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ON

MODELLING OF FACTORS FOR SUCCESSFUL IMPLEMENTATION OF LEAN MANUFACTURING

A THESIS SUBMITTED IN FULFILMENT OF
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IN

PRODUCTION & INDUSTRIAL ENGINEERING

Submitted By

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CANDIDATE'S DECLERATION

I hereby certify that the work which is being presented in this thesis entitled, "**Modelling of Factors for Successful Implementation of Lean Manufacturing**" is partial fulfillment of the requirements for the award of degree of **"Master of Technology"** with specialization in **Production & Industrial Engineering** submitted to **Delhi Technological University**, **Delhi** is an authentic work carried out by me under the supervision of. Dr. Rajesh Kumar Singh, Associate Professor in Mechanical & Production Engineering department.

The matter embodied in this report has not submitted to any other university/institute for award of any degree or diploma or any other purpose whatsoever.

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CERTIFICATE OF DISSERTATION

This is to certify that dissertation entitled “**Modelling of Factors for Successful Implementation of Lean Manufacturing”** being submitted by **Mr. Naveen Kumar** in the Fulfillment for the award of degree of **“MASTER of TECHNOLOGY”** with Specialization in **“PRODUCTION AND INDUSTRIAL ENGINEERING”** submitted to **DELHI TECHNOLOGICAL UNIVERSITY, DELHI** is a bona fide thesis work carried out by him under my supervision.

The matter in this dissertation has not been submitted to any other university or institute for the award of any degree.

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ABSTRACT

In present context of globalization, organizations need to improve their performance in terms of high productivity and cost minimization. These organizations are in continuous pressure to meet customers' requirements on regular basis. To meet these challenges, lean manufacturing has emerged as an important tool. Therefore present study has been carried out in context of successful implementation of lean manufacturing in manufacturing organizations. In first part, study has tried to justify the lean manufacturing vs. traditional manufacturing with the help of analytic hierarchy process (AHP) on basis of major benefits of lean manufacturing. By using AHP, global desirability index of lean manufacturing and traditional manufacturing are calculated and compared.

In second part, critical success factors of lean manufacturing have been identified based on literature review. Then these critical success factors have been ranked with the help of technique for order preference by similarity to ideal solution (TOPSIS). TOPSIS method has relatively high rationality and applicability when it is used to rank the critical success factors of lean manufacturing in organization.

In next part, study identified and prioritized the solutions for lean manufacturing implementation to overcome its barriers. It will help organizations to concentrate on high ranked solutions and develop strategies to implement them on priority. Study proposed a framework based on fuzzy AHP and fuzzy TOPSIS to identify and rank the solutions of lean manufacturing in organization and overcome to its barriers. This proposed framework provides more accurate, effective and systematic decision support tool for stepwise implementation of solutions of lean manufacturing in organization to increase its success rate.

Finally all findings from different sections have been synthesised in last chapter.

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Chapter 1

Introduction

1.1 Background of Lean Manufacturing

Top Japanese manufacturing industries have achieved excellent international competitiveness in a number of industries such as auto, electronics, and machinery in the past two decades. So due to intensive competition from the world, increasing manufacturing cost, and increasing operational problems, many manufacturing firms around the world, have made tremendous efforts to understand Japanese manufacturing practices. According to Hall (1983) and Schonberger (1982), Japanese had developed a new approach to increase the production rate and decrease overall cost in manufacturing firms.

Japanese developed Lean manufacturing which was previously known as the Toyota Production System (TPS) or the Just-in-Time (JIT) system (Toyota, 1988; Womack et al., 1990). Lean manufacturing attracted a lot of attention in the United States from both academia and industry. In recent time many automobiles and other manufacturers are actively adopting the lean manufacturing concepts. Most auto manufacturers have now adopted at least some aspects of this system. Maccoby's (1997) did a study and according to his study one-fourth of United States plants have tried to adopt the lean manufacturing system in their industries. However, to transfer the lean production system in a foreign country is a very long journey and a very challenging work because so many different aspects of plant operation are involved to manufacture a component. The transfer of Just in time approach to Toyota Production System, need a large amount of efforts.

Lean manufacturing, developed by Toyota, involves quality and inventory control, industrial relations, labor management, and supplier-manufacturer practices. Some researchers (Cusumano and Takeishi, 1991; Liker, 1997; Womack and Jones, 1996b) suggest that transfer of traditional manufacturing system to lean manufacturing had a significant positive impact on the performance of manufacturing firms.

1.2 Practices of lean manufacturing-

JIT works on the principle of small-lot production and JIT delivery (Purchasing, 1992). According to Nakamura et al. (1998), just in time has improved the performance of manufacturing firms. The results of a study of 200 US manufacturers by Germain and Droge

(1997) states that improved inventory, financial, and market performance correlates with increased adoption of Just in time purchasing methods.

Zayko et al. (1997) states that, with the help of lean manufacturing we can reduced 50 percent of human effort, manufacturing space, tool investment, and product development time, and also 200-500 percent improvement in product quality. However, Toyota recently makes a dramatic policy change for its lean support service. A decade after providing free instruction in lean manufacturing to all suppliers, Toyota is curtailing the service. Parts suppliers need to pay the tuition if they want to learn the lean manufacturing system (Chappell, 2002).

Logistics or supply chain management learns the art to manage the flow of materials and products from source to consumer (Copacino, 1997). Levy (1997) states that, JIT delivery and low inventory are the main part of logistics or supply chain management.

According to Bowersox et al., (2002) Lean logistics refers to the superior ability to design and administer systems to control movement and geographical positioning of raw materials, work-in-process, and finished inventories at the minimum cost.

Jones et al. (1997) states that the “value stream” is a new and more useful term to analysis the supply chain or the individual firm. They reinforce the importance of the value stream concept that extends both upstream from the product assembler into the “supply chain” and downstream into the “distribution chain”. However, large manufacturers have a better chance in achieving such “lean logistics” than their suppliers do, because large firms to have more resources and bargaining powers than their suppliers. For suppliers, though it may not be possible for them to optimize their supply chain effectively, it is still critical for suppliers to have a responsive logistics system in place to meet the customer’s demand.

Helper (1991) states that if United States automakers wish to continue to compete in the global industry, which is characterized by technology, time, and quality-based competition, they will need to establish long-term, mutual trust relationships between the suppliers and customers. According to Keller et al. (1991), for industries, supplier support was a very critical factor for the successful implementation of lean manufacturing system in industries. Helper’s (1991) surveyed in industries and he states that to survive in long-term competition, it is important to encourage suppliers and customers to develop capabilities of JIT production as well as JIT delivery. Customers can obtain improvements in quality and delivery by motivating suppliers to adopt JIT production and JIT delivery. Similarly, suppliers have to learn to respond to the increasingly demanding needs of its customers in this competitive market, which is driven by ever-increasing requirements for cost reduction, responsiveness to customer needs, and JIT supply (Owen and Kruse, 1997).

According to Helper (1991), automakers have significantly reduced their number of suppliers and also it becomes essential for automakers to choose suppliers who can meet their product development, production, and logistics requirements due to high supplier switching costs. According to Helper's study, Japanese automakers (particularly Toyota) showed that a skilled and loyal supplier base could be a key source of competitive advantage.

According to Suzaki (1987), automobile manufacturers are striving toward the lean manufacturing and demand JIT logistics from suppliers, suppliers with lean systems in place are more likely to be incorporated into the total system. As Heim and Compton (1992) put it, "A world-class manufacturer encourages and motivates its suppliers to become coequals with the other elements of the manufacturing system." An analysis conducted by Swenseth and Buffa (1990) shows that the implementation of lean strategy results in an increase in the total logistics cost of a manufacturer and his vendors. These cost increases are in the form of increased transportation, inventory carrying, and expected stock out costs.

If a supplier is armed with the lean system, the supplier can keep its inventory to a minimal level and lower its expected stock out costs. Therefore, suppliers who adopt internal lean production practices should be more compatible with the buyer's JIT logistics requirements. A wealth of literature has been written regarding the positive strategic impact of lean manufacturing on a company's competitiveness in the past two decades. Relatively few empirical analyses are undertaken to understand whether adoption of internal lean manufacturing techniques is also related to external logistics practices.

A supplier may take different strategies to satisfy the requirements set by a particular customer (Wu, 2002). A comparative analysis of lean manufacturing performance by Liker and Wu (2000) reveals that a buyer's lean logistics practices and internal policies can have a profound impact on its suppliers' ability to optimize operations. This exploratory study compares many different independent variables in more of a descriptive mode. The literature on lean manufacturing methods as compared to traditional production methods suggests some possible propositions for directions of differences.

Zipkin (1991) states that inventory reduction are a result of the adoption of lean manufacturing. Lean manufacturing achieves inventory turnovers of 20 in comparison with three to five for the traditional production setting (Nakamura et al., 1998; Schonberger, 1986; Wurz, 1995). A survey by Germain and Droge (1997) shows that lean manufacturing have less inbound inventory in industries.

1.3 Benefits from Lean Manufacturing-

To fully benefit from lean manufacturing, lean suppliers understand that they can meet customer demands for an ever increasing variety of products with frequent, quick changeovers in combination with other JIT techniques (Suzaki, 1987). In addition, high machine mobility and multi-skilled workers can help lean manufacturing adjust production to changes in customer demand quickly (Hirano, 1989; Suzaki, 1987).

