products and variability in production (Naylor, Naim and Berry; 1999)

In this figure 2.11, it is shown that lean manufacturing is suitable when demand for variability in production and demand for variety of products is low whereas agile manufacturing is suitable when demand for variability in production and demand for variety of products is high. In figure 2.12, horizontal axis represents the focus of organization, consisting of lean efficiency and agile responsiveness, whereas the vertical axis represents the level of demand uncertainty, ranging from low to high.

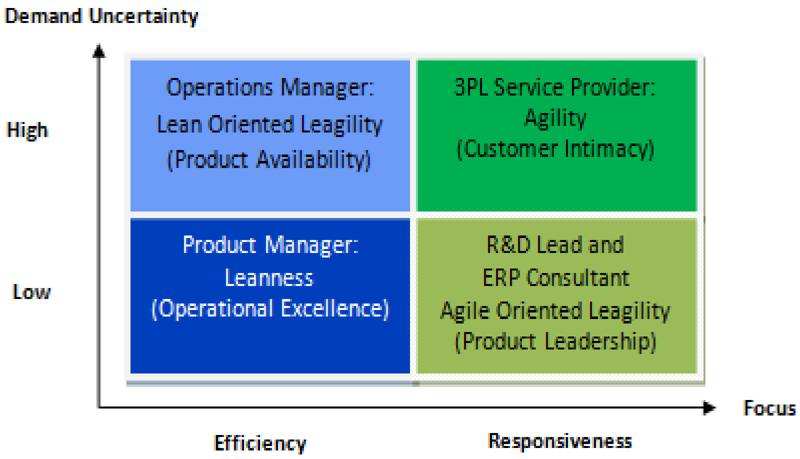


Figure 2.12: Lean, Agile and Leagile choices based on company's focus and demand uncertainty (Zheng, 2010)

The matrix suggests that when the demand uncertainty is high and company focus is to gain efficiency, a lean oriented leagilty can be utilized to ensure the product availability. The agile element within the approach is meant to prevent the company from becoming overly lean, as being overly lean might harm the availability of innovative products as well as availability of existing products. In contrast when the demand uncertainty is low, and the company's focus is to become responsive, the adequate approach might be agile oriented leagility.This approach requires the companies to incorporate the customer's changing requirements in to product design and thus achieve product leadership (Zheng,2010).

Chan and Kumar (2008), Fadaki (2015), discussed that leagile manufacturing system is found to be deal better with market complexities. Leagile system is among one of the prominent strategy which has increased the capability of the firm to survive in the market. Wikner and Rudberg (2005), has discussed the importance of decoupling point in the leagile system.

2.4 Discussion

Leagile manufacturing system has attributes of lean as well as agile manufacturing systems. Lean system is suitable when the demand is stable and known with certainty whereas agile manufacturing is used when demand is highly unpredictable; like in case of fashionable goods.

Leagile manufacturing is different from lean and agile and is separated by a de-coupling point. Proper knowledge and implementation of leagile system in any manufacturing industry results in increased profitability of firm, better customer relations, increased quality of product, increased sales, better utilization of resources, increased employee morale by reducing inventory cost and all other costs which exists and do not contribute in enhancing value to the product. Lean manufacturing focuses on reducing the inventory but at the same time to make the system agile, it must have some inventories to meet fluctuating needs of customers. So there is a need to place de-coupling point at proper place in the leagile supply chain. The decision regarding adopting the type of strategy (Lean, Agile or Leagile) depends upon experience and skill set of managing director of organization.

2.5 Research Methodologies Used

The following research methodologies have been used for analysis and identification of leagile environment in manufacturing industries.

2.5.1 Interpretive Structural Modeling (ISM)

ISM stands for interpretive structural modeling. This technique was developed by J. Warfield in 1973. It is a technique in which the variables affecting the given research problem are identified and contextual relationship is established. Iterations are performed, interrelationships among variables are found out rand hierarchy of variables is developed which enables the managers to understand concisely the research problem and implement the desired strategy with relative ease. The objectives of ISM are as follows:

1. To understand the research problem and variables/factors affecting it.
2. To analyze the interrelationship between these identified variables and develop the hierarchy to show their significance levels.
3. To guide the manager in proper direction so that to tackle the research problem easily.

2.5.2 Total Interpretive Structural Modeling (TISM)

This technique was developed by Professor Sushil IIT Delhi. It is similar to ISM. The only difference is in digraph; TISM is used to show both nodes as well as links whereas ISM shows only nodes. Also, in ISM, all transitive links are eradicated while in TISM; transitive links are also shown to interpret better explanation of the interrelationship among the identified variables.

2.5.3 Decision Making Trial and Evaluation Laboratory (DEMATEL)

This technique was developed by Gabus and Fontela in 1972. The technique is used to solve complex and complicated problems. The variables affecting the problem are identified and experts are asked to give their opinions and rate the variables/factors. The calculations are performed and variables are classified in to cause and effect categories. The manager needs to focus more on cause category variables so that effect category variables can be implemented easily and problem can be solved quickly.

2.5.4 Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL)

The technique is hybrid of fuzzy logic and DEMATEL. The fuzzy logic is used to remove the complexities associated with the research problem and to obtain better and consistent solution of the research problem. The experts are asked to rate the identified variables in terms of linguistic variables.

2.5.5 Modified Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)

This technique was found out by Hwang and Yoon in 1981. This technique is used to evaluate the different feasible alternatives. The variables/factors are identified and experts are asked to rate the variables. Calculations are performed and best alternative is obtained which is nearest to positive ideal solution and farthest from negative idea solution.

2.5.6 Graph Theoretic and Matrix (GTMA) Approach

This technique consists of representation of digraph, permanent function etc. It transforms the unmanageable factors in to manageable factors and is generally used to evaluate single numerical index for any problem or objective (Rao, 2007). The method was discovered by Euler in 1736 when he give solution the renowned Konigsberg bridge problem. Afterwards, the methodology was used and adopted by many researchers working in different fields. The methodology consists of the following:

1. Representation of digraph
2. Representation of Matrix
3. Representation of permanent function

CHAPTER 3

QUESTIONNAIRE ADMINISTRATION AND DESCRIPTIVE STATISTICS

Questionnaire has been prepared by extensive literature review and in discussion with experts. The mean score of each attribute is calculated and bar graph has been drawn to show the relative importance of each one of them.

3.1 INTRODUCTION

In this chapter, questionnaire preparation and its administrations have been discussed. The questionnaire response related to barriers, social implications, critical success factors, key performance indicators etc. have been discussed.

3.2 QUESTIONNARE DEVELOPMENT

The questionnaire was prepared and developed using expert opinion, literature review and by discussion with experts. Normally, the experts from industries are busy with their daily schedule and so are reluctant to provide responses; so questionnaire was designed concisely and precisely.

5 Point likert scale was used in filling the questionnaire; 1 means no importance, 2 means less importance, 3 means important, 4 means more importance and 5 means very important. The whole questionnaire was divided into two parts: part 1 contains company profile and part 2 contains attributes of leagile manufacturing system.

3.3 Questionnaire Administration

The personal meeting, e-mail and postal method was used for collecting the response of questionnaire. Survey was conducted in Indian automobile ancillary companies. In all, questionnaire was send to 950 manufacturing firms.

3.4 Questionnaire survey response and respondent profile

280 filled questionnaire was received out of 950; which implies the response rate of 29.5 %, which is sufficient for evaluating the results (Malhotra and Grover, 1998). In some situations, senior managers filled the questionnaire in place of their juniors.

Table 3.1 Respondents Profile

Criteria		Number of respondents	Percentage of Respondents
Job Title	Managers	141	50.35
	General Managers	85	30.35
	Vice President	47	16.78
	President	7	2.5
Work experience (years)	≤ 14	138	49.28
	15-20	109	38.92
	Above 20	33	11.78
Age of firm	≤ 14	145	51.78
	15-20	98	35
	Above 20	37	13.21
Number of employees	100-249	136	48.57
	250-500	89	31.78
	Greater than 500	55	19.64

3.5 Observations from the survey

The responses were collected regarding various aspects of leagile manufacturing system like barriers, social implications, key factors, critical success factors, key performance indicators of leagile manufacturing system etc.

3.5.1 Related to barriers of leagile manufacturing system

The response related to barriers of leagile manufacturing system are shown in Table 3.1

Table 3.2: Analysis of response of barriers of leagile manufacturing system

Barriers	Mean Score	Rank
Lack of top management commitment	3.32	1
Employee’s Resistance to change	3.28	2
Lack of training of employees	3.26	3
Inadequate use of empowerment	3.02	4
Lack of R & D activities	2.96	5
Lack of information technology facilities	2.80	6
Lack of supplier integration	2.75	7
Lack of interpersonal skills	2.43	8
Communication gap	2.31	9
Lack of advanced manufacturing capabilities	2.10	10
Lack of continuous improvement culture	2.04	11
No benchmarking	2.0	12
Poor planning	1.95	13
Non availability of good vendors	1.92	14
Lack of time for transition	1.88	15
Lack of Recognition and Rewards	1.85	16
Lack of funds for training	1.82	17

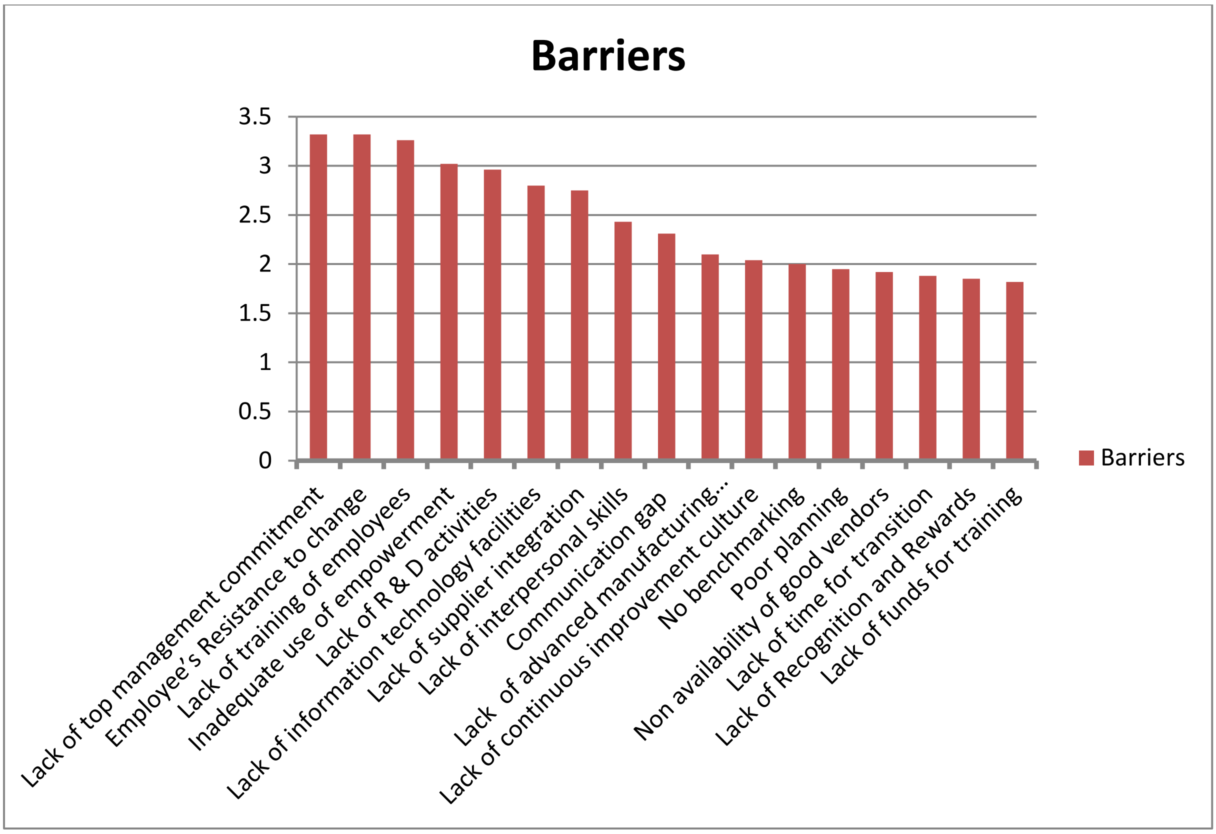


Figure 3.1: Barriers of leagile manufacturing system

3.5.2 Related to Social Implications of Leagile manufacturing system: The response related to social implications of leagile manufacturing system are shown in Table 3.2

Table 3.3: Analysis of response regarding social implications of leagile manufacturing system

Social Implication	Mean score	Ranking
Unemployment	3.81	1
High Initial Investment	3.80	2
Reduced Manufacturing Lead Time	3.72	3
Better Product Quality	3.71	4
Better ROI	3.59	5
Improved Employee Morale	3.52	6

Increased Production Volume	3.48	7
Improved Customer Satisfaction	3.40	8
Better Utilization of Resources	3.34	9
Reduced Labor	3.30	10
Fear of Technology Change	3.20	11
Reduced Cost per item	3.18	12
Better incentives, recognition and rewards	2.80	13
Reduced Scrap	2.40	14
Increased Market Share	2.25	15
Better Supplier Relationship	1.95	16

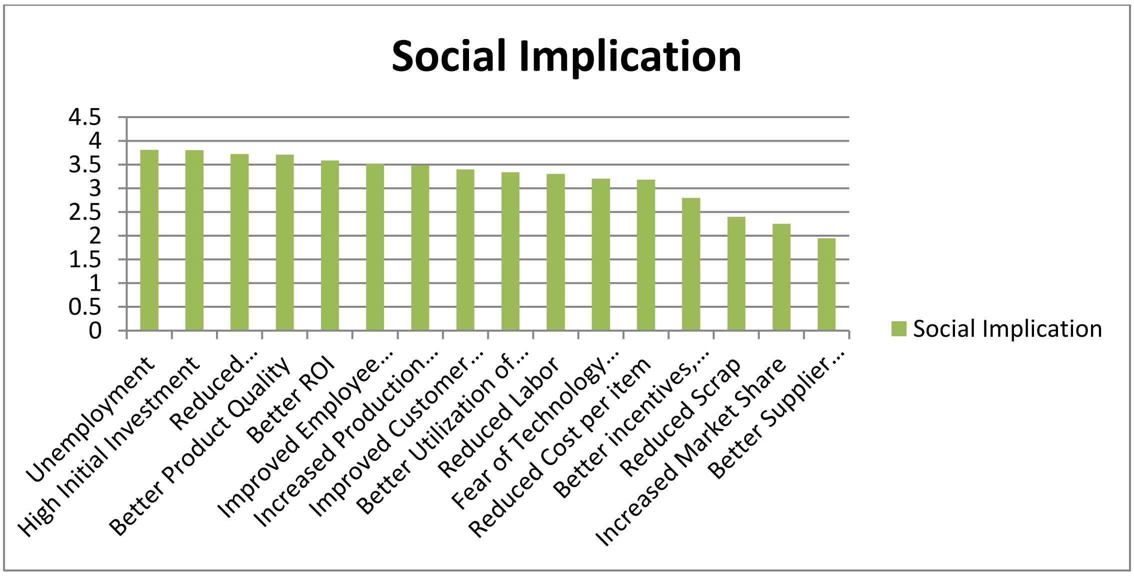


Figure 3.2: Social implications of leagile manufacturing system

3.5.3 Related to critical success factors of Leagile manufacturing system: The response related to critical success factors of leagile manufacturing system are shown in Table 3.3

Table 3.4: Analysis of response regarding critical success factors of leagile manufacturing system

Critical Success Factors	Mean Score	Ranking
Collaborative relationship	3.80	1
Management support towards implementation of policies	3.76	2
Strategic Management	3.62	3
Training and development programs	3.51	4
Customer and Market sensitiveness	3.47	5
Design and Engineering	3.34	6
Human Resource management	3.24	7
Virtual Enterprises	3.21	8
Use of advance manufacturing technologies	3.14	9
Supply chain Management	3.12	10
Flexible manufacturing system	3.04	11
Knowledge and IT management	3.00	12
Rapid Reconfiguration	2.95	13
Human Resource management	2.87	14
Benchmarking	2.67	15

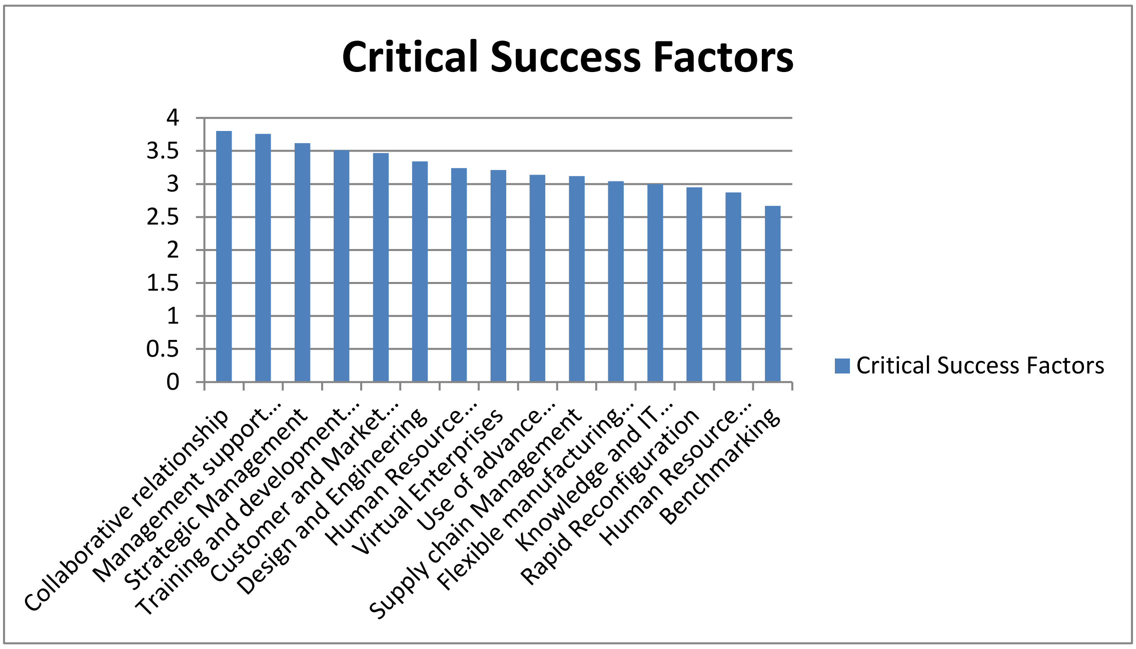


Figure 3.3: Critical success factors of leagile manufacturing system

3.5.4 Responses Related to Leagile Criteria's:

The response related leagile criteria's are shown in Table3.4

Table 3.5: Analysis of response regarding leagile criteria

Leagile Criteria	Mean score	Ranking
Six Sigma	3.82	1
Supplier Development	3.75	2
Information Technology	3.60	3
Kaizen	3.55	4
Remuneration and Increment Policies	3.48	5
Training and Motivational Programs	3.35	6
Poka Yoke	3.21	7
FMEA (Failure Mode and Effect	3.15	8
ERP (Enterprise Resource Planning)	3.10	9
Group Technology	3.04	10
Organizational Culture	2.95	11
Innovation and R & D	2.84	12
TQM	2.74	13
Reconfiguration capabilities	2.68	14

Concurrent Engineering	2.54	15
Supply Chain Management (SCM)	2.45	16
CIM (Computer Integrated	2.20	17

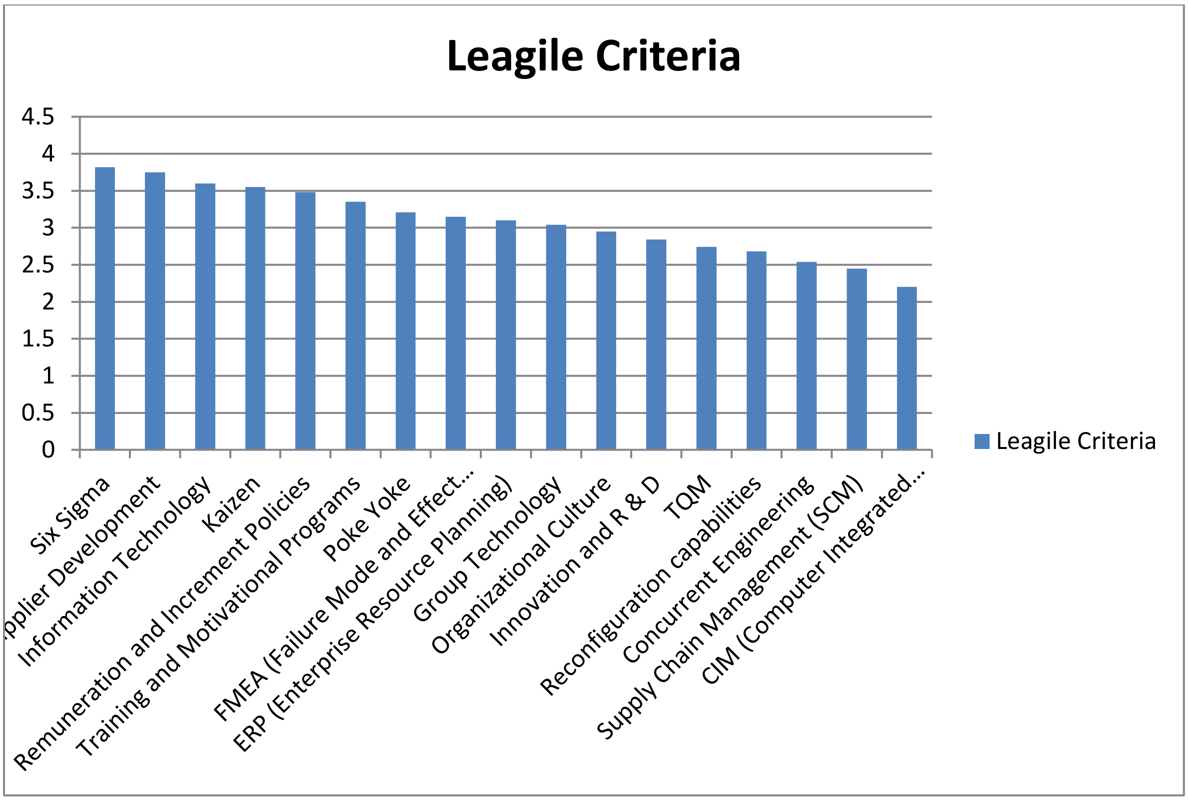


Figure 3.4: Leagile criteria

3.5.5 Related to Key performance indicators of leagile manufacturing system: The response related to key performance indicator's of leagile manufacturing system are shown in Table 3.5

Table 3.6: Analysis of response regarding Key performance indicators of leagile manufacturing system

Key performance indicator	Mean score	Ranking
Optimum Inventory Level	3.84	1
Relationship between suppliers/Customers	3.82	2
Human Resource Management	3.75	3
Reduction of wastages/Non value added activities	3.60	4
Takt Time	3.54	5
Product Variety	3.48	6
Reconfiguration Capabilities	3.47	7
Cost of Production	3.27	8
Quality of Products	3.14	9
Customer Satisfaction	3.04	10
Impact on Environment	2.72	11
Sales/ Turnover	2.30	12

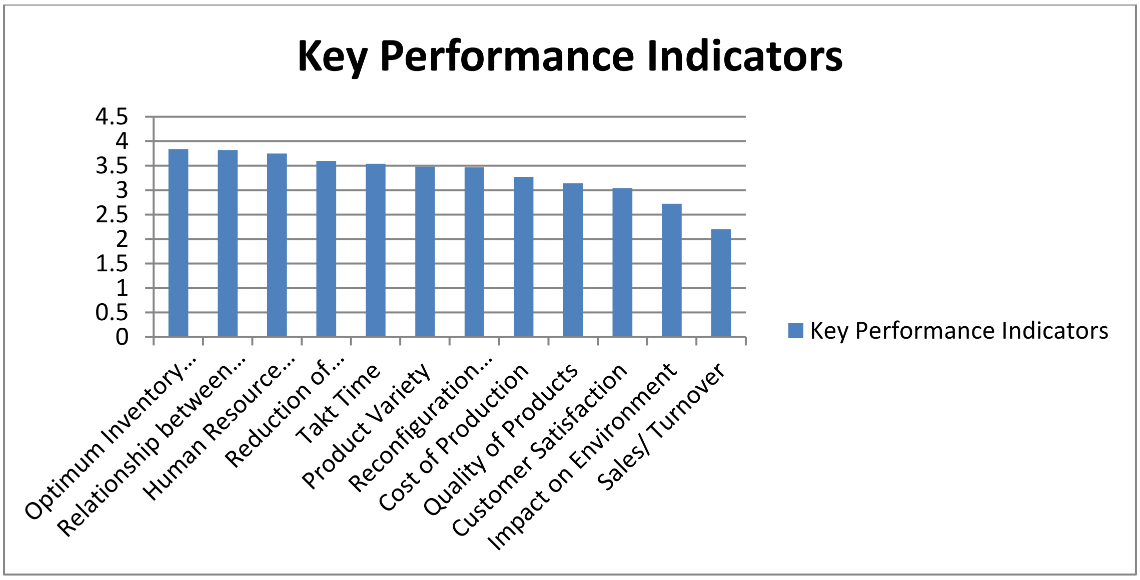


Figure 3.5: Key performance indicators of leagile manufacturing system

3.6 Discussion

Different aspects related to leagile manufacturing system have been examined and analyzed using questionnaire based survey. The major purpose of conducting survey was to find out the leagile scenario in Indian manufacturing industries. From the results, the key factors have been found out. The response for various barriers of leagile manufacturing system, social implications, critical success factors, key performance indicators have been recorded and examined.

CHAPTER 4

BARRIERS OF LEAGILE MANUFACTURING SYSTEM

In this chapter, barriers of leagile manufacturing have been found out by extensive literature review and in discussion with experts. Interpretive structural modeling technique has been applied to find the interrelationships among these barriers.

4.1 Introduction

The ultimate aim of every organization is to maximize profit by providing quality products to the customers. Leagility can help the industries to harness greater profits, increased quality of products, increased market share, better customer satisfaction, and more flexibility in system etc. Various barriers affecting Leagile manufacturing system are identified in this paper based on literature review and survey. 17 barriers were identified through literature review and expert opinions are listed in table 3.1. ISM technique has been used for analyzing these barriers. ISM methodology is found to be more suitable in establishing relationship among barriers. The barriers identified are further classified as driving barriers and dependent barriers by MICMAC analysis.

The purpose behind segregation of barriers is aware the managers about these barriers so that the managers can take preliminary actions to overcome these barriers and leagile strategy can be easily implemented in industries.

In present work, the barriers have been identified through literature review and in discussion with experts and analyzed using ISM technique.

The objectives are as follows:

- To analyze and develop relationship among the barriers in implementation of leagile manufacturing system in context with Indian manufacturing industries.
- To develop relationship between identified barriers with the help of ISM
- To present managerial implications of research
- To propose scope for future work.

The barriers of leagile manufacturing system are identified through literature and 80 expert opinions is listed in table 4.1. Section 4.2, discusses procedure of ISM methodology. Section 4.3, discusses the calculations involved using ISM. Section 4 .4 gives the MICMAC analysis of identified barriers and categorize the barriers in to dependent, independent, linkage and autonomous categories. Section 4.5 discusses the modified Tecnique of Order Preference by Similarity to Ideal Solution (TOPSIS). Section 4.6 discusses the calculations involved by modified TOPSIS technique. Section 4.7 discusses the managerial implications.

Implementation of Leagile manufacturing system is not an easy task and it require lot of efforts from everybody including suppliers, customers, workers etc. It also requires commitment and dedication from employees.

Mostafa, Dumrak and Soltan (2013), have suggested various factors like expert team building, situational analysis, lean communication planning, training process, lean tools, value stream mapping, lesson learned review, lean assessment, lean monitoring and controlling or lean sustaining. Gunasekaran (1998), have developed a model for agile manufacturing enablers like Customer focus, JIT, CAD/CAM, TQM, Language skills, team work, Incentive schemes, Adaptability, partnerships, leadership, employee empowerment. Raj, Sudheer and Vinodh (2013), discussed various agile manufacturing enablers like knowledge management, customer response adoption, employee status, employee empowerment, team work, creativity, fast production and delivery, new product development, design improvement etc. Raj, Jaykrishna and Pandiyan (2014), have evaluated leagility index of manufacturing organization by applying a fuzzy approach by taking factors production rate, cost, cycle time, productivity etc. Mahajan and Bodade (2013) discussed expensive equipments, sophisticated customer requirement demand, capacity planning methodology that promotes agile response in a complex production environment.

Based on the literature review and discussions with the experts both from industry and academia, 17 barriers were identified and used in questionnaire survey. These barriers are enlisted in table 4.1. The barriers like poor planning, lack of time for transition, lack of recognition and rewards are selected in discussion with the experts. The remaining barriers like lack of advance manufacturing capabilities, lack of supplier integration, lack of interpersonal skills, communication gap, lack of top management commitment etc. are identified through literature review. Once the list of barriers has finalized and it is included in a questionnaire. Then, a survey of Indian industries was conducted. The purpose of questionnaire based survey was to identify the impact of various barriers in transition from conventional manufacturing system to Leagile manufacturing in Indian industries context. Later, the mutual relationship among different barriers is defined with the opinions of experts and self structural interpretive matrix is prepared. This matrix is used as an input towards the development of ISM-based framework for the barriers. The ISM based framework will help the managers in tackling the barriers of leagile manufacturing with relative ease and leagile system can be effectively implemented in industries.

The various barriers in implementation of Leagile manufacturing are shown in table 4.1.

Table 4.1: Barriers of leagile manufacturing system

S.No	**Barriers of Leagile manufacturing system**	**References**
1	Lack of training of employees	Agarwal et al.(2013), Atkinson (2010)
2	Employee's Resistance to change	Baird, Hu and Reeve (2011) and Liker and Franz (2012)
3	Inadequate use of empowerment	Bortolotti , Boscari and Danese (2015)
4	Lack of research and development activities	Matsui (2007), Narasimhan, Kull and Nahm (2012)
5	Lack of information technology facilities	Wince and Kull(2013), Calvo-Mora, Picón, Ruiz and Cauzo
6	Lack of supplier integration	Shah and Ward (2003), Jung et. al. (2009)
7	Lack of interpersonal skills	Naor, Goldstein , Linderman and Schroeder (2008), Kull and
8	Communication gap	Mackalprang and Nair(2010), Panizzolo, Garengo, Sharma and
9	Lack of advanced manufacturing capabilities	Olhagar and Prajago (2012), Petersen (2012)
10	Lack of continuous improvement culture	Moyano-fuentes and Sacristán-Díaz (2012)

11	No benchmarking	Sim and Rogers(2009), Patel and Cardon (2010)
12	Poor planning	Expert Opinion
13	Non availability of good vendors	Bortolotti , Boscari and Danese (2015), Naor, Linderman and
14	Lack of time for transition	Expert Opinion
15	Lack of Recognition and Rewards	Expert Opinion
16	Lack of funds	Chavez et. al (2015), Prajogo and McDermott (2011)
17	Lack of top management commitment	Tyagi, Choudhary and Cai (2014), Chavez et. al. (2015)

4.2 An ISM methodology for modeling of barriers

The ISM methodology is an interactive learning process in which a set of different and directly related variables affecting the system under consideration is structured into a comprehensive systemic model. The beauty of the ISM model is that it portrays the structure of a complex issue of the problem under study in a carefully designed pattern employing graphics as well as words (Ravi and Shankar, 2005). ISM can act as a tool for imposing order and direction on the complexity of relationships among elements of a system (Farris and Sage, 1977; Singh, Shankar, Narain, Agarwal, 2003). The steps involved are:

Step 1: Development of the contextual relationship between leagile barriers

Keeping in mind the contextual relationship for each barrier, the existence of a relation between any two barriers (*i* and *j*) and the associated direction of the relation has been decided (Rao, 2007). The following four symbols have been used to denote the direction of relationship between two barriers (*i* and *j*):

- *V* means that barrier *i* affects barrier j .
- *A* means barrier *i* will be affected by barrier *j*.
- *X* means both barriers *i* and *j* affect each other.
- O means barriers *i* and *j* are distinct.

Step 2: Building up of Structural Self-Interaction Matrix (SSIM)

Step 3: initial Reachability Matrix development (RM)

Step 4: Building up of final RM

Step 5: Level partitioning of reachability matrix

Step 6: Conical matrix

Step 7: Construction of digraph

4.3 ISM Calculations Involved

Step 1 Establishment of the contextual connection among leagile barriers

After finding 17 barriers through literature review and survey conducted, the next step was to make a decision about the contextual connection between the barriers.

Many Experts, both from industry and academics, have been consulted in finding the contextual relationship among the barriers. The contextual relationship among identified barriers has been done as per expert's opinion. The symbols used to express relationship among barriers are:

- *V* if barrier *i* affects barrier *j*
- *A* if barrier *I gets* affected by barrier *j*)
- *X* if barriers *i* and *j* both affect each other
- O if barriers *i* and *j both* have no link between them.

Step 2: Development of Structural Self-Interaction Matrix (SSIM)

Self Structural Interaction Matrix (SSIM) is developed on the basis of pair wise appropriate association between the leagile barriers. Group of experts were consulted to develop SSIM. Table 4.3 shows the SSIM matrix. SSIM matrix shows relationships between the leagile barriers with the help of following symbols:

• Symbol V is selected for cell (1, 12) as leagile barrier 1 effects leagile barrier 12

• Symbol A is selected for cell (4, 17) as leagile barrier 17 influences leagile barrier 4

• Symbol X is selected for cell (4, 16) as leagile barrier 4 and 16 influence each other

• Symbol O is selected for cell (6, 17) as leagile number 6 and 17 have no relation between them.

Table 4.2: Some applications of ISM methodology

S.No	Author	Application
1	Saxena, Sushil and Vrat (1992)	Power preservation situation analysis of Indian cement industry
2	Mandal and Deshmukh (1994)	Selection of supplier
3	Sharma, Gupta and Sushil (1995)	Management of waste in india
4	Singh, Shankar, Narain and Agarwal (2003)	Information supervision in engineering industries
5	Ravi and Shankar (2005)	Reverse logistics barriers interaction
6	Jharkharia and Shankar (2005)	Barriers of IT-enabled supply chain
7	Thakkar, Kanda and Deshmukh (2010)	Analyze the relationship between buyer and supplier
8	Kumar et. al. (2013)	lean manufacturing implementation
9	Raj, Sudheer and Vinodh (2013)	Agility enablers assessment
10	Calvo-Mora, Picon, Ruiz and Cauzo (2013)	TQM factors analysis- both soft and hard
11	Raj, Jaykrishna and Pandiyan 2014)	Evaluation of leagile system in industries
12	Jain and Raj (2015)	Assessment of factors for Flexible manufacturing system

Table 4.3.: Development of Self Structural Interaction Matrix (SSIM)

	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	A	A	O	A	O	V	O	V	O	O	O	O	O	V	O	O
2	O	O	O	O	O	V	O	V	O	O	O	O	V	V	O	
3	O	O	O	A	O	V	O	V	O	O	O	V	V	V		
4	A	X	O	O	O	V	V	O	V	V	O	O	V			
5	A	A	O	O	O	V	O	V	O	O	O	O				
6	O	O	O	A	A	V	A	V	O	V	O					
7	O	O	V	V	X	V	O	V	O	V						
8	O	O	O	V	V	V	O	V	0							
9	O	A	O	A	O	O	O	O								
10	A	A	V	A	O	O	O									
11	O	O	V	A	O	V										
12	A	O	A	O	A											
13	O	O	O	O												
14	O	A	O													
15	O	A														
16	O															

Step 3: Construction of the initial reachability matrix (IRM)

Initial reachability matrix is developed using SSIM. It can be tested in two steps. For converting the SSIM in to initial reachability matrix, binary numbers i.e. 0 and 1 are used. It is constructed according to the following:

• if cell (i, j) have symbol V in SSIM then 1 is assigned to cell (i, j) and cell (j, i) will be assigned 0 in the initial reachability matrix.

• if cell (i, j) have symbol A in SSIM then 0 is assigned to cell (i, j) and cell (j, i) will be assigned 1 in the initial reachability matrix.

• if cell (i, j) have symbol X in SSIM then 1 is assigned to cell (i, j) and cell (j, i) will be assigned 1 in the initial reachability matrix.

• if cell (i, j) have symbol 0 in SSIM then 0 is assigned to cell (i, j) and cell (j, i) will be assigned 0 in the initial reachability matrix.

Table 4.4: Initial Reachability Matrix

S.no	**Barrier**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	Lack of training of employees	1	1	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0
2	Employee's Resistance to change	2	0	1	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0
3	Inadequate use of empowerment	3	0	0	1	1	1	1	0	0	0	1	0	1	0	0	0	0	0
4	Lack of research and development activities	4	0	0	0	1	1	0	0	1	1	0	1	1	0	0	0	1	0
5	Lack of information technology facilities	5	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0
6	Lack of supplier integration	6	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0	0
7	Lack of continuous improvement culture	7	0	0	0	0	0	0	1	0	0	1	0	1	1	1	1	0	0
8	Communication gap	8	0	0	0	0	0	0	0	1	0	1	0	1	1	1	0	0	0
9	Lack of advanced manufacturing	9	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0

	capabilities																	
10	Lack of interpersonal skills.	10	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0
11	No benchmarking	11	0	0	0	0	1	1	0	0	0	0	1	1	0	0	1	0	0
12	Poor planning	12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
13	Non availability of good vendors	13	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0
14	Lack of time for transition	14	1	0	1	0	0	1	0	0	1	1	1	0	1	1	0	0	0
15	Lack of Recognition and Rewards	15	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
16	Lack of funds	16	1	0	0	1	1	0	0	0	1	1	0	0	0	1	1	1	0
17	Lack of top management commitment.	17	1	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	1

Step 4: Construction of final RM

Transitivity concept helps in constructing final reachability matrix. The objective of transitivity is to block up the gaps, if any while building of SSIM. This principle entails that if the leagile barrier A is related to B and leagile barrier B is related to C then both A and C are also related. The driving power of leagile barrier is obtained by summation of 1's in the rows and dependence power of each leagile barrier is obtained by summations of 1's in the columns.

Table 4.5: Final Reachability Matrix

S. no	Barrier		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Driving Power	Rank
1	Lack of training of employ-ees	1	1	0	0	1	1*	0	0	1*	1*	1	1*	1	0	0	1*	1*	0	10	V
2	Employee's Resistance to change	2	0	1	0	1	1	0	0	1*	1*	1	1*	1	0	0	1*	1*	0	10	V
3	Inadequate use of empowerment	3	0	0	1	1	1	1	0	1*	1*	1	1*	1	0	0	0	1*	1*	11	IV
4	Lack of research and development activities	4	1*	0	0	1	1	1*	0	1	1	1*	1	1	1*	1*	1*	1	0	13	II
5	Lack of information technology facilities	5	0	0	0	0	1	0	0	0	0	1	0	1	0	0	1*	0	0	4	VIII
6	Lack of supplier integration	6	0	0	0	0	0	1	0	1	0	1	0	1	1*	1*	1*	0	0	7	VII
7	Lack of continuous improvement culture	7	1*	0	0	0	0	1*	1	0	1*	1	1*	1	1	1	1	0	0	12	III
8	Communication gap	8	1*	0	0	0	0	1*	1*	1	1*	1	1*	1	1	1	1*	0	0	12	III

9	Lack of advanced manufacturing capabilities	9	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	1	XI
10	Lack of interpersonal skills.	10	0	0	0	0	0	0	0	1	0	1	0	1*	0	0	1	0	0	3	IX
11	No benchmarking	11	0	0	0	0	1	1	0	1*	0	1*	1	1	0	0	1	0	0	7	VII
12	Poor planning	12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	XI
13	Non availability of good vendors	13	0	0	0	0	0	1	1	1*	0	1*	0	1	1	1*	1*	0	0	8	VI
14	Lack of top management commitment	14	1	0	1	1*	1*	1	1*	1*	1	1	1	1*	1	1	1*	0	0	13	II
15	Lack of Recognition and Rewards	15	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	2	X
16	Lack of funds.	16	1	0	1*	1	1	1*	0	1*	1	1	1*	1*	1*	1	1	1	0	14	I
17	Lack of time for transition	17	1	0	0	1	1	0	0	1*	1*	1	1*	1	0	0	1*	1*	1	11	IV
	Dependence Power		7	1	5	7	9	9	4	12	10	14	10	16	7	7	15	6	1		
	Rank		VII	XI	IX	VII	VI	VI	X	IV	V	III	V	I	VII	VII	II	VIII			

Step 5: Level partitioning the RM

Final RM is prepared in this step and is presented in Table 4.5. According to the Warfield (1974) and Farris and Sage (1975), final reachability matrix decides the levels of reachability and antecedent cell. The iteration starts and for those leagile barrier's in support of which reachability and intersection set are same are assigned first level or top level. After this top level barrier gets eliminated from subsequent iterations or tables. The process of iterations lasts till every barrier is assigned some level. The iterations have been shown in Table 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, 4.15

Table 4.6: Iteration 1

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
1	1,2,3,4,5,6,7,8,9,10,11 12,13,14	1	1	
2	2,3,5,6,7,9,10,11,12,13,14	1,2	2	
3	3,5,6,8,11,12,13,14	1,2,3	3	
4	4,5,6,7,8,9,10,11,12,13,14	4	4	
5	5	1,2,3,4,5,6,7,8,9,10,12,13,14	5	I
6	5,6,7,11,12,13,14	1,2,3,4,6,7,8,9,10,12,13,14	6,7,12,13,14	
7	5,6,7,8,11,12,13,14	1,2,4,6,7,8,10,13	6,7,8,13	
8	5,6,7,8,9,10,11,12,13,14	3,4,7,8,10,12,14	7,8,10,12,14	
9	5,6,9,11,12,13,14	1,2,4,8,9,10	9	
10	5,6,7,8,9,10,11,12,13,14	1,2,4,8,10,14	8,10,14	
11	11	1,2,3,4,6,7,8,9,10,11,12,13,14	11	I
12	5,6,8,11,12,13,14	1,2,3,4,6,7,8,9,10,12,13,14	6,8,12,13,14	
13	5,6,7,11,12,13,14	1,2,3,4,6,7,8,9,10,12,13,14	6,7,12,13,14	
14	5,6,8,10,11,12,13,14	1,2,3,4,6,7,8,9,10,12,13,14	6,8,10,12,13,14	
15	12,15	1,2,3,4,5,6,7,8,10,11,13,14,15 ,16,17	15	

16	1,3,4,5,6,8,9,10,11,12,13,14,15,16	1,2,3,4,16,17	1,3,4,16	
17	1,4,5,8,9,10,11,12,15,16,17	17	17	

Table 4.7: Second Iteration

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
1	1,4,5,8,10,11,15,16	1,4,7,8,14,16,17	1,4,8,16	
2	2,4,5,8,10,11,15,16	2	2	
3	3,4,5,6,8,10,11,15,16	3,7,8,14,16	3,8,16	
4	1,4,5,6,8,10,11,13,14,15,16	1,2,3,4,14,16,17	1,4,14,16	
5	5,10,15	1,2,3,4,5,11,14,16,17	5	
6	6,8,10,13,14,15	3,4,6,7,8,11,13,14,16	6,8,13,14	
7	1,3,6,7,8,10,11,13,14,15	7,8,13,14	7,8,13,14	
8	1,3,6,7,8,10,11,13,14,15	1,2,3,4,6,7,8,,11,13,14,16,17	1,3,,6,7,8,11,13,14	
10	10,15	1,2,3,4,5,6,7,8,10,11,13,14,16,17	10	
11	5,6,8,10,11,15	1,2,3,4,7,8,11,14,16,17	8,11	
13	6,7,8,10,13,14,15	4,6,7,8,13,14,16	6,7,8,13,14	
14	1,3,4,5,6,7,8,10,11,13,14,15	4,6,7,8,13,14,16	4,6,7,8,14	
15	15	1,2,3,4,5,6,7,8,10,11,13,14,15,16,17	15	II
16	1,3,4,5,6,8,10,11,12,13,14,16	1,2,3,4,16,17	1,3,4,16	
17	1,4,5,8,10,11,15,16,17	17	17	

Table 4.8: Third Iteration

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
1	1,4,5,8,10,11,16	1,4,7,8,14,16,17	1,4,8,16	
2	2,4,5,8,10,11,16	2	2	
3	3,4,5,6,8,10,11,16	3,7,8,14,16	3,8,16	
4	1,4,5,6,8,10,11,13,14,16	1,2,3,4,14,16,17	1,4,14,16	
5	5,10	1,2,3,4,5,11,14,16,17	5	
6	6,8,10,13,14	3,4,6,7,8,11,13,14,16	6,8,13,14	
7	1,3,6,7,8,10,11,13,14	7,8,13,14	7,8,13,14	
8	1,3,6,7,8,10,11,13,14	1,2,3,4,6,7,8,,11,13,14,16,17	1,3,,6,7,8,11,13,1 4	
10	10	1,2,3,4,5,6,7,8,10,11,13,14,16,17	10	III
11	5,6,8,10,11	1,2,3,4,7,8,11,14,16,17	8,11	
13	6,7,8,10,13,14	4,6,7,8,13,14,16	6,7,8,13,14	
14	1,3,4,5,6,7,8,10,11,13,1 4	4,6,7,8,13,14,16	4,6,7,8,14	
16	1,3,4,5,6,8,10,11,12,13, 14,16	1,2,3,4,16,17	1,3,4,16	
17	1,4,5,8,10,11,16,17	17	17	

Table 4.9: Fourth Iteration

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
1	1,4,5,8,11,16	1,4,7,8,14,16,17	1,4,8,16	
2	2,4,5,8,11,16	2	2	
3	3,4,5,6,8,11,16	3,7,8,14,16	3,8,16	
4	1,4,5,6,8,11,13,14,16	1,2,3,4,14,16,17	1,4,14,16	
5	5	1,2,3,4,5,11,14,16,17	5	IV
6	6,8,13,14	3,4,6,7,8,11,13,14,16	6,8,13,14	IV
7	1,3,6,7,8,11,13,14	7,8,13,14	7,8,13,14	
8	1,3,6,7,8,11,13,14	1,2,3,4,6,7,8,,11,13,14,16,17	1,3,,6,7,8, 11,13,14	IV
11	5,6,8,11	1,2,3,4,7,8,11,14,16,17	8,11	
13	6,7,8,113,14	4,6,7,8,13,14,16	6,7,8,13,1 4	IV
14	1,3,4,5,6,7,8,11,13,14	4,6,7,8,13,14,16	4,6,7,8,14	
16	1,3,4,5,6,8,11,12,13,14,16	1,2,3,4,16,17	1,3,4,16	
17	1,4,5,8,11,16,17	17	17	

Table 4.10: Iteration 5

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
1	1,4,11,16	1,4,7,14,16,17	1,4,8,16	
2	2,4,11,16	2	2	
3	3,4,11,16	3,7,14,16	3,8,16	

4	1,4,11,14,16	1,2,3,4,14,16,17	1,4,14,16	
7	1,3,7,11,14	7,14	7,8,13,14	
11	11	1,2,3,4,7,11,14,16,17	11	V
14	1,3,4,7,11,14	4,7,14,16	4,6,7,8,14	
16	1,3,4,11,12,14,16	1,2,3,4,16,17	1,3,4,16	
17	1,4,11,16,17	17	17	

Table 4.11: Iteration 6

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
1	1,4,16	1,4,7,14,16,17	1,4,16	
2	2,4,16	2	2	
3	3,4,16	3,7,14,16	3,16	
4	1,4,14,16	1,2,3,4,14,16,17	1,4,14,16	VI
7	1,3,7,14	7,14	7,14	
14	1,3,4,7,14	4,7,14,16	4,7,14	
16	1,3,4,12,14,16	1,2,3,4,16,17	1,3,4,16	
17	1,4,16,17	17	17	

Table 4.12: Iteration 7

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
1	1,16	1,14,16,17	1,16	VII
2	2,16	2	2	
3	3,16	3,7,14,16	3,16	VII
7	1,3,7,14	7,14	7,14	
14	1,3,7,14	7,14,16	7,14	
16	1,3,12,14,16	1,2,3,16,17	1,3,16	
17	1,16,17	17	17	

Table 4.13: Iteration 8

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
2	2,16	2	2	
7	7,14	7,14	7,14	VIII
14	7,14	7,14,16	7,14	VIII
16	12,14,16	2,4,16,17	16	
17	16,17	17	17	

Table 4.14: Iteration 9

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
2	2,16	2	2	
16	12,16	2,4,16,17	16	IX
17	16,17	17	17	

Table 4.15: Iteration10

Barriers	Reachabiliy Set	Antecedent Set	Intersection Set	Level
2	2	2	2	X
17	17	17	17	X

Step 6: Conical matrix

In sixth step, reachability matrix is converted in to conical matrix. Many of the leagile barriers are assigned zero in upper half diagonal leagile barriers are unitary in lower half leagile diagonal. The procedure is based on integrating leagile barriers of same level. The conical matrix is shown in Table 4.15

Table 4.16: Conical Matrix

Barrier	**9**	**12**	**15**	**10**	**5**	**6**	**8**	**13**	**11**	**4**	**1**	**3**	**7**	**14**	**16**	**2**	**17**
9	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0
5	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
6	0	1	1	1	0	1	1	1	0	0	0	0	0	1	0	0	0
8	1	1	1	1	0	1	1	1	1	0	1	1	1	1	0	0	0
13	0	1	1	1	0	1	1	1	0	0	0	0	1	1	0	0	0
11	0	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0
1	1	1	1	1	1	0	1	0	1	1	1	0	0	0	1	0	0
3	1	1	1	1	1	1	1	0	1	1	0	1	0	0	1	0	0
7	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0
14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
16	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0
2	1	1	1	1	1	0	1	0	1	1	0	0	0	0	1	1	0
17	1	1	1	1	1	0	1	0	1	1	1	0	0	0	1	0	1

Step 7: Development of digraph

Digraph is constructed on the basis of levels identified in iterations. A concluding digraph (Figure 4.1) is constructed by eliminating the transitive links. In the digraph, top leagile barrier is positioned at the top of ISM model and second level barrier is placed at second position and so on up to last level.

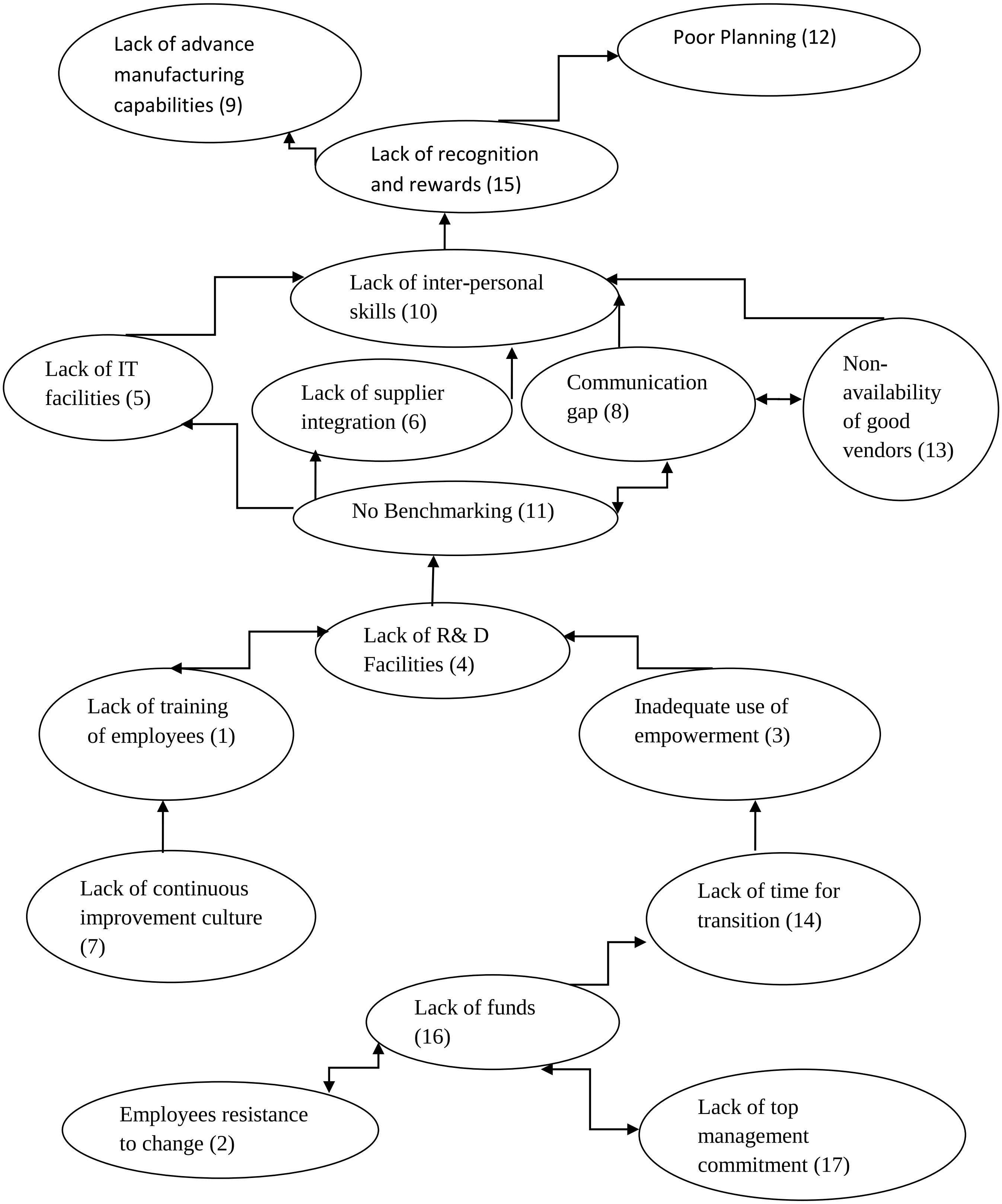


Figure 4.1: Interpretive structure Model of different identified barriers

4.4 MICMAC ANALYSIS

The objective of MICMAC investigation is to found out the driving power and dependence power of identified barriers. The barriers are categorized in to four groups on the basis of their driving power and dependence power.

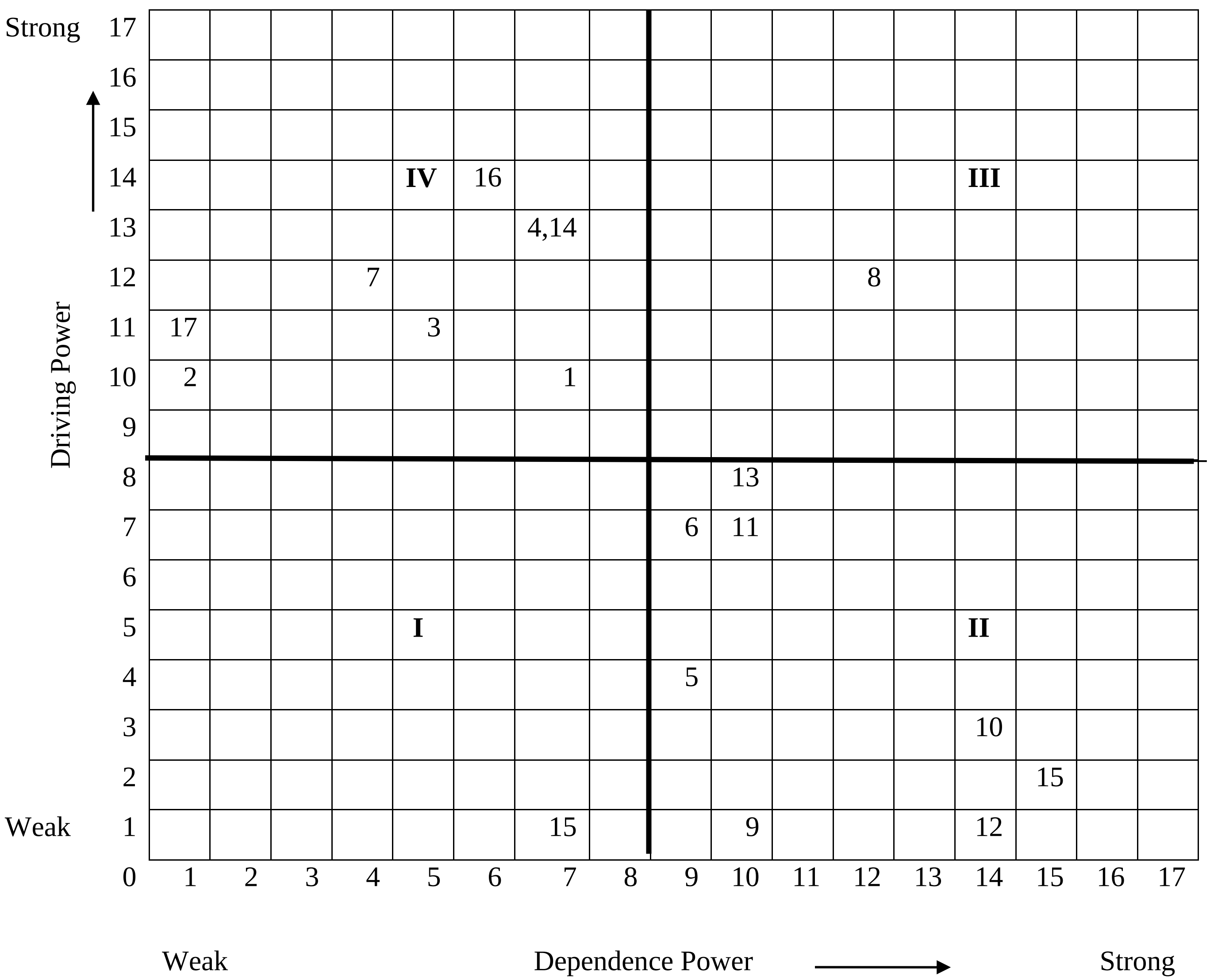


Figure 4.2: Driving Power and dependence diagram

Autonomous barriers: This includes barriers which have less driving power and less dependence power. These barriers are generally detached and have little connections.

Dependent barriers: These barriers have less driving power and high dependence power and are dependent on other barriers

Linkage barriers: The barriers which have high drive power and high dependence power. These barriers are normally uncontrolled.

Independent barriers: The barriers which have high drive power and less dependence power. The barriers which fall under this category are generally called key barrier.

Mandal and Deshmukh (1994), done the above classification of elements. Table 4.5 shows the driving power and dependence power of barriers. After that, figure 4.1 shows the drive –dependence power relationship. The figure is categorized in to four groups. First group shows ‘autonomous barriers’, second group explains ‘dependent barriers’, third group shows ‘linkage barriers’ and fourth group explains ‘independent-barriers’. Since barrier no. 2 have driving power 10 and dependence power 1, so in figure 4.2, it is placed at a corresponding position i.e. it is positioned in the fourth group which shows that it is a independent barrier.

4.5 Modified TOPSIS technique

The main procedure of the modified TOPSIS method for the ranking the factors affecting leagile manufacturing system has been described. The experts were asked to fill the questionnaire by assigning fuzzy or crisp values as shown in table II, 0.045 stands for exceptionally low while 0.955 stands for exceptionally high (Rao, 2007).

Step 1 : The first step is to determine the objective

Step 2: This step represents a matrix based on all the information available on factors.

Each row of the matrix is allocated by onefactor and each column is assigned value by expert. In the case of a subjective attribute (i.e. objective value is not available), a ranked value judgement is adopted. Various researchers proposed an approach for solving more than ten alternatives in the system first converts linguistic terms into fuzzy numbers and after that the fuzzy numbers are converted into crisp scores. An 11-point scale is used in this paper for crisp score is shown in Table 4.17

Step 3: In this step both, Positive ideal solution (best) and negative ideal solution (worst) are calculated.

$$R^{+} = \left\{ \left(\sum_{1}^{Max} R_{ij} \ / \ j \in J \right), \left(\left(\sum_{1}^{Min} R_{ij} \ / \ j \in J' \right) / \ i = 1,2..N \right) \right\} \qquad (1)$$

$$= \left\{ R_1^{+}, R_2^{+}, R_3^{+} \ldots\ldots\ldots R_M^{+} \right\}$$

$$R^{-} = \left\{ \left(\sum_{1}^{Max} R_{ij} \ / \ j \in J \right), \left(\left(\sum_{1}^{Min} R_{ij} \ / \ j \in J' \right) / \ i = 1,2..N \right) \right\} \qquad (2)$$

$$= \left\{ R_1^{-}, R_2^{-}, R_3^{-} \ldots\ldots\ldots R_M^{-} \right\}$$

Table 4.17: Conversion of Linguistic Terms into Fuzzy Scores (11 Point Scale)

Linguistic Term	Fuzzy Number	**Crisp No.**
Exceptionally Low	M1	0.045
Extremely low	M2	0.135
Very low	M3	0.255
Low	M4	0.335
Below average	M5	0.410
Average	M6	0.500
Above average	M7	0.59
High	M8	0.665
Very High	M9	0.745
Extremely high	M10	0.865
Exceptionally high	M11	0.955

Step 4: In this step, Relative importance is decided in context with objective.

It can be explained as:

$$GM_j = \left(\sum_{i}^{M} b_{ij} \right)^{1/m} \quad (3)$$

And $\quad W_J = GM_j / \sum_{j=0}^{M} GM_j$

Step 5: Weighted Euclidean distances is calculated and is given by relations:

$$D_i^+ = \left\{ \sum_{j=1}^{M} W_j \left(R_{ij} - R_j^+ \right)^2 \right\}^{1/2} \quad where \ i = 1, 2, 3, ...N \quad (4)$$

$$D_i^- = \left\{ \sum_{j=1}^{M} W_j \left(R_{ij} - R_j^- \right)^2 \right\}^{1/2} \quad where \ i = 1, 2, 3, ...N \quad (5)$$

Step 6: The relative closeness of a specific attribute , *Pi*–mod is calculated and can be expressed as

$$P_{i\,\mathrm{mod}} = D_i^- / \left(D_i^+ + D_i^- \right) \quad (6)$$

Step 7: The different attributes are arranged in descending order as per the value of *Pi*–mod calculated in step (6), indicating the most significant and least significant attribute influencing the particular objective.

4.6 Modified TOPSIS calculations involved

Step 1: Table 4.18 shows fuzzy or crisp values of the barriers of leagile manufacturing system and are given by experts.