According to Shingo (1989), Lean manufacturing focuses on preventing defects, not merely finding them. As a result, lean manufacturing are expected to be responsive to quality problems on the shop floor so defects can be prevented. Zayko et al. (1997) states that with the help of lean manufacturing, we improved the quality of product to 250-550 percent from traditional manufactured product. According to Levery (1998), preventive maintenance in industries put a significant impact on quality, quantity, and cost of a product.

1.4 Requirements of lean manufacturing-

Levy (1997) states that lean manufacturing needs frequent and rapid flows of information and goods along the value chain in industry. In addition to the famous kanban system extensively used by Toyota, lean manufacturers are also increasingly exchanging computerized information with suppliers who can help them reduce the lead time from product design to market (Kasarda and Rondinelli, 1998). It is important for lean manufactures to have good communication networks with their customers to get information on communication, order, production schedule, track and management material flow and inventory.

According to Udoka (1993), in lean manufacturing, due to a large number of parts in small quantities coming into the assembly plant, efficient, effective containerization is important. According to Nicholas (1998), use of containers of a standardized size can help reduce inventories and facilitate the distribution process in plant. According to Schniederjans (1993), use of bar-coding can result in reduction in wasteful activities of inspection, classification, and storage of inventory and use of reusable containers can lead to improvement in materials handling methods.

According to Florida (1996), he examines the relationship between advanced production practices and innovative approaches to environmentally conscious lean manufacturing. He states that industries that are innovative in terms of their manufacturing process are likely to be more active in addressing environmental costs. According to Maxwell et al. (1993), we maintain a good relationship between lean manufacturing and innovative environmental manufacturing practices in industries.

1.5 Concluding Remarks – Above analysis shows that lean manufacturing is very important for all kind of organizations to improve sustainable competitiveness. In these chapter different issues of lean manufacturing such as main practices, benefits and requirements have been discussed. Next chapter will discuss about literature review of lean manufacturing.

Chapter 2

Literature Review

2.1 Introduction

The term “lean manufacturing” or “lean production” was first used by Womack et al. (1990) in their historical book “The Machine That Changed the World”. The lean manufacturing describes the profound revolution that was initiated by the Toyota Production System against mass production system. Womack and Jones continued their research in lean production and studied the transfer of other companies into lean crusade in their second book, “Lean Thinking” (Womack and Jones, 1996). They explained that lean manufacturing is much more than a technique, it is a way of thinking, and the whole system approach that creates a culture in which everyone in the organization continuously improve operations. Liker (1997) wrote the third book in this series with the title of “Becoming Lean – Inside Stories of U.S. Manufacturers”. The most recent book about the Toyota system is also by Liker (2004) where he describes the management principles of Toyota that he claims to be the world’s greatest manufacturer.

Interestingly, every company has to find its own way to implement the lean method: there is no universal way that will apply to all. Despite the wide knowledge and available resources, many companies are struggling to stay “lean”. The decade of 1990s was witness to many transformation of traditional manufacturing into lean approach. Many companies either transformed or created new cellular production system. There are also examples of how a complete factory could be designed in lean principles.

Taj and Ghorashyzadeh (2003) address the strategic issues for planning lean manufacturing plants and Taj et al. (2000) show a real example of designing a factory with a future in mind. In order to improve manufacturing operations, we need to assess the state of operations at the manufacturing facilities. Assessment is a valuable tool that must be used to study the current state. Goodson (2002) has developed a tool kit which helps experts to understand the plant within 30 minutes and tells that plant is truly lean or not. He describes his approach as rapid plant assessment (RPA). To do this assessment you would need a team of experts to tour the plant. During the tour, the team observes all aspects of plant’s environment and looks for the evidence that the plant adheres to best practices. Lee (2004) an international renowned expert in lean manufacturing has also developed a lean assessment tool.

The goal of lean manufacturing is to reduce waste in human effort, inventory, time to market and manufacturing space to become highly responsive to customer demand while producing quality products in the most efficient and economical manner. Lean means “manufacturing without waste”. According to Russell and Taylor (1999), waste is anything other than minimum amount of equipment, materials, parts, and working time that are absolutely essential to production. Waste (“muda” in Japanese) has seven types: waste from overproduction, waste of waiting time, transportation waste, inventory waste, processing waste, waste of motion, and waste from product defects. Most companies waste 70-90 percent of their available resources. Even the best lean manufacturers probably waste 30 percent. Nicholas (1998) found that waste takes many forms and can be found at any time and in any place.

Lean manufacturing combines the best features of both mass and craft production: the ability to reduce costs per unit and dramatically improve quality while at the same time providing an ever wider range of products and more challenging work (Womack et al., 1990). Value stream refers to those specifics of the firms that add value to the product or service under consideration. It is a far more focused and contingent view of the value adding (VA) process. Lean manufacturing uses tools like one-piece flow, visual control, Kaizen, cellular manufacturing, inventory management, Poka yoke, standardized work, workplace organization, and scrap reduction to reduce manufacturing waste (Russell and Taylor, 1999).

Monden (1993) suggested a new scheme of classifying operations into three generic categories as non-VA, necessary but non-VA and VA. This scheme proved to be more generic and was extended to different areas. Over the years, many lean manufacturing tools to support value stream have been developed and many more are being proposed every day (Womack et al., 1990; Barker, 1994; Cusumano and Nobeoka, 1998; Childerhouse et al., 2000).

Value stream mapping are used primarily for two requirements: one to understand the interdependence of one function, department or even whole unit over another, and second to capture a holistic view about a situation where the conventional industrial engineering recording tools do not help much. As the complexity of manufacturing and business is growing newer, value stream tools are emerging. Recently, there exists a plethora of different tools and techniques developed for different purposes and waste reduction or elimination. The classification scheme suggested by Hines and Rich (1997) about seven new mapping tools (namely, process activity mapping, supply-chain response matrix, production variety funnel, quality. Filter mapping, demand amplification mapping, decision point analysis and physical structure mapping) regarding their major application areas is very useful. Chitturi et al. (2007) explored practical issues in job shop using a standard VSM and also explained how improved VSM can eliminate some limitations of old VSM.

Al-Sudairi (2007) built a simulation model to study the impact of certain lean manufacturing principles for enhancing the flow of construction material and found that lesser the time spend in the value stream, leaner is a process. Lian and Van Landeghem (2007) discussed on the application of VSM-based simulation generator in a manufacturer of poultry and pig-raising equipments for feeding, drinking, feed storage and feed transportation systems.

Singh et al. (2009) suggested industries to apply lean manufacturing techniques to find money drain points in their balance sheets and also apply these techniques to cut down operational cost to save business during recessionary times. Singh and Sharma (2009) showed that value stream mapping is a versatile tool for lean implementation by a case study of an Indian manufacturing industry and witnessed 92.58 percent reduction in lead time, 2.17 percent reduction in processing time, 97.1 percent reduction in work in process and 26.08 percent reduction in manpower requirement.

Singh et al. (2010a), developed an index for measuring leanness of any manufacturing firm based on the scores awarded by leanness measurement team members. Various types of manufacturing wastes addressed by lean manufacturing are taken as one parameter for measuring leanness index. This assessment tool helps to investigate, evaluate, and measure key areas of manufacturing. The tool is very user-friendly and the result is a deeper understanding of key issues, problem areas, and potential solutions.

2.2 Lean manufacturing indicators:

Sanchez and Perez (2001) focused on six Lean Manufacturing indicators.

i) Elimination of zero-value adding activities

ii) Continuous improvement

iii) Multifunctional teams

iv) Just-in-time production and delivery

v) Integration of suppliers

vi) Flexible information system

i) Elimination of zero-value adding activities

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

ii) Continuous improvement

Continuous improvement is a process that requires involvement of employees at different levels and support of management. This process relates to the *Jidoka* concept, which states that since people are not working for the machines, they have the ability to use their best judgment to improve the process. In addition, they will assume more than minimum responsibilities making sure the machines function correctly. All members in the company should strive for continuous improvement in products and processes. This would require the creation of improvement teams to lead the organization to move toward zero defects.

iii) Multifunctional teams

Multifunctional teams are also related to the *Jidoka* concept in that floor workers are not tied to one machine and do not work in "isolated is lands."

Workers should be trained to work on multiple tasks and thus al low the company to flexibly "accommodate changes in production levels."

iv) Just-in-time production and delivery

Just-in-time is also related to the first indicator of eliminating waste because it reduces excess inventories and work-in-progress.

v) Integration of suppliers

Suppliers can play an important role in achieving the just-in-time production concept. By reducing the amount of time required to wait for parts and arrival of materials, manufacturing companies can place an order after they are certain of the quantity and products desired by their customers. This can greatly reduce "just-in-case" inventories in the system and production lead time.

vi) Flexible information system

Excessive paper work is considered to be one of the traditional areas of waste. Lean production requires the diffusion of useful and relevant information to the production line. By decentralizing responsibilities to the first line workers, the amount of time wasted in processing documents can be reduced.

Rather than embracing one or two isolated tools it is suggested that it is important that companies practice most, if not all, of the following:

Continuous improvement/kaizen: The continual pursuit of improvements in quality, cost, delivery and design.