Step 2: Normalized Decision matrix is calculated by equation (7) and is shown in Table 4.19

$$N_{ij} = m_{ij} / \left(\sum_{j=1}^{m} {m_{ij}}^2 \right)^{1/2} \quad (7)$$

Table 4.18: Crisp values of leagile barriers

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0.865	0.5	0.41	0.335	0.59	0.335	0.41	0.745	0.41	0.5	0.41	0.5	0.41	0.5	0.41	0.41	0.41
0.665	0.5	0.745	0.5	0.41	0.59	0.335	0.335	0.59	0.41	0.59	0.5	0.5	0.41	0.59	0.59	0.59
0.59	0.41	0.5	0.5	0.5	0.665	0.745	0.59	0.335	0.865	0.41	0.41	0.5	0.5	0.5	0.5	0.5
0.335	0.335	0.5	0.335	0.5	0.41	0.59	0.59	0.5	0.335	0.5	0.5	0.665	0.41	0.59	0.255	0.255
0.41	0.41	0.335	0.41	0.41	0.5	0.865	0.5	0.59	0.5	0.59	0.5	0.865	0.335	0.255	0.59	0.59
0.41	0.5	0.5	0.5	0.335	0.5	0.59	0.5	0.59	0.5	0.41	0.41	0.955	0.41	0.865	0.5	0.5
0.5	0.335	0.665	0.5	0.665	0.665	0.665	0.41	0.5	0.59	0.41	0.335	0.41	0.135	0.335	0.255	0.5
0.335	0.865	0.665	0.665	0.135	0.5	0.335	0.335	0.865	0.335	0.745	0.5	0.5	0.5	0.5	0.255	0.41
0.135	0.59	0.59	0.255	0.865	0.5	0.5	0.5	0.865	0.745	0.335	0.865	0.5	0.5	0.5	0.5	0.135
0.865	0.59	0.5	0.5	0.5	0.335	0.41	0.5	0.41	0.41	0.255	0.955	0.255	0.135	0.41	0.41	0.41
0.41	0.5	0.135	0.59	0.5	0.41	0.865	0.59	0.5	0.41	0.5	0.5	0.5	0.255	0.255	0.59	0.255
0.59	0.59	0.59	0.59	0.255	0.5	0.59	0.665	0.59	0.255	0.5	0.41	0.41	0.41	0.335	0.5	0.41
0.59	0.665	0.41	0.255	0.335	0.5	0.59	0.5	0.41	0.745	0.745	0.255	0.5	0.41	0.41	0.5	0.255
0.335	0.59	0.5	0.5	0.41	0.665	0.5	0.59	0.5	0.665	0.5	0.41	0.255	0.5	0.5	0.41	0.255
0.5	0.59	0.59	0.335	0.5	0.5	0.59	0.255	0.335	0.5	0.5	0.5	0.5	0.255	0.5	0.59	0.335
0.5	0.59	0.41	0.335	0.255	0.41	0.335	0.745	0.255	0.665	0.255	0.335	0.665	0.41	0.41	0.59	0.41
0.335	0.5	0.5	0.41	0.5	0.5	0.59	0.335	0.5	0.255	0.5	0.5	0.335	0.5	0.865	0.135	**0.5**

Table 4.19 : Normalized Matrix of Experts

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
0.4	0.24	0.2	0.19	0.31	0.17	0.18	0.37	0.19	0.24	0.21	0.24	0.19	0.32	0.22	0.22	0.26
0.31	0.24	0.36	0.28	0.22	0.3	0.15	0.17	0.27	0.19	0.3	0.24	0.24	0.27	0.31	0.32	0.37
0.27	0.19	0.24	0.28	0.26	0.33	0.32	0.29	0.16	0.41	0.21	0.2	0.24	0.32	0.27	0.27	0.32
0.15	0.16	0.24	0.19	0.26	0.21	0.26	0.29	0.23	0.16	0.25	0.24	0.31	0.27	0.31	0.14	0.16
0.19	0.19	0.16	0.23	0.22	0.25	0.38	0.25	0.27	0.24	0.3	0.24	0.41	0.22	0.14	0.32	0.37
0.19	0.24	0.24	0.28	0.18	0.25	0.26	0.25	0.27	0.24	0.21	0.2	0.45	0.27	0.46	0.27	0.32
0.23	0.16	0.32	0.28	0.35	0.33	0.29	0.2	0.23	0.28	0.21	0.16	0.19	0.09	0.18	0.14	0.32
0.15	0.41	0.32	0.37	0.07	0.25	0.15	0.17	0.4	0.16	0.38	0.24	0.24	0.32	0.27	0.14	0.26
0.06	0.28	0.29	0.14	0.46	0.25	0.22	0.25	0.4	0.35	0.17	0.42	0.24	0.32	0.27	0.27	0.09
0.4	0.28	0.24	0.28	0.26	0.17	0.18	0.25	0.19	0.19	0.13	0.46	0.12	0.09	0.22	0.22	0.26
0.19	0.24	0.07	0.33	0.26	0.21	0.38	0.29	0.23	0.19	0.25	0.24	0.24	0.17	0.14	0.32	0.16
0.27	0.28	0.29	0.33	0.13	0.25	0.26	0.33	0.27	0.12	0.25	0.2	0.19	0.27	0.18	0.27	0.26
0.27	0.31	0.2	0.14	0.18	0.25	0.26	0.25	0.19	0.35	0.38	0.12	0.24	0.27	0.22	0.27	0.16
0.15	0.28	0.24	0.28	0.22	0.33	0.22	0.29	0.23	0.32	0.25	0.2	0.12	0.32	0.27	0.22	0.16
0.23	0.28	0.29	0.19	0.26	0.25	0.26	0.13	0.16	0.24	0.25	0.24	0.24	0.17	0.27	0.32	0.21
0.23	0.28	0.2	0.19	0.13	0.21	0.15	0.37	0.12	0.32	0.13	0.16	0.31	0.27	0.22	0.32	0.26
0.15	0.24	0.24	0.23	0.26	0.25	0.26	0.17	0.23	0.12	0.25	0.24	0.16	0.32	0.46	0.07	0.32

Step 3: Weights of different factors are taken by AHP methodology and the weights as given below:

Table 4.20: Weights of barriers

Barriers	**Weights**
W_1	0.075
W_2	0.08
W_3	0.071
W_4	0.13
W_5	0.067
W_6	0.125
W_7	0.081

W_8	0.025
W_9	0.084
W_{10}	0.047
W_{11}	0.025
W_{12}	0.018
W_{13}	0.02
W_{14}	0.021
W_{15}	0.032
W_{16}	0.047
W_{17}	0.053

Step 4: Table 4.21 shows Positive Ideal Solution (PIS) which is calculated by equation (1) and Negatve Ideal Solution (NIS) which is calculated by equation (2)

Table 4.21: Positive Ideal Solutions (*R*+) and Negative Ideal Solutions (*R*−)

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
(R^+)	0.3988	0.4081	0.3635	0.3676	0.4599	0.3331	0.3759	0.3681	0.4025
(R^-)	0.0622	0.1581	0.0659	0.1409	0.0711	0.1678	0.1456	0.126	0.1187
Factors	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	
(R^+)	0.4104	0.4104	0.377	0.4509	0.3248	0.4589	0.3227	0.3725	
(R^-)	0.121	0.129	0.129	0.1204	0.0877	0.1353	0.0738	0.0852	

Table 4.22: Weighted Euclidian Distance

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
(D^+)	0.0278	0.0197	0.0193	0.0324	0.0249	0.0204	0.0227	0.0287	0.0282
(D^-)	0.0214	0.0296	0.0281	0.0121	0.0228	0.0231	0.0252	0.0305	0.0306
Factors	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	
(D^+)	0.0267	0.0299	0.0237	0.0294	0.0246	0.026	0.2882	0.384	
(D^-)	0.0228	0.0193	0.0225	0.0173	0.0188	0.0173	0.0147	0.0177	

Step 6: Weighted eucledian distances are calculated and is shown in Table 4.22

Step 7: Relative closeness of each factor is calculated by equation (5) and is shown in table 4.23

Table 4.23: Relative closeness of particular factor to ideal solution (P_{i-mod})

Factors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
(P_{i-mod})	0.4353	0.6006	0.5925	0.2719	0.4774	0.531	0.5252	0.5153	0.5204
Factors	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	
(P_{i-mod})	0.4601	0.3928	0.4865	0.37	0.4326	0.3999	0.2882	0.384	

Step 8: The barriers are arranged in descending order of their relative importance

2-3-6-7-9-8-12-5-10-1-14-15-11-17-13-16-4

Step 9: The ranking of barriers affecting leagile manufacturing system are given in table 4.23

Table 4.24: Ranking of barriers

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Ranking	2	3	6	7	9	8	12	5	10	1	14	15	11	17	13	16	4

4.7 Discussion

The main purpose of the research was to recognize the barriers, which significantly are responsible for transformation from conventional manufacturing system to Leagile manufacturing so as to direct the managers to work in a comprehensive way and implement leagile system with relative ease. The ISM methodology in research conducted concludes that the barrier number 17 (i.e., lack of top management for big changes) and barrier 16 (i.e.lack of funds) and barrier 4 (lack of R&D facilities) are the barriers which have very high driving power and placed at the bottom level of the ISM model (Figure 4.1). Lack of information technology facilities, lack of supplier integration and no benchmarking are middle-level barriers as they have intermediate dependence and intermediate driving power. Lack of advance manufacturing facilities and poor planning, identified as the slightest significant barriers, it is seen that they are positioned at top level in ISM hierarchy and have maximum dependence power but minimum driving power.

It provides managerial implications also. From figure 4.1, it is also seen that non commitment of top management is placed at the bottom of ISM model implying high driving power of this barrier. So, it is required for the management to support fully the employees working in the organization so that the initiatives taken by them for improvement can be further enhanced and motivated. The management should also understand the needs of the employees in terms of their salaries, increments, promotions etc.

so that attrition rate can be minimized in industries. As this barrier have high driving power and drive all other identified barriers, lack of top management commitment will results in collapse of entire leagile transformation process. Lack of funds, lack of advanced manufacturing capabilities, poor planning etc. are also imposes a lot of problems because modern production system needs a very large investment for setting plant, purchase of latest equipments and machinery, which is prerequisite of Leagile manufacturing. In India, the managers are reluctant to use this technology as it requires high investment, high maintenance of equipments, employees resistance to change etc. So, theses barriers needs to be examined carefully before planning to implement leagile manufacturing system.

It is also shown by modified topsis technique that employees resitance ranked no.1 barrier. In industries, employees are reluctant to change and want to stick to their normal schedule. The employees needs to be motivated and trained so that they took interst in implementation of leagile system. Production managers are required to look after these identified barriers and find the best solutions to overcome these barriers. The results can be used by managers and the system can be made better by implementing leagile system.

CHAPTER 5

SOCIAL IMPLICATIONS OF LEAGILE MANUFACTURING SYSTEM

*In this chapter, social implications of leagile manufacturing system have been discussed and TISM (Total Interpretice Structural Modeling) technique have been applied to discuss the interrelationship among these social implications***.**

5.1 Introduction

In this work, advantages and disadvantages of Leagile manufacturing, social implications of leagile system have been analyzed. The identified social implications have been found out through the literature review, and in discussion with 80 experts. The social implications found are unemployment, initial high investment, reduced labor, fear of technology change, improved customer satisfaction, better utilization of resources, better product quality, better return on investment, reduced manufacturing lead time, reduced cost per item etc. In this paper, a framework has been constructed using Total Interpretive Structural Modeling (TISM) which provides guidelines to the managers about the latest and advancement in the working standards and procedures.

The purpose of carrying out research was:

1. To analyze identified social implications of Leagile manufacturing obtained through literature review and expert opinion and rank them.
2. To develop TISM model to found out relationship among social implications of leagile manufacturing system
3. To found out pivotal social implications of Leagile manufacturing
4. To propose scope of future work and scope in the field of leagile manufacturing.

Section 5.1 contains introduction. Section 5.2 includes some applications of Total Interpretive Structural Modeling (TISM). Sections 5.3 contain identified social implications of leagile manufacturing obtained by literature review and discussion with academicians and industrialists. Research methodology and steps of TISM methodology and calculations involved are done in section 5.4. MICMAC analysis is explained in section 5.5 and Section 5.6 discusses conclusion.

5.2 Identification of social implications of Leagile manufacturing

After the findings of literature review and survey conducted in discussion with experts, 16 social implications of leagile manufacturing have been found out and are listed in Table 5.1as follows:

Table 5.1: Social Implications of Leagile Manufacturing System

S. No	Social Implications	References
1	Unemployment	Droge, Vickery and Jacobs (2012) ; Jayaram, Vickery and Droge (2008)
2	Initial high investment	Browning and Heath (2009)
3	Reduced Labor	Paulraj and Chen (2007)
4	Fear of Technology change	Expert opinion
5	Improved Customer satisfaction	Fullerton and McWatters (2001) ; Eroglu and Hoffer, (2011)
6	Better utilization of resources	Fullerton and McWatters (2001) ; Eroglu and Hoffer (2011)
7	Better Product quality	Shah and Ward (2003) ; Li, Sian and Li (2002)
8	Better Return on Investment	Liker and Sobek II (1996) ; Perez, Castro, Simons and Gimenez (2010)
9	Reduced Manufacturing lead time	Song, Droge, Hanvanich and Calantone (2005) ;Paulraj and Chen (2007)
10	Reduced Cost per item	Cannon (2008) ; Trkman and McCormack (2009)

11	Improved employee morale	Buvik and Halskau,2001
12	Better incentives, recognition and rewards	Hong and Modi (2011); Min and Mentzer (2000)
13	Reduced Scrap	Perez, Castro, Simons and Gimenez (2010), Mclvor (2001)
14	Increased production volume	Durmusoglu et. al. (2014) ; Chavez et. al. (2015), Mills(2011)
15	Increased Market Share	Azadegan, Patel, Zangoueinezhad and Linderman (2013) ; Martínez-Jurado and Moyano-Fuentes (2014)
16	Better supplier relationship	Martínez-Jurado and Moyano-Fuentes (2014); Fullerton and McWatters , 2001 ; Eroglu and Hoffer, 2011

Table 5.2: Some applications of TISM

S.no	Name of the Author	Application
1	Jharkharia and Shankar (2005)	Barriers identification of IT-enabled supply chain
2	Agarwal, Shankar and Tiwari (2007)	Analysis of agility of supply chain
3	Fan and Liu (2010)	Analysis of group decision making problem
4	Nasim (2011)	Analysis of forces of e-government
5	Prasad and Suri (2011)	Analysis of forces in higher education system
6	Haleem and Sushil 2012)	Assessment of factors of world-class production system
7	Yadav and Kumar (2013)	Measurement of performance of telecom industries

8	Mangla, Kumar and Barua (2014)	Evaluation of performance of supply chains
9	Dubey and Gunasekaran (2014)	Analysis of dimensions of flexible manufacturing system
10	Khatwani, Singh, Trivedi and Chauhan (2015)	Group decision making decision
11	Gothwal and Raj (2016)	FMS flexibility analysis

Leagile manufacturing can be established when the industries uses latest techniques like automation, one of the biggest disadvantage of automation is unemployment. For producing high quality products and achieving better customer satisfaction, latest equipments are needed which requires high capital investment, which may be one of the hindrance in achieving leagile manufacturing system. Introduction of latest tools and techniques helps in increasing the productivity but at the same time, it results in decrease in labor force required in accomplishing the target. Most of the employees are generally have fear of technology change; they want to confine themselves with the older techniques and are unwilling to adopt newer technologies. Advance techniques results in increased accuracy and quality of the products and hence results in better customer satisfaction. One of the means by which productivity can be increased is better utilization of resources. When all resources like men, machine, material, money will be utilized fully then the production will be maximum and as a result, profitability of industry will be maximum. By using leagile manufacturing, the products can be manufactured within close tolerances and better product quality is achieved. When product quality is better, the sales of product will automatically rise and hence better return on investment is achieved. Leagile manufacturing tries to reduce the takt time as minimum as possible. Since, all resources will be utilized fully; the cost of manufacturing per unit item is low and demand will increase. Also, leagile manufacturing helps in reducing the scrap as minimum as possible. Before industrial revolution, the production of industries was very less, after that machines comes in market and production increased drastically. Now days, with latest strategies like machines and automation, the mass production is achieved, hence production volume is very high. Better return on investment (ROI) results in better market reputation. As a result market shares increases.

5.3 TISM methodology

The process of TISM involves the following steps:

1. Social Implications of research problem is found out by literature review and discussion with academicians and industrialists.
2. The relationship among social implications is identified.
3. Develop structural self-interaction matrix (SSIM) for identified social implications. Pair wise comparison is shown in the matrix which shows relationship among social implications of leagile manufacturing system.
4. Matrix is verified for transitivity.
5. Develop initial reachability matrix (RM) from the structural self-interaction matrix (SSIM).
6. Reachability matrix (RM) is divided in to different levels.
7. Reachability matrix (RM) is converted into conical form.
8. Directed graph is constructed based on based on relationship as explained in reachability matrix and remove transitive links
9. Digraph is transformed in to TISM model and nodes are replaced with statements..

5.4 Calculations Involved

The Steps, used for TISM model development are as follows

Step 1: Establishment of the contextual connection among social implications

Many Experts, both from industry and academics, have been consulted in finding the contextual relationship among the social implications. The contextual relationship among identified social implications has been done as per expert's opinion. The symbols used to express relationship among barriers are:

- *V* if social implication *i* influence social implication *j*
- *A* if social implication *i gets* influenced by social implication *j*)

- *X* if social implication *i* and *j* both influence each other
- O if social implication *i* and *j* both have no relation between them.

Step 2: Construction of SSIM

Self-interaction matrix (SSIM) is constructed on the basis of pair wise appropriate association between the leagile social implications. Group of experts were consulted to develop SSIM. Table 5.3 shows the SSIM matrix. SSIM matrix shows relationships between the leagile social implications with the help of following symbols:

• Symbol V is used for cell (2, 15) as leagile social implication 2 affects leagile barrier 15

• Symbol A is used for cell (5, 14) as leagile social implication 14 affect leagile barrier 5

• Symbol X is used for cell (11, 16) as leagile social implication 11 and 16 affect each other

• Symbol O is used for cell (4, 15) as leagile social implication number 4 and 15 have no relation between them.

Table 5.3: Development of SSIM (Structural Self-Interaction Matrix)

Social Implications	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2
1	V	V	V	V	V	V	V	V	V	V	V	V	V	V	V
2	V	V	V	V	V	V	V	V	V	V	V	V	V	V	
3	O	V	O	O	V	O	O	O	O	O	V	O	O		
4	V	O	O	O	O	O	O	O	O	O	O	O			
5	V	V	A	A	A	A	A	A	V	A	A				
6	V	V	V	V	V	V	V	V	V	V					
7	V	V	O	A	V	A	O	O	V						
8	V	V	A	A	V	V	A	A							
9	X	V	V	X	X	A	V								
10	A	V	A	A	V	V									

11	X	V	V	V	V
12	V	V	V	V	
13	A	V	V		
14	V	V			
15	V				

Step 3: Development of the initial RM

Initial reachability matrix is developed using SSIM. It can be tested in two steps.

For converting the SSIM in to initial reachability matrix, binary numbers i.e. 0 and 1 are used. It is developed as per the following:

if cell (i, j) have symbol V in SSIM then 1 is assigned to cell (i, j) and cell (j, i) will be assigned 0 in the initial reachability matrix.

• if cell (i, j) have symbol A in SSIM then 0 is assigned to cell (i, j) and cell (j, i) will be assigned 1 in the initial reachability matrix.

• if cell (i, j) have symbol X in SSIM then 1 is assigned to cell (i, j) and cell (j, i) will be assigned 1 in the initial reachability matrix.

• if cell (i, j) have symbol 0 in SSIM then 0 is assigned to cell (i, j) and cell (j, i) will be assigned 0 in the initial reachability matrix.

Table 5.4: Initial Reachability Matrix (RM)

S.No	**Social Implications**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
1	Unemployment	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Initial high investment	2	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	Reduced Labor	3	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0
4	Fear of Technology change	4	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1
5	Improved Customer satisfaction	5	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1	1
6	Better utilization of resources	6	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1
7	Better Product quality	7	0	0	1	1	0	0	1	1	0	0	0	1	0	0	1	1
8	Better Return on Investment	8	0	0	1	1	1	0	0	1	0	0	1	1	0	0	1	1
9	Reduced Manufacturing lead	9	0	0	1	1	1	0	1	1	1	1	0	1	1	1	1	1

	time																
10	Reduced Cost per item	10	0	0	1	1	1	0	1	1	0	1	1	1	0	0	1	0
11	Improved employee morale	11	0	0	1	1	1	0	1	0	1	0	1	1	1	1	1	1
12	Better incentives, recognition and rewards	12	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	1
13	Reduced Scrap	13	0	0	1	1	1	0	1	1	0	1	0	0	1	1	1	0
14	Increased production volume	14	0	1	1	1	1	0	1	1	0	1	0	0	0	0	1	1
15	Increased Market Share	15	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
16	Better supplier relationship	16	0	0	1	0	0	0	0	0	0	1	0	0	1	1	0	1

Step 4: Construction of final RM

Transitivity concept is used in developing final reachability matrix. The purpose of transitivity is to block up the left out gaps, if any while construction of SSIM. This principle implies that if the leagile barrier A is related to B and leagile barrier B is related to C then both A and C are also related. The driving power of leagile barrier is calculate by summation of 1's in the rows and dependence power of each leagile barrier is calculated by summation of 1's in the columns.

Table 5.5: Development of Final Reachability Matrix

S.no	Social Implication		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Driving Power	Rank
1	Unemployment	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	I
2	Initial high investment	2	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15	II
3	Reduced Labor	3	0	0	1	1*	1*	1	1*	1*	1*	1*	1*	1	1*	1*	1	1*	14	III
4	Fear of Technology change	4	0	0	1	1	0	1*	0	0	0	1*	0	1*	1*	0	1*	0	7	VII
5	Improved Customer satisfaction	5	0	0	1	1	1	1*	0	0	0	1*	0	1*	1*	0	1	1	9	V
6	Better utilization of resources	6	0	0	1*	1*	1*	1	1	1	1	1*	1	1	1	1	1	1	14	III

7	Better Product quality	7	0	0	1	1	1*	1*	1	1	0	1*	1*	1	1*	1*	1	1	13	IV
8	Better Return on Investment	8	0	0	1	1	1	1*	1*	1	1*	1*	1	1	1*	1*	1	1	14	III
9	Reduced Manufacturing lead time	9	0	0	1	1	1	1*	1	1	1	1	1*	1	1	1	1	1	14	III
10	Reduced Cost per item	10	0	0	1	1	1	1*	1	1	1*	1	1	1	1*	1*	1	1*	14	III
11	Improved employee morale	11	0	0	1	1	1	1*	1	1*	1	1*	1	1	1	1	1	1	14	III
12	Better incentives, recognition and rewards	12	0	0	1*	1	1	0	1*	1*	0	1*	0	1	1	1	1	1	9	V
13	Reduced Scrap	13	0	0	1	1	1	1*	1	1	0	1	1*	1*	1	1	1	1*	13	IV
14	Increased production volume	14	0	0	1	1	1	1*	1	1	0	1	1*	1*	0	1	1	1	13	IV
15	Increased Market Share	15	0	0	1*	1	0	1*	0	0	0	1*	0	1*	1*	0	1	1	8	VI
16	Better supplier relationship	16	0	0	1	1*	1*	1*	1*	1*	0	1	1*	1*	1	1*	1*	1	13	IV
	Dependence Power		1	1	16	16	14	15	13	13	8	16	12	16	15	13	16	1		
	Rank		VIII	VII	I	I	III	II	IV	IV	VI	I	V	I	II	IV	I	VII		

Step 5: Level partitioning the RM

Farris and Sage (1975), final reachability matrix decides the levels of reachability and antecedent cell. The iteration starts and for those leagile barrier's for which reachability and intersection set are same are assigned first level or top level. After this top level barrier gets eliminated from subsequent iterations or tables. The process of iterations lasts till every barrier is assigned some level. The iterations have been shown in Table 5.6, 5.7, 5.8, 5.9 and 5.10, 5.11

Table 5.6: Iteration 1

Social Implication	**Reachability Set**	**Antecedent Set**	**Intersection Set**	**Level**
1	1,3,4,5,6,7,8,9,10,11,12,13,14,15,16	1	1	

2	2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	4	2	
3	3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	3,4,5,6,7,8,9,10,11,12,13,14,15,16	I
4	3,4,6,10,12,13,15	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	3,4,6,10,12,13,15	I
5	3,4,5,6,10,12,13,15,16	1,2,3,5,6,7,8,9,10,11,12,13,14,16	3,5,6,10,12,13,16	
6	3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,13,14,15,16	3,4,5,6,7,8,9,10,11,13,14,15,16	
7	3,4,5,6,7,8,10,11,12,13,14,15,16	1,2,3,6,7,8,9,10,11,12,13,14,16	3,6,7,8,10,11,12,13,14,16	
8	3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,2,3,6,7,8,9,10,11,12,13,14,16	3,6,7,8,9,10,11,12,13,14,16	
9	3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,2,3,6,8,9,10,11	3,6,8,9,10,11	
10	3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	3,4,5,6,7,8,9,10,11,12,13,14,15,16	I
11	3,4,5,6,7,8,9,10,11,12,13,14,15,16	1,2,3,6,7,8,9,10,11,13,14,16	3,6,7,8,9,10,11,13,14,16	
12	3,4,5,7,8,10,12,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	3,4,5,7,8,10,12,13,14,15,16	I
13	3,4,5,6,7,8,10,11,12,13,14,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,15,16	3,4,5,6,7,8,10,11,12,13,15,16	I
14	3,4,5,6,7,8,10,11,12,14,15,16	1,2,3,6,7,8,9,10,11,12,13,14,16	3,4,6,10,12,13,15,16	
15	3,4,6,10,12,13,15,16	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16	3,4,6,10,12,13,15,16	I
16	3,4,5,6,7,8,10,11,12,13,14,15,16	1,2,3,5,6,7,8,9,10,11,12,13,14,15,16	3,5,6,7,8,10,11,12,13,14,15,16	I

Table 5.7: Iteration 2

Social Implication	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,5,6,7,8,9,11,14	1	1	
2	2,5,6,7,8,9,11,14	2	2	
5	5,6	1,2,5,6,7,8,9,11,14	5,6	

6	5,6,7,8,9,11,14	1,2,5,6,7,8,9,11,14	5,6,7,8,9,11,14	II
7	5,6,7,8,11,14	1,2,6,7,8,9,11,14	6,7,8,11,14	
8	5,6,7,8,9,11,14	1,2,6,7,8,9,11,14	6,7,8,9,11	
9	5,6,7,8,9,11,14	1,2,6,8,9,11	6,8,9,11	
11	5,6,7,8,9,11,14	1,2,6,7,8,9,11,14	6,7,8,9,11,14	
14	5,6,7,8,11,14	1,2,6,7,8,9,11,14	6,7,8,11,14	

Table 5.8: Iteration 3

Social Implication	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,5,7,8,9,11,14	1	1	
2	2,5,7,8,9,11,14	2	2	
5	5	1,2,5,7,8,9,11,14	5	III
7	5,7,8,11,14	1,2,7,8,9,11,14	7,8,11,14	
8	5,7,8,9,11,14	1,2,7,8,9,11,14	7,8,9,11	
9	5,7,8,9,11,14	1,2,8,9,11	8,9,11	
11	5,7,8,9,11,14	1,2,7,8,9,11,14	7,8,9,11,14	
14	5,7,8,11,14	1,2,7,8,9,11,14	7,8,11,14	

Table 5.9: Iteration 4

Social Implication	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,7,8,9,11,14	1	1	
2	2,7,8,9,11,14	2	2	
7	7,8,11,14	1,2,7,8,9,11,14	7,8,11,14	IV

8	7,8,9,11,14	1,2,,7,8,9,11,14	7,8,9,11,14	IV
9	7,8,9,11,14	1,2,8,9,11	8,9,11	
11	7,8,9,11,14	1,2,7,8,9,11,14	7,8,9,11,14	IV
14	7,8,11,14	1,2,7,8,9,11,14	7,8,11,14	IV

Table 5.10: Iteration 5

Social Implication	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,9	1	1	
2	2,9	1	2	
9	9	1,2,9	9	V

Table 5.11: Iteration 6

Social Implication	Reachability Set	Antecedent Set	Intersection Set	Level
1	1	1	1	VI
2	2	1	2	VI

Step 6: Conical matrix

In sixth step, reachability matrix is converted in to conical matrix. Many of the leagile barriers are assigned zero in upper half diagonal leagile social implications are unitary in lower half leagile diagonal. The procedure is based on integrating leagile social implications of same level.

Table 5.12: Conical Matrix

Social Implication	3	4	10	12	13	15	16	6	5	7	8	11	14	9	2	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
4	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
12	1	1	1	1	1	1	1	0	1	1	1	0	1	0	0	0
13	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
15	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
16	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
5	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
7	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
14	1	1	1	1	0	1	1	1	1	1	1	1	1	0	0	0
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

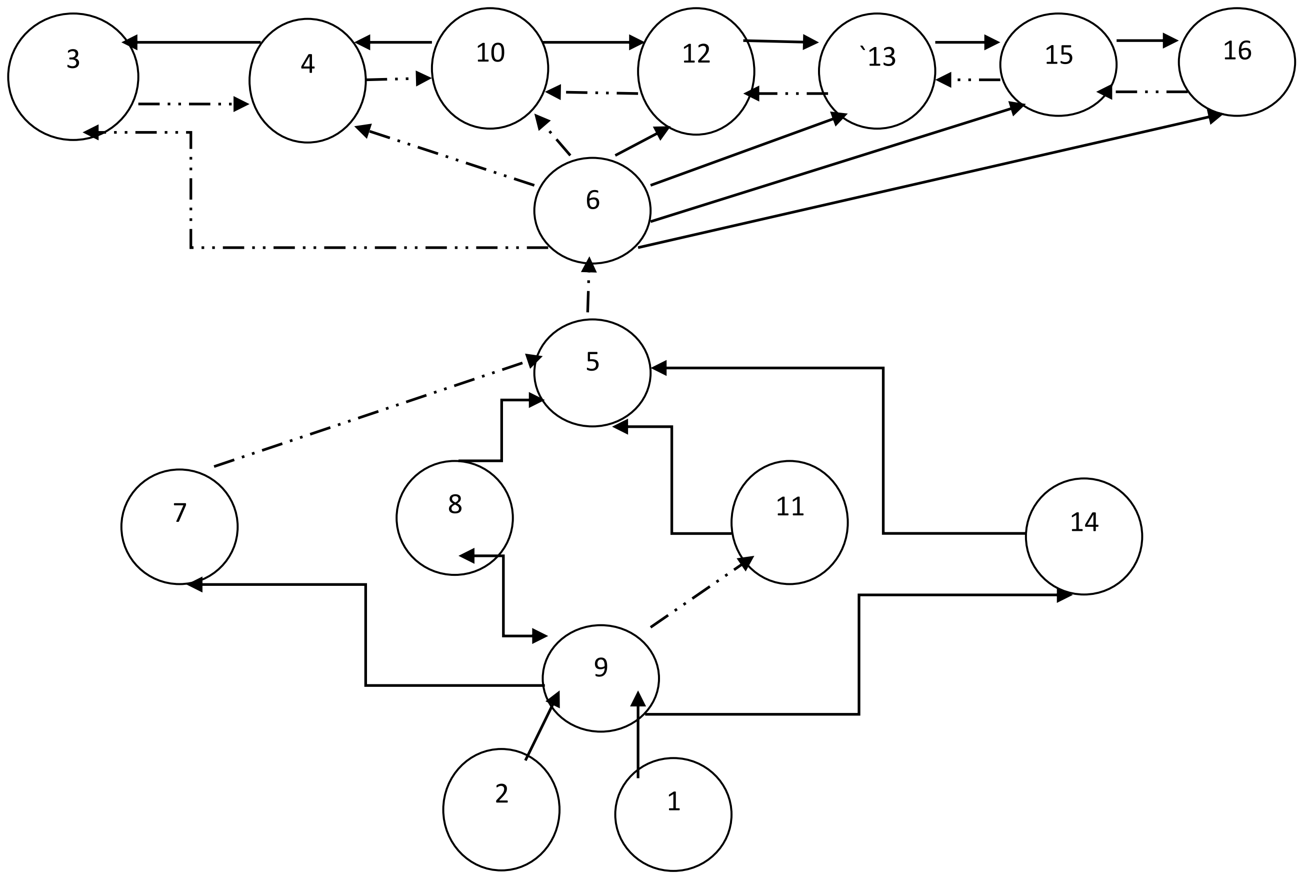


Figure 5.1: Digraph showing the level of social implications with significant transitive links

Step 7: Development of digraph

Digraph is constructed on the basis of levels identified in iterations. A concluding digraph (figure 5.1) is constructed by eliminating the transitive links In the digraph, top leagile social implication is positioned at the top of hierarchy and second level barrier is placed at second level and so on up to last level. Table 5.13 shows arrow type and level of influence.

Step 8 Final TISM Model

TISM model is developed in which all transitive links are also shown by dotted lines. Figure 5.2 shows the TISM model.

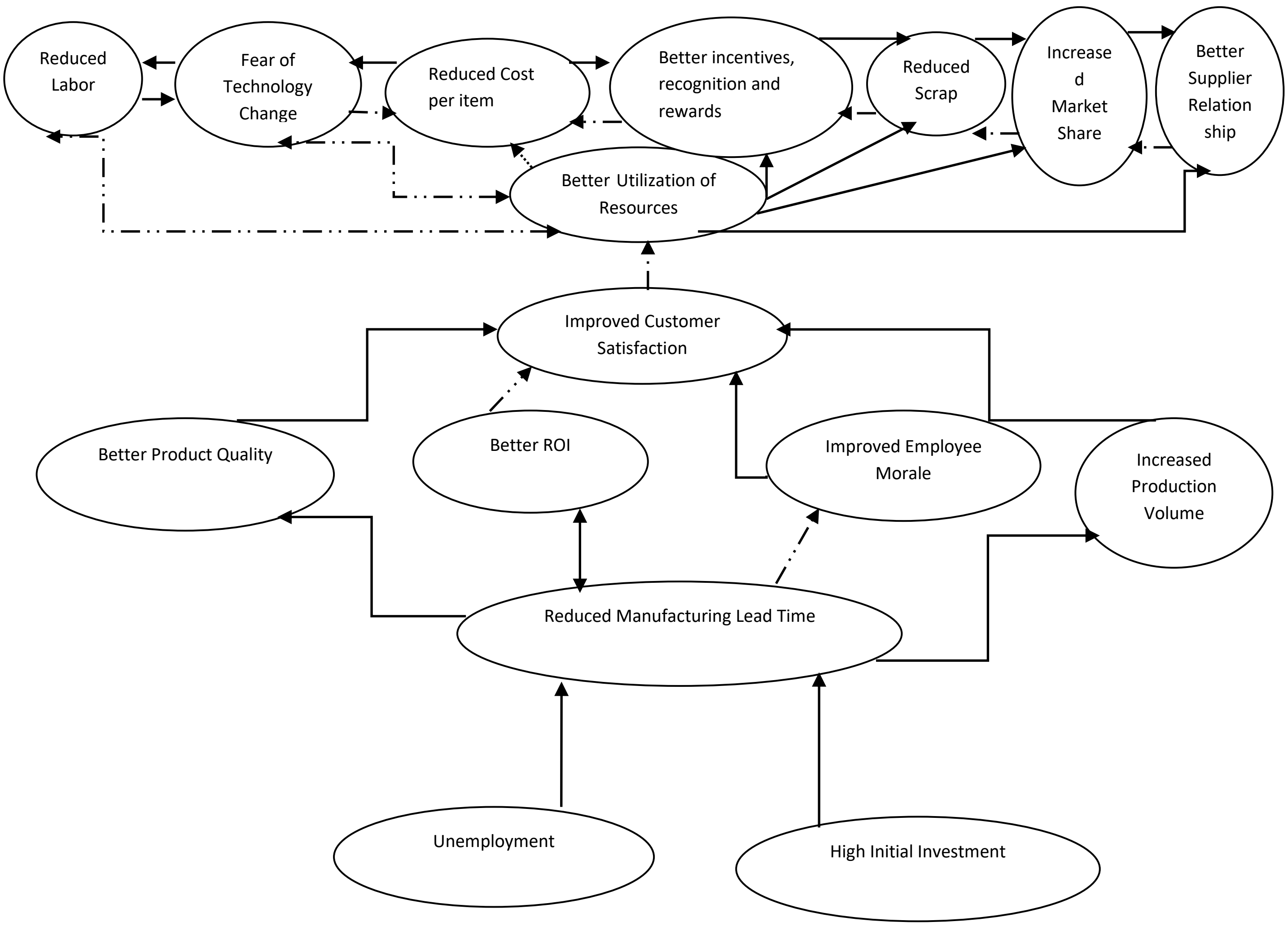


Figure 5.2: TISM Model of social implications

Table 5.13: Arrow type for different level of influence

S.No	Level of Influence	Arrow Type
1	High	——→
2	Low	—··—··→

5.5 MICMAC analysis

The objective of MICMAC investigation is to found out the driving power and dependence power of identified barriers. The social implications are categorized in to four groups on the basis of their driving power and dependence power. The figure 5.3 shows classification of social implications in to different categories.

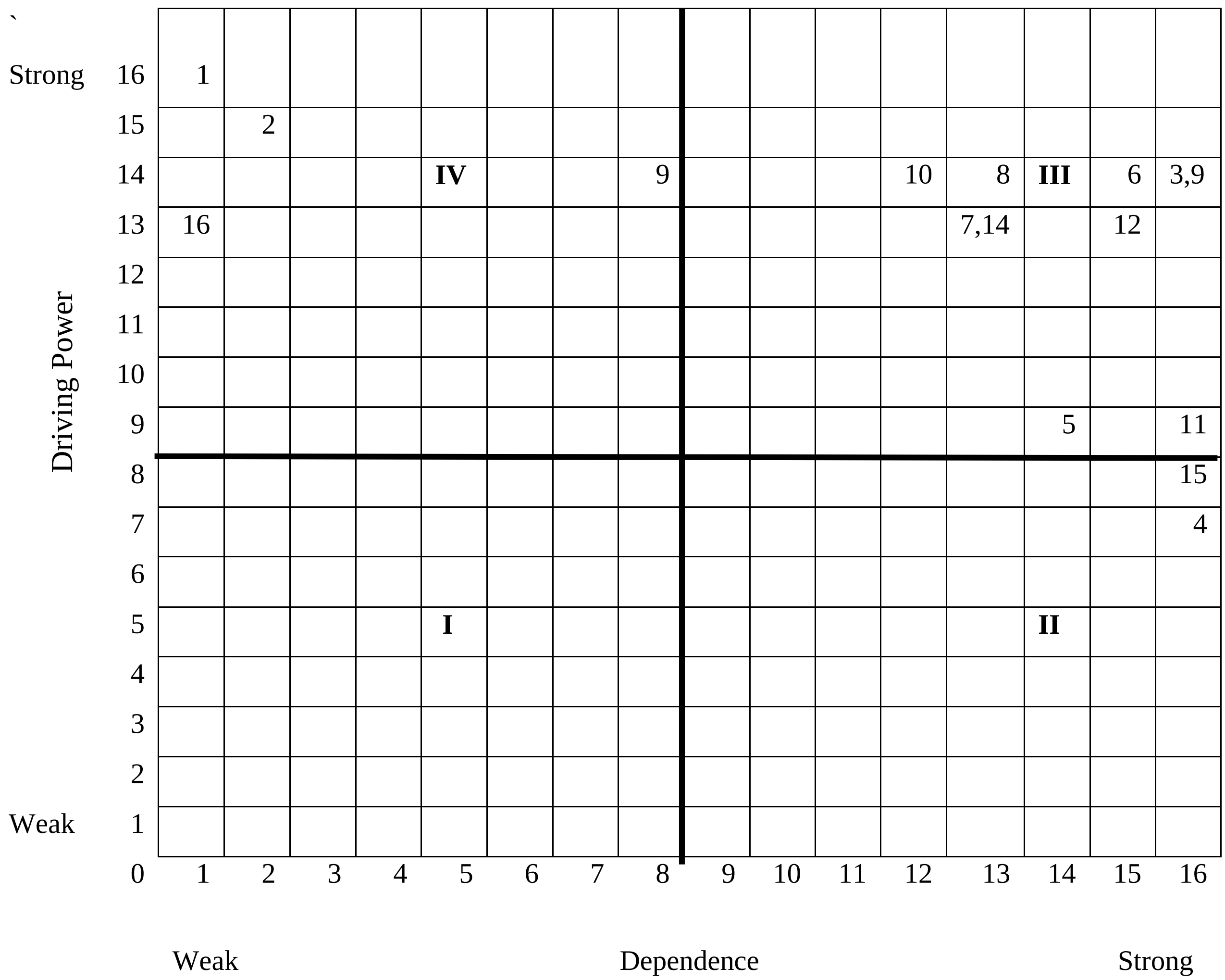


Figure 5.3: MICMAC analysis of social implications of leagile manufacturing

Autonomous social implication: Those social implication who have which less driving power and less dependence power. These barriers are detached and have little connections.

Dependent social implication: The social implication which category have less driving power and high dependence power.

Linkage social implication: The social implication which have high drive power and high dependence power. These barriers are normally uncontrolled. .

Independent social implication: The social implication which have high drive power and less dependence power. The barriers which fall under this category are generally called key barrier.

5.6 Discussion

The objective of carrying out research was to understand the social implications of leagile manufacturing system so that mangers can understand the concept more quickly and leagile system can be implemented in the industry with relative ease. TISM model have been used to understand the relationship and interaction among the identified social implications. The managers may analyze the driving power and dependence power and this may set the guidelines and directions in which they are required to work. Based upon, driving and dependence power, the social implications have been categorized in to different groups as shown in figure

• In autonomous group, there is no social implication. This category contains implications which can be detached from the system. Since there is no social implication falling in this group, so managers are required to focus on all identified social implications. The implications falling under this group have less driving power and less dependence power and have less impact on overall behavior of system.

• The next group have dependent social implications like fear of technology change and increased market share. In this group, identified social implications have less driving power and high dependence power; managers should take appropriate steps and understand it while dealing with these social implications.

• The next is linkage social implications group which have high driving power and high dependence power. Social implications like improved customer satisfaction, better utilization of resources better product quality, better return on investment, reduced manufacturing lead time, reduced cost per item, improved employee morale, better incentives, recognition and rewards, reduced Scrap, increased production volume. The social implications falling under this category have a profound effect on other social implications.

• The social implications for instance, unemployment, high capital investment requirement and improved customer satisfaction and better supplier relationship are independent social implications. These come under pivotal social implications and have high drive power. These are the social implications which require highest attention of the managers.

The work carried out tries to explain the concept of leagile manufacturing system and social implication associated with it. TISM methodology have been used which gives the contextual relationship among the identified social implications. The levels of social implications have been determined. Digraph have been constructed and developed to understand the influence of identified social implications among each other. At the bottom level, unemployment and initial high investment is analyzed. Huge investment is required as for implementing leagile system, the production system must have advance manufacturing facilities like Abrasive Jet Machining (AJM), Ultra Sonic Machining(USM), Robotics, PLC'S, SCADA, Automated Guided Vehicle System (AGVS). These machines are costly and flexible enough to deal the fluctuating demand patterns of the customers; at the same time products manufactured are of high quality and economic in costs. In general, peoples are reluctant to change and want to adhere with their routine schedules; which is one of the barriers of leagile manufacturing implementation. So, adopting leagile manufacturing will result in unemployment; which is another social implication. It will reduce the opportunity for the people and rather it will force the employees to become update and learn new methodologies and techniques. The managers should take initiatives to overcome these type of problems. The managers can organize motivational programs of experts and training programs on techniques like Six sigma, Kaizen, Benchmarking, Rapid prototyping, Robotics and Automation, CNC’s or on any other advance and latest techniques. Similarly, the managers should be able to convince the management to invest in the equipments and machineries and should be able to explain the benefits of implementing leagile manufacturing system in their industries.

CHAPTER 6

ANALYZING CRITICAL SUCCESS FACTORS OF LEAGILE MANUFACTURING SYSTEM

In this chapter, critical success factors of leagile manufacturing system have been identified through literature review and fuzzy DEMATEL technique have been applied to categorize and find the causal relationship among the critical success factors

6.1 Introduction

Leagile manufacturing has emerged out as innovative and marvelous strategy in the last two decades. Lean manufacturing is concerned with reducing all the activities which are considered to be wasteful or do not enhance the value of product, agile system is concerned with how fast firm can be reconfigured in order to meet changing demand patterns of the customers. So both, lean and agile, are combined together to make the system lean as well as agile. Lean focuses on JIT (Just In Time) concept or no inventory concept, but for the system to be agile, it should have certain level of inventories in order to meet fluctuating needs of customers. In leagile system, lean and agile are combined together and separated by de-coupling point. Upstream, demand is relatively stable; lean system is adopted. While downstream, agile system is considered to be more suitable as demand is unpredictable. Critical Success Factors (CSF's) affecting leagile manufacturing has been identified through literature review and with discussion with industrialists and academicians. Fuzzy DEMATEL (Decision Making Trial and Evaluation Laboratory) technique has been used to categorize the CSF into cause and effect categories.

6.2 Critical Success Factors affecting leagile manufacturing system

Critical success factors have been found by literature review and discussion with 80 experts are listed in Table 6.1

Table 6.1: Critical Success Factors (CSF's) affecting leagile manufacturing system

S.No	Critical Success Factors	References
1	Collaborative relationship	Mccullen and Towill (2001), Naylor, Naim and Berry (1999), Ketcehn and Giunipero (2004)
2	Management support towards implementation of policies	Li, Rao, Ragu-Nathan and Ragu-Nathan (2005), Mccullen and
3	Strategic Management	Bortolotti, Boscari and Danese (2015), Chavez et. al. (2015)
4	Training and development programs	Brien and Al-Biqami (1998), Chavez et. al. (2015)
5	Customer and Market sensitiveness	David (2011), Mcculeen and Towill (2001)
6	Design and Engineering	Hofer, Hofer, Eroglu and Waller (2011), Karlsson and Ahlstrom (1996), Liker and Hoseus (2010)
7	Human Resource management(HRM)	Needy, Abdulmalek and Rajgopal (2006), Rother (2009)
8	Virtual Enterprises	Olhager and Prajago (2012), Meredith and Francis (2000)
9	Use of advance manufacturing technologies	Pandey and Garg (2009), Thakkar, Kanda and Deshmukh (2010)
10	Supply chain Management	Piercy and Rich (2015), Dora, Kumar, Gouberen and Molnar
11	Flexible manufacturing system	Chavez et. al. (2015), Wagner, Eggert and Lindermann (2010)
12	Knowledge and IT management	Thawesaengskultha and Tannock (2008), Spear and Bowen (1999)

13	Rapid Reconfiguration	Stratton and Warburton (2003), Hofer, Hofer, Eroglu and Waller (2011), Li, Rao, Ragu-Nathan and
14	Human Resource management	Swafford, Ghosh and Murthy (2008), Vinodh and Aravindraj
15	Benchmarking	Prince and kay (2003), Sharifi, Colquhoun and Barclay (2001)

Table 6.2: Some applications of fuzzy DEMATEL approach

S.NO	Author	Title of the Paper
1	Hsu, Cheng and Tzeng (2007)	Analysis of customer choice
2	Wu and Lee (2007)	Assessment of criteria's for global managers
3	Tseng (2009)	Analysis of beef cattle and interpreting agriculture information
4	Chang and Wang (2009)	Identifying criteria for knowledge management
5	Chou, Sun and Yen (2011)	Assessment of factors of human resource in science and technology
6	Zhou, Huang and Zhang (2011)	Assessment of critical success factors of emergency
7	Wu, Tseng and Vy (2011)	Analysis of drivers affecting green supply chain
8	Gharakhani (2012)	Criteria for Supplier Selection
9	Chang, Chang and Wu (2012)	Assessment of supplier selection criteria
10	Buyukozkan and cifci (2012)	Analysis of Green suppliers

11	Lin (2013)	Understanding the importanceof green supply chain management
12	Abbasi, Hosnavi and Tabrizi (2013)	Assessment of evaluation of risks in knowledge based networks
13	Rahman and Yuan (2013)	Analysis of waste management
14	Kabak (2013)	Analysis of personnel selection problem
15	Danaei , Jabbari and Omidifar (2013)	Measurement of performance and strategic planning
16	Patil and Kant (2014)	Determining the role of knowledge management in supply chain
17	Rouhani, Ashrafi and Afshari(2014)	Assessment of criteria for excellence in
18	Khosravi, Esmaeil, Hoseyn and Marziye (2014)	Analysis of Customer's satisfaction influencing factors
19	Govindan, Khodaverdi and Vafadarnikjoo (2015)	Assessment of green supply chain management
20	Mavi and Shehabi (2015)	Evaluation of criteria for supplier selection
21	Tsai et. al. (2015)	Analysis of performance of printed circuit board industry
22	Mirmousa and Dehnavi (2016)	Analysis of criteria for selecting supplier
23	Kozik (2016)	Evaluation of factors for selection of subcontractors

6.3 Research Methodology

Fuzzy sets were introduced by Lotfi A. Zadeh at University of California in 1965. Many times decision making in industries becomes a tedious task for managers. So it becomes necessary to integrate fuzzy theory with DEMATEL technique to come out for better and consistent solution. Triangular fuzzy number is used Z = (l, m, u), where l, m, u used to denote the lower, medium and upper numbers of fuzzy sets ($x \le y \le z$). The membership function of fuzzy number is written as:

$$\mu = \left\{ \begin{array}{ll} 0, & x<l \\ (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x \ge u \end{array} \right\}$$

Figure 6.1: Fuzzy Membership function (Rao, 2007)

Step 1: Industry Experts and Academicians are consulted to confirm Critical Success factors affecting leagile manufacturing system identified through literature review.

Step 2: Obtain Evaluation of group decision makers: The factor analysis of experts response is done and evaluate them in terms of linguistic variables No, Very Low(VL), Low(L), High(H), Very High(VH).

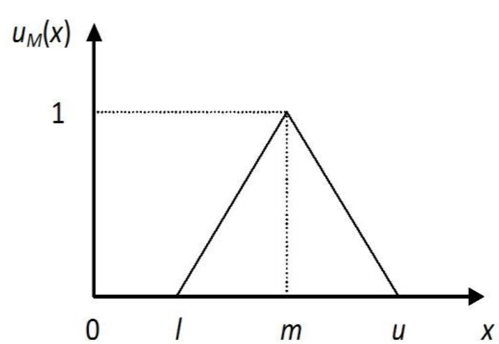


Figure 6.2: Triangular Fuzzy Number

The connection among linguistic terms and triangular fuzzy numbers are given in Table no 6.2.

Table 6.3: Linguistic scale for influence

Linguistic terms	**Linguistic Values**
Very high influence (VH)	(0.75, 1.0, 1.0)
High influence (H)	(0.5, 0.75, 1)
Low influence (L)	(0.25, 0.5, 0.75)
Very low influence (VL)	(0, 0.25, 0.5)
No influence (No)	(0, 0, 0.25)

Step 3: The linguistic terms are converted in to linguistic values and initial direct relation fuzzy matrix is developed.

$$T = \begin{pmatrix} 0 & ..... & .... & ...... & T_{1n} \\ .... & .... & .... & ..... & .... \\ .... & ..... & ..... & ..... & ..... \\ ..... & ..... & ..... & ..... & ..... \\ ..... & ..... & ..... & ..... & ..... \\ T_{n1} & ..... & ..... & ..... & 0 \end{pmatrix} \qquad (1)$$

Where

$$T_{ij} = (l_{ij}, m_{ij}, u_{ij}) \qquad (2)$$

Step 4: Establish Normalized direct relation fuzzy matrix: for this, β triangular fuzzy number is calculated

$$\beta = \max\left(\sum_{1}^{n} u_{ij}\right) \qquad (3)$$

Li**n**ear scale transformation is done to calculate normal direct relation fuzzy matrix (F)

$$F = \begin{pmatrix} F_{11} & F_{12} & .... & ...... & F_{1n} \\ .... & .... & .... & ..... & .... \\ .... & ..... & ..... & ..... & ..... \\ ..... & ..... & ..... & ..... & ..... \\ ..... & ..... & ..... & ..... & ..... \\ F_{n1} & F_{n2} & ..... & ..... & F_{nn} \end{pmatrix} \tag{4}$$

Where $F_{ij} = T_{ij} / \beta$

Step 5: Calculation of Total Relation Fuzzy Matrix

$$E = \begin{pmatrix} e_{11} & e_{12} & .... & ...... & e_{1n} \\ .... & .... & .... & ..... & .... \\ .... & ..... & ..... & ..... & ..... \\ ..... & ..... & ..... & ..... & ..... \\ ..... & ..... & ..... & ..... & ..... \\ e_{n1} & e_{n2} & ..... & ..... & e_{nn} \end{pmatrix} \tag{5}$$

Where $eij = \left(l_{ij}^{''}, m_{ij}^{''}, u_{ij}^{''}\right)$

Matrix

$$\left[l_{ij}^{''}\right] = F_l \ X \left(I - F_l\right)^{-1} \tag{6}$$

Matrix

$$\left[m_{ij}^{''}\right] = F_m \ X \left(I - F_m\right)^{-1} \tag{7}$$

Matrix

$$\left[u_{ij}''\right] = F_u \, X \left(I - F_u\right)^{-1} \tag{8}$$

Step 6: Analysis of structural model

$r_i + c_j$ and $r_i - c_j$ values are calculated. $r_i + c_j$, which represents addition of rows and columns of matrix E and $r_i - c_j$ denote net outcome of factor i.

Step 7: Compute defuzzified $r_i + c_j$ and $r_i - c_j$

In this, $r_i + c_j$ and $r_i - c_j$ are defuzzified to conclude BNP (best non fuzzy performance).

$$BNP = \left(u_{ij} - l_{ij} + m_{ij} - l_{ij}\right)/3 + l_{ij} \tag{9}$$

Step 8: Construct cause and effect diagram

The critical success factors are grouped in cause and effect groups. If r_i-cj is positive, that CSF is placed in cause group and if r_i-c_j is negative, it falls under effect group.

6.4 Calculations Involved

Table 6.4: Linguistic Assessment of Industrial Experts Consensus

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	NO	NO	H	H	NO	NO	H	L	NO	NO	NO	NO	VH	NO	H
2	H	NO	H	L	NO	VH	H	H	H	L	H	H	VL	H	H
3	H	NO	NO	NO	NO	L	NO	L	NO	L	NO	H	H	H	H

4	NO	NO	L	NO	NO	L	H	H	H	H	L	NO	NO	L	H
5	NO	NO	H	L	NO	L	NO	NO	NO	NO	NO	NO	H	NO	NO
6	NO	NO	NO	NO	NO	NO	H	VH	H	NO	NO	NO	H	H	NO
7	NO	NO	NO	NO	NO	H	NO	H	VH	H	VH	NO	H	NO	NO
8	NO	H	NO	NO	H	NO	NO	NO	H	H	H	NO	NO	NO	NO
9	NO	NO	L	L	H	NO	NO	NO	NO	H	H	L	VH	NO	NO
10	NO	NO	NO	H	NO	NO	NO	NO	NO	NO	H	NO	NO	NO	NO
11	L	VH	VH	NO	NO	H	NO	VH	VH	H	NO	NO	H	H	NO
12	NO	NO	H	H	NO	H	H	H	H	H	NO	NO	NO	H	VH
13	NO	NO	NO	NO	NO	H	NO	NO	H	H	NO	H	NO	H	NO
14	NO	NO	H	NO	NO	H	H	H	H	L	NO	H	H	NO	H
15	NO	NO	H	H	NO	H	H	H	L	H	NO	NO	NO	NO	NO

Table 6.5: Initial Direct Relation Fuzzy Matrix

	1	2		14	15
1	(0, 0, 0.25)	(0, 0, 0.25)	……………………	(0, 0, 0.25)	(0.5, 0.75, 1)
2	(0.5, 0.75, 1)	(0, 0, 0.25)	……………………	(0.5, 0.75, 1)	(0.5, 0.75, 1)
3	(0.5, 0.75, 1)	(0, 0, 0.25)	……………………	(0.5, 0.75, 1)	(0.5, 0.75, 1)
4	(0, 0, 0.25)	(0, 0, 0.25)	……………………	(0, 0, 0.25)	(0.5, 0.75, 1)
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
12	(0, 0, 0.25)	(0, 0, 0.25)	……………………	(0.5, 0.75, 1)	(0, 0, 0.25)
13	(0, 0, 0.25)	(0, 0, 0.25)	……………………	(0.5, 0.75, 1)	(0.75, 1, 1)
14	(0, 0, 0.25)	(0, 0, 0.25)	……………………	(0.5, 0.75, 1)	(0, 0, 0.25)
15	(0, 0, 0.25)	(0, 0, 0.25)	……………………..	(0, 0, 0.25)	(0, 0, 0.25)

Table 6.6: Normalized Initial Direct Relation Fuzzy Matrix

	1	2		14	15
1	(0, 0, 0.02)	(0, 0, 0.02)	………	(0, 0, 0.02)	(0.04, 0.07, 0.09)
2	(0.04, 0.07, 0.09)	(0, 0, 0.02)	………	(0.04, 0.07, 0.09)	(0.04, 0.07, 0.09)
3	(0.04, 0.07, 0.09)	(0, 0, 0.02)	………	(0.04, 0.07, 0.09)	(0.04, 0.07, 0.09)
4	(0, 0, 0.02)	(0, 0, 0.02)	………	(0.02, 0.04, 0.07)	(0.04, 0.07, 0.09)
……	………………	………………	………	………………	………………
……	………………	………………	………	………………	………………
……	………………	………………	………	………………	………………
……	………………	………………	………	………………	………………
……	………………	………………	………	………………	………………
……	………………	………………	………	………………	………………
……	………………	………………	………	………………	………………
12	(0, 0, 0.02)	(0, 0, 0.02)	………	(0.04, 0.07, 0.09)	(0, 0, 0.02)
13	(0, 0, 0.02)	(0, 0, 0.02)	………	(0.04, 0.07, 0.09)	(0.07, 0.09, 0.09)
14	(0, 0, 0.02)	(0, 0, 0.02)	………	(0, 0.02, 0.04)	(0.04, 0.07, 0.09)
15	(0, 0, 0.02)	(0, 0, 0.02)	………	(0, 0, 0.02)	(0, 0, 0.02)

Table 6.7: Total Relation Fuzzy Matrix

	1	2		14	15
1	(0, 0.01, 0.11)	(0, 0.01, 0.11)	……………………	(0.01, 0.02, 0.17)	(0.05, 0.08, 0.22)
2	(0.05, 0.08, 0.23)	(0.01, 0.02, 0.16)	……………………	(0.06, 0.11, 0.31)	(0.06, 0.1, 0.29)
3	(0.04, 0.07, 0.19)	(0, 0.01, 0.12)	……………………	(0.05, 0.09, 0.25)	(0.05, 0.09, 0.23)
4	(0, 0.01, 0.13)	(0, 0.01, 0.13)	……………………	(0.03, 0.06, 0.23)	(0.05, 0.08, 0.23)
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
……	………………	………………	……………………	………………	………………
12	(0, 0.01, 0.14)	(0, 0.01, 0.14)	……………………	(0.05, 0.09, 0.27)	(0.07, 0.11, 0.25)
13	(0, 0, 0.11)	(0, 0, 0.1)	……………………	(0.05, 0.08, 0.22)	(0.01, 0.02, 0.14)
14	(0, 0.01, 0.14)	(0, 0.01, 0.13)	……………………	(0.01, 0.03, 0.2)	(0.05, 0.08, 0.25)
15	(0, 0.01, 0.12)	(0, 0.01, 0.12)	…………………… ..	(0.01, 0.02, 0.17)	(0.01, 0.01, 0.16)

Table 6.8: Defuzzified Threshold Values of E Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	0.041	0.149	0.123	0.264	0.041	0.078	0.12	0.114	0.085	0.09	0.063	0.055	0.143	0.065	0.116	1.547

2	0.12	0.221	0.168	0.306	0.064	0.191	0.16	0.187	0.192	0.173	0.155	0.141	0.136	0.159	0.15	2.524
3	0.1	0.162	0.078	0.182	0.045	0.12	0.076	0.124	0.093	0.116	0.064	0.118	0.137	0.129	0.125	1.669
4	0.047	0.174	0.114	0.182	0.051	0.122	0.128	0.149	0.154	0.158	0.113	0.061	0.088	0.107	0.12	1.768
5	0.034	0.12	0.108	0.187	0.032	0.095	0.049	0.059	0.063	0.064	0.045	0.046	0.115	0.055	0.047	1.118
6	0.036	0.143	0.061	0.143	0.044	0.07	0.113	0.141	0.139	0.105	0.063	0.055	0.129	0.115	0.05	1.406
7	0.041	0.156	0.067	0.157	0.046	0.13	0.057	0.133	0.158	0.152	0.139	0.055	0.135	0.067	0.05	1.544
8	0.043	0.22	0.07	0.158	0.099	0.071	0.055	0.07	0.132	0.135	0.12	0.052	0.072	0.061	0.052	1.414
9	0.043	0.152	0.108	0.228	0.098	0.079	0.06	0.076	0.082	0.122	0.118	0.092	0.146	0.07	0.058	1.532
10	0.031	0.115	0.049	0.22	0.029	0.052	0.043	0.055	0.057	0.058	0.101	0.036	0.049	0.046	0.041	0.983
11	0.092	0.256	0.161	0.2	0.056	0.154	0.082	0.172	0.18	0.175	0.084	0.078	0.158	0.145	0.077	2.072
12	0.05	0.184	0.144	0.308	0.055	0.154	0.14	0.161	0.166	0.17	0.085	0.069	0.096	0.137	0.146	2.067
13	0.036	0.137	0.064	0.155	0.04	0.126	0.061	0.072	0.134	0.135	0.058	0.11	0.07	0.118	0.055	1.37
14	0.049	0.179	0.139	0.197	0.054	0.152	0.135	0.155	0.163	0.153	0.079	0.126	0.15	0.081	0.127	1.938
15	0.043	0.158	0.124	0.273	0.046	0.133	0.122	0.14	0.123	0.14	0.072	0.055	0.078	0.067	0.059	1.633
	0.809	2.531	1.579	3.159	0.801	1.725	1.401	1.808	1.923	1.947	1.358	1.15	1.701	1.422	1.272	

Table 6.9: fuzzy values of r_i, c_j, r_i+c_j, r_i-c_j

	r_i	c_j	r_i+c_j	r_i-c_j
1	(0.365,0.683,2.816)	(0.148,0.291,1.987)	(0.513,0.974,4.803)	(-1.622,0.392,2.668)
2	(0.72,1.407,4.437)	(0.163,0.295,1.906)	(0.883,1.702,6.343)	(-5.623,1.112,4.274)
3	(0.4,0.754,3.155)	(0.491,0.915,3.33)	(0.891,1.669,6.485)	(-6.085,-0.161,2.664)
4	(0.424,0.866,3.295)	(0.327,0.658,2.83)	(0.751,1.524,6.125)	(-2.406,0.208,2.968)
5	(0.181,0.377,2.2)	(0.144,0.287,1.97)	(0.325,0.644,4.17)	(-1.789,0.09,2.056)
6	(0.335,0.67,2.629)	(0.537,1.029,3.61)	(0.872,1.699,6.239)	(-3.275,-0.359,2.092)
7	(0.425,0.766,2.815)	(0.409,0.749,3.05)	(0.834,1.515,5.865)	(-2.625,0.017,2.406)
8	(0.312,0.591,2.663)	(0.605, 1.12, 3.7)	(0.917,1.711,6.363)	(-3.388,-0.529,2.058)
9	(0.36,0.644,2.867)	(0.653,1.212,3.904)	(1.013,1.856,6.771)	(-3.544,-0.568,2.214)
10	(0.136,0.269,1.924)	(0.603,1.192,4.045)	(0.739,1.461,5.969)	(-3.909,-0.923,1.321)
11	(0.649,1.185,3.616)	(0.389,0.748,2.936)	(1.038,1.933,6.552)	(-2.287,0.437,3.227)
12	(0.574,1.051,3.648)	(0.285,0.564,2.600)	(0.859,1.615,6.248)	(-2.026,0.487,3.363)
13	(0.306,0.572,2.635)	(0.556,1.036,3.512)	(0.862,1.608,6.147)	(-3.206,-0.464,2.079)
14	(0.516,0.992,3.547)	(0.402,0.776,3.088)	(0.918,1.768,6.635)	(-2.572,0.216,3.145)
15	(0.385,0.709,2.996)	(0.374,0.665,2.775)	(0.759,1.374,5.771)	(-2.611,0.044,2.622)

Table 6.10: Crisp values of ri, cj, ri+cj, ri-cj

S.NO	CSF	ri	Cj	ri+cj	ri-cj	Category
1	Collaborative relationship	1.547	0.809	2.36	0.7379	Cause

2	Management support towards implementation of policies	2.524	2.531	5.06	-0.007	Effect
3	Strategic Management	1.669	1.579	3.25	0.0896	Cause
4	Training and development programs	1.768	3.159	4.93	-1.391	Effect
5	Customer and Market sensitiveness	1.118	0.801	1.92	0.3165	Cause
6	Design and Engineering	1.406	1.725	3.13	-0.319	Effect
7	Human Resource management(HRM)	1.544	1.401	2.94	0.1426	Cause
8	Virtual Enterprises	1.414	1.808	3.22	-0.394	Effect
9	Use of advance manufacturing technologies	1.532	1.923	3.45	-0.391	Effect
10	Supply chain Management	0.983	1.947	2.93	-0.964	Effect
11	Flexible manufacturing system	2.072	1.358	3.43	0.7135	Cause
12	Knowledge and IT management	2.067	1.15	3.22	0.9171	Cause
13	Rapid Reconfiguration	1.37	1.701	3.07	-0.331	Effect
14	Availabilty of funds	1.938	1.422	3.36	0.5165	Cause
15	Benchmarking	1.633	1.272	2.91	0.3614	Cause

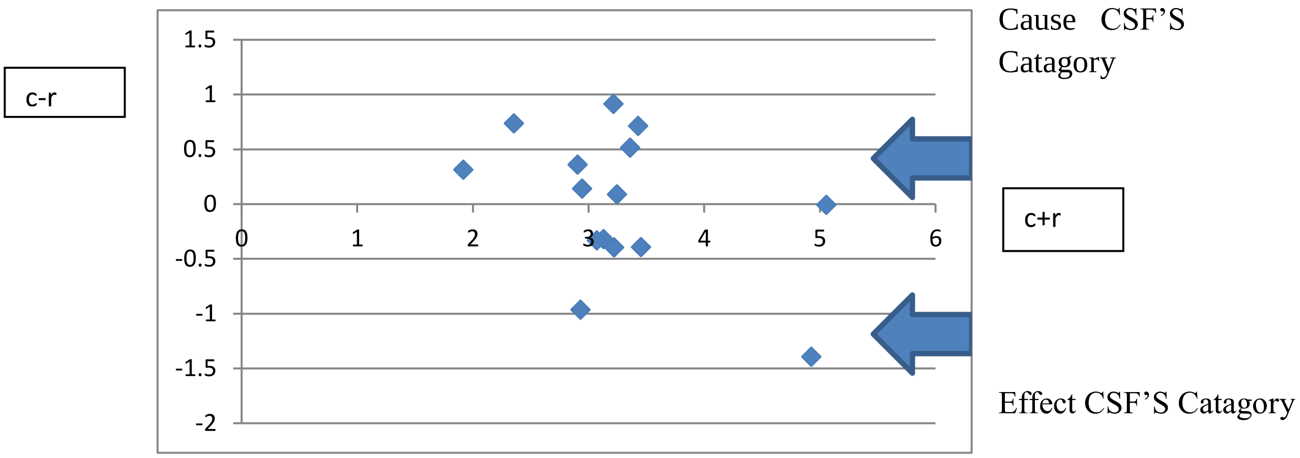


Figure 6.3: Cause Effect Relation Diagram of critical success factos

6.5 Discussions

Fuzzy DEMATEL approach gives effective decision making approach for introducing the leagile strategy in manufacturing organizations. Cutthroat competition in the market has forced the industries to do the things differently. Industries are required to increase their productivity and make optimum use of resources in order to survive in the marketplace. Implementation of leagile manufacturing system will help the industries to reduce the cost and at the same time will help to deliver the product to customer at very fast pace. In this paper, fuzzy DEMATEL technique has been used to categorize the critical success factors in to cause and effect categories. By focusing on cause critical success factors, the effect critical success factors can be implemented with relative ease. Visual cause and effect diagram is drawn in figure 6.3. It has been seen that critical success factors 1 (Collaborative relationship), 3 (Strategic Management), 5 (Customer and Market sensitiveness), 7 (Human resource management), 11 (Flexible Manufacturing System), 12 (knowledge and IT management), 14 (Availability of funds), 15 (Benchmarking) falls under cause group while critical success factors like 2 (Management support towards Implementation of policy), 4 (Training and development programs), 6 (Design and Engineering), 8 (Virtual Enterprises), 9 (Use of advance manufacturing technologies), 10 (Supply chain Management), 13

(Rapid Reconfiguration) falls under effect group. For example, if the management have sufficient availability of funds, then only the management can take decisions to buy new and advanced technologies like AJM (Abrasive Jet Machining), EDM (Electric Discharge Machining), ECM (Electrochemical Machining), Robotics, CNC etc. Fuzzy DEMATEL explains the interrelationship between cause and effect critical success factors. Collaborative relationship will give common platform to industrialists to exchange ideas and information about advance and latest trends of manufacturing techniques and customer demand patterns. Accordingly, the industries can make themselves prepared about having state of art facilities. Collaborative relationship also help in finding better possible solution of any problem faced by industries. Benchmarking helps in improving the productivity greatly. It is concerned with comparing business performance with best similar type of industry. If benchmarking metrics and procedures are successfully implemented then other critical success factors like proper and efficient supply chain management, use of advanced manufacturing facilities, rapid reconfiguration will automatically improved. Also, if customer and market sensitiveness is more then the company will think of having flexible manufacturing system to produce variety of components with in less duration of time. Similarly, if human resources are properly managed and strategic decisions are taken, then supply chain management, can be properly managed and flexible manufacturing system can be implemented. In industries, the employees are normally reluctant to change and adopt new techniques and strategies. So, they are required to be trained and motivated time to time. Although, the training requires some funds but the results of training of employees, workers are remarkable. Also, Training and Motivational programs play a crucial role in enhancing the firm's productivity. The training programs on latest technologies like robotics, CNC's, PLC, SCADA, rapid prototyping and quality techniques like 6 sigma, kaizen, benchmarking, 5S etc. must be held time to time.