Cellular manufacturing: It is vital to group closely all the facilities required to make a product (or related group of products), in order to reduce transport, waiting and process time.

Kanban: A kanban system needs to be in place.

Single piece flow needs to be in operation: Where products proceed, one complete product at a time through various operations in design, order taking and production, without interruptions, backflows or scrap.

Process mapping exercise is required: This is a detailed mapping of the order fulfilment process.

Single minute exchange of dies (SMED): In order to reduce the lead-time and improve flows it is necessary to eliminate delays in change-over times on machines.

Step change/kaikaku: There is a need to make radical improvements of an activity to eliminate waste.

Supplier development: The organization needs to actively develop links with suppliers and working closely with them for mutual benefit.

Supplier base reduction: Further attempting to reduce the number of suppliers an organization engages with.

Five S and general visual management: To reduce the clutter and inefficiency of any typical production and office environment.

Total productive maintenance (TPM): This is aimed at improving the reliability, consistency and capacity of machines through maintenance regimes as dwelled on originally by Ohno (1988).

Value and the seven wastes. The notion of value should never be ignored and essentially is the capability provided to the customer at the right time at an appropriate price, as defined in each case by the customer.

2.3 Concluding Remarks- Above analysis shows that lean manufacturing is very useful in organizations. It eliminates zero value adding process and continuous improvement in production system. It increases flexibility in organizations. Next chapter will discuss about justification of lean manufacturing using analytic hierarchy process (AHP).

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Chapter 3

Justification of Lean manufacturing using Analytic Hierarchy Process (AHP)

3.1 Introduction

In this chapter, lean manufacturing has been compared with traditional manufacturing. To justify use of lean manufacturing in place of traditional manufacturing different benefits have been analyzed. With the help of literature review, different benefits of lean manufacturing are shown in table 3.1. According to Sohal and Eggleston (1994), lean manufacturing increases the net profit because it reduced the wastages in the production system. Lean manufacturing increases productivity of the plant so that production rate increases (Philips, 2002). Shingo (1989) states that lean manufacturing decrease waste in the plant. Lean manufacturing eliminates the non value adding process so that wastage decreased. Gilson et al. (2005) have observed that Lean manufacturing improves the quality of product because it uses the standard process to make a product. According to Monden (1983), lean manufacturing improves the flexibility in production system. According to Suzuki (1995), the amount of inventory gets reduced in industry by using lean manufacturing. With the help of Lean manufacturing, lead time gets reduced because it decreases the set up time of machine (Al-Najjar and Alsyouf, 2000). For justifying use of lean manufacturing based on these benefits, Analytic Hierarchy Process (AHP) approach has been applied.

3.2 Research Methodology

Saaty (1980) had suggested analytic hierarchy process (AHP) which is used to solve complex problems. Basically, decision makers have to decompose the goal of the decision process into its constituent parts, progressing, from the general to the specific perspective. It organises the basic rationality by breaking down a problem into its smaller and smaller constituent parts and then guides decision makers through a series of pair wise comparison judgements to express relative strength or intensity of impact of the elements in the hierarchy. Once the hierarchy has been structured, decision makers judge the importance of each criterion in pair-wise comparisons, structured in matrices. According to Satty (1980) the final scoring has been on relative basis after that compare the importance of one decision alternative to another. In analytic hierarchy process takes both objective and subjective evaluations. In subjective evaluation, we directly question the decision makers after that we get the priority weight of element. Kodali and Chandra (2001) used AHP for justification of total productive maintenance.

In this research, justify the lean manufacturing vs. traditional manufacturing with the help of Analytic hierarchy process (AHP). In this methodology, we follow four phases to reach the final result.

This study has gone through four phases, as follows:

1 structuring the problem and building the AHP model
2 collecting data from expert interviews
3 determining the normalized priority weights of individual factors and sub factors
4 synthesis-finding solution to problem.

3.2.1 Phase 1: structuring a hierarchy model

In this phase, formulate the appropriate hierarchy of AHP model consisting of goal, main factors and result. The goal of our problem is to justify the lean manufacturing over traditional manufacturing. This goal is placed on the first level of the hierarchy as shown in Figure 1. Seven major benefits, namely Improve net profit, improve productivity, waste reduction, improve quality, improve flexibility, inventory reduction and lead time reduction are identified to achieve this goal, which make the second level of hierarchy. The major benefits of lean manufacturing used in the second level of hierarchy can be assessed using the basic AHP approach of pair wise comparison of elements in each level with respect to every parent element located one level above. The third and last level consists of two alternatives, i.e., lean manufacturing and traditional manufacturing. AHP model is shown in Figure 3.1.

3.2.2 Phase2: measuring and collecting data

After building the AHP hierarchy, then our next step is to measurement and data collection. It was done by a team of experts and assigning pair-wise comparison to the main factors used in the AHP hierarchy. We use nine-point scale (Table 3.2) to assign relative scores to pair wise comparisons amongst the main factors. With the help of scale, experts assign a score to each comparison. Experts continue this process until all levels of the hierarchy and eventually a series of judgment matrices for the major factors were obtained. Team consisted of twelve experts, Out of these twelve experts; six were from industry, mainly from manufacturing sector such as automobile and electronics equipment sectors and six from academic sector. Each one of them has more than eleven year of experience in lean manufacturing area. A questionnaire consisting of all main factors of the two levels of AHP model is designed and is used to assemble the pair wise comparison judgment from all the experts.

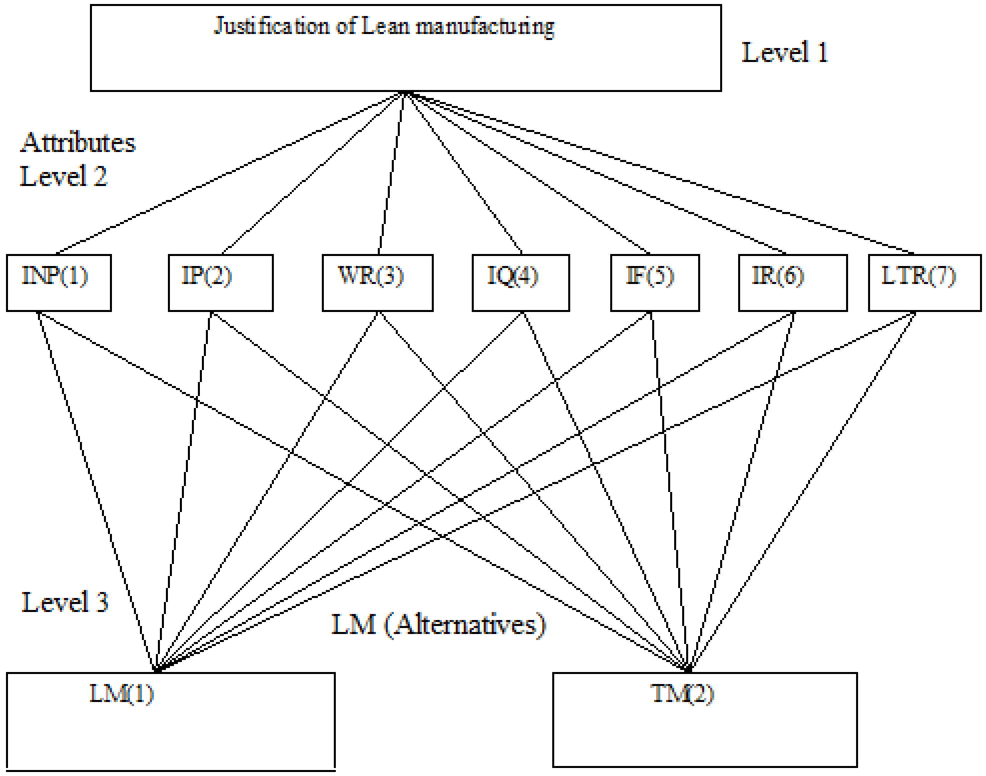


Fig. 3.1 Schematic of AHP model (Source- Rajesh K. Singh, 2012)

We do this process continue until consensus made otherwise decision of majority gives more importance. In past, some researchers adopted a team of decision makers which have less than ten experts. Bayazit (2005) used AHP approach in decision making for flexible manufacturing system by having a team of six experts from various departments. Zaim et al. (2012) also used a team of five decision experts while selecting maintenance strategy.

Table 3.1: Benefits of LM

S.NO.	Abbreviation	Benefits of LM	References
1	INP	Improve Net Profit	Sohal and Eggleston, (1994) Standard and Davis (2000)
2	IP	Improve Productivity	Lathin (2001) Philips (2002)
3	WR	Waste Reduction	Shingo, S. (1989) Ferch (1998) Claudius Consulting (2004)
4	IQ	Improve Quality	Gilson, L.L., Mathieu, J.E., Shalley, C.E. and Ruddy, T. (2005) Molleman, E. (2000)
5	IF	Improve Flexibility	Womack, J. et al. (1990) Allwood, J.M. and Lee, W.L. (2004) Monden, Y. (1983)
6	IR	Inventory Reduction	Shingo, S. (1990) Suzuki, T. (1995) Shen, C.H. and Wacker, J. (1997)
7	LTR	Lead Time Reduction	Al-Najjar and Alsyouf (2000) Schonberger (1986) Tajiri and Gotoh (1992) Teresko (1992)

Table 3.2: Thomas Saaty’s nine-point scale

Intensity of importance	Definition	Explanations
1	Equal Importance	Two activities contribute equally to the objective
3	Weak Importance one over another	Experience and judgment slightly favor one activity over another
5	Essential or Strong Importance	Experience and judgment strongly favor one activity over another
7	Demonstrated Importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute Importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgment	When compromise is needed
Reciprocals of above non-zero	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j* then *j* has the reciprocal value when compared with *i*	A reasonable assumption

Source : Saaty (1994)

3.2.3 Determine normalized weights

In order to find out the relative importance of seven major factors, then we make pair wise comparison judgment matrices with the help of experts’ opinion, in the measurement and also data collection phase. For finding normalized weight, we follow following Steps:

3.2.3.1 Construction of pair-wise comparison matrices

We make a set of pair-wise comparison matrices for each of lower levels attributes. An element, which is places at higher level is said to be a governing element which is placed in the lower level. Lower level elements are compared to each other based on their effect on the governing element at higher level. This yields a square matrix of judgments. We make pair-wise comparisons in such manner that one element dominate to other. Then these judgments expressed as integers. If element X dominates over Y, then the whole number integer is entered in row X, column Y and reciprocal is entered in row Y, column X If the elements being compared are equal, a one is assigned to both positions. Table 3.4 shows the pair-wise comparison matrix for level 2 criteria. There are n(n – 1)/ 2 judgments required to develop the set of matrices (reciprocal are automatically assigned in pair-wise comparison).

3.2.3.2 Find out the degree of consistency in order to validate the results

It is known that people are often inconsistent in answering questions, and thus one of the important tasks of AHP is to find out the consistency level of the estimated vector. In pair wise comparison, we use the Consistency ratio (CR) to measure the consistency level. Saaty (1994), gives the acceptable level of Consistency ratio (CR) for different matrices. For 3×3 matrix acceptable Consistency ratio (CR) is 0.05 and for 8×8 matrix is 0.08 and for large matrix is 0.1. If consistency level with in the acceptable range, then weight result is valid. When completed all the pair-wise comparisons and fill the data then the consistency is determined by using the eigen values. After that we normalize the columns by dividing each entry to the sum of all entries. After that we do sum of each row of the normalized values then take the average. This gives priority vector (PV). We check the consistency of judgments by following steps:

- Let the pair-wise comparison matrix is denoted by P1 and principal matrix is denoted by P2
- Then define P3 = P1 * P2; and P4 = P3 / P2
- $\lambda_{max.}$ = average of the elements of P4
- Consistency index (CI) = $\frac{(\lambda_{\max} - n)}{n-1}$

- Consistency ratio (CR) = CI / RCI corresponding to n.

Where RCI = Random Consistency Index and n = Numbers of elements (Table 3.3)

Table 3.3: Average random index values

N	1	2	3	4	5	6
RCI	0	0	0.58	0.90	1.12	1.24

Source: Saaty (1980)

3.3 Results and discussion

When we make AHP hierarchy model, table 3.1 shows seven main factors which are considered for analysis. AHP model developed as shown in Figure 3.1 is used for justification of Lean manufacturing in SMEs. Then we make pair-wise comparison judgment matrices to find out the normalized weight. Pair wise criteria comparison matrix shown in table 3.4, this table shows all the seven major benefits of lean manufacturing. After that we calculate the CR value to check the degree of consistency of the pair wise comparison matrix and CR for level 1 are shown in table 3.5. Then we follow same procedure to find the PV and CR for other levels. Then table 3.6 shows the results. We observed from table 3.6 that all seven factors of lean manufacturing have more PV in comparison to traditional manufacturing. We also examined that CR value is less than 0.1 for all decision factors. Local weight of attributes for alternatives shows in table 3.7. Global weight of major benefits for lean manufacturing shown in table 3.8. Global weights have been calculated by following method:

Individual weight of the main factor = P.V. value from the respective normalized table

Individual weight of the sub factor = P.V. value from the respective normalized table

Global weight of main factor = individual weight of that main factor

Similarly, global weights for other strategic factors and sub factors can be calculated:

Global Wt. of lean manufacturing (LM) = Level 2 Wt. × LM Wt.

Global Wt. of traditional manufacturing (TM) = Level 2 Wt. × TM Wt.

Total global Wt. = sum of the global wt. of respective column.

Out of seven major benefits of lean manufacturing, lead time reduction has highest global weight (0.33832). minimum lead time is required to obtain maximum profit because lead time decrease production increase. Second highest global weight is to increase productivity (0.22258). If productivity increased then net profit increase. So we increase the productivity in such a manner that overall cost of operation decrease. Improve flexibility has third highest global weight whose global weight is (0.15218). If flexibility increases in production system then our profit increased.

Fourth highest global weight is improves quality (0.07793). With the help of lean manufacturing, quality of product increased because we use standard process to make a product. Waste reduction is the fifth benefit of lean manufacturing whose global weight is 0.04861. With the help of lean manufacturing we eliminate non value added process so that our wastage is reduced. Six benefit of lean manufacturing is inventory reduction and its global weight is 0.03804. With the help of lean manufacturing, raw material and work in process inventory decreased because of standard process and JIT. Next benefit of lean manufacturing is increased net profit. When lean manufacturing used then production increased, inventory decreased, waste decrease, lead time decrease, increase flexibility and improve quality. So that effect of these factors our net profit increased. Global desirability index of lean manufacturing and traditional manufacturing shown in table 3.9.Global desirability index of lean manufacturing is 0.89568 and traditional manufacturing is 0.10431. So this analysis shows that application of lean manufacturing is better than traditional manufacturing.

Table 3.4: Criteria pair wise comparison matrix (level 2)

	INP	IP	WR	IQ	IF	IR	LTR	P.V
INP	1	1/9	1/5	1/5	1/8	1/4	1/9	0.02025
IP	9	1	6	5	3	6	1/4	0.24732
WR	5	1/6	1	1/3	1/5	2	1/7	0.05556
IQ	5	1/5	3	1	1/4	3	1/4	0.08907
IF	8	1/3	5	4	1	4	1/3	0.16908
IR	4	1/6	1/2	1/3	1/4	1	1/8	0.04279
LTR	9	4	7	4	3	8	1	0.37591

Following steps are used to normalize the table of seven main benefits and to calculate the CR value.

Let P_1 is pair wise comparison matrix

P_2 is principal vector matrix

$$P_2 = \begin{Bmatrix} 0.02025 \\ 0.24732 \\ 0.05556 \\ 0.08907 \\ 0.16909 \\ 0.0428 \\ 0.37591 \end{Bmatrix}$$

Then $P_3 = P_2 \times P_1$

$$P_3 = \begin{Bmatrix} 0.1502595 \\ 2.0663064 \\ 0.4008324 \\ 0.671103 \\ 1.3440995 \\ 0.3117478 \\ 3.142288 \end{Bmatrix}$$

$P_4 = P_3/P_2$

$$P_4 = \begin{Bmatrix} 7.420271 \\ 8.35473 \\ 7.214518 \\ 7.534481 \\ 7.949064 \\ 7.284357 \\ 8.359096 \end{Bmatrix}$$

Average of elements of P_4 ($\lambda_{\max.}$) = 7.7309308

Now consistency index (CI) = $\dfrac{(\lambda_{\max} - n)}{n-1}$ = 0.121822

And consistency ratio (CR) = CI / RCI = 0.092289

Table 3.5: Consistency ratio of comparison matrix

CR	0.092289

So CR is less than 0.1, result is consistent.

Table 3.6: Pair wise comparison judgment matrices for Alternatives

Alternative analysis with respect to [INP]			
	LM	TM	P.V.
LM	1	8	0.8889
TM	1/8	1	0.1111
TOTAL	1.125	9	**CR<0.1**
Alternative analysis with respect to [IP]			
	LM	TM	P.V.
LM	1	9	0.9
TM	1/9	1	0.1
TOTAL	1.1111	10	**CR<0.1**
Alternative analysis with respect to [WR]			
	LM	TM	P.V.
LM	1	7	0.875
TM	1/7	1	0.125
TOTAL	1.4285	8	**CR<0.1**
Alternative analysis with respect to [IQ]			
	LM	TM	P.V.
LM	1	7	0.875
TM	1/7	1	0.125
TOTAL	1.4285	8	**CR<0.1**
Alternative analysis with respect to [IF]			
	LM	TM	P.V.
LM	1	9	0.9
TM	1/9	1	0.1
TOTAL	1.111	10	**CR<0.1**

Alternative analysis with respect to [IR]			
	LM	TM	P.V.
LM	1	8	0.8889
TM	1/8	1	0.1111
TOTAL	1.125	9	**CR<0.1**
Alternative analysis with respect to [LTR]			
	LM	TM	P.V.
LM	1	9	.9
TM	1/9	1	.1
TOTAL	1.111	10	**CR<0.1**

Table 3.7: Weights of attributes for alternatives

S.NO.	ATTRIBUTES	Level 2 Wt. (P.V.)	LM Wt. (P.V.)	TM Wt.(P.V.)
1	INP	0.02025	0.8889	0.1111
2	IP	0.24732	0.9	0.1
3	WR	0.05556	0.875	0.125
4	IQ	0.08907	0.875	0.125
5	IF	0.16908	0.9	0.1
6	IR	0.04279	0.8889	0.1111
7	LTR	0.37591	0.9	0.1

Table 3.8: Desirability index table of alternatives global weight

S.NO.	ATTRIBUTES	LM GLOBAL WT.	TM GLOBAL WT.
1	INP	0.01799	0.00225
2	IP	0.22258	0.02473
3	WR	0.04861	0.00694
4	IQ	0.07793	0.01113
5	IF	0.15218	0.01690
6	IR	0.03804	0.03759
7	LTR	0.33832	0.104316

Table 3.9: Global desirability index of alternatives

GLOBAL DESIRABILITY INDEX OF LM	0.89568
GLOBAL DESIRABILITY INDEX OF TM	0.10431

3.4 Conclusion and Remarks- Above analysis shows that lean manufacturing is better than traditional manufacturing. Global desirability index of lean manufacturing is 0.89568 and global index of traditional manufacturing is 0.10431. So global desirability index of lean manufacturing is higher than traditional manufacturing. Next chapter will describe prioritizing the critical success factors for lean manufacturing implementation by TOPSIS approach.