CHAPTER 7

KEY PERFORMANCE INDICATORS OF LEAGILE MANUFACTURING SYSTEM

In this chapter, key performance indicators (KPI) of leagile manufacturing system have been identified through literature review. Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) technique have been applied to categorize KPI in to cause and effect categories.

7.1 Introduction: Leagile manufacturing strategy has emerged as one of the important strategy as adopted by manufacturing organizations now a days. It has advantages of both lean as well as agile manufacturing system. Lean manufacturing tries to eliminate all different types of wastages like overproduction, inventory, unnecessary motion etc. , while agile manufacturing focus on changing the production system as per the requirements of the customer and provide customized products within short span of time. Lean manufacturing focuses on no inventory and try to implement JIT (Just In Time) methodology but for the system to be agile, there should be at least some inventory in store so that production can be started as soon as customer order is achieved. Key Performance Indicators (KPI) of leagile manufacturing have been identified through discussion with the experts and Fuzzy TISM approach have been applied to find levels of different KPI. MICMAC analysis is done to found out the driving and dependence power of various KPI's and KPI's are segregated as autonomous, dependent, linkage, independent etc. Finally, digraph is drawn to show relationship between various KPI's.

7.2 Key Performance Indicators affecting leagile manufacturing system

The KPI'S as identified through literature review and shown in Table 7.1

1. **Optimum Inventory Level (OIL):** Lean manufacturing tries to eliminate all different types of wastages like overproduction, unnecessary motion, inventory etc. and focus on JIT (Just In Time) concept, while for system to be agile; there should be some inventory in the system. Leagile system is one which tries to keep the inventories at the optimum level.
2. **Takt Time:** It is the time between customers raising the demand and receiving the goods. For achieving this goal, the industry should be equipped with latest manufacturing facilities like Advanced Manufacturing facilities, CNC's (Computer Numerical Control), Robotics, CAD (Computer Aided Design), Rapid Prototyping, Concurrent Engineering (CE) etc.
3. **Quality of the Product:** Various Researchers like Joseph Juran, Philip Crosby and Garvin etc. defined quality differently. According to Juran, quality is 'fitness for purpose'; whereas Philip defined quality as 'Conformance to requirements'. Garvin (2006), have given eight dimensions of quality; Performance, Features, Reliability, Conformance, Durability, Serviceability, Aesthetics, Perceived quality etc. Quality is the attribute of the product for which customer is willing to pay.
4. **Customer Satisfaction:** Customer Satisfaction directly related to sales. If customer is satisfied with the product then automatically the sales will rise which in turn will increase the profitability of the firm.
5. **Product Variety:** If the company is making product of several varieties, it can fulfill the demands of different customers**.** This will results into better sales and profitability of industry.

Table 7.1: Key Performance Indicators of leagile manufacturing system

S.No	**Key performance indicator**	**References**
1	Optimum Inventory Level	Krishnamurthy and Yauch (2007), Belokar, Kharb and Kumar (2012), Fiaona (2013), Flinchbaugh (1998)

2	Relationship between suppliers/Customers	Naylor, Naim and Berry (1999), Anderson, Fine and Parker (2000), Gunasekaran, Patel and Tirtrioglu (2001)
3	Human Resource Management	Jayaram, Vickery and Droge (2008), Gunasekaran, Patel and Tirtrioglu (2001)
4	Reduction of wastages/Non value added activities	Mccullen and Towill (2001), Eswaramoorthi, Kathiresan, Prasad and Mohanram (2011)
5	Takt Time	Garza-Reyes et. al. (2012), Ghosh (2013)
6	Product Variety	Naylor, Naim and Berry (1999), Hallam and keating (2014)
7	Reconfiguration Capabilities	Iris and Cobeci (2014), Jasti and Kodali (2014)
8	Cost of Production	Shah and Ward(2003), Eroglu and Hoffer (2011)
9	Quality of Products	Agarda and Bassetto (2013), Schmenner and Vastag (2006)
10	Customer Satisfaction	Shah and Ward(2007), Schemenner et. al. (2009)
11	Impact on Environment	Devadasan, Goshteeswaran and Gokulachandran (2005), Borrisova, Fairweather and Goltz (2006)
12	Sales/ Turnover	Mason Jones, Naylor and Towill (2000), Chavez et. al. (2015)

6. Impact on Environment: Today, it is mandatory for all organizations to operate their production system as per the norms laid down by government. The products need to be made eco-friendly which does not harm the environment.

7. Sales/Turnover: Better the quality of the products, better is the customer satisfaction and higher the sales of a product which in turn means higher profitability and growth of firm.

8. Reconfiguration Facilities: These facilities are must in order to produce customized product in a short span of time. Today, the production system is required to be equipped with different kind of flexibilities like product flexibility, production flexibility, volume flexibility, expansion flexibilities etc. (Jain et. al, 2013)

9. Reduction of wastages and non- value added activities: This is the main aim of lean manufacturing. Lean manufacturing tries to eliminate all wastes and all those activities which do not add value to the product.

10. **Relationship with suppliers/ customers:** Suppliers and customer relations plays an important role in improving the production system. Suppliers can provide the solutions to the problems in manufacturing a product and customers also helps in increasing the quality of product by providing proper feedback and the changes required in the product. The customer relations are maintained by providing better after sale services, guarantee etc.

11. **Human Resource Management:** The employees growth is directly associated with the growth of firm. The employees should be well qualified, knowledgable and experienced for better work output. The employees should be empowered at least to some extent so that they can take some decisions on their own. There should be proper incentive and remuneration for the employees. In this pursuit, government has laid down norms also for minimum wages.

12. **Cost of Production:** If the cost of production per item is less, it will affect the sales of the firm. Law of demand in economics also implies that there is inverse relationship between demand of product and price. Higher is the price, lower is the demand and lower is the price, higher is the demand.

7.3 Fuzzy TISM Methodology

The following steps were used in this process:

Step 1: Determining the key performance indicators (KPI's which affect the objective function. Crisp method is used in fuzzy TISM approach and linguistic values are used. The KPI's either impact the others or influenced by others. The varied degree of impact/influence is articulated by means of five linguistic terms {very high, high, low, very low, No}. The linguistic scale used is shown in Table 3

Table 7.2: Linguistic scale for influence

Linguistic Terms	Linguistic Values
Very high influence (VH)	(0.75, 1.0, 1.0)
High influence (H)	(0.5, 0.75, 1)
Low influence (L)	(0.25, 0.5, 0.75)
Very low influence (VL)	(0, 0.25, 0.5)
No influence (No)	(0, 0, 0.25)

Step 2: Gathering response and creating Structural self interaction matrix (SSIM)

The relationship between various KPI's as listed in Table 7.2 is established in discussion with a group of experts. The symbols used to establish relationship includes:

- V : Implies that element i affects j ; the connection can be further represented as V followed by { Very high (VH), High (H), Very low (VL), Low (L)}
- A: : Implies that element j affects i; the connection can be further represented as A followed by { Very high (VH), High (H), Very low (VL), Low (L)}

- X: Implies that both i and j affect each other; the connection can be further represented as A followed by { Very high (VH), High (H), Very low (VL), Low (L)}
- O: Implies that neither i nor j affect each other; the connection can be further represented as O followed by {No}. for example O (No)

Step 3: Computation of Aggregated SSIM and Final Fuzzy Reachability Matrix

For preparing Aggregated SSIM, mode method is used i.e. the max. frequency responses are segregated and selected for further analysis. The linguistic values have been assigned as given in Table 3. The fuzzy reachability matrix is prepared according to following different possible situations.

i. If the entry (i,j) is V(VH) : The entry (i,j) will be allocated (0.75,1.0,1.0) and entry (j,i) will be 0{No} which will be allocated value (0,0,0.25)
ii. If the element (i,j) is V(H) : The entry (i,j) may be allocated value (0.5,0.75,1.0) and entry (j,i) will be 0{No} which will be allocated value (0,0,0.25)
iii. If the element (i, j) is V (L): The element (i, j) can be allocated value (0.25, 0.5, 0.75) and entry (j, i) will be 0{No} which will be allocated value (0, 0, 0.25)
iv. If the entry (i, j) is V (VL): The entry (i, j) can be allocated value (0, 0.25, 0.5) and entry (j, i) will be 0{No} which will be allocated value (0, 0, 0.25)
v. If the entry (i, j) is A (VH): The entry (i, j) will be 0{No} which will be allocated value (0, 0, 0.25) and entry (j, i) will be allocated value (0.75, 1.0, 1.0)
vi. If the entry (i, j) is A (H): The entry (i, j) will be 0{No} which will be allocated value (0, 0, 0.25) and entry (j, i) will be allocated value (0.5, 0.75, 1.0)
vii. If the entry (i, j) is A (L): The entry (i, j) will be 0{No} which will be allocated value (0, 0, 0.25) and entry (j, i) will be allocated by (0.25, 0.5, 0.75)
viii. If the entry (i, j) is A (VL): The entry (i, j) will be 0{No} which will be allocated value (0, 0, 0.25) and entry (j, i) will be allocated value (0, 0.25, 0.5)
ix. If the entry (i, j) is X (VH): The entry (i, j) will be allocated value (0.75, 1.0, 1.0) and entry (j, i) will be allocated value (0.75, 1.0, 1.0)

x. If the entry (i, j) is X (H): The entry (I ,j) will be allocated value (0.5, 0.75, 1.0) and entry (j, i) will be allocated value (0.5, 0.75, 1.0)

xi. If the entry (i, j) is X (L): The entry (i, j) will be allocated value (0.25, 0.5, 0.75) and entry (j, i) will be assigned value (0.25, 0.5, 0.75)

xii. If the entry (i, j) is X(VL): The element (i, j) will be assigned value (0, 0.25, 0.5) and entry (j, i) will be allocated value (0, 0.25, 0.5).

Step 4: In this step, crisp value of each KPI's is calculated according to following procedure:

a. : Calculate $L = (\min\ l_k)\ ; R = \max(u_k)\ ;\ k = 1,2,3..........n$

$and\ \ \Delta = R - L$

$X_{lk} = (l_k - L) / \Delta$

$X_{mk} = (m_k - L) / \Delta$

$X_{uk} = (u_k - L) / \Delta$

(1)

Calculate normalized values of left score (ls) and right score (rs)

$$X_k^{ls} = X_{mk} / (1 + X_{mk} - X_{lk}) \qquad (2)$$

and

$$X_k^{rs} = X_{uk} / (1 + X_{uk} - X_{mk}) \qquad (3)$$

b. : Calculate total normalized crisp value

$$X_k^{crisp} = \left[X_k^{ls} \left(1 - X_k^{ls}\right) + \left(X_k^{rs}\right)^2 \right] / \left(1 - X_k^{ls} + X_k^{rs}\right) \qquad (4)$$

c. : Calculate crisp value

$$B_k^{crisp} = L + \left(X_k^{crisp}\right)\Delta$$

Step 5: Driving and dependence power are calculated by summing rows and columns respectively as shown on Table

Step 6: Iterations are performed based on defuzzified reachability matrix and levels are found out.

Step 7: TISM diagraph is drawn based on linguistic terms.

Step 8: MICMAC analysis is done based on crisp values as found out in Step 4.

7.4 Calculation Involved:

TISM methodology has been used to found out interrelationship between various KPI's and rank them.

Step 1: Determining the key performance indicators (KPI's): A list of KPI's affecting has been found out through literature review as shown in Table 7.1.

Step 2: Experts are asked to assign Linguistic terms in order to found out interrelationship between various KPI's with influence/impact level.

The linguistic values are shown in Table 7.2.The responses collected through experts are shown in Tables 7.3, 7.4, 7.5, 7.6, 7.7

The Aggregated SSIM is given in Table 7.8.

Table 7.3: SSIM of Expert 1

	K12	K11	K10	K9	K8	K7	K6	K5	K4	K3	K2
K1	O	O	O	V(L)	O	O	O	O	O	O	V(L)
K2	O	O	A(VH)	A(H)	A(H)	V(H)	O	O	V(H)	O	
K3	O	A(H)	A(L)	O	O	V(VH)	O	O	V(VH)		
K4	A(L)	O	O	A(VH)	A(H)	V(VH)	O	A(VH)			
K5	O	O	O	O	O	V(L)	O				

K6	O	O	O	A(L)	O	V(H)
K7	A(L)	A(L)	A(L)	A(L)	A(H)	
K8	O	O	O	O		
K9	V(VH)	A(H)	A(L)			
K10	V(L)	O				
K11	V(L)					

Table 7.4 : SSIM of Expert 2

	K12	K11	K10	K9	K8	K7	K6	K5	K4	K3	K2
K1	O	O	O	V(L)	O	O	O	O	O	O	V(H)
K2	O	O	A(VH)	A(L)	A(H)	V(H)	O	O	V(H)	O	
K3	O	A(H)	A(L)	O	O	V(VH)	O	O	V(VH)		
K4	A(L)	O	O	A(H)	A(L)	V(VH)	O	A(L)			
K5	O	O	O	O	O	V(VH)	O				
K6	O	O	O	A(L)	O	V(H)					
K7	A(L)	A(L)	A(L)	A(L)	A(VH)						
K8	O	O	O	O							
K9	V(L)	A(H)	A(L)								
K10	V(H)	O									
K11	V(H)										

Table 7.5 : SSIM of Expert 3

	K12	K11	K10	K9	K8	K7	K6	K5	K4	K3	K2
K1	O	O	O	V(L)	O	O	O	O	O	O	V(L)
K2	O	O	A(VH)	A(L)	A(L)	V(VH)	O	O	V(H)	O	
K3	O	A(L)	A(L)	O	O	V(VH)	O	O	V(VH)		
K4	A(H)	O	O	A(L)	A(VH)	V(L)	O	A(H)			

K5	O	O	O	O	O	V(H)	O				
K6	O	O	O	A(L)	O	V(L)					
K7	A(H)	A(L)	A(H)	A(L)	A(L)						
K8	O	O	O	O							
K9	V(L)	A(H)	A(L)								
K10	V(L)	O									
K11	V(H)										

Table 7.6: SSIM of Expert 4

	K12	K11	K10	K9	K8	K7	K6	K5	K4	K3	K2
K1	O	O	O	V(H)	O	O	O	O	O	O	V(H)
K2	O	O	A(VH)	A(H)	A(VH)	V(L)	O	O	V(L)	O	
K3	O	A(L)	A(L)	O	O	V(H)	O	O	V(VH)		
K4	A(H)	O	O	A(H)	A(H)	V(VH)	O	A(H)			
K5	O	O	O	O	O	V(L)	O				
K6	O	O	O	A(VH)	O	V(L)					
K7	A(H)	A(L)	A(H)	A(H)	A(H)						
K8	O	O	O	O							
K9	V(VH)	A(H)	A(H)								
K10	V(H)	O									
K11	V(H)										

Table 7.7: SSIM of Expert 5

	K12	K11	K10	K9	K8	K7	K6	K5	K4	K3	K2
K1	O	O	O	V(VH)	O	O	O	O	O	O	V(H)
K2	O	O	A(VH)	A(H)	A(H)	V(H)	O	O	V(VH)	O	
K3	O	A(L)	A(L)	O	O	V(H)	O	O	V(VH)		

K4	A(L)	O	O	A(H)	A(H)	V(H)	O	A(H)
K5	O	O	O	O	O	V(L)	O	
K6	O	O	O	A(H)	O	V(L)		
K7	A(L)	A(L)	A(L)	A(VH)	A(H)			
K8	O	O	O	O				
K9	V(VH)	A(H)	A(H)					
K10	V(H)	O						
K11	V(H)							

Step 3: Aggregated SSIM is calculated based on responses collected from experts and is given in Table 7. 8 and fuzzy reachability matrix is prepared.

Table 7.8: Aggregated SSIM

	K12	K11	K10	K9	K8	K7	K6	K5	K4	K3	K2
K1	O	O	O	V(L)	O	O	O	O	O	O	V(H)
K2	O	O	A(VH)	A(H)	A(H)	V(H)	O	O	V(H)	O	
K3	O	A(L)	A(L)	O	O	V(VH)	O	O	V(VH)		
K4	A(L)	O	O	A(H)	A(H)	V(VH)	O	A(H)			
K5	O	O	O	O	O	V(L)	O				
K6	O	O	O	A(L)	O	V(L)					
K7	A(L)	A(L)	A(L)	A(L)	A(H)						
K8	O	O	O	O							
K9	V(VH)	A(H)	A(L)								
K10	V(H)	O									
K11	V(H)										

Table 7.9: Fuzzy reachability matrix based on aggregated fuzzy SSIM with transitive links shown by 1*

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
K1	1	1	0	1*	0	1*	1*	0	1	0	0	1*
K2	0	1	0	1	0	0	1	0	0	0	0	0
K3	0	0	1	1	0	0	1	0	0	0	0	0
K4	0	0	1*	1	0	0	1	0	0	0	0	0
K5	0	0	0	1	1	0	1	0	0	0	0	0
K6	0	0	0	0	0	1	1	0	0	0	0	0
K7	0	0	0	0	0	0	1	0	0	0	0	0
K8	0	1	0	1	0	0	1	1	0	0	0	0
K9	0	1	0	1	0	1	1	0	1	0	0	1
K10	0	1	1	1*	0	0	1	0	1	1	0	1
K11	0	1*	1	1*	0	1*	1	0	1	0	1	1
K12	0	0	0	1	0	0	1	0	0	0	0	1

Step 4: Crisp Value of each KPI's is calculated by equations 1, 2, 3, 4, 5.

Dependence Power for fuzzy value (1, 1, 3.75) of KPI 1

$L = \min(l_k) = 1$, $R = \max(u_k) = 9.75$, $\Delta = 8.75$, $l_1 = 1$, $m_1 = 1$ $u_1 = 3.75$

$X_{lk} = (l_k - L)/\Delta = 0$

$X_{mk} = (m_k - L)/\Delta = 0$

$X_{uk} = (u_k - L)/\Delta = 0.3142$

$X_k^{ls} = X_{mk}/(1 + X_{mk} - X_{lk}) = 0$

and $X_k^{rs} = X_{uk}/(1 + X_{uk} - X_{mk}) = 0.2391$

$X_k^{crisp} = [X_k^{ls}(1 - X_k^{ls}) + (X_k^{rs})^2]/(1 - X_k^{ls} + X_k^{rs}) = 0.04614$

And $B_k^{crisp} = L + (X_k^{crisp})\Delta = 1.40379$

Similarly Driving Power for fuzzy value (1.75, 2.25, 5) of KPI 1

L= min (l_k)= 1.75 , R= max(u_k)= 7 , Δ= 6 , l_1=1.75 , m_1= 2.25 u_1=5

X_{lk} =(l_k-L)/ Δ = 0.125

X_{mk} = (m_k –L) / Δ= 0.0.20833

X_{uk} = (u_k –L)/ Δ =0.66667

$X_k^{ls} = X_{mk}/(1+ X_{mk}-X_{lk})$ = 0.1923

and $X_k^{rs} = X_{uk}/(1+ X_{uk}- X_{mk})$ = 0.4571

$X_k^{crisp} = [X_k^{ls}(1- X_k^{ls)}+ (X_k^{rs})^2]/(1- X_k^{ls}+ X_k^{rs})$ =0.288026

And B_k^{crisp}= L+ (X_k^{crisp})Δ = 2.7282

Step 5: Based on aggregated fuzzy reachability matrix Table 7.9, iterations are done. For the KPI's, whose reachability and antecedent set are same are eliminated from subsequent iterations. The process is continued till all KPI's are assigned some level. The iterations are shown in Tables 7.10, 7.11, 7.12, 7.13, 7.14

Table 7.10: First Iteration

KPI'S	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,4,6,7,9,12	1	1	
2	2,4,7	1,2,8,9,10,11	2	
3	3,4,7	3,4,10,11	3,4	
4	4,7	1,2,3,4,5,8,9,10,11,12	4	
5	4,5,7	5	5	
6	6	1,6,9,12	6	
7	7	1,2,3,4,5,6,7,8,9,10,11,12	7	I
8	2,4,7,8	8	8	
9	2,4,6,7,9,12	1,9,10,11	9	

10	2,3,4,7,9,10,12	10	10	
11	2,3,4,6,7,9,11,12	11	11	
12	4,7,12	1,8,9,10,11,12	12	

Table 7.11: Second Iteration

KPI'S	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,2,4,6,9,12	1	1	
2	2,4	1,2,8,9,10,11	2	
3	3,4	3,4,10,11	3,4	II
4	4	1,2,3,4,5,8,9,10,11,12	4	II
5	4,5	5	5	
6	6	1,6,9,12	6	II
8	2,4,8	8	8	
9	2,4,6,9,12	1,9,10,11	9	
10	2,3,4,9,10,12	10	10	
11	2,3,4,6,9,11,12	11	11	
12	4,12	1,8,9,10,11,12	12	

Table 7.12: Third Iteration

KPI'S	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,9,12	1	1	
2	2	1,2,8,9,10,11	2	III
5	5	5	5	III
8	8	8	8	III
9	9,12	1,9,10,11	9	
10	9,10,12	10	10	
11	9,11,12	11	11	

12	12	1,8,9,10,11,12	12	III

Table 7.13: Fourth Iteration

KPI'S	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,9	1	1	
9	9	1,9,10,11	9	IV
10	9,10	10	10	
11	9,11	11	11	

Table 7.14: Fifth Iteration

KPI'S	Reachability Set	Antecedent Set	Intersection Set	
1	1	1	1	V
10	10	10	10	V
11	11	11	11	V

7.5 MICMAC analysis: The Key performance indicators are categorized in to different categories as shown in figure 7.1

Autonomous KPI's: These are key performance indicators which have low drive power and low dependence power. Quadrant 1 represents autonomous KPI's. The KPI's like optimum inventory level, quality of product, product variety etc. falls under this category.

Dependent KPI'S: These are key performance indicators which have low drive power and high dependence power and are positioned in second quadrant. The KPI's like takt Time, Customer Satisfaction and sales turnover falls under this category.

Linkage KPI’s: In this category, KPI’s have high driving and dependence power and are placed in quadrant III. They are unstable. In the present paper no KPI’s falls under this category.

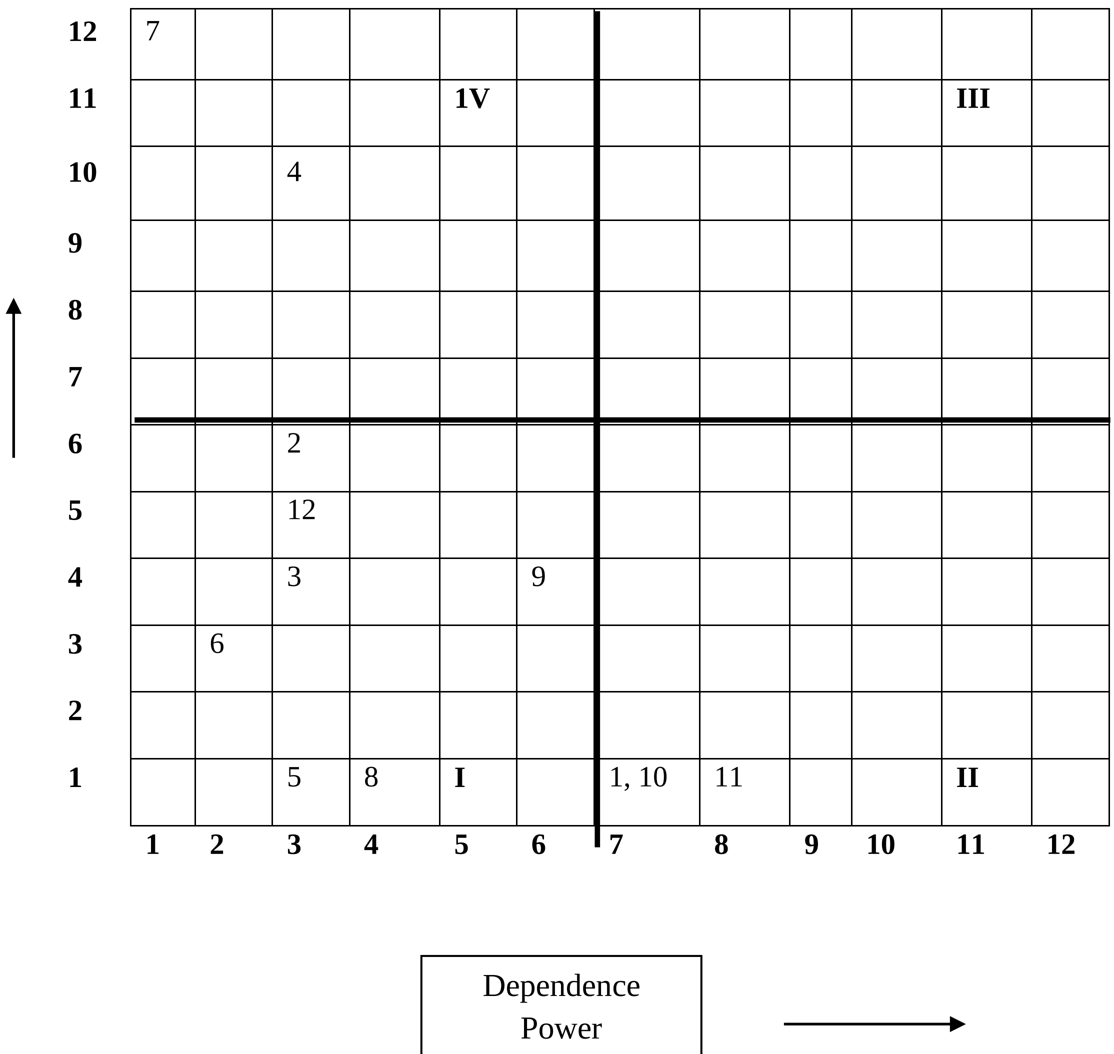


Figure 7.1: Driving and dependence power of KPI’s based on fuzzy reachability matrix

Independent KPI’s: They have high driving power and low dependence power. The KPI’s like reconfiguration capabilities, reduction of wastages and non-value added activities, relationship with suppliers/Customers etc. falls under this category.

7.6 Digraph construction

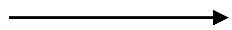
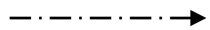
Finally diagraph is prepared showing different levels of KPI's and their interrelationships. Following symbols are used for this purpose. Figure 7.2 shows the final digraph. The significance of various types of arrows used is given in table 7.16

Table 7.15: Fuzzy Reachability Matrix based on fuzzy SSIM matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11	K12
K1		H	NO	NO	NO	NO	NO	NO	L	NO	NO	NO
K2	NO		NO	H	NO	NO	H	NO	NO	NO	NO	NO
K3	NO	NO		VH	NO	NO	VH	NO	NO	NO	NO	NO
K4	NO	NO	NO		NO	NO	VH	NO	NO	NO	NO	NO
K5	NO	NO	NO	H		NO	L	NO	NO	NO	NO	NO
K6	NO	NO	NO	NO	NO		L	NO	NO	NO	NO	NO
K7	NO	NO	NO	NO	NO	NO		NO	NO	NO	NO	NO
K8	NO	H	NO	H	NO	NO	H		NO	NO	NO	NO
K9	NO	H	NO	H	NO	L	L	NO		NO	NO	VH
K10	NO	VH	L	NO	NO	NO	L	NO	L		NO	H
K11	NO	NO	L	NO	NO	NO	L	NO	H	NO		H
K12	NO	NO	NO	L	NO	NO	L	NO	NO	NO	NO	

7.7 Discussion: The levels of different KPI's are shown in figure 7.2. Optimum inventory level will reduce the wastages; the same is the aim of lean manufacturing. Lean Manufacturing tries to eliminate all different types of wastages like overproduction, inventory, unnecessary motion, transportation etc. If the relations with the suppliers/vendors are good, they can provide the solution to the manufacturing defects or problems faced in manufacturing a product. Customers also help in improving the quality of the product by providing proper feedback to the producers. Human Resource Management impact level is high in reducing the wastages and non-value added activities because skills and expertise of the professionals can help in better layout of the production process and better design and production.

Table 7.16: Arrow type for different level of influence

S.No	Level of Influence	Arrow Type
1	Very High	
2	High	
3	Low	

There should be rewards and recognition system, proper incentives and remuneration, empowerment to the employees, adequate facilities, healthy work environment etc. for the staff. Otherwise the persons will try to look for better options and will change the job. Also, there should be training programmes on latest manufacturing and quality techniques like robotics, rapid prototyping, CNC (Computer Numerical Control), CAD software’s (Computer Aided Design), Kaizen, Just In Time, Poka yoke, Enterprise Resource Planning (ERP), Flexible Manufacturing System (FMS) etc.

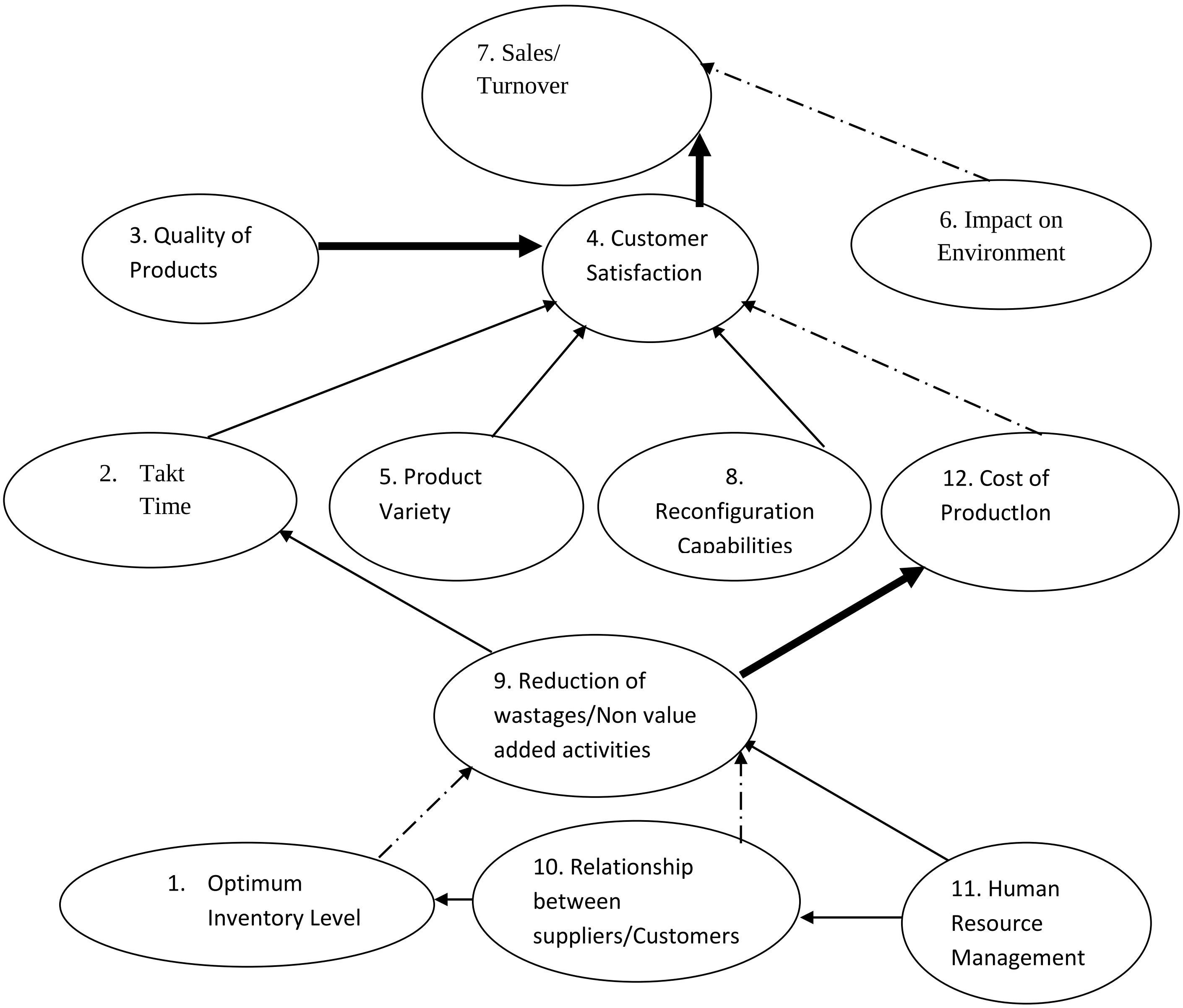


Figure 7.2: Digraph showing levels of KPI's and their interrelationships

Reduction of wastages and non-value added activities impact very high on cost of production because if the wastages and non-value added activities are eliminated, it will directly reduce the material, labor, space, time etc. and automatically cost of production will reduce. Product variety, Reconfiguration capabilities, takt time have a high impact on customer satisfaction while cost of production have low impact on customer satisfaction. Today, the market is excessively competitive and customers have lots of option with them, so they do not want to wait while purchasing the product. If the firm is equipped with advanced and latest manufacturing capabilities like AGVS (Automated Guided Vehicle System), Automation capabilities like Robotics, Programmable Logic Controller (PLC's), then time required to produce the product is less, and the customer gets product within short duration of time and he will be satisfied. Similarly, product varieties also results in increased satisfaction of the customers. Quality of products has very high impact on customer satisfaction. If quality of products is good, then customers will like the product and will result in increased customer satisfaction. The aim of every organization is to earn more and more profits. If the customers are satisfied, it will results in increase in sales of the product, and ultimately increase in profitability of the firm. Once the reputation of firm is established in eyes of the customers, customers will have a blind faith on industry. Impact on environment has low impact on sales. Also, if impact on environment is less, government approve the production of that particular industry and it will not have any obstacles or hindrance in manufacturing the product and will result in increase in sales.