Chapter 4

Prioritizing the critical success factors for lean manufacturing implementation by TOPSIS approach

4.1 Introduction

The term Lean first defined by Womack, Jones and Roos (Womack et al., 1990, Womack and Jones 1996) which is another name of Toyota production system (TPM). Womack at al. (1990) wrote a book whose name is "The Machine That Changed the World". In this book first time "Lean manufacturing" or "Lean Production" was used. Womack and Jones (1996) write second book whose name is "Lean Thinking". In this book they described that lean manufacturing is not only a technique but it is a way of thinking and we improve the organization culture in such a way that everyone in the organization take participate to continuously improve operations. Karlsson and Ahlstrom (1996), states that lean production spread throughout the organization. It consists of lean procurement, lean development, lean manufacturing and lean distribution. They states that lean manufacturing contain following items i.e. continuous improvement, elimination of waste, zero defects/JIT, multifunctional teams, decentralized responsibilities/integrated functions, vertical information system and pull versus push. The main aim of lean is to continuous improve in effectiveness and efficiency of organization by reducing waste. According to Womack and Jones (1996), an organization must find out the customer need and what a customer think as a value. Then an organization eliminates the non-value added process or waste and use only value added process. According to Nicholas (1998) waste can be found in any place and in any time in a production system and waste are found in various forms. These wastes cannot add any value to the product but consume resources. Azharul and Kazi (2013) have observed that organization should identify the various manufacturing wastes and should improve the manufacturing processes to make them more effective. According to Russell and Taylor (1999), if we use more than minimum required resources to make a product then wastage occurs in the production system. The main aim to introduce lean production in any organization is to reduce waste, lead time and cost by increasing productivity and improving quality (Shriparavastu and Gupta, 1997). According to Roberto et al. (2013), there is positive and significant relationship between lean practices, quality, delivery, cost and flexibility. According to Melles

(1997), lean production is not a new principle of management technique but it is combination of existing principles. Khokela (1992) observed that there are different methods to reduce cycle time like we use Just in Time principle to decrease stock of inventory and we decentralized the organization hierarchy. Khokela also suggest that if we decrease the number of component in a product and reducing the material flow helps to simplify the production processes. Boyer and Sovilla (2003), states that successful implementation of lean manufacturing in an organization depends upon the top management support. Top management courage their employees and respect their efforts. If top management does not respect their efforts and discourage them then lean manufacturing cannot achieve their goal and ultimately lean manufacturing fail. Hayes (2000) states that first we proper plan the lean manufacturing after that we implement the lean manufacturing. Holland and Light (1999) states that any productivity improvement technique implemented in an organization then top management have clear vision and strategy about the cost and duration of project. Storch and Lim (1999) states that a clear communication required between shifts as well as all value stream to successfully implement the lean manufacturing in an organization. Robert and Rapinder (2013) make a lean system reliability model which determines the reliability of whole lean system. According to Manimay (2013) implementation of lean in Indian industry decrease manufacturing lead time, increased productivity and improve first pass correct output.

4.2 Identification of CSFs of Lean Manufacturing

Critical success factors are very important to implement Lean manufacturing because these factors affect the performance of Lean manufacturing. Boynton and Zmud (1984) state that critical success factors are those things which must go well to get success. According to Rockart (1979) critical success factors are those areas in which satisfactory result will give better performance of an organization. CSFs give early warning to the management. According to Laudon and Laudon (2002) satisfactory CSFs give successful competitive performance and advantage for the organization. Critical success factors in Lean Manufacturing decrease cost and premature failure but increase success rate. Critical success factors of lean manufacturing are following:

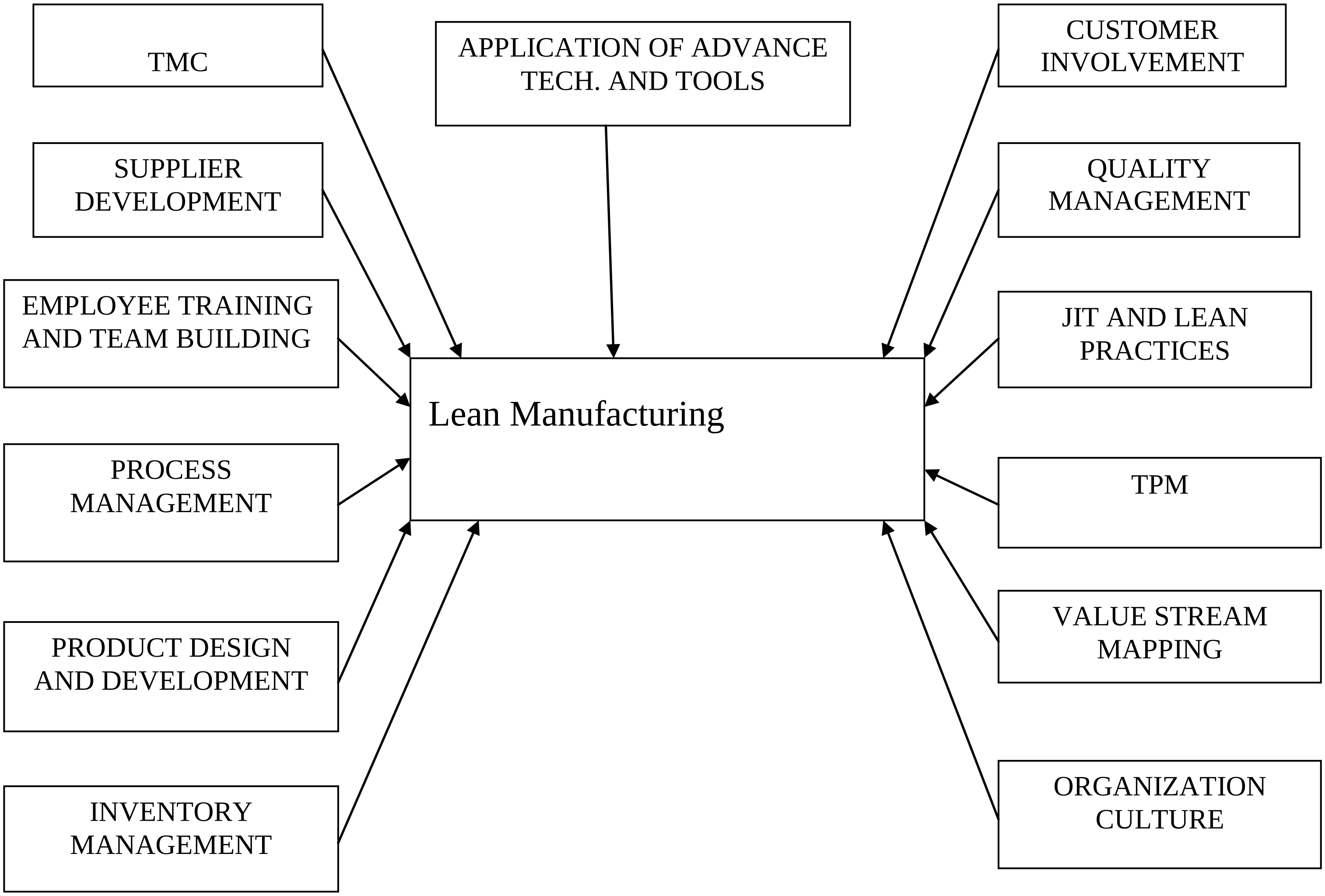


Fig. 4.1 critical success factors

Top Management commitment (TMC):

Top Management Commitment is very important to implement the lean manufacturing. Top Management creates interest in organization to implement the lean manufacturing and also communicate to everyone for implement the lean manufacturing (Boyer and Sovilla, 2003). For implementing lean manufacturing, clear communication required between shifts as well as all value streams (Storch and Lim, 1999). If workers feel that Top Management does not respect their work, then discouragement occurs in workers and implementation of lean manufacturing fail. So all the staff members including top management involves an active engagement for implementing lean manufacturing. McLachlin (1997) describe the visible demonstration of commitment by managers is one of the usual management initiatives to support lean manufacturing. Management should manage the LP adoption process with proper planning and within time limit so that LP gives its outcome (Pedro et al. 2013).

Employee Training and Team Building:

Lean manufacturing focuses on proper training and education so that employees improve their skill and knowledge. Employees training include some specific training as well as general training. A study undertaken by Thomas and Webb (2003) shows the main reason which companies failed to adopt new and advanced technologies was that the managing directors felt that their workforce did not have the technical and intellectual capacity to take on such new technologies so management fear that the technology would be under-utilized and thus will not return a cost effective yield on investment. Allwod and Lee describe that training for a new task is a time consuming but it is necessary to develop multiskilling. However a long training period may make multiskilling expensive and even unadvisable (Allwood and Lee, 2004).

Supplier Development:

Supplier Development plays an important role to implement lean manufacturing effectively in the organization. Quality of production depends upon the raw material supplied by the supplier. We must maintain good relationship to a few suppliers rather than many suppliers and this relationship goes to long term and mutually beneficial to both the parties. According to Sheridan (1995) on time delivery of material is very important.

Process Management:

Lean manufacturing implementation decentralized the responsibility of workers in production line. Lean manufacturing requires flow of information to all the levels (Womack and jones, 1996). Lean manufacturing requires useful information deliver timely to the production line. We find out the strengths, opportunities, threats and weaknesses of the organization. Then we do our production with existing strengths and best external practices (koskela, 1992). More scrap is produce by a low quality manufacturing process. So a periodic review of manufacturing process is done and takes remedial action of defective manufacturing process to maintain quality of product. “The set of cross functional processes and activities directed at creating and satisfying customers through continuous assessment” (Deshpande´ and Farley, 1996).

Product Design and Development:

A good product design directly impacts the product success or failure. A good product design fulfills the expectations and requirements of customer. Koskela (1992) states that using modularized product designs, changeovers and setups difficulty are decreased and training a multi-skilled workforce help to increase output flexibility. Good product design decrease the product lead time. Organization launches new products periodically into the market. For low manufacturing cost and high quality product, organization reconfigures their manufacturing system (Wainwright, 1995; Bessant and Haywood, 1998). Koskela (1992) identified two reasons for reducing process variability. First, a uniform product is better from the customer point of view. Secondly, variability increases the amount of non-value adding activities.

Inventory Management:

Inventory management is the process of efficiently overseeing the constant flow of units into and out of an existing inventory. Inventory Management control the transfer of units in the organization to prevent the inventory too high or low. There are many techniques to reduce the inventory. According to Suzuki, we reduce standing time of machine due to breakdown or malfunction by predictive and preventive maintenance (Suzuki, 1995). Second technique is the simultaneous reduction of setup time and manufacturing lot size (Shingo, 1990). Third technique is the use of common parts to manufacture different products in order to reduce inventories and lead time (Shell and Wacker 1997). We can reduce the buffer stock in organization when vendors’ delivery performance is high (Schonberger, 1983). According to Levy(1997), if distance between supplier and buyer increased then amount of inventory also increased.

Customer involvement:

Levy (1997) states that in lean manufacturing a good coordination is required between suppliers and customers to get desired quality and delivery. Customer gives the feedback to supplier so that supplier improves the value of product.

Quality Management:

Quality is a top level objective in an organization. So we maintain the quality of a product by continuous improvement, zero defect, standardisation, inspection and rectification. In continuous improvement, we improve the processes so that our wastage reduces and product performance improves. Quality can also be improved by finding the reason that can cause the defect in product. Monden (1983) describes that standardisation is essential for lean manufacturing, standardisation depend upon the sequence of task done by each worker and how these task are done.

Application of advance Tech. and Tools:

Rapid Process Improvement (RPI) event is focused action workouts of 1-5 days where workers tackle a process improvement opportunity in a data driven approach to develop and maybe even partially implement the process improvements. Single minute exchange of die (SMED), in this technique we divide the set-up and change-over procedures into external and internal elements and concentrating on reducing the internal time taken so that less of the equipment's available time is consumed during a change-over (Shingo, 1985). SMED technique is used to eliminate small stop time loss. This technique is very useful to improve the changeover loss (Samuel et al. 2013).

JIT and Lean Practices:

Calvasina et al. (1989) States that, "JIT is a system of production control that seeks to minimize raw materials and WIP inventories, control (eliminate) defects, stabilize production, continuously simplify the production process, and create a flexible, multi-skilled work force. Schonberger (1987) states that, JIT was the "most important productivity enhancing management innovation since the turn of the century". JIT practices experience greater benefits in (i) quality improvement; (ii) time-based responses; (iii) employee flexibility; (iv) accounting simplification; (v) financial performance; and (vi) inventory reduction. According to Gusman et al. (2013), Lean practices have a significant and positive impact on business performance and operation performance.

TPM:

TPM is used to improve overall efficiency by productive maintenance. It covers the whole equipment life, equipment related to planning, maintenance etc. and participation of all employees from shop floor workers to top management, to promote productive maintenance (Tsuchiya, 1992). According to Swanson (2001), design and function of production equipment's in an organization are improved by TPM. According to Nakajima (1988), TPM is a maintenance system which covers the whole life of equipment including planning, manufacturing and maintenance. The main aim of the TPM is to increase the effectiveness of equipment's. TPM is related to long term maintenance in an organization to improve the equipment's life. TPM also improve the quality of product as well as it decrease the cost of product.

Value Stream Mapping (VSM):

A value stream means collection of all the process (value added and non-value added) which is required for a product from its raw material to ending of customer (Rother and shook 1999). The main aim of VSM is to find out the all types of waste in value stream and eliminate or reduce these wastes (Rother and Shook 1999). Value Stream Mapping eliminates the wastage in product cycle, so that costs of the product decrease also total time of a product cycle decrease. With the help of VSM we can find the hidden wastage and also find out the source of wastage.

Organization Culture:

The culture of an organization must be honest and open so that employees give suggestions without any fear and they participate in process mapping (Green, 2002). Managers have a challenge to make such organization culture which supports the innovation. Organization culture is associated with innovation so that performance of firm increase (O'Regan et al., 2006a,b). Managers manage the organization culture so effectively that organization gets its objective or goal without any hurdle. When employees are satisfied with job then creativity of employees increase which help the organization and co-workers (Zhou and George, 2001).

4.3 Use of TOPSIS:

Critical success factors are ranked by various methods. Lee and Eom (1990) suggested that multiple criteria decision making is very important tool used for dealing that problems which contain potentially conflicting and multiple objectives. To handle the problem of engineering and management, different multiple criteria decision making techniques had been developed i.e. TOPSIS, AHP, simple average weight and ELECTRE (Stelios et al., 1998). Hwang and Colleagues in 1981, make a tool whose name is TOPSIS to solve the problems of MCDM. In TOPSIS the most preferred alternative is that one whose has shortest distance to the positive ideal solution or longest distance from negative ideal solution (Hawang et al. 1993). Positive Ideal Solution is that one which has minimum possible cost and maximum benefits of all other alternatives. Negative Ideal Solution is that one which has maximum possible cost and minimum benefits of all other alternatives.

Following steps have been used in TOPSIS to calculate the rank.

Step 1:

Calculate the normalized decision matrix as:

$$R = [\ r_{ij}\ ] \qquad \text{..................} \ (1)$$

Where

$$r_{ij} = \frac{X_{ij}}{(\sum X_{ij}^2)^{1/2}}$$

R is normalized matrix of element r_{ij}.

Step 2:

Construct the weighted normalized matrix by multiplying the elements by weights of corresponding criteria.

$$V_{ij} = r_{ij} * W_j \qquad \text{..................} \ (2)$$

Step 3:

Find out the positive and negative ideal solutions as V_i^+ and V_j^- respectively by finding the maximum and minimum values of weighted normalized elements in each column.

V_i^+ = Max. weighted normalized elements in each column .... (3)

V_j^- = Min. weighted normalized elements in each column .... (4)

Step 4:

Calculate the separation measures for each alternative.

$$S_i^+ = [\sum(V_{ij} - V_i^+)^2]^{1/2} \quad \text{................................ (5)}$$

And

$$S_i^- = [\sum(V_{ij} - V_j^-)^2] \quad \text{................................. (6)}$$

Step 5:

Calculate the relative closeness to ideal solution using the formula:

$$C_i^+ = \frac{s_i^-}{s_i^+ + s_i^-} \quad \text{................................ (7)}$$

4.4 Case Application:

We studied the three companies which are from the manufacturing sector. These companies were certified by ISO 9001:2000 certificate. We provide the list of critical success factors to the decision makers of these companies and told them to give the rating of these critical success factors on five point scale. A factor which is very important, give them five points and a factor which is least important give them one point.

4.5 Findings and discussion:

Three decision makers give the score to the critical factors which is shown in table 4.1. After that we normalized the matrix. Table 4.2 shows normalized decision matrix. Then we multiply the normalized matrix to the weight. Weight is given by the experts. Table 4.3 shows the weighted normalized matrix. Then we find out the separations of each alternative. Table 4.4 shows the positive ideal solution and table 4.5 shows the negative ideal solution for each alternative. Then we find out the separation from positive ideal solution which is shown in table 4.6 and separation from negative ideal solution in table 4.7. Table 4.8 shows the relative closeness to ideal solution. Minimum distance to the ideal solution has most critical factor and maximum distance to the ideal solution is least critical factor. Table 4.9 shows the rank of alternatives which depend upon the distance from ideal solution.