CHAPTER-8

RANKING OF CRITICAL SUCCESS FACTORS OF LEAGILE MANUFACTURING SYSTEM

In this chapter, Critical Success Factors (CSF's) of leagile manufacturing system have been identified through literature review. The ranking of these CSF's have been found out by using Modified Technique of Order Preference by Similarity to Ideal Solution Technique (TOPSIS.)

8.1 Introduction and Literature review

Leagile is combination of both lean and agile system. Lean is concerned with less of everything i.e. less material, less time, less space, less manpower to produce a product, while agile is concerned with quick respond to customer demand and to reconfigure the system as soon as possible to meet the customer expectations well on time. The market is excessively competitive, so there is a dire need for the companies to adopt new and modern technologies with latest equipments. It has been seen that implementation of leagile system become tedious so the purpose of the paper is to find Critical Success Factors (CSF) affecting leagile manufacturing system using literature review and rank them by using Modified Technique of Order Preference by Similarity to Ideal Solution Technique (TOPSIS).

Leagile manufacturing system is found to have many advantages in the manufacturing system. Various researchers have described the leagile model. Naylor, Naim and Berry (1999), proposed a leagile model where lean and agile system operates by positioning de-coupling point at different points in a manufacturing supply chain. The de-coupling point separates lean and agile system; upstream lean system is followed while downstream agile system is adopted. Prince and kay and Kay (2003), have also developed similar model of importance of de-coupling which is applicable to single manufacturing plant. Stratton and Warburton (2003), also discussed the importance of de-coupling point. Bunce and Gould (1996), pointed out that lean and agile paradigm has become the necessity for the success of any supply chain in twenty first century. Therefore, integration of both the strategies led to the development of the leagile principles. Mason-Jones, Naylor and Towill (2003), was the first one to introduce the concept of leagility. Leagile system helps in reducing the excess inventories and losses that can be there when the demand changes.

In recent years there is a drastic change in the competition. To tackle with competitive in the market, companies are required to use advanced manufacturing technologies and smart strategies such as Computer Integrated Manufacturing (CIM), flexible manufacturing system, poka yoke, TQM (Total Quality Management), Just In Time, Quality Management System, Rapid Manufacturing, Rapid Prototyping (RP), six sigma, Lean Manufacturing (LM), Agile Manufacturing (AM), Business Process Reengineering (BPR) and business excellence models, which have claimed to support organization's improvement. Karlsson and Ahlstrom (1996), developed an operational model which can be used to assess changes required to introduce lean manufacturing and also explains some guidelines about applicability of lean practices in industry..

8.2 Identification of Critical Success Factors (CSF's) Affecting Leagile Manufacturing System

Various factors affecting leagile manufacturing system have been identified through literature review. These are listed in Table 8.1

Table 8.1: CSF Affecting Leagile Manufacturing System

S.No	Critical Success Factors	References
1	Collaborative relationship	Mccullen and Towill (2001), Naylor, Naim and Berry (1999), Ketcehn and Giunipero (2004)
2	Management support towards implementation of policies	Li, Rao, Ragu-Nathan and Ragu-Nathan (2005), Mccullen and Towill (2001),
3	Strategic Management	Bortolotti, Boscari and Danese (2015), Chavez et. al. (2015)

4	Training and development programs	Brien and Al-Biqami (1998), Chavez et. al. (2015)
5	Customer and Market sensitiveness	David (2011), Mcculeen and Towill (2001), Lee (1999)
6	Design and Engineering	Hofer, Hofer, Eroglu and Waller (2011), Karlsson and Ahlstrom (1996), Liker and Hoseus (2010)
7	Human Resource management	Needy, Abdulmalek and Rajgopal (2006), Rother (2009)
8	Virtual Enterprises	Olhager and Prajago (2012), Meredith and Francis (2000)
9	Use of advance manufacturing	Pandey and Garg (2009), Thakkar, Kanda and Deshmukh (2010)
10	Supply chain Management	Piercy and Rich (2015), Dora, Kumar, Gouberen and Molnar (2013)
11	Flexible manufacturing system	Chavez et. al. (2015), Wagner, Eggert and Lindermann (2010)
12	Knowledge and IT management	Thawesaengskultha and Tannock (2008), Spear (1999)
13	Rapid Reconfiguration	Stratton and Warburton (2003), Hofer, Hofer, Eroglu and Waller (2011), Li,
14	Human Resource management	Swafford, Ghosh and Murthy (2008), Vinodh and Aravindraj (2012)
15	Benchmarking	Prince and kay (2003), Sharifi, Colquhoun and Barclay (2001)

Table 8.2: Some applications of Modified TOPSIS

S.NO	Author's	Applications
1	Deng, Yeh and Wills (2000)	Choice location of New hospitals in china by direct foreign investment

2	Jahanshahloo, Lotfi and Izadikah (2006)	Measurement of Performance model of aviation industries in Turkey
3	Shyur (2006)	Analysis of product design according to customer preference
4	Dagdeviren, Yavuz and Kilmc et.al. (2007)	Analysis of selection criteria for weapon
5	Wang and Chang(2007)	Aircraft training
6	Gumus(2009)	Analysis of transportation of wastes in industries
7	Chamodrakas, Alexopoulou and Martakos (2009)	Customers analysis for acceptance of order
8	Azzam and Mousa (2010)	Analysis of compensation for reactive power
9	Awasthi, Chauhan, Omrani and Panahi (2011)	Analysis of system of sustainable transportation
10	Aydogan (2011)	Analysis of performance indicators for aviation companies
11	Chamodrakas , Leftheriotis and Martakos (2011)	Analysis for ranking of alternatives
12	Li, Liu and Chen (2011)	Analysis for selection of logistics centre
13	Tavana and Hatami- Marbini (2011)	Analysis of simulators for investigation of mars

Table 8.3: Conversion of Linguistic Terms into Fuzzy Scores (11 Point Scale)

Linguistic Term	Fuzzy Number	**Crisp No.**
Exceptionally Low	M1	0.045
Extremely low	M2	0.135
Very low	M3	0.255
Low	M4	0.335
Below average	M5	0.410
Average	M6	0.500
Above average	M7	0.59
High	M8	0.665
Very High	M9	0.745
Extremely high	M10	0.865
Exceptionally high	M11	0.955

8.3 Modified TOPSIS technique

Step 1: Objective is determined in first step

Step 2: In this step, each row was assigned to one factor and each column carries assigned value from industrial experts. In the case of a subjective problem, an 11-point scale was used for assigning crisp score

Step 3: Positive ideal solution (best) and negative ideal solution (worst) is obtained in this step. The ideal (best) and negative ideal (worst) solutions can be given as:

$$R^{+} = \left\{ \left(\sum_{1}^{Max} R_{ij} \,/\, j \in J \right), \left(\left(\sum_{1}^{Min} R_{ij} \,/\, j \in J' \right) / \, i = 1,2..N \right) \right\} \qquad (1)$$

$$= \left\{ R_1^{+}, R_2^{+}, R_3^{+} .... R_M^{+} \right\}$$

$$R^{-} = \left\{ \left(\sum_{1}^{Max} R_{ij} \,/\, j \in J \right), \left(\left(\sum_{1}^{Min} R_{ij} \,/\, j \in J' \right) / \, i = 1,2..N \right) \right\} \qquad (2)$$

$$= \left\{ R_1^-, R_2^-, R_3^- ....R_M^- \right\}$$

Step 4: In this step, Relative importance is decided in context with objective.

This can be represented as

$$GM_j = \left(\sum_i^M b_{ij} \right)^{1/m} \quad (3)$$

And $$W_J = GM_j / \sum_{j=0}^{M} GM_j$$

Step 5: Weighted Euclidean distances are calculated in this step and can be expressed as:

$$D_i^+ = \left\{ \sum_{j=1}^{M} W_j \left(R_{ij} - R_j^+ \right)^2 \right\}^{1/2} \; where \; i = 1, 2, 3, ...N \quad (4)$$

$$D_i^- = \left\{ \sum_{j=1}^{M} W_j \left(R_{ij} - R_j^- \right)^2 \right\}^{1/2} \; where \; i = 1, 2, 3, ...N \quad (5)$$

Step 6: The relative closeness of a specific attribute , *Pi*–mod is calculated and can be expressed as

$$P_{i\,\text{mod}} = D_i^- / \left(D_i^+ + D_i^- \right) \quad (6)$$

Step 7: The different attributes are arranged in descending order as per the value of *Pi*–mod calculated in step (6), indicating the most significant and least significant attribute influencing the particular objective.

8.4 Calculations involved

Step 1: Table 8.4 shows fuzzy or crisp values of the factors affecting leagile manufacturing system taken from Table 8.3 and are given by experts.

Table 8.4: Fuzzy or crisp value of factors

	Experts														
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**	**E12**	**E13**	**E14**	**E15**
CSF	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
F1	0.41	0.41	0.865	0.335	0.335	0.255	0.335	0.665	0.59	0.255	0.5	0.59	0.5	0.41	0.59
F2	0.865	0.665	0.59	0.5	0.5	0.59	0.5	0.745	0.335	0.865	0.59	0.41	0.5	0.59	0.41
F3	0.745	0.59	0.5	0.5	0.59	0.59	0.5	0.5	0.41	0.745	0.41	0.5	0.41	0.41	0.5
F4	0.135	0.665	0.5	0.335	0.41	0.5	0.41	0.5	0.5	0.5	0.59	0.5	0.59	0.5	0.5
F5	0.41	0.5	0.665	0.41	0.5	0.59	0.5	0.665	0.59	0.59	0.5	0.59	0.335	0.5	0.255
F6	0.335	0.335	0.41	0.5	0.5	0.41	0.745	0.59	0.59	0.59	0.5	0.59	0.745	0.665	0.59
F7	0.335	0.255	0.335	0.5	0.5	0.335	0.59	0.59	0.41	0.41	0.5	0.255	0.335	0.335	0.5
F8	0.41	0.335	0.665	0.665	0.5	0.865	0.665	0.41	0.745	0.59	0.41	0.41	0.41	0.59	0.59
F9	0.665	0.135	0.59	0.255	0.5	0.59	0.5	0.5	0.865	0.5	0.59	0.255	0.59	0.41	0.135
F10	0.5	0.5	0.5	0.5	0.335	0.5	0.59	0.255	0.5	0.5	0.745	0.335	0.59	0.5	0.255
F11	0.5	0.5	0.255	0.59	0.135	0.5	0.665	0.41	0.59	0.335	0.665	0.745	0.745	0.135	0.41
F12	0.5	0.59	0.665	0.59	0.255	0.665	0.745	0.41	0.59	0.255	0.255	0.5	0.335	0.5	0.59
F13	0.59	0.665	0.665	0.255	0.5	0.5	0.59	0.5	0.41	0.665	0.5	0.5	0.255	0.5	0.5
F14	0.335	0.59	0.5	0.5	0.335	0.5	0.5	0.59	0.335	0.745	0.5	0.255	0.5	0.255	0.5
F15	0.5	0.59	0.59	0.335	0.41	0.255	0.59	0.335	0.335	0.255	0.41	0.5	0.5	0.5	0.41

Step 2: Normalized Decision matrix is calculated by equation (5) and is shown in Table 8.5

$$N_{ij} = m_{ij} / \left(\sum_{j=1}^{m} m_{ij}^{2} \right)^{1/2} \tag{7}$$

Table 8.5: Normalized Matrix

	Experts														
	E1	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**	**E9**	**E10**	**E11**	**E12**	**E13**	**E14**	**E15**
CSF	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
F1	0.206	0.206	0.390	0.185	0.198	0.123	0.151	0.325	0.281	0.119	0.246	0.315	0.253	0.224	0.325
F2	0.435	0.334	0.266	0.276	0.296	0.286	0.225	0.365	0.16	0.404	0.291	0.219	0.253	0.322	0.225
F3	.374	0.297	0.225	0.276	0.349	0.286	0.225	0.245	0.195	0.348	0.202	0.267	0.207	0.224	0.275
F4	0.067	0.334	0.225	0.185	0.242	0.242	0.184	0.245	0.238	0.233	0.291	0.267	0.299	0.273	0.275
F5	0.206	0.251	0.300	0.226	0.296	0.286	0.225	0.325	0.281	0.276	0.246	0.315	0.169	0.273	0.140
F6	0.168	0.168	0.185	0.276	0.296	0.199	0.336	0.289	0.281	0.276	0.246	0.315	0.377	0.364	0.325
F7	0.168	0.128	0.151	0.276	0.296	0.162	0.266	0.289	0.195	0.191	0.246	0.136	0.169	0.183	0.275
F8	0.206	0.168	0.300	0.367	0.296	0.419	0.299	0.200	0.355	0.276	0.202	0.219	0.207	0.322	0.325
F9	0.334	0.068	0.266	0.140	0.296	0.286	0.225	0.245	0.413	0.233	0.291	0.136	0.299	0.224	0.074
F10	0.251	0.251	0.225	0.276	0.198	0.242	0.266	0.124	0.238	0.233	0.367	0.179	0.299	0.273	0.140
F11	0.251	0.251	0.115	0.326	0.079	0.242	0.299	0.200	0.281	0.156	0.328	0.398	0.377	0.073	0.225
F12	0.251	0.297	0.300	0.326	0.150	0.322	0.336	0.200	0.281	0.119	0.125	0.267	0.169	0.273	0.325
F13	0.296	0.334	0.300	0.140	0.296	0.242	0.266	0.245	0.195	0.311	0.246	0.267	0.129	0.273	0.275
F14	0.168	0.297	0.225	0.276	0.198	0.242	0.225	0.289	0.16	0.348	0.246	0.136	0.253	0.139	0.275
F15	0.251	0.297	0.266	0.185	0.242	0.123	0.266	0.164	0.16	0.119	0.202	0.267	0.253	0.273	0.225

Step 3: Table 8.6 shows positive ideal solution (PIS) which is calculated by equation (1) and Negative Ideal Solution (NIS) which is calculated by equation (2)

Table 8.6: Positive Ideal Solutions (*R*+) and Negative Ideal Solutions (*R*−)

Factors	1	2	3	4	5	6	7
(R^+)	0.4351	0.3348	0.3905	0.3676	0.3492	0.4199	0.336
(R^-)	0.0679	0.068	0.1151	0.1409	0.0799	0.1238	0.1511

Factors	8	9	10	3	12	13	14	15
(R^+)	0.365	0.4131	0.4046	0.3674	0.3986	0.3776	0.364	0.325
(R^-)	0.1249	0.16	0.1193	0.1258	0.1364	0.1293	0.0739	0.0744

Step 4: Weights of different factors are taken by AHP methodology and the weights as given in Table 8.7

Table 8.7: Weights of different critical success factors

Factors	**Weights**
W_1	0.086
W_2	0.085
W_3	0.078
W_4	0.136
W_5	0.067
W_6	0.121
W_7	0.096
W_8	0.035
W_9	0.095
W_{10}	0.053
W_{11}	0.019
W_{12}	0.037
W_{13}	0.030
W_{14}	0.027
W_{15}	0.035

Step 5: Table 8.8 shows weighted Euclidian distances which is calculated by equation (4) and equation (5)

Table 8.8: Weighted Euclidian distance

Factors	1	2	3	4	5	6	7
(D^+)	0.1826	0.1187	0.1216	0.1765	0.1332	0.1490	0.1901
(D^-)	0.1340	0.1970	0.1759	0.1310	0.1480	0.1521	0.1084

Factors	8	9	10	3	12	13	14	15
(D^+)	0.1120	0.1619	0.1495	0.1640	0.1334	0.1491	0.1648	0.1859
(D^-)	0.1939	0.1550	0.1330	0.1480	0.1693	0.1591	0.1340	0.1248

Step 6: Relative closeness of each factor is calculated by equation (6) and is shown in table 8.9

Table 8.9: Relative closeness of particular factor to ideal solution ($P_{i\text{-mod}}$)

Factors	1	2	3	4	5	6	7
$(P_{i\text{-mod}})$	0.4231	0.6240	0.5912	0.4260	0.5262	0.5050	0.3631

Factors	8	9	10	11	12	13	14	15
$(P_{i\text{-mod}})$	0.6338	0.4890	0.4708	0.4744	0.5592	0.5161	0.4484	0.4017

Step 7: The alternatives are arranged in descending order of their relative closeness:

8-2-3-12-5-13-6-9-11-10-14-4-1-15-7

Step 8: The ranking of CSF affecting leagile manufacturing system are given in Table 8.10:

Table 8.10: Ranking of critical success factors

Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Ranking	8	2	3	12	5	13	6	9	11	10	14	4	1	15	7

8.5 Discussion

The objective of research was to rank critical success factors so that leagile manufacturing system can be successfully implemented in industries. The factors have been found out by literature review discussion with academicians and industrialists and ranking of factors have been done by Modified TOPSIS technique. It has been seen that use of advance manufacturing technology is the top most factor, it produces the better quality products, wastages are minimum and the customized products can be produced on time. The second factor is management support towards implementation of policies; the management should support their employees in implementing leagile system. The employees, especially managers, should be empowered at least to some extent so that they can take decision on their own. The third critical success factor is strategic management. The manager should plan proper strategies to deal with the customers in market as well as should look properly in to the production system. He should take quick actions for the problems encountered while implementing leagile system. Similarly, the fourth critical success factor is training and development programs. The training and development programs on various topics like six sigma, kaizen, poka yoke, rapid reconfiguration, advance manufacturing technologies, CNC, robotics etc. should be organized time to time so that the employees should be well acquainted with the latest technologies and quality tools and techniques to make the system leagile.

CHAPTER-9

QUANTIFICATION OF KEY FACTORS AFFECTING LEAGILE MANUFACTURING SYSTEM

In this chapter, key factors of leagile manufacturing system have been found though literature review. Graph theroretic and matrix approach have been applied to calculate leagility index. The leagility index can be used used to compare the performance of industries in contaxt of leagile environment.

9.1 Introduction:

In today's market, companies are striving hard to survive due to the fierce competition and globalization. They are required to do the things differently to stay ahead of their competitors. In earlier days, there were few sellers and limited numbers of buyers, so customers were having fewer options to buy the product. But today, the market is highly competitive and volatile and industries are focusing on Robotics, Advance Manufacturing Methods like AJM (Abrasive Jet Machining), EDM (Electric Discharge Machining) and ECM (Electrochemical Machining) etc., CAD/CAM, CAE to make quality products and market them in shortest possible time. Leagile manufacturing system is ensuring best available solution at minimum cost to meet the market demand. It has attributes of lean as well as agile manufacturing systems and they are applied simultaneously in organization. Although, both systems, lean and agile are separated by de-coupling point. This paper tries to assimilate the concept of Leagile manufacturing system in today's scenario and evaluating key factors affecting Leagile manufacturing using digraph technique.

Lean is concerned with elimination of all types of wastes which do not add value to the product. It also means maximizing the value of product by using less of everything i.e. less manpower, fewer resources, less time, less investment etc. It mainly focuses on value stream to make the product at less cost in short span of time. Prince and kay and Kay (2003), Needy, Abdulmalek and Rajgopal (2006) and others have defined leagile production system. Lean Production concept was introduced by Taichi Ohno to enhance productivity of Toyota.

According to Naylor, Naim and Berry (1999), the definition of value stream in lean depends on a customer and cost perspective, rather than organization's viewpoint. A lean manufacturing typically has predictable demand, low product variety, longer product life cycles, and cost driven customers. Goldman, Nagel and Priess (1995), defines lean system as an incorporated scientific and procedural system; the main purpose of which is to eradicate the wastes associated with the process and reducing the variability of suppliers, customers as well as internal variability. The wastes in lean production system can be overproduction, over-processing, transport, defects, inventory, waiting and motion. The various advantages of implanting lean system are reduced inventory, reduced lead time, wastage reduction, financial savings, increased productivity, increased market share etc. Spear and Bowen (1999), the implementation of lean manufacturing depends on type and size of industry. 'Values' are important personal beliefs that people hold with respect to themselves and the goals for which they strive. According to Mccullen and Towill (2001), Lean manufacturing includes seven different types of wastes. Leanness means removing all wastes including time and cost and develops a standardized procedure to perform the process.

Table 9.1: Some applications of Graph Theoretic Approach

S.No	**Author (s)**	**Applications**
1	Gandhi and Agrawal (1996)	Analysis of cause of failures
2	Venkatasamy and Agrawal (1996)	Evaluation for automobile vehicle selection
3	Rao and Gandhi (2002)	Evaluation of machinability of different work materials
4	Grover, Agrawal and Khan (2004)	Evaluation of TQM environment
5	Grover, Agrawal and Khan (2006)	function of Human Factors in TQM

6	Rao and Padmanabhan (2006)	Analysis of diifrent kinds of industrial robots
7	Prabhakaran, Babu and Agarwal (2006)	Analysis of composite materials
8	Faisal, Banwet and Shankar (2007)	Analaysis of effective supply chain management barriers
10	Jangra, Grover and Aggarwal (2010)	Analysis of carbide compacting die produced by electric discharge machining
11	Raj , Shankar, Suhaib and Khan (2010)	Analysis of barriers of flexible manufacturing system
12	Saha and Grover (2011)	Evaluation of critical factors of website performance
13	Gurumurthy, Mazumdar, Muthusubramanaian(2013)	Analysis of criertia for lean thinking in industries
14	Safari, Faghih and Fathi (2013)	Analysis of criterias for selection of equipement
15	Dev , Kachhwaha and Attri (2014)	Evaluation of reliability index of thermal power plant

Agile manufacturing deals with speed with which system can be reconfigured so as to respond to meet changing needs of customers. According to Mason Jones, Naylor and Towill (2000), agile manufacturing is defined as capability of industry to work and prosper in market full of competition. Gupta and Mittal (1996) defined agile manufacturing as meeting the `total needs' of the customer and concurrently work for lean system.

Leagility concept has emerged as a profitable strategy now days. It has attributes of lean as well as agile manufacturing systems and they are applied simultaneously in organization; although both systems lean and agile are separated by de-coupling point. Upstream of de-coupling the demand is predictable and stable and there is a level schedule, so lean system is used. Downstream of de-coupling point the agile system is used to meet the changing needs of customers. Goldsby, Griffith and Roath (2006), discusses the basis concept of leagility using postponement as one of the central principles. Postponement is delaying of operational activities in a system until customer orders are received rather than completing activities in advance and then waiting for orders

9.2 Matrix Representation of the Digraph

Digraph gives one-to-one representation of leagility attributes. Leagility attributes relative importance matrix is explained and represented. Binary matrix (a_{ij}) representation method have been used, where a_{ij} is used to express relative importance among attributes i and j

a_{ij} = 1, if i-th leagility attribute is more significant as compared to the j-th attribute

= 0, if not.

It is noted that a_{ii} = 0 for all i, as an attribute cannot have relative importance over itself.

9.3 Key factors affecting Leagile manufacturing systems

[A]Human Resources

1. Commitment of employees towards work (Naylor, Naim and Berry; 1999)
2. Experience of employees (Mason-Jones, Naylor and Towill; 2000)
3. Multi-skill ness of operator (Prince and kay and Kay; 2003)
4. Attitude of employees (Wong and Wong; 2011)
5. Team work (Krishnamurthy and Yauch; 2007)
6. Interpersonal skills (Shah and Ward; 2003)
7. Interest of employees towards R&D activities (Mccullen and Towill; 2001)
8. Resistant to change (Rother; 2009)

[B]Production and Automation Engineering Aspects

1. Group Technology, cellular layouts (Perez , Castro, Simons and Gimenez ; 2010)
2. Use of advanced manufacturing methods like AJM (Abrasive Jet Machining, EDM (Electric Discharge Machining) etc.(Shah and ward; 2003)
3. Use of FMS, CNC, DNC (Naylor, Naim and Berry; 1999)
4. Use of Robotics and PLC (Martinez-Juardo and Moyano-fuentes; 2014)
5. Route sheet or sequence of operation to be followed (Mason-Jones, Naylor and Towill; 2000)

[C] Quality Tools and Techniques

1. 7 QC Tools (Yusuf and Adeleye; 2003)
2. Six sigma (Pavnaskar, Gershenson and Jambekar; 2003)
3. Acceptance sampling (Rother and Shook; 1999)
4. Poka-Yoke (Sanchej and Perez; 2011)
5. TQM (Zhou and Besant; 1999)
6. Benchmarking (Parry and Turner; 2006)
7. Kaizen (Motwani; 2003)
8. Kanban (Moutabian; 2005)
9. Single Minute Exchange of Dies (SMED) (Parry and Turner; 2006)
10. Value Stream Mapping (VSM) (Moore; 1997)

[D]Design Aspects

1. Design of product i.e. simplicity (Fullerton and Wempe; 2009)
2. Techniques and Methodology used (Chavez et. al. ; 2015)
3. Availability of R& D facilities (Marvel and Standridge; 2009)
4. Supplier and customer involvement in product design (Kumar et. al. ; 2013)

[E] Management Aspects

1. Supply Chain Management (SCM) (Bortolotti, Boscari and Danese; 2015)

2. Management support towards implementation of strategies (Sternberg et. al., 2013)
3. Financial expenditure towards training & development (Kulhang, Hempen, Sihn and Deuse; 2013
4. Decentralized authority (Liker and Franz; 2012)
5. Increment and remuneration Policies (Karlsson and Ahlstrom; 1996)
6. Employee empowerment (Mohager and Kabasian; 2014)

These factors affect Leagile manufacturing system differently. The relationship between these different factors and the amount by which individual factor affect the main objective function (Leagile manufacturing system) is equivocal. There are many techniques like graph theory, simulated annealing, grey relational analysis etc. Inheritance and interactions quantification cannot be determined by using Delphi technique, Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Structural Equation Modeling (SEM) and Fuzzy logic etc. The interaction between different identified attributes can be better analyzed using Graph Theory and Matrix Approach (GTMA) (Gandhi and Agrawal, 1996; Grover, Agrawal, Khan, 2004)

9.4 Leagility Evaluation- Graph Theoretic Representation

Numerous attributes affects Leagile environment. Inheritance of these attributes and interaction among them determines the effectiveness of environment. The traditional method is not able to compute these calculations. Both dependent and independent interactions may be there. Graph representation is used to model the interactions among the identified attributes. Undirected graph is used if interactions among attributes do not depend upon direction. A schematic diagram of leagile key factors is given in figure 9.1

Visual analysis can be easily done with the help of graph theoretic representation. Computer analysis can be done or it may be represented as mathematical term. The traditional system like Ishikava diagram or cause and effect diagram, flow charts, histogram etc. do not provide a way to analyze interaction among the attributes. For this purpose, digraph is more suitable methodology. The identified attributes are placed under five main categories using Exploratory Factor Analysis (EFA). Leagility index have been used to evaluate the effectiveness of leagile environment.

leagile index = f (critical elements)

Effort is made to establish correlation among five identified leagile factors, the quantification is based upon inter-relationship and inter-dependency of attributes. On the basis of this, the performance of industry can be analyzed in context with leagile environment. This task can be established with graph theoretic approach which involves representation of matrix, digraph, and permanent function. Digraph is the visual way of representing the characteristic and dependencies among leagile factors. Further, mathematical model is used to determine leagility index.

9.5 Matrix Representation

Digraph is used for visual illustration of attributes. It is used to obtain relationship among leagile attributes. Matrix form is represented which is more better way for analysis by means of computer (Grover, Agrawal, Khan, 2004).

For signifying diagraph of n factors, symmetric matrix of order is used and is represented by A = [T_{ij}]. The association among factors, i.e. T_{ij} is used to express relation of ith factor in context with jth factor

T_{ij} = 1; implies factor i affects factor j

= 0, if not

Usually, $T_{ij} \neq T_{ji}$ because Leagile factors are normally directional.

Also, T_{ii} = 0, if a given factor is not having any relation with itself. The Leagile matrix is characterized by square as well as non-symmetric nature which is very similar to adjacency matrix used in graph theory technique. The digraph is represented in figure 9.2:

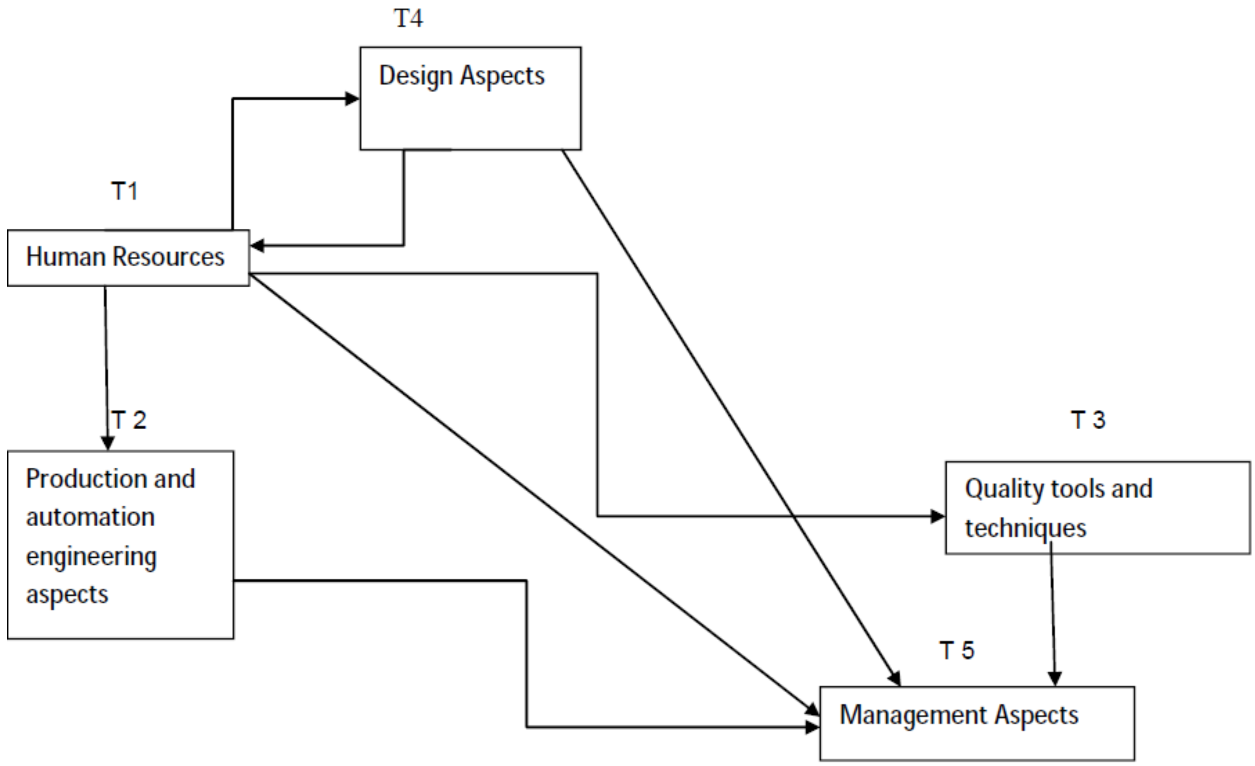


Figure 9.1: Schematic representation of Leagile Enablers

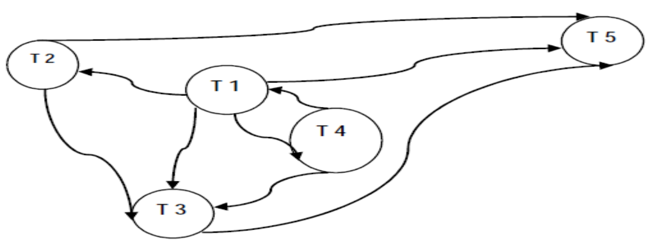


Figure 9.2: Leagility Digraph

Leagile elements interdependency is shown by non diagonal elements by digits 0 or 1. Since the inheritance of leagile factors are not considered; the diagonal values are 0. For this purpose another matrix called leagile characteristic is considered.

$$
\begin{array}{cccccccc}
 & 1 & 2 & 3 & 4 & 5 & \text{Vertex} \\
 & & & & & & \\
\end{array}
$$

$$
A = \begin{pmatrix} 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \qquad (1)
$$

9.5.1 Leagility Characteristic Matrix (LCM)

For instance, the leagile factors are contained in matrix I and T; where I is the identity matrix. Leagile factors are characterized by matrix called characteristic matrix. Another matrix B, called leagile characteristic matrix which is used for digraph representation can be expressed as [T I-A], where equation 1 is used to represent matrix A (Grover, Agrawal, Khan, 2004).

$$
\begin{array}{cccccc}
1 & 2 & 3 & 4 & 5 & \text{Vertex}
\end{array}
$$

$$
B = \begin{pmatrix} T & -1 & -1 & -1 & -1 \\ 0 & T & -1 & 0 & -1 \\ 0 & 0 & T & 0 & -1 \\ -1 & 0 & -1 & T & -1 \\ 0 & 0 & 0 & 0 & T \end{pmatrix} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \qquad (2)
$$

The value of diagonal elements is similar in the above expressed matrix; which generally can have distinct values based on the variables influencing them. Furthermore, interdependencies may be expressed by digits 0 and 1 based upon their presence or not in leagile system. For this purpose another matrix called Leagile variable characteristic matrix is developed.