Table 4.1: Score provided by three Decision makers

CRITICAL SUCCESS FACTOR	**DM1**	**DM2**	**DM3**
Top mgmt commitment	5	5	4
Supplier development	4	3	3
Employee training and team building	4	4	5
Process management	5	4	5
Product design and development	4	3	5
Inventory management	3	3	5
Customer involvement	3	4	3
Quality management	4	4	5
Application of advance tech. And Tools	4	4	4
JIT and lean practices	5	4	3
TPM	4	3	4
Value stream mapping	3	4	5
Organization culture	5	4	4

By using equation 1, calculate normalised decision matrix.

Table 4.2: Normalised decision matrix

CRITICAL SUCCESS FACTORS	**DM1**	**DM2**	**DM3**
Top mgmt commitment	0.334824765	0.363696484	0.257662651
Supplier development	0.267859812	0.21821789	0.193246988
Employee training and team building	0.267859812	0.290957187	0.322078313
Process management	0.334824765	0.290957187	0.322078313
Product design and development	0.267859812	0.21821789	0.322078313
Inventory management	0.200894859	0.21821789	0.322078313
Customer involvement	0.200894859	0.290957187	0.193246988
Quality management	0.267859812	0.290957187	0.322078313
Application of advance tech. And tools	0.267859812	0.290957187	0.257662651
JIT and lean practices	0.334824765	0.290957187	0.193246988
TPM	0.267859812	0.21821789	0.257662651
Value stream mapping	0.200894859	0.290957187	0.322078313
Organization culture	0.334824765	0.290957187	0.257662651

By using equation 2, calculate normalized decision matrix.

Table 4.3: Weighted normalized decision matrix

CRITICAL SUCCESS FACTORS	**DM1**	**DM2**	**DM3**
Top mgmt commitment	0.133929906	0.109108945	0.077298795
Supplier development	0.107143925	0.065465367	0.057974096
Employee training and team building	0.107143925	0.087287156	0.096623494
Process management	0.133929906	0.087287156	0.096623494
Product design and development	0.107143925	0.065465367	0.096623494
Inventory management	0.080357944	0.065465367	0.096623494
Customer involvement	0.080357944	0.087287156	0.057974096
Quality management	0.107143925	0.087287156	0.096623494
Application of advance tech. And tools	0.107143925	0.087287156	0.077298795

JIT and lean practices	0.133929906	0.087287156	0.057974096
TPM	0.107143925	0.065465367	0.077298795
Value stream mapping	0.080357944	0.087287156	0.096623494
Organization culture	0.133929906	0.087287156	0.077298795

By using equation 3 and 4, calculate the ideal solution and negative ideal solution.

Table 4.4: Ideal solution

DM1	DM2	DM3
0.133929906	0.109108945	0.096623494

Table 4.5: Negative ideal solution

DM1	DM2	DM3
0.080357944	0.065465367	0.057974096

By using equation 5, calculate separation from positive ideal solution.

Table 4.6: Separation from positive ideal solution

CRITICAL SUCCESS FACTORS	**S_i^+**
Top mgmt commitment	0.019324699
Supplier development	0.064155856
Employee training and team building	0.034549664
Process management	0.021821789
Product design and development	0.051207916
Inventory management	0.069099328
Customer involvement	0.069569545
Quality management	0.034549664
Application of advance tech. And tools	0.039586908
JIT and lean practices	0.044384304
TPM	0.05473294

Value stream mapping	0.057845878
Organization culture	0.02914849

By using equation 6, calculate separation from Negative ideal solution.

Table 4.7: Separation from Negative ideal solution

CRITICAL SUCCESS FACTORS	**S_i**
Top mgmt commitment	0.071750687
Supplier development	0.026785835
Employee training and team building	0.051840671
Process management	0.069569545
Product design and development	0.047024087
Inventory management	0.038649398
Customer involvement	0.021821789
Quality management	0.051840671
Application of advance tech. And tools	0.039586908
JIT and lean practices	0.057845878
TPM	0.033029271
Value stream mapping	0.044384304
Organization culture	0.060988438

By using equation 7, calculate relative closeness to ideal solution.

Table 4.8: Relative closeness to the ideal solution

CRITICAL SUCCESS FACTORS	**C_i^+**
Top mgmt commitment	0.78781645
Supplier development	0.2945379
Employee training and team building	0.6000749
Process management	0.76122693
Product design and development	0.47870434

Inventory management	0.35869935
Customer involvement	0.23877307
Quality management	0.6000749
Application of advance tech. And tools	0.5
JIT and lean practices	0.56583953
TPM	0.37634958
Value stream mapping	0.43416047
Organization culture	0.67661989

Rank the alternatives according to the preference order as C_i^+. Shortest distance to the ideal solution shows the best alternative among all. The relationship between alternatives reveals that any alternative which has longest distance to negative ideal solution is guaranteed to have shortest distance to ideal solution.

Table 4.9: Rank of critical success factors

CRITICAL SUCCESS FACTORS	**C_i^+**	**RANK**
Top mgmt commitment	0.78781645	1
Supplier development	0.2945379	11
Employee training and team building	0.6000749	4
Process management	0.76122693	2
Product design and development	0.47870434	7
Inventory management	0.35869935	10
Customer involvement	0.23877307	12
Quality management	0.6000749	4
Application of advance tech. And tools	0.5	6
JIT and lean practices	0.56583953	5
TPM	0.37634958	9
Value stream mapping	0.43416047	8
Organisation culture	0.67661989	3

4.6 Result and conclusion:

According to TOPSIS analysis, alternative 1 shows the highest closeness to the ideal solution so alternative 1 gives highest rank i.e. rank 1. So Top Management Commitment is the most critical factor in lean manufacturing. Lean manufacturing fail in organization if top management is not interested so successful of lean manufacturing in an organization is depends on top management. Process management is ranked at number 2. So process management is also a important critical factor, so we improve our process time to time. Organization culture is ranked 3. Organization culture shows the interest of employees towards lean manufacturing. Quality management and Employee training and team building is ranked at number 4. We continuously improve our product quality so that faith of product increases in customer's mind. Employee training and team building is a important factor, employees need proper and timely training so that production increases. All the employees in an organization work like a team to fulfil the common objective. JIT and Lean practices is ranked at number 5. JIT reduces raw material and WIP inventories so that cost of the product reduces. Application of advance technology and tools is ranked at number 6. Advance technology reduces the lead time of product and also improves quality of product. Product design and development is ranked at number 7. We continuous improved our product so that it's demand increase. Customer involvement is very low ranked because customer can't take participate directly to manufacture a product.

4.7 Concluding Remarks

Above analysis shows that critical success factors are very important for implementation of lean manufacturing in organizations. With the help of TOPSIS method, ranked the critical success factors. Top management commitment has highest rank and customer involvement has lowest rank. Next chapter will describe the ranking to the solutions of lean manufacturing to overcome its barriers.

Chapter 5

Ranking the solutions of lean manufacturing to overcome its barriers

5.1 Introduction

Global competition increased in last few decade so that new technology developed which optimized the manufacturing process. Advanced manufacturing processes produce high quality product, increase productivity and manufacturing flexibility, reduce lead time and wastage in manufacturing. With the help of advanced manufacturing technique, we better utilization of man power and process control so that manufacturing organization takes advantages in global competition (Karim et al., 2008a; Allway and Corbett, 2002; Papadopoulou and Ozbayrak, 2005). Lean manufacturing originates from Toyota production system (TPS). The main aim of lean manufacturing is to produce same output with fewer amounts of resources. Available resources are material, machine, man and space. So lean manufacturing optimized these available resources. According to Schonbergerm (2007), lean manufacturing reduces the wastage from product design, factory management, production processes and supplier network. Lean manufacturing decreased human effort, inventory and time to develop a product in organization. So lean manufacturing make good quality product with most efficient and economic manner with in organization.

The rest of this work is organized as follows:

Section 2:	Briefly reviews the literature on barriers and solutions of MM adoption in manufacturing sector.
Section 3:	The Fuzzy AHP and fuzzy TOPSIS methods are presented.
Section 4:	The proposed framework for prioritize the solutions of MM adoption in manufacturing sector is described.
Section 5:	The empirical case study is conducted and described.
Section 6:	Finally, the conclusion is discussed in.

5.2 Literature review

5.2.1 Identification of barriers for lean manufacturing

Lean manufacturing is much more than a technique, it is a way of thinking, and the whole system approach that creates a culture in which everyone in the organization continuously improve operations. According to Chavez et al. (2013), sometimes top management is not support the change in the organization so management cannot put full effort to implement the lean manufacturing. Dean and Bowen (1994), states that in industries lack of coordination between the departments occurs so that there is lack of communication between the departments. In organizations, there is lack of new learning facilities provided to the employees and also lack of motivation to the employees in industries (Shingo, 1981; Hackman and Oldham, 1980). According to Wainwright (1995), industries spend very less amount in new and advanced technology. Ghosh (2013) states that to increase production in industries we continuous improved in production system. In order to improve manufacturing operations, we need to assess the state of operations at the manufacturing facilities. Assessment is a valuable tool that must be used to study the current state. Goodson (2002) has developed a tool kit that aids experts in as little as 30 minutes to “Read a plant fast” to tell if a factory is truly lean. According to Whitfield and Poole (1997), in industries there is lack of training facility provided to the employees so that employees cannot develop their skills. In industries, Inventory consumes lot of money in the form of raw materials, WIP and finished goods. So control the inventory to save the resource of plant (Shingo 1990; Suzuki 1995; Shen and Wacker 1997). According to Monden (1983), lack of zero defect policy used in plant to manufacture a product. If we reduced the defect then overall net profit increased. According to Nakajima (1988), proper maintenance is necessary to smooth working of plant. We used the preventive maintenance in industries so that downtime of machine decreased and production increased.