9.5.2 Leagile Variable Characteristic Matrix (VCM- Leagile)

The result of leagile factors and their interaction is contained in leagile variable characteristic matrix. The digraph which is shown in figure 9.2 is used to define matrix VCM- leagile. The symbols Ti's and Tij's are used to show nodes and edges respectively. Let us consider another matrix C with Tij as off diagonal elements which are used to show interactions among Leagile factors. Also, one more matrix D is defined with T_i diagonal emenents where i = 1, 2, 3, 4, 5 and T_i is used to show consequence of various leagile factors. (Grover, Agrawal, Khan, 2004)

Let us consider another matrix E i.e. VCM- leagile = [D-C]

$$
\begin{array}{cc}
 & \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & \text{Vertex} \end{array} \\
E = & \begin{array}{c} \begin{pmatrix} T_1 & -T_{12} & -T_{13} & -T_{14} & -T_{15} \\ 0 & T_2 & -T_{23} & 0 & -T_{25} \\ 0 & 0 & T_3 & 0 & -T_{35} \\ -T_{41} & 0 & -T_{43} & T_4 & -T_{45} \\ 0 & 0 & 0 & 0 & T_5 \end{pmatrix} \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \end{array}
\end{array} \qquad (3)
$$

The matrix known as variable characteristic Leagile multinomial (VC-Leagile) is used as pivotal strategy by calculation of its determinant. This is the feature of system considered and used to represent leagile scenario in industries.

Determinant of above mentioned Equation (3) is calculated. As positive and negative signs are linked with some coefficients, whole information in the Leagile environment will not be obtained as some will be lost while sum and subtraction of elements placed at diagonal and non diagonal positions (i.e. $T_i^{'}s$ and $T_{ij}{}^{'}s$). So, the information of leagile environment is not provided completely as given by determinant of matrix expressed in equation 3 (Grover, Agrawal, Khan, 2004).

9.5.3 Leagile Variable Permanent Matrix (VPM- Leagile)

The environment of the industry is leagile if the leagile elements effect is maximum. In general, leagile variable permanent matrix is used for measuring the performance of industries.

$$T = D + C \qquad (4)$$

$$T = \begin{array}{cc} \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} & \text{Vertex} \\ \begin{pmatrix} T_1 & T_{12} & T_{13} & T_{14} & T_{15} \\ T_{21} & T_2 & T_{23} & T_{24} & T_{25} \\ T_{31} & T_{32} & T_3 & T_{34} & T_{35} \\ T_{41} & T_{42} & T_{43} & T_4 & T_{45} \\ T_5 & T_{52} & T_{53} & T_{54} & T_5 \end{pmatrix} & \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \end{array} \qquad (5)$$

Also, VPM - LEAGILE = $T^* =$

$$\begin{array}{cc} \begin{array}{ccccc} 1 & 2 & 3 & 4 & 5 \end{array} & \text{Vertex} \\ \begin{pmatrix} T_1 & T_{12} & T_{13} & T_{14} & T_{15} \\ T_{21} & T_2 & T_{23} & T_{24} & T_{25} \\ T_{31} & T_{32} & T_3 & T_{34} & T_{35} \\ T_{41} & T_{42} & T_{43} & T_4 & T_{45} \\ T_5 & T_{52} & T_{53} & T_{54} & T_5 \end{pmatrix} & \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{array} \end{array} \qquad (6)$$

The input of leagile factors identified is shown by T_1, T_2, T_3, T_4, T_5 diagonal elements interdependencies among leagile factors are expressed by elements placed at non diagonal positions.

9.6 Permanent Representation

The digraph representation and matrix representation can be altered by altering the labeling of nodes. To get rid of this, another matrix i.e. VPM-leagile is used which do not get affected by labeling of nodes. The combinatorial method also makes use of standard matrix called permanent matrix. The computation of permanent function is same as that of determinant; the only difference is that all negative signs coming during calculation are replaced with positive sign. The calculation involves the introduction of many terms in the equation as shown in (7), every term have significance in context with leagile environment. The polynomial used carries each and every information for building up of leagile environment interaction among several identified leagile factors. Leagile quantification is done by putting values of Ti's and Tij's in VPF- Leagile. Quantitative evaluation of leagile environment is done by using single numerical index. The VPF- Leagile represent the features of Leagile environment and is used for analysis. The VPF- Leagile is used to show digraph. (Grover, Agrawal, Khan, 2004)

VPF - Leagile =per T^*

$$
\begin{aligned}
&\prod_{1}^{5} T_i + \sum_i \sum_j \sum_k \sum_l \sum_m \left(T_{ij} T_{ji}\right) T_k T_l T_m + \\
&\sum_i \sum_j \sum_k \sum_l \sum_m \left(T_{ij} T_{jk} T_{kl} + T_{ik} T_{kj} T_{ji}\right) T_l T_m + \\
&\sum_i \sum_j \sum_k \sum_l \sum_m \left(T_{ij} T_{jk}\right)\left(T_{kl} T_{lk}\right) T_m + \\
&\sum_i \sum_j \sum_k \sum_l \sum_m \left(T_{ij} T_{jk} T_{kl} T_{li} + T_{il} T_{lk} T_{kj} T_{ji}\right) T_m + \\
&\sum_i \sum_j \sum_k \sum_l \sum_m \left(T_{kl} T_{lm} T_{mk} + T_{km} T_{ml} T_{lk}\right) T_{ij} T_{ji} + \\
&\sum_i \sum_j \sum_k \sum_l \sum_m \left(T_{ij} T_{jk} T_{kl} T_{lm} T_{mi} T_{ml} + T_{im} T_{ml} T_{lk} T_{kj} T_{ji}\right)
\end{aligned}
\tag{7}
$$

Equation 7 contains mathematical expression for evaluating permanent of matrix and is used to calculate the degree of implementation of leagile environment. Equation 7 carries N + 1 groups, where N represents number of leagile elements. The physical significance of the groups can be explained as:

– The unconnected N Leagile elements are shown in group 1, i.e. $\boldsymbol{T}_1$, $\boldsymbol{T}_2$ ………….$\boldsymbol{T}_N$

– self-loops absence eliminates the second group.

–The sets of two-element Leagile loops (i.e$\left(T_{ij}T_{ji}\right)$) is contained in group 3.

– The set of three-element Leagile loops ($T_{ij}T_{jk}T_{kl}$ or its pair $T_{ik}T_{kj}T_{ji}$) is contained in fourth group.

– The fifth grouping involves two subgroups. Leagile loops of two elements (i.e. $T_{ij}T_{ji}$ and T_{kl} T_{lk}) and also leagile component (T_m) is contained in first sub grouping. Leagile loops of four elements (i.e. $T_{ij}T_{jk}T_{kl}\ T_{li}$) and its pair (i.e. $T_{il}T_{lk}T_{kj}T_{ji}$) and also leagile component (T_m) is contained in second sub grouping

– The sixth grouping terms are also set in two sub groupings. Two-element leagile loop (i.e. $T_{ij}T_{ji}$) and a three- element leagile loop (i.e. $T_{kl}T_{lm}T_{mk}$) or its pair (i.e. $T_{km}T_{ml}T_{lk}$) are contained in first sub grouping. Five-component leagile loop (i.e. $T_{ij}T_{jk}T_{kl}\ T_{lm}T_{mi}$) or its pair ($T_{im}T_{ml}T_{lk}T_{kj}T_{ji}$) is contained in second sub-grouping (Grover, Agrawal, Khan, 2004)

9.7 Quantification of $T_i^{'}s$ and $T_{ij}^{'}s$

For analysis of VPM-leagile, quantification of the $T_i^{'}s$ and $T_{ij}^{'}s$ needs to be done Each T_i is considered as subsystem, quality of each is evaluated to make the performance of the system better and the graph theoretic approach is used to analyze the given system. Several sub factors influencing T_i are found out. The digraph is constructed for sub system and permanent function value is computed as in equation 7. This may be affected by inheritance of T_i . In the same way, other $T_i^{'}s$ are computed by taking into account sub factors influencing every Ti. Values for inheritance can be taken from table 9.1 in order to avoid any confusion and make the computation simpler. Non diagonal elements which are used to show interdependencies are quantized using T_{ij}'s and are allocated numerical values. The dependency among the identified elements is difficult to analyze and interpret directly. Qualitative values of interdependencies are shown in table 9.2 (Grover, Agrawal, Khan, 2006)

Table 9.2: Quantification measure of leagility factors

S.No	Qualtitative measure of Leagility element	Assigned Value
1	Exceptionally low	1
2	Very low	2
3	Low	3
4	Below average	4
5	Average	5
6	Above average	6
7	High	7
8	Very High	8
9	Exceptionally high	9

Table 9.3: Quantification measure of leagility factors interdependencies

S.No	Qualtitative measure of dependencies	Assigned Value
1	Very strong	5
2	Strong	4
3	Medium	3
4	Weak	2
5	Very weak	1

9.8 Leagility Index (LI)

Five key factors and interdependencies among them decide the leagile environment. Although quantitative analysis of leagility is difficult to measure; permanent function gives the reliable and accurate results of leagile environment in manufacturing industries. It includes various leagile attributes; their interdependencies.

Leagile Index is expressed as

Leagile = per T^* = Permanent value of VPM – leagile

The performance of several similar organizations can be compared with the help of this methodology by calculating the leagile index. The new variables can also be incorporated and their effects can be better analyzed and evaluated.

9.9 Methodology

This technique computes leagile index of given industry and that is given by numerical index. The technique makes use of influence of factors and interdependencies, their implications. The steps in the research conducted is given which set the guidelines for managers to take the computation and performance measurement of their industry.

1. Find out several elements influencing leagile environment. Different companies may have different elements based upon type and size of organization, their location.
2. The elements are expressed in combined form to avoid any confusion.
3. Digraph is developed among the identified factors on the basis of interdependencies.
4. Find out the subfactors influencing each other.
5. Variable permanent matrix is constructed
6. For every factor; construct digraph of each subfactor on the basis of interdependencies.
7. Permanent value is obtained for each subsystem. While examining subsystem level, the values of inheritance and interdependencies can be taken from tables 9.2 and 9.3.
8. For each factor considered, the permanent value of subsystem gives inheritance. The non diagonal element values are given by experts.

9. Leagile Index is calculated which shows the performance of organization in context with leagile environment.

9.10 Case study

For the better understanding of methodology explained, an example has been taken. A set of values have been assumed as it is obtained by conducting a questionnaire based survey. Leagile index value is determined by assigning numeral values to all identified factors as in equation (6).

For analyzing each and every factor pertaining to leagile environment i.e. T_1, T_2, T_3, T_4 and T_5, numeral value is assigned to each. Every identified factor is considered as subsystem and the GTMA technique is used to analyze every subsystem or sub-subsystem. For instance, in first factor considered human resource management; commitment of employees towards work is referred as subsystem. The human resource management factor consists of eight attributes.

1. Commitment of employee towards work
2. Experience of Employee
3. Multi-skill ness of operator
4. Attitude of Employee
5. Team work
6. Interpersonal Skills
7. Interest of employees towards R&D activities
8. Resistant to change

On the basis of interdependencies of attributes, subsystem digraph is constructed as in (5), which develops variable permanent matrix for the sub-subsystem human resource and is expressed as:

The permanent value of equation (8) is used to analyze the input of commitment of employee toward work in context with leagile environment. Similarly, the several identified sub-factors are examined and their matrices are established. Appropriate scale may be used to avoid any confusion. If there is requirement of normalization, that can be done. For analysis at system level, values are taken from table 9.1

T_1 = 6, T_2 = 8, T_3 = 7, T_4 =7 T_5 = 7

Similarly values of Tij are taken from Table 9.2 as

T_{12} = 4, T_{13} = 5, T_{14} = 5, T_{15} = 34, T_{23} = 4, T_{25} = 3, T_{35} =4, T_{41} = 5, T_{43} = 2, T_{45} = 3

Putting the values of $T_i^{'}s$ and $T_{ij}^{'}s$, equation (6) is rewritten as

$VPM - Leagile_e =$

$$\begin{array}{cc}
\begin{matrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 \end{matrix} & \text{Vertex} \\
\begin{pmatrix}
T_{e1} & T_{e12} & T_{e13} & T_{e14} & T_{e15} & T_{e16} & T_{e17} & T_{e18} \\
T_{e21} & T_{e2} & T_{e23} & T_{e24} & T_{e25} & T_{e26} & T_{e27} & T_{e28} \\
T_{e31} & T_{e32} & T_{e3} & T_{e34} & T_{e35} & T_{e36} & T_{e37} & T_{e38} \\
T_{e41} & T_{e42} & T_{e43} & T_{e4} & T_{e45} & T_{e46} & T_{e47} & T_{e48} \\
T_{e51} & T_{e52} & T_{e53} & T_{e54} & T_{e5} & T_{e56} & T_{e57} & T_{e58} \\
T_{e61} & T_{e62} & T_{e63} & T_{e64} & T_{e65} & T_{e6} & T_{e67} & T_{e68} \\
T_{e71} & T_{e72} & T_{e73} & T_{e74} & T_{e75} & T_{e76} & T_{e7} & T_{e78} \\
T_{e81} & T_{e82} & T_{e83} & T_{e84} & T_{e85} & T_{e86} & T_{e87} & T_{e8}
\end{pmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \end{matrix}
\end{array} \quad (8)$$

VPM - LEAGILE =

$$\begin{array}{cc}
\begin{matrix} 1 & 2 & 3 & 4 & 5 \end{matrix} & \text{Vertex} \\
T = \begin{pmatrix}
6 & 4 & 5 & 5 & 4 \\
0 & 8 & 4 & 0 & 3 \\
0 & 0 & 7 & 0 & 4 \\
5 & 0 & 2 & 7 & 3 \\
0 & 0 & 0 & 0 & 7
\end{pmatrix} & \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \end{matrix}
\end{array} \quad (9)$$

The permanent value of the matrix comes out to be 26264 using equation (7), which represents leagile index for given industry. Leagile index of other similar industries can be further evaluated which can be used for comparision. Large value of leagile index indicated the more favorable leagile environment in that particular industry. As leagile environment gets influenced by many factors, it is better to use tables for subsystems. Moreover, the performance of industry can also be measured by establishing threshold value for particular type of industry. This will aid the organizations to realize their present status and their performance can be measured time to time. The technique is relatively simpler as it provides single numerical index and tells the status of firm.

The data in context with matrix can be fed in to computer memory and retrieved when required. Also, it is easy to process on computers. Sensitivity analysis can be carried out easily i.e. effect of change in any of variable on system performance is analyzed with the help of variable permanent matrix.

9.11 Comparison of industries

The comparison of industries working in similar fields is evaluated using this methodology by determining their VPF- leagile. The industries are said to be similar form leagile point of view if the digraphs are isomorphic. Also leagile digraphs are said to be isomorphic if their VPF- leagile is similar. This means not only numbers of terms in each grouping/sub-grouping are the same but also the values are the same. Based on this a composite leagile identification set for an organization is written as:

$$\begin{bmatrix} \left(J_1^T / J_2^T / J_3^T / J_4^T / J_{51}^T / J_{52}^T / J_{61}^T / J_{62}^T / ......\right) \\ \left(V_1^T / V_2^T / V_3^T / V_4^T / V_{51}^T + V_{52}^T / V_{61}^T + V_{62}^T / ....\right) \end{bmatrix} \qquad (10)$$

Where J_i^T implies the total figure of i^th grouping, terms and J_{ij}^T implies total figure jth subgrouping terms. The value of J_{ij} and J_i^T are same when there is no sub-grouping. Likewise V_i^T implies i^th grouping; V_{ij}^T implies j^th sub grouping of ith grouping. To obtain V_{ij}^T, the $T_i^{'s}$ and $T_{ij}^{'s}$ values are put in the grouping or sub grouping.

Coefficient of similarity also used to perform comparison. It is determined with the help of structure which is distinct clubbing of terms and permanent function. Let us consider that the different terms of jth subgrouping which is part of ith grouping of VPF-LEAGILE of any given two firms and is denoted by V_{ij}^{T}.

And coefficient of dissimilarity can be expressed by

$$C_{d-1}^{T} = \left(1/Y_1 \sum_i \sum_j \phi_{ij} \right)^{1/2} \tag{11}$$

Where $Y_1 = \max \sum\sum | V_{ij}^{T} | and \sum\sum | V_{ij}'^{T} |$

Where sub groupings are absent $V_{ij} = V_i^{T}$ and $V_{ij}' = V_i'^{T}$

Where

$\phi_{ij} = | V_{ij} - V_{ij}' |$, If subgrouping is present

$\phi_{ij} = | V_i - V_i' |$, If subgrouping is not present

Coefficient of dissimilarity i.e. Criterion 2 may be expressed as

$$C_{d-2}^{T} = \left(1/Y_2 \sum_i \sum_j \phi^2{}_{ij} \right)^{1/2} \tag{12}$$

where ϕ_{ij} means the same as explained earlier

$$Y_2 = \max \sum\sum \left(V_{ij}^{T}\right)^2 and \sum\sum \left(V_{ij}'^{T}\right)^2$$

When subgrouping is not present $V_{ij} = V_i^{T}$ and $V_{ij}'^{T} = V_i'^{T}$

Using (11) and (12), the co-efficient of similarity is given as

C_{s-1}^{T} = 1- C_{d-1}^{T}

C_{s-2}^{T} = 1- C_{d-2}^{T}

C_{s-1}^{T} and C_{s-2}^{T} implies the basis of criterion 1 and 2 and is used to find out coefficient of similarity for performance comparison of two firms. The value of coefficient of similarity always lies between 0 and 1. Coefficient of similarity is 1, if the firms considered are isomorphic and its value is 0, otherwise.

9.12 Example for Comparison of organizations

The leagile environment may be analyzed on the basis of likeness and unlikeness, explained in last section.

Illustration has been considered for purpose of better understanding. The firms considered are analyzed whose leagile environment is influenced by three factors. The factors can be represented by T_1 , T_2 , T_3 and $T_1^{'}$, $T_2^{'}$, $T_3^{'}$ for firm 1 and firm 2 correspondingly. Irrespective of factor considered for both the firms, interdependence and inheritance of considered factors results in distinct performance of firms. The Variable Permanent Matrix (VPM) of firm 1 can be expressed by

$$\begin{array}{cccc} 1 & 2 & 3 & \text{Vertex} \end{array}$$

$$N = \begin{pmatrix} T_1 & T_{12} & T_{13} \\ T_{21} & T_2 & T_{23} \\ T_{31} & T_{32} & T_{33} \end{pmatrix} \begin{array}{c} 1 \\ 2 \\ 3 \end{array} \qquad (13)$$

Variable permanent function as calculated by (13) results in permanent of the matrix per T_1^* by equation (7)

$$Per\,T_1^* = T_1T_2T_3 + T_{12}T_{21}T_3 + T_{13}T_{31}T_2 + T_{23}T_{32}T_1 + T_{12}T_{23}T_{31} + T_{13}T_{32}T_{21} \qquad (14)$$

Since self loops are absent, so there is no second group in expression of per T_1^* , set of N + 1 i.e. four groups and carries N!, six terms.

Permanent function and VPM of firm 2 can be expressed similarly to (13) and (14)

Ti's and Tij's values for firm 2 are assigned by industry specialist. The values are taken from Tables 1 and 2.

T_1 =9, T_2 = 5, T_3 = 6, T_{12} = 4, T_{13} =4, T_{21} =4, T_{23} =3, T_{31} = 5, T_{32} = 3:

And $T_1' = 8$, $T_2' = 5$, $T_3' = 6$, $T_{12}' = 3$, $T_{13}' = 4$, $T_{21}' = 6$, $T_{23}' = 5$, $T_{31}' = 4$, $T_{32}' = 3$

After putting the values, the permanent of firm 1 can be expressed by equation (14) as

per T_1^* = 270 + 96 + 100 +81 + 60 + 48 = 655.

Similarly the value of per T_1^* of firm 1, based on equation (10) and (14) can be expressed as

[1/0/3/2] [270/0/277/108]

Likewise, the permanent for firm 2 can be expressed by

per T_2^* = 240 + 108+80+120 + 60+ 72 = 680

Firm 2 identification set can be expressed as

[1/0/3/2] [240/0/308/132]

Equation (11) and (12) is generally used for comparing the likeliness of firms in context with leagile environment. On the other hand, identification set are used to identify the efficiency and effectiveness of several groups. Coefficient of dissimilarity of two considered firms, based on criterion 1 is computed as 0.315 and coefficient of similarity comes out to be 0.685. This helps the firms to analyze the delicate links and set the guidelines and direction in which the firm is required to work. (Grover, Agrawal, Khan, 2004)

Also, the performance of firms may be analyzed and they can be ranked on the basis of coefficient of similarity or dissimilarity. Also, the value of leagile index can be computed with in defined range of the coefficient.

9.13 Discussion

In the work carried, leagile index is projected with the help of Graph Theoretic and Matrix Approach (GTMA). This technique is helpful in identifying the implementation of leagile environment in the organization. It is based upon the five identified key factors; which decides leagile implementation. It consists of construction of digraph, matrix and permanent function.

Leagile digraph is used for visual analysis of variables and their associated interdependencies.

Mathematical form of digraph is more common. Leagility index is calculated by leagile permanent function which is a mathematical model. So, this methodology helps in qualitative analysis of leagile terms. It is also helpful in comparing the performance, efficiency and effectiveness in context of leagile manufacturing system.

The following list set the guidelines for firms to compete in market.

1. Both, qualitative and quantitative analysis can be done for analysis of leagile environment with this methodology.
2. Interactions and interdependencies among the identified factors is allowed.
3. Various models like graph theoretic, permanent function and matrix can be used to analyze leagile environment.
4. Leagile environment can be judged by using single index called leagile index.
5. Sensitivity analysis may be easily done and it does not involve any complexity
6. The technique founds very suitable for overall improvement in working procedures.
7. Alternatives can be better analyzed and better decision can be taken without any confusion.

In the context of leagile environment, the graph theoretic methodology helps in putting vast ocean of knowledge. It helps in exploring the scope for research in leagile area. The systematic and chronological sequence of its implementation will help the industries to increasing the productivity, enhancing the quality of their products, better customer satisfaction, better sales, increased profitability and market share. The comparison of firms in context of leagility environments also helps the firms to acquaint with latest and modern technologies and strategies coming in industries. It will act as motivation for the industries and helps in continuously and systematically improvement in process.

CHAPTER 10

LEAGILE CRITERIA'S ASSESSMENT USING DEMATEL APPROACH

In this chapter, leaglile criteria's have been found through literature review. Decision Making Trial and Evaluation Laboratory (DEMATEL) technique has been applied for assessment of leagile criteria and for finding the causal relationaship among these criteria's.

10.1 Introduction

Globalization has resulted in lot of competition in the current scenario. It has become mandatory for the industries to become aware of latest and advance manufacturing technologies and smart strategies Leagile manufacturing is one of the best techniques to minimize the wastes and meeting customers' requirements in minimum time possible. However, it becomes difficult to implement all leagile tools simultaneously in industry. In this paper, 17 main criteria of leagile manufacturing have been found and Decision Making Trial and Evaluation Laboratory (DEMATEL) approach is used to identify significance of identified criteria and relations among identified criteria's.

Leagile is a combination of both lean and agile manufacturing. Lean tries to eliminate all those activities which do not add value to the product. The wastes include overproduction, motion, transportation, defects, inventory, waiting, over processing etc. Naylor, Naim and Beery (1999), defined agility as business wide practice that comprise ability to respond to sudden changes and meet sudden changes in customer demand patterns in context of price, specification, quality, quantity, and deliver postponement. It is one of the central principles. Postponement is delaying of operational activities in a system until customer orders are received rather than completing activities in advance and then waiting for orders.

For better understanding of leagility concept, it is necessary to study both concepts i.e. lean and agile separately also. Implementation of lean manufacturing in industries fully started from Toyota production system. The lean manufacturing concept focuses on maximum customer satisfaction by providing quality products at reasonable cost. Cil and Turkan (2013), implementing lean concepts has become mandatory for all organizations in order to survive in the market. Value Stream Mapping (VSM) is found to be important tool by enhancing the value of the product by eliminating all those activities which do not add value to the product. Pandey and Garg (2009), explained Lean manufacturing requires implementation of various tools and techniques which have ultimately objective of achieving maximum customer satisfaction by proving quality products to customers. Lean and agile manufacturing are most widely used strategies in the current scenario.

Agility means using knowledge, experience and virtual corporation to understand the fluctuating needs of customers and work accordingly. Christopher and Towill (2000), leagile system has characteristics of both lean and agile manufacturing systems. Mason-Jones, Naylor and Towill (2000), defined agile manufacturing as the capability of organization to grasp opportunities and provide quality products at quickly to customers. The data regarding leagile criteria's have been collected by conducting survey. Table 10.3 shows the data collected by one of the expert's and table 10.4 shows the average score's given by 50 experts.

10.2 Identification of Leagile Manufacturing Criteria's

17 leagile manufacturing criteria identified by literature review are given in

Table 10.1: List of Leagile Criteria

S.No	Leagile Manufacturing Criteria	Authors
1	Six Sigma	Koenigsaecker (2013); Bonavia and Martin-Garcia (2011)
2	Supplier Development	Purvis, Gosling and Naim, 2014; Yao and Carlson, 2003

3	Information Technology (IT)	Lander and liker, 2007
4	Kaizen	Ramesh, Banwet and Shankar (2010)
5	Remuneration and Increment Policies	Shah, Chandrasekaran, Linderman (2008)
6	Training and Motivational Programs	Liker and Convis (2012)
7	Poka Yoke	Hodge, Ross, Joines and Thoney (2011)
8	FMEA (Failure Mode and Effect Analysis)	Elmoselhy (2013)
9	ERP (Enterprise Resource Planning)	Swafford, Ghosh and Murthy (2008), Herrmann, Minis and Ramachandran (1995)
10	Group Technology (GT)	Hoek (2000)
11	Organizational Culture	Scherrer-Rathje, Boyle and Deflorin (2009), Pullen, Bhasi and Madhu (2011)
12	Innovation and R & D	Mohanraj, Sakthivel and Vonodh (2011), Vinodh, Kumar and Girubha (2012)
13	TQM	Swafford, Ghosh and Murthy (2008)
14	Reconfiguration capabilities	Mostafa, Dumrak and Soltan (2013)
15	Concurrent Engineering	Sisson and Elsehnnawy (2015)

16	Supply Chain Management (SCM)	Miller (2011), Bicheno (2004)
17	CIM (Computer Integrated Manufacturing)	Pullen, Bhasi and Madhu (2011), Tu (1997)

Table 10.2: Some applications of DEMATEL approach

S.NO	Author's	Application
1	Kim(2006)	Analysis of agricultural information
2	Tzeng, Chiang and Li (2007)	Analysis of E-learning programs
3	Wu (2008)	Analysis of strategies of knowledge management
4	Tseng (2009)	Management of municipal solid waste
5	Tsai and Chou (2009)	Sustainable manufacturing in small and medium enterprises
7	Tseng(2009a)	Perceptions of hotel service quality
8	Tseng(2009 b)	Expectation of service quality
9	Shieh, Wu and Huang (2010)	success factors analysis of hotel service quality
10	Zhou, Huang and Zhang (2011)	Analysis of factors of emergency management
12	Lin, Yang, Kang and Yu (2011)	Analysis of competencies of IC design industry
13	Wu and Tsai (2011)	Automobile industry success factors
14	Nosratabadi, Pourdarab and Nadali (2011)	Assessment of Credit Risk for Customers of bank
15	Sumrit and Anuntavoranich (2012)	Causal Relations analysis of Technological Innovation factors
16	Lirajpour, Hajimirza, Alavi and Kazemi (2012)	Analysis of green supplier selection factors

17	Bai and Sarkis(2013)	Analysis of process of business
18	Lee, Hsieh and Guo (2013)	Analysis of library website
19	Hsu, Kuo, Chen and Hu (2013)	Selection of supplier in green supply chain management
20	Senvar, Tuzkaya and Kahraman (2014)	Measurement of performance of supply chain
21	Sharma, Dixit and Qadri (2016)	Lean criterion assessment

10.3 DEMATEL methodology

Step 1: Obtain the experts opinion and construct average matrix A

A Group of experts were consulted to express level of influence between 1 and 5 based on pair-wise comparison. After that average matrix S is constructed. The notation of x_{ij} indicates the degree which the expert believes factor i have an effect on factor j. Zero, indicates no influence.

$$a_{ij} = \sum_{j=1}^{n} x_{ij}{}^{k} \qquad where\ k = 1,2,3 \ldots\ldots\ldots\ldots\ldots n \tag{1}$$

Where n is the number of respondents

Step 2: Calculation of normalized initial direct relation matrix D

$D = A\ X\ S$

$$S = 1/\max 1 \leq \sum_{j=-1}^{n} a_{ij} \tag{2}$$

Every component in matrix lies between 0 and 1

Step 3: Calculation of Total Relation Matrix,

$$T = D(I - D)^{-1} \qquad (3)$$

Where I is the identity matrix.

Step 4: Calculate the sums of rows and columns of matrix T. In the total-influence matrix T, the sum of rows and the sum of columns are represented by vectors r and c respectively.

Step 5: Determine C + Rand C – R and compute threshold value.

Step 6: Set up a threshold value to obtain the digraph. Since matrix T provides information on how one factors affects another, it is necessary for a decision maker to set up a threshold value to filter out some negligible effects. In doing so, only the effects greater than the threshold value would be chosen. In this study, the threshold value is set up by computing the average of the elements in matrix T. The digraph can be acquired by mapping the data set of (C+R, C−R)

10.4 Calculations Involved

Table 10.3: Assessment data of General Manager

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1		3	2	1	3	4	2	3	4	4	1	2	3	2	4	3	3
2	*2*		3	4	3	5	3	2	4	3	1	2	3	1	3	2	3
3	4	3		4	4	2	3	4	3	1	4	2	4	1	4	3	3
4	4	3	4		4	3	3	3	4	1	4	3	2	4	1	4	3
5	4	3	3	4		4	1	4	1	4	4	3	1	1	4	4	3
6	1	2	4	3	1		2	3	2	3	2	3	4	2	1	3	2
7	3	2	4	1	2	3		3	2	3	4	2	3	3	2	2	1
8	3	2	2	2	3	4	2		1	2	3	2	4	2	3	4	2
9	3	2	3	4	1	5	2	1		2	3	2	2	3	2	4	2

10	3	4	2	3	4	3	2	1	3		3	4	2	4	2	3	1
11	5	3	2	4	3	4	2	3	3	2		2	3	4	3	2	3
12	4	3	4	3	2	3	1	4	3	4	4		3	4	3	4	2
13	2	3	2	4	3	4	3	2	4	3	4	3		4	2	1	2
14	1	4	2	1	2	1	1	2	3	4	2	4	3		1	2	2
15	2	3	3	2	4	5	1	2	1	2	3	2	1	2		3	1
16	3	2	4	3	2	3	3	2	4	1	3	1	3	1	2		1
17	4	3	2	1	2	3	2	3	2	1	3	2	4	1	3	2	2

Table 10.4: Initial Average Matrix A for leagile criteria

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	0	3.8	1.9	1.4	2.9	3.5	1.8	2.6	3.6	3.8	1.2	2.1	2.7	1.7	3.4	2.7	3.2	42.3
2	1.8	0	2.8	3.5	2.8	4.8	2.7	1.8	3.8	2.9	1.2	1.8	2.8	1.2	3.1	1.8	2.7	41.5
3	3.5	2.8	0	3.4	3.5	1.8	2.8	3.7	3.1	1.1	3.5	1.9	3.8	1.2	3.7	2.8	3.1	45.7
4	3.8	2.7	3.8	0	3.8	2.7	2.8	2.8	3.7	1.2	3.8	2.8	1.2	3.8	1.1	3.8	2.6	46.4
5	3.8	2.8	3.9	2.8	0	3.7	1.3	3.8	1.1	3.8	3.9	2.7	1.2	1.2	3.7	3.7	2.8	46.2
6	1.2	1.9	3.8	2.8	1.2	0	1.8	2.7	1.9	2.7	1.2	2.4	3.8	2.2	1.2	2.7	1.9	35.4
7	2.8	1.8	3.7	1.2	2.5	2.7	0	2.8	2.1	2.9	3.8	1.9	2.9	3.2	1.8	1.7	1.2	39
8	2.9	1.9	2.1	1.5	2.8	3.8	1.3	0	1.2	2.1	2.7	1.9	3.8	2.2	2.7	3.5	1.7	38.1
9	2.9	1.9	2.7	1.3	1.2	4.5	1.4	1.2	0	2.1	2.8	1.8	2.1	3.2	1.8	3.6	1.8	36.3
10	2.7	3.8	1.6	2.8	3.7	2.7	1.1	1.1	2.9	0	2.8	3.7	2.2	3.8	1.9	2.8	1.1	40.7
11	4.7	2.8	1.5	3.5	2.7	3.6	1.2	2.7	2.7	2.1	0	1.8	3.2	3.8	2.7	1.8	2.9	43.7
12	3.8	2.9	3.5	2.5	1.8	2.7	1.1	3.7	2.6	3.6	3.8	0	2.8	3.7	2.8	3.7	1.9	46.9
13	1.9	2.8	1.9	3.5	2.7	3.7	2.8	1.1	3.5	2.8	3.8	2.8	0	3.6	1.9	1.2	1.8	41.8
14	1.8	3.8	1.8	1.2	1.8	1.2	1.2	1.9	2.9	3.7	1.9	3.5	2.8	0	1.1	1.8	1.9	34.3
15	1.8	2.8	2.9	1.2	3.8	4.8	1.1	2.1	1.1	1.1	2.7	1.8	1.2	1.8	0	2.8	1.1	34.1
16	2.7	1.8	3.7	2.8	1.8	2.6	2.9	2.2	3.7	1.2	2.8	1.2	2.8	1.2	1.9	0	1.3	36.6
17	3.8	2.9	1.6	1.1	1.6	2.7	1.2	2.8	1.8	1.1	2.8	1.8	3.8	1.1	2.8	1.8	0	34.7
	45.9	43.2	43.2	36.5	40.6	51.5	28.5	39	41.7	38.2	44.7	35.9	43.1	38.9	37.6	42.2	33	

Table 10.5: Normalized Initial Direct Relation Matrix D

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	0	0.074	0.037	0.027	0.056	0.068	0.035	0.05	0.07	0.074	0.023	0.041	0.052	0.033	0.066	0.052	0.062
2	0.03	0	0.054	0.068	0.054	0.093	0.052	0.035	0.074	0.056	0.023	0.035	0.054	0.023	0.06	0.035	0.052
3	0.07	0.054	0	0.066	0.068	0.035	0.054	0.072	0.06	0.021	0.068	0.037	0.074	0.023	0.072	0.054	0.06
4	0.07	0.052	0.074	0	0.074	0.052	0.054	0.054	0.072	0.023	0.074	0.054	0.023	0.074	0.021	0.074	0.05
5	0.07	0.054	0.076	0.054	0	0.072	0.025	0.074	0.021	0.074	0.076	0.052	0.023	0.023	0.072	0.072	0.054
6	0.02	0.037	0.074	0.054	0.023	0	0.035	0.052	0.037	0.052	0.023	0.047	0.074	0.043	0.023	0.052	0.037
7	0.05	0.035	0.072	0.023	0.049	0.052	0	0.054	0.041	0.056	0.074	0.037	0.056	0.062	0.035	0.033	0.023
8	0.06	0.037	0.041	0.029	0.054	0.074	0.025	0	0.023	0.041	0.052	0.037	0.074	0.043	0.052	0.068	0.033
9	0.06	0.037	0.052	0.025	0.023	0.087	0.027	0.023	0	0.041	0.054	0.035	0.041	0.062	0.035	0.07	0.035
10	0.05	0.074	0.031	0.054	0.072	0.052	0.021	0.021	0.056	0	0.054	0.072	0.043	0.074	0.037	0.054	0.021
11	0.09	0.054	0.029	0.068	0.052	0.07	0.023	0.052	0.052	0.041	0	0.035	0.062	0.074	0.052	0.035	0.056
12	0.07	0.056	0.068	0.049	0.035	0.052	0.021	0.072	0.05	0.07	0.074	0	0.054	0.072	0.054	0.072	0.037
13	0.04	0.054	0.037	0.068	0.052	0.072	0.054	0.021	0.068	0.054	0.074	0.054	0	0.07	0.037	0.023	0.035
14	0.03	0.074	0.035	0.023	0.035	0.023	0.023	0.037	0.056	0.072	0.037	0.068	0.054	0	0.021	0.035	0.037
15	0.03	0.054	0.056	0.023	0.074	0.093	0.021	0.041	0.021	0.021	0.052	0.035	0.023	0.035	0	0.054	0.021
16	0.05	0.035	0.072	0.054	0.035	0.05	0.056	0.043	0.072	0.023	0.054	0.023	0.054	0.023	0.037	0	0.025
17	0.07	0.056	0.031	0.021	0.031	0.052	0.023	0.054	0.035	0.021	0.054	0.035	0.074	0.021	0.054	0.035	0

Table 10.6: Total Relationship Matrix T

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
1	0.19[a]	0.25	0.21	0.18[a]	0.22	0.28	0.15[a]	0.21	0.24	0.23	0.2[a]	0.19[a]	0.2a	0.19a	0.22	0.23	0.2[a]	3.57
2	0.22	0.18[a]	0.23	0.22	0.22	0.3	0.17[a]	0.19	0.24	0.21	0.2a	0.18[a]	0.21	0.18a	0.21	0.21	0.19[a]	3.56
3	0.27	0.25	0.2[a]	0.23	0.25	0.27	0.18[a]	0.24	0.25	0.19[a]	0.26	0.2a	0.24	0.2[a]	0.24	0.24	0.21	3.91
4	0.28	0.25	0.27	0.17[a]	0.25	0.28	0.19[a]	0.23	0.26	0.2[a]	0.27	0.22	0.2[a]	0.24	0.2[a]	0.26	0.21	3.97
5	0.28	0.25	0.27	0.22	0.19[a]	0.3	0.16[a]	0.25	0.21	0.24	0.27	0.21	0.2[a]	0.2[a]	0.24	0.26	0.21	3.96
6	0.18[a]	0.19[a]	0.22	0.19[a]	0.17[a]	0.18[a]	0.14[a]	0.19[a]	0.19[a]	0.19[a]	0.18	0.17[a]	0.2[a]	0.18[a]	0.16[a]	0.2[a]	0.16[a]	3.07
7	0.23	0.2[a]	0.23	0.17[a]	0.2[a]	0.25	0.11[a]	0.2[a]	0.2[a]	0.2[a]	0.24	0.18[a]	0.2[a]	0.21	0.18[a]	0.2[a]	0.16[a]	3.37
8	0.22	0.2[a]	0.2[a]	0.17[a]	0.2[a]	0.26	0.14a	0.15[a]	0.18[a]	0.19[a]	0.21	0.17[a]	0.21	0.19a	0.19[a]	0.22	0.16[a]	3.27
9	0.21	0.19[a]	0.2[a]	0.16[a]	0.17[a]	0.26	0.13[a]	0.16[a]	0.15[a]	0.18[a]	0.21	0.16[a]	0.18[a]	0.2a	0.17[a]	0.22	0.15[a]	3.09
10	0.23	0.25	0.21	0.2[a]	0.23	0.26	0.14[a]	0.18[a]	0.23	0.16[a]	0.23	0.21	0.19[a]	0.23	0.19[a]	0.22	0.16[a]	3.51
11	0.28	0.24	0.21	0.22	0.22	0.29	0.15[a]	0.22	0.23	0.21	0.19[a]	0.19[a]	0.22	0.23	0.21	0.22	0.2[a]	3.72
12	0.28	0.25	0.26	0.22	0.22	0.29	0.16[a]	0.25	0.24	0.24	0.27	0.17[a]	0.23	0.25	0.23	0.26	0.19[a]	3.99
13	0.22	0.23	0.22	0.22	0.22	0.28	0.17[a]	0.18[a]	0.24	0.21	0.25	0.2[a]	0.16[a]	0.23	0.19[a]	0.2[a]	0.17[a]	3.59
14	0.19[a]	0.22	0.18[a]	0.15[a]	0.17a	0.2	0.12a	0.17[a]	0.2[a]	0.2a	0.19[a]	0.19[a]	0.18[a]	0.13[a]	0.15a	0.18[a]	0.15[a]	2.97
15	0.19[a]	0.2[a]	0.2[a]	0.15[a]	0.21	0.26	0.12[a]	0.17[a]	0.16[a]	0.15[a]	0.2[a]	0.16[a]	0.15[a]	0.16a	0.13a	0.2[a]	0.14[a]	2.95
16	0.22	0.19[a]	0.23	0.19[a]	0.18	0.24	0.16[a]	0.18a	0.22	0.16a	0.21	0.15[a]	0.19[a]	0.17a	0.17[a]	0.16[a]	0.15[a]	3.17
17	0.22	0.2[a]	0.18[a]	0.15[a]	0.17	0.23	0.12[a]	0.19a	0.18[a]	0.15a	0.2[a]	0.16[a]	0.2[a]	0.15[a]	0.18[a]	0.18[a]	0.12[a]	2.98
	3.91	3.72	3.72	3.22	3.49	4.42	2.51	3.37	3.62	3.32	3.77	3.11	3.35	3.33	3.27	3.65	2.91	

Note: [a] values below threshold.

Table 10.7: Degree of total influence of leagile criteria's

Criteria	Leagile Criteria	Sum(C)	Sum R	Prominence(C+R)	Net Effect (C-R)	Group
C1	Six Sigma	3.57	3.91	7.479	-0.337	Effect
C2	Supplier Development	3.56	3.72	7.277	-0.153	Effect
C3	Information Technology (IT)	3.91	3.72	7.628	0.192	Cause
C4	Kaizen	3.97	3.22	7.188	0.756	Cause

C5	Remuneration and Increment Policies	3.96	3.49	7.441	0.471	Cause
C6	Training and Motivational Programs	3.07	4.42	7.488	-1.342	Effect
C7	Poka Yoke	3.37	2.51	5.882	0.86	Cause
C8	FMEA (Failure Mode and Effect Analysis)	3.27	3.37	6.637	-0.097	Effect
C9	ERP (Enterprise Resource Planning)	3.09	3.62	6.713	-0.525	Effect
C10	Group Technology (GT)	3.51	3.32	6.823	0.187	Cause
C11	Organizational Culture	3.72	3.77	7.484	-0.052	Effect
C12	Innovation and R & D	3.99	3.11	7.1	0.888	Cause
C13	TQM	3.59	3.35	6.937	0.247	Cause
C14	Reconfiguration capabilities	2.97	3.33	6.294	-0.364	Effect
C15	Concurrent Engineering	2.95	3.27	6.212	-0.322	Effect
C16	Supply Chain Management (SCM)	3.17	3.65	6.818	-0.478	Effect
C17	CIM (Computer Integrated Manufacturing)	2.98	2.91	5.885	0.069	Cause

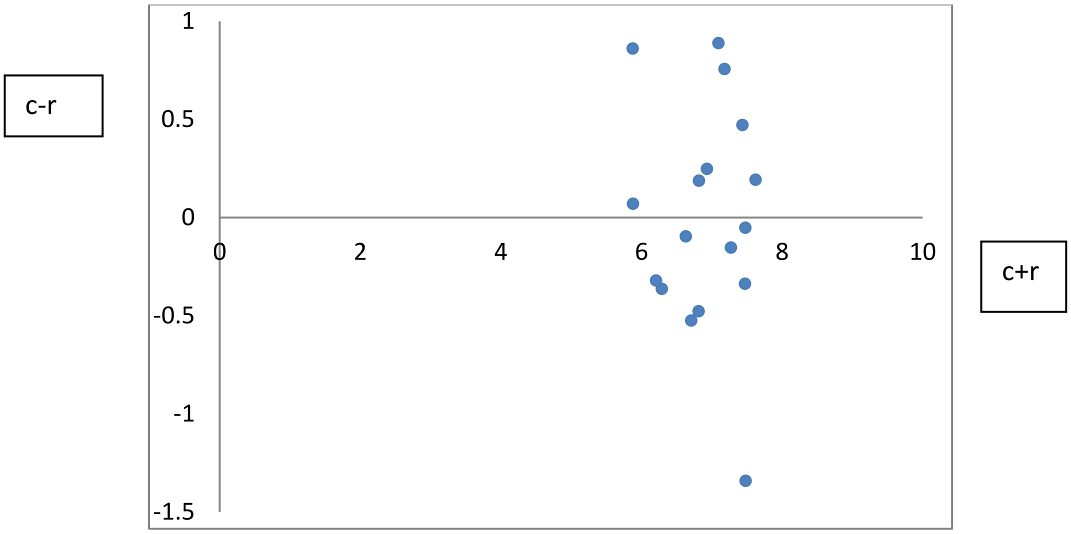


FIGURE 10.1: CAUSE AND EFFECT DIAGRAM OF LEAGILE CRITERIA'S

10.5 DISCUSSION AND IMPLICATION

For successfully implementing leagile system, it will be convenient to categorize the leagile criteria. DEMATEL approach categorizes the criteria based on C-R values. The leagile criteria are classified in to cause and effect categories. If C-R value is positive, leagile criteria will fall under cause category and if C-R value is negative, leagile criteria will fall under effect category The Criteria 1 (Six sigma), 2(Supplier Development), 6 (Training and development programs), 8 (FMEA), 9 (ERP), 11 (Organizational Culture), 14 (Reconfiguration capabilities), 15 (Concurrent Engineering), 16 (Supply Chain Management) represents effect group. The criteria 3 (Information Technology), 4 (Kaizen), 5 (Remuneration and Increment Policy), 7 (Poka Yoke), 10 (Group Technology), 12 (Innovation and R & D), 13 (TQM), 17 (CIM) are placed under cause group. The paper provides a comprehensive set of criteria and their interrelationships for implementing leagile manufacturing successfully. With the help of casual diagram, the complex problem can be easily solved and better decisions can be made with relative ease. The manager can better understand the implications involved and in better position to make sound and effective decision.

CHAPTER 11

SUMMARY, KEY FINDINGS, IMPLICATIONS AND SCOPE FOR FUTURE WORK

This chapter describes the summary of the research work, key findings of the research carried out, its implications and scope for future work.

11.1 INTRODUCTION

To compete in the market, it has become necessary for the organization to have state of art facilities and aware of latest techniques and strategies so that the product can be made of right quality in right quantity at right time. Leagile manufacturing i.e. combination of lean manufacturing and agile manufacturing is proved to be one of the most influential strategies by the researchers in the recent manufacturing era. Low awareness about leagile manufacturing has motivated researchers to work in this area. There is lot of literature available for lean and agile manufacturing; but little literature is available for leagile manufacturing.

11.2 SUMMARY OF RESEARCH WORK

The research activity was started with the pre-determined objectives to analyze the leagile manufacturing scenario in the recent scenario. Questionnaire was prepared and survey has been done to validate the attributes. Exploratory factor analysis was done to validate data and group the attributes in to factors. The present work has provide the framework for successfully implementing the leagile manufacturing system. The barriers of leagile manufacturing system, critical success factors, key performance indicators, social implications have been analyzed, which help the managers to implement leagile system with relative ease.

- The literature review done is exhaustive. Various reputed journals of Emerald, Elsevier, Taylor and Francis, Springer, Inderscience and other reputed journals were selected.

- The attributes were identified from literature review and in discussion with industrialists and academicians. Questionnaire was prepared. The questionnaire was containing questions related to barriers, social implications, key performance indicators, critical success factors etc. The experts were asked to rate the factors identified.
- The responses were recorded and analyzed.
- Exploratory Factor Analysis (EFA) was done to validate the data and grouped them into factors. SPSS 16.0 was used for this purpose.
- ISM (Interpretive Structural Modeling) technique has been used to find the interrelationship between barriers of leagile manufacturing system. MICMAC analysis is also done and barriers are categorized into autonomous, linkage, dependent and independent on the basis of driving and dependence power. ISM model was prepared to show the interrelationship among the barriers.
- Social Implications have also been identified through literature review and in discussions with experts. MICMAC analysis is also done and social implications are categorized into autonomous, linkage, dependent and independent on the basis of driving and dependence power. TISM model was prepared to show the interrelationship among the social implications
- Critical success factors identified through literature review was analyzed using TOPSIS technique. Positive ideal solution and negative ideal solution, Euclidian distances are calculated corresponding to each critical success factor and they are ranked.
- Key performance indicators identified through literature review was analyzed using fuzzy TISM technique. Fuzzy TISM tries to remove vagueness and complexities associate with the process and helps in giving better and consistent results.
- Leagile Criteria's (LC) found through literature review was analyzed using DEMATEL technique.
- Critical Success Factors identified through literature review also analyzed using fuzzy DEMATEL to categorize the CSF's using cause and effect categories.

11.3 KEYCONTRIBUTION OF THE RESEARCH

The key contribution of the research includes

- The literature review done was exhaustive and explains completely the work done so far in context of lean manufacturing, agile manufacturing and leagile manufacturing.
- The interest of Indian automobile ancillaries companies towards implementation of leagile manufacturing has been identified.
- The need of leagile manufacturing system has been identified. Also, the advantages of leagile manufacturing over lean and agile system have been explained.
- Benefits of implementation of leagile manufacturing system have been analyzed over lean and agile system alone.
- Several barriers faced by industries in implementing leagile manufacturing have been identified and ISM model has been developed.
- The social implications of leagile manufacturing system have been identified and TISM methodology has been applied. TISM model have been developed which provide better framework and clear understanding of relationship among social implications.
- Various leagile criteria's have been found out and experts were asked to rate these. DEMATEL approach was applied to categorize criteria's under cause and effect categories.
- Critical success factors have identified and TOPSIS technique has been used to evaluate them. The critical success factors are ranked in decreasing order of their significance.
- The factors are categorized using EFA. Graph theoretic and matrix approach have been identified to understand interrelationship among the key factors affecting leagile manufacturing system. Also, leagility index have been developed which can be used to compare the performance of industries.
- The key performance indicators have also been identified. Fuzzy DEMATEL method has been used to categories these KPI's into cause and effect category.

11. 4 Key findings of the Research

The key findings of the research are:

- Most of the companies are interested to implement leagile manufacturing system.
- Top management commitment and employees resistance to change are the most important barriers of implementing leagile system. If management takes initiatives and committed to do things; it will help in improving the faith of employees. Also, the employees needs to be motivated about the benefits of implementing leagile manufacturing system and should be given proper training.
- Four barriers such Communication gap , Lack of continuous improvement culture , Poor planning , Lack of Recognition and Rewards, having strong driving power and weak dependency on other barriers.
- Use of advance manufacturing technology is found to be most important critical success factor. The advance manufacturing technology will help in reducing the wastages as minimum as possible; it also tries to produce the products in minimum possible time.
- Social implications like unemployment, initially high capital investment and Improved customer satisfaction and better supplier relationship are independent variables.
- Leagile manufacturing index has been proposed which can be used for comparing the performance of organizations. The small industries can benchmark the leagility index of big and reputed companies and work in the correct direction.
- Since, implementation of leagile manufacturing system is not an easy task. The leagile tools have been identified which will help the managers to implement leagile manufacturing system easily.
- Use of advanced manufacturing technology is found to be most important critical success factor.
- The criteria's like six sigma, supplier development, training and development programs, FMEA, ERP, organizational culture, reconfiguration capabilities, concurrent engineering, supply chain management represents effect group. Remaining criteria's like information technology, kaizen, remuneration and

increment policy, poka yoke, group technology, innovation and R&D, TQM, CIM are placed under cause group

- The benefits of leagile manufacturing system have been found out, which will attract the management attention to implement it.
- Sales and turnover found to be most important key performance indicator of leagile manufacturing system. If sales of company is more, it will have funds to purchase latest machineries and equipments; will be in position to give better remuneration to employees and so on.

11.5 Implication of Research

The research carried out is useful for practitioners, academicians, managers etc. Different MADM techniques like ISM, TISM, TOPSIS, DEMATEL was used which can be used for other field of industrial management also. Similar, Questionnaire may be used to identify the related research in leagile domain. The developed GTA, TISM, ISM, TOPSIS models help to remove the complexities and direct the managers to implement leagile system easily. Insights may be developed by managers. The leagile framework will help the managers to increase their profit and market share by maximizing sales through maximum customer satisfaction. The work carried out in this research provides insights to the manager which will help them in successful implementation of leagile manufacturing system. This will help the industries to produce quality products at right time which will result in increased customer satisfaction. The sales of firm will increase and ultimately profit and market share will increase. Leagile tools have been identified through literature review. Some of the tools include six sigma, kaizen, poka yoke, benchmarking. This will make the task of managers simpler. The benefits of implementing leagile manufacturing system have been analyzed. The barriers of leagile manufacturing system identified through literature review were analyzed using Interpretive Structural Modeling (ISM) technique. ISM model was developed to show interdependence of these barriers. Also, MICMAC analysis was done to categorize the barriers in to autonomous, linkage, dependent and independent. Social Implication, also identified through literature review was analyzed using Interpretive Structural Modeling (ISM) technique. ISM model was developed to show interdependence of these implications. Also, MICMAC analysis was done to categorize the implications in to autonomous, linkage, dependent and independent.

Critical success factors identified through literature review was analyzed using Technique of Order Preference by Similarity to Ideal Solution (TOPSIS); Positive Ideal Solution (P.I.S) and Negative Ideal Solution (N.I.S) along with euclidian distances was calculated. Finally, ranking order of critical success factors was identified. Leagile criteria's identified through literature review was analyzed using Decision Making Trial and Evaluation Technique (DEMATEL). The leagile criteria's grouped into cause and effect categories. This help the managers to focus more on cause criteria's ; by means of which effective criteria automatically get incorporated in to the system. Key Performance Indicators (KPI's), identified through literature review was analyzed using fuzzy Total Interpretive Structural Modeling (TISM) technique. These indicators are ranked by using TISM model to show interrelationship between various KPI's.

11.6 Limitations

This research will help the managers to successfully remove the bottlenecks associated with different processes. Also, it will help the organization to increase its sales through maximum customer satisfaction. Although, a lot of effort was put to analyze the impact of different attributes affecting leagile manufacturing system; still it is not limitation free. The limitations are:

- Most of the industries which were considered in research work are automobile ancillaries industries. The results obtained may differ if any other industries like garments, electronics industries are taken.
- This research has been carried out for select industries in India. The scenario may change according to geographical locations i.e. other countries.

- The managers were not aware of leagile concept. So they were explained about leagile strategy and its principles before collecting the survey response.
- The response rate of collecting the survey data was low as industrialists were usually busy with their schedules.

11.7 Scope for future work

The ISM model can be validated by using Structural Equation Modeling (SEM), which is widely been used for the purpose of validating the models by the researchers. In graph theory matrix technique, interaction among various factors can be evaluated and transformed in to mathematical equations.TOPSIS technique used to evaluate the critical success factors can be further extended to fuzzy TOPSIS. The results obtained can be compared with other MADM techniques like Genetic Algorithm (GA), Preference Ranking Organization Method for Enrichment of Evaluations (PROMETHEE), Weighted Product Method (WPM).

- More case studies can be done to make the study more interesting.
- Some other attributes can also be considered, if any, which affect the leagile system.
- Type 2 fuzzy sets may be used instead of type 1 which results in removing the complexities and helps in better decision making.
- The responses are collected and analyzed from automobile ancillaries companies. The leagility of other industries like garments, electronics, computers etc. can be analyzed.
- ISM technique can be further extended to weighted ISM.

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APPENDIX A1

QUESIONNAIRE

To,

M/S ……………………..……………………………………

……………………..……………………………………

Subject: Regarding Questionnaire for Ph.D. Research Work on “Effective Decision support system for leagile manufacturing in select Indian industries”

Respected Sir/Madam,

As a part of my PhD research, I am conducting a survey of Indian manufacturing industries on different issues related to **Leagile Manufacturing system i.e. combination of both lean as well as agile manufacturing system** , mentioned in questionnaire. To make it possible, the industry is requested to share their views. Your feedback in this regard would be a significant input to this study. The **objective** of the survey is **purely research and academic only**. Therefore, **all responses would be kept strictly confidential** and would be used only for this academic work.

A humble request to spare your valuable time in responding to the enclosed questionnaire.

With thanks and regards

Yours faithfully

Naveen Virmani

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Registration No. Ph.D./33/2K12

Research Supervisors

1. Dr. Rajeev Saha, YMCAUST, Faridabad(Supervisor)
2. Dr. Rajeshwar Sahai, Director, Rattan college, Faridabad(Co-supervisor)

Responding Person Details:

Note: Please fill your name and tick the appropriate option out of the following.

1. Name (If you please): …………………………………………………..
2. Designation:

(a) CEO [ ] (b) Sr. Manager [ ] (c) Manager [ ] (d) Dept. Manager [ ] (e) Engineer [ ] (f) Junior Staff [ ]

3. In which Department you are working:

(a) H.R.D/Personal [ ] (b) R&D [ ] (c) Manufacturing/ Production [ ] (d) Q.A/Q.C [ ] (e) Purchase/Sales/Marketing [ ]

4. Your association in years with current organization:

(a) Less than 5 [ ] (b) 5-7 [ ] (c) 8-10 [ ] (d) More than 10 [ ]

5. Yours total experience in years

a. 0-2 [ ] b. 2-4 [ ] c. 4-6 [ ] d.6-8 [ ] e. more than 8 [ ]

Manufacturing Industry profile-

Note: For Question no.**1 to 7**, Please fill the following:

1**.** Name of Manufacturing Industry…………………………………….

2. Type of Manufacturing industry ……………………………………………….

3. Average Manufacturing process time of single piece is (approx) ……………………….

4. Manufacturing cost of one piece is (approx)………………………………….
5. Labor cost per piece is (approx)……………………………………………..
6. Number of shift in one day is……………………………………..
7. Number of parts produced in one shift of 8 hours is…………………

Note: For Question no.**8 to11**, Please **tick** the best option out of the followings:

8. How much turnover of your organization in Rs. of Crores?

(A) Less than 50 [ ] (B) 50 to 100 [ ] (C) 100 to 500 [ ]

(D) 500 to 1000 [ ] (E) More than 1000 [ ]

9. How many number of employees at your organization?

(A) Less than 500 [ ] (B) 501 to 1000 [ ] (C) 1001 to 2000 [ ]
(D) More than 2000 [ ]

10. How many number of product (variety) being manufactured?

(A) 1-5 [ ] (B) 6-10 [ ] (C) 11-20 [ ] (D) More than 20 [ ]

11**.** How much percentage of components being manufactured in house?

(A) Less than 25 [ ] (B) 25-50 [ ] (C) 50-75 [ ] (D) 75-100 [ ]

Note: For Question no.**12 to 16**, Please fill the followings details according to your manufacturing product:

12. Type of plant layout used by company

a. product layout

b. process layout

c. combination layout

d. Cellular Layout

13. To what extent plant runs automatically (%)

a. less than 50

b. 50-60

c.60-70

d70-80

e.80-90

f. Fully automatic

Q14. Please give rating for the following factors affecting leagile manufacturing system

S.No	**Factors of Leagile manufacturing system**	**Very Low**	**Low**	**Mode rate**	**High**	**Very High**
		1	**2**	**3**	**4**	**5**
1	Commitment of Employee					
2	Experience of Employee					
3	Multiskillness					
4	Passion for work					
5	Team Work Capabilities					
6	Inter-Personal Skills					
7	Interest towards R&D					
8	Communication Skills					
9	Resistance to Change					
10	Flexibility in Manufacturing System					
11	Group Technology					
12	Competitive Unit Cost					

13	General Purpose Equipments					
14	Concurrent Engineering					
15	Rapid Prototyping					
16	Work Simplification					
17	Rapid Reconfiguration					
18	Cellular Manufactuirng					
19	Job Rotation					
20	Sequencing and Schduling					
21	Lead Time Minimization					
22	Prodcution Planning and Control					
23	CIM					
24	Supplier Quality Management					
25	Optimum Inventory Level					
26	Resources Optimization					
27	Spaghetti diagramming					
28	Virtual Enterprise					
29	Advance Manufacturing Methods					
30	Motivational Programs					
31	Training Programs					
32	Top Mgmt. Commitment					
33	Supply Chain Management					
34	ERP					
35	Increment & Remuneration Policies					

36	Employee Empowerment					
37	Recognitions and Rewards					
38	Decentralized Authority					
39	Risk Assessment					
40	Business Support System					
41	Oragnaizational Culture					
42	Collaborative Relationship					
43	Supplier Integration					
44	Availability of Funds					
45	Timely delivery of Payment to suppliers					
46	Timely payment of Remuneration to Employees					
47	Listening to Customers					
48	Information Technology Facilities					
49	SPC(Statistical Process Control)					
50	Benchmarking					
51	JIT					
52	Kaizen					
53	Poka Yoke					
54	SMED(Single Minute Exchange of Dies)					
55	Kanban					
56	VSM(Value Stream Mapping)					
57	5S					

58	TPM					
59	FMEA					
60	TQM					
61	One Piece Flow					
62	PDCA					
63	Andon					
64	Time Value Mapping					
65	EDI					
66	Proper Feedback from Customers					
67	Marketing Strategy					
68	Accuracy of Data Collected for Sale forecast					
69	Market sensitiveness and Responsiveness					
70	Physically Distributed Teams					
71	Focus on Innovation					
72	Techniques or Softwares Used					
73	Cost Reduction					
74	Product Simplicity					
75	Supplier Involvement in Product Design					
76	Customer Involvement in Product Design					
77	Availability of R & D Facilities					

APPENDIX A2

BRIEF PROFILE OF THE RESEARCH SCHOLAR

Naveen Virmani is working as Assistant Professor in Department of Mechanical Engineering in IIMT College of Engineering, Greater Noida. He has passed his B.E in Mechanical Engineering from Lingayas Institute of Management and Technology, Faridabad in 2008 and M.Tech in Manufacturing and Automation from YMCA University of Science and Technology, Faridabad in 2011. He is pursuing PhD from YMCA University of Science and Technology, Faridabad. He is working in the field of leagile manufacturing, operations management. He has published 15 research papers in various international journal, international and national conferences.

APPENDIX A3

LIST OF PUBLICATIONS OUT OF THESIS

List of Papers published in International Journal

S.No	Title of the Paper	Name of the Journal	Publisher	Whether you paid any money for publication
1	Understanding the barriers in implementing Leagile manufacturing system 2017, Vol. 22, No.4, pp. 499-520	International Journal of Productivity and Quality Management(IJPQM)	Inderscience	No
2	Evaluating Key Performance Indicators of Leagile Manufacturing using Fuzzy TISM approach d.o.i: 10.1007/s13198-017-0687-4	International Journal of System Assurance and Engineering Management	Springer	No
3	Identifying and Ranking Critical Success Factors for Implementing Leagile Manufacturing Industries Using Modified TOPSIS 2017, Vol.11, No.4, pp. 943-947	International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering	World Academy of Science Engineering and Technology (Waset); Scopus Indexed	No
4	Evaluation of leagile criteria using DEMATEL	Empirical International Journal of Social, Behavioral,	World Academy of Science	No

	approach 2018, Vol.11, No.4, 974-978	Educational, Economic, Business and Industrial Engineering	Engineering and Technology (Waset); Scopus Indexed	
5	Quantification of key factors affecting Leagile manufacturing system 2017, Vol.11, No.4, pp.1023-1030	International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering	World Academy of Science Engineering and Technology (Waset); Scopus Indexed	No
6.	Leagile Manufacturing: A review Paper 2018, Vol. 23, No.3, pp. 385-421.	International Journal of Productivity and Quality Management(IJPQM)	Inderscience	No
7.	Social Implications of Leagile Manufacturing system: TISM approach 2018, Vol. 23, No.4, pp. 423-445	International Journal of Productivity and Quality Management(IJPQM)	Inderscience	No
8	Emperical Assessment of Critical Success Factors of Leagile Manufacturing using Fuzzy DEMATEL approach 2018, Vol.11, No.4, pp. 293-314	International Journal of Agile System and Management	Inderscience	No

List of Papers communicated in International Journal

S.No	Title of the Paper	Name of the Journal	Publisher	Whether you paid any money for publication
9.	Identifying the factors for implementing leagile manufacturing and clubbing them using Exploratory Factor Analysis (EFA)	European Journal of Industrial Engineering	Inderscience	No
10.	Identifying and ranking barriers of implementing leagile manufacturing industries using modified TOPSIS	European Journal of Industrial Engineering	Inderscience	No
11.	Evaluation of Leagile Manufacturing Social Implications Using DEMATEL Approach	International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering	World Academy of Science Engineering and Technology (Waset)	No

List of Papers Presented in National Conferences

S.No	Title of the Paper	Name of the Journal	Publisher
12.	Key enablers affecting Leagile manufacturing system	Role of Science and Technology Towards Make in India	YMCAUST, Faridabad, March 5-7, 2016
13.	Understanding the benefits of Implementing Leagile Manufacturing in Indian Manufacturing Industries	National Conference, Innovative Trends in Mechanical Engineering(NCITME)	Shri Mata Vaishno Devi University, Katra, 3-4 March, 2017
14.	Identification Of Tools Of Leagile Manufacturing System : A Case Study	National Conference on Trends and Advances in Mechanical Engineering	YMCAUST, Faridabad, March16-17, 2017