5.2.2 Solutions to overcome the barriers of lean manufacturing

According to Schonbergerm (2007), to increase the production, we must reduce the lead time because if lead time decrease in profit increase and overall working hours of machine increased. So JIT is a good tool to reduce the lead time in production system. JIT is also related to the first indicator of eliminating waste because it reduces excess inventories and work-in-progress

(Cammarano 1996); Gleckman et al. 1994). Gilson et al. (2005) states that use of standard work eliminate waste and increase productivity. According to Brox and Fader (2002), lean manufacturing improve the material handling in production system so that it reduce material flow time and also improve material flow path in production line. Proper material handling reduces wastage in industries and improves net profit. According to Ohno (1988), Total productive maintenance (TPM) is aimed to improving the reliability, consistency and capacity of machines through maintenance so that downtime of machines decrease, efficiency of machine increases and quality of product improves. According to Karim and Zaman (2013), Value stream mapping refers to those specifics of the firms that add value to the product or service under consideration. It is a far more focused and contingent view of the value adding (VA) process in industries. Martinez-Jurado et al. (2013), states that proper communication system developed in organizations so that information easily flow from top management to workers and workers to top management. According to Shingo (2000), we use single minute die exchange (SMED) so that lead time decrease and machine ready within few second for doing operations.

Table 5.1: Initial hierarchy model of barriers of lean manufacturing and its criteria

Main Criterion	**Criterion Code**	**Sub criterion**	**Reference**
Top Management Barriers	TMB 1	Lack of Leadership and support	Boyer and Sovilla (2003), Alavi (2003), Emiliani (2001) Chavez et al. (2013)
	TMB 2	Lack of Lean organization structure	Dean and Bowen (1994)
	TMB 3	Lack of investment in R & D	Kaplan and Norton (2005) Neely et al. (2005)
	TMB4	Lack of integrated system	Dyer (1996), Ghosh (2013)
Organizational Cultural Barriers	OCB 1	Lack of new learning	Shingo (1981), Krajewski and Ritzman (2003)
	OCB 2	Lack of motivation	Hackman and Oldham(1980)
	OCB 3	Lack of 5S environment	Osada (1991)

	OCB 4	Lack of common vision and goal	Cutcher-Gershenfeld et al.(1994)
Technological Barriers	TB 1	Lack of advance technology approach	Wainwright (1995)
	TB 2	Lack of flexible information system	Womack et al. (1990) Chavez et al. (2013)
	TB 3	Lack of continuous improvement in production	Hayes (1981), Ghosh (2013)
	TB 4	Lack of specalized training	Whitfield and Poole (1997)
Individual Barriers	IB 1	Lack of knowledge and skill	Thomas and Webb (2003)
	IB 2	Lack of commitment	Walton (1985)
	IB 3	Lack of confidence to take new Challenges	Pillai and Min (2010)
Quality Barriers	QB 1	Lack of process control	Koskela (1992), Martinez-Jurado et al. (2013)
	QB 2	Improper inventory management	Shingo (1990), Suzuki (1995), Ghosh (2013)
	QB 3	Lack of zero defect policy in production system	Monden (1983), Oakland (1993), Chavez et al. (2013)
	QB 4	Lack of customer-supplier Relationship	Lambert et al. (1998), Levy (1997), Keller et al. (1991) Carlborg et al. (2013)
	QB 5	Lack of effective maintenance	Nakajima (1988)

Table 5.2: Solutions of lean manufacturing

Code	**Solutions**	**References**
S1	Effective maintenance strategy	Swanson (2001), Schippers (2001)
S2	Cross functional training and HRM	Wright and Snell (1998), Ridder et al. (2012a)
S3	Use of ICT	Abrahamson (2004), Boyer and Sovilla (2003)
S4	use standardized work	Monden (1983), Gilson et al. (2005), Molleman (2000),

		Martinez-Jurado et al. (2013)
S5	Reduce lead time	Schonbergerm (2007),Abdulmaleka and Rajgopal (2007) Ghosh (2013)
S6	Use of lean manufacturing process	Womack et al. (1990), Shingo (1989), Nawanir et al. (2013)
S7	Improve flexibility in prod. System	Koskela (1992)
S8	Improve material handling in organization	Wisner et al. (2005), Brox and Fader, (2002)
S9	use of right first time approach	Bicheno (1999), Ghosh (2013)
S10	use of new tech. and product innovation	Bessant and Haywood (1988)
S11	use of JIT	Cammarano (1996), Gleckman et al. (1994)
S12	Use of single minute die exchange	Shingo (2000), Chao (2001), Benjamin et al. (2013)
S13	Use of value stream mapping	Fawaz and Jayant (2007), Sean (2012), Karim and Zaman (2013)
S14	Improved communication system	Miles and Huberman (1994), Storch and Lim (1999) Martinez-Jurado et al. (2013)
S15	Improved small group activities	Kuipers and de Witte (2005), Koike and Inoki (1990)

5.3 Research Methodology-

In this research we find out the barriers of lean manufacturing. Then we find out the solutions and prioritize the solutions against the barriers. We use the multi criteria decision making (MCDM) method to prioritize the solutions of lean manufacturing. Human judgment is hard and unclear to estimate the exact numerical values for particular solutions. So fuzzy logic is very useful to solve the ambiguous problems in multi criteria decision making (MCDM). In this research we use fuzzy Analytical hierarchy process (AHP) and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) framework to prioritize the solutions of lean manufacturing. We use the fuzzy AHP (Saaty, 1980) method to determine importance weights of the barriers and fuzzy TOPSIS (Hwang & Yoon,1981) methods to find out the performance ratings of feasible solutions with the help of triangular fuzzy numbers (TFN).

5.3.1 Fuzzy sets:

Decision making is very difficult for vague and uncertain environment so vagueness and uncertainty handled by using fuzzy set theory. Zadeh (1965) gives fuzzy set theory. A fuzzy set defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually vary from [0, 1]. If we assign zero value then the element does not belong to the fuzzy set i.e. it has no membership. If we assign one value assigned then the element belongs completely to the fuzzy set i.e. it has total membership. If the value lies between the intervals, the element has a certain degree of membership. In particular, to deal with the ambiguities involved in the process of linguistic estimation, it is a constructive way to convert these linguistic terms into fuzzy numbers. These linguistic terms can be represented by fuzzy numbers, and the Triangular Fuzzy Number (TFN) is commonly used. We use a character tilde "$\sim$" above a symbol if the symbol shows a fuzzy set. We briefly analyze some essential definitions of fuzzy logic.

Definition 1: A Fuzzy set $\tilde{F}$ is a subset of universe of discourse D, which is a set of ordered pairs and is characterized by a membership function $U_{\tilde{F}}(d)$ representing a mapping $U_{\tilde{F}}$:- d→[0,1]. The function value of $U_{\tilde{F}}(d)$ for the fuzzy set $\tilde{F}$ is called the membership value of d in $\tilde{F}$, which represent the degree of truth that d is a element of fuzzy set $\tilde{F}$. It is assumed that $U_{\tilde{F}}(d) \in [0,1]$, where $U_{\tilde{F}}(d) = 1$ reveals that d completely belongs to $\tilde{F}$, while $U_{\tilde{F}}(d) = 0$ indicates that d does not belong to the fuzzy set $\tilde{F}$.

$$\tilde{F} = \{(d, U_{\tilde{F}}(d))\}, \qquad d \in D$$

Where $U_{\tilde{F}}(d)$ is the membership function and D = {d} represent a collection of elements d.

Definition 2. A fuzzy set $\tilde{F}$ of the universe of discourse d is normal if max

$$\text{Max } U_{\tilde{F}}(d) = 1$$

Definition 3: A Fuzzy set $\tilde{F}$ of the universe of discourse d is convex if

$U_{\tilde{F}} (\lambda d_1 + (1-\lambda)d_2)$
$\geq \min(U_{\tilde{F}} (d_1), U_{\tilde{F}}(d_2)) \, \forall \, d \in [d_1, d_2],$

Where $\lambda \in [0,1]$

Definition 4: A fuzzy number Õ is a fuzzy subset in the universe of discourse d, which is both convex and normal.

Definition 5: In a triangular fuzzy number (TFN) if the membership function $U_{\tilde{F}}(d)$ of fuzzy set $\tilde{F} = (X,Y,Z)$ in universe D is defined as follows, where X,Y,Z are real numbers and $X \leq Y \leq Z$.

$$\mu_{\tilde{n}} = \begin{cases} 0 & (d<X) \\ \dfrac{d-X}{Y-X} & (X \leq d \leq Y) \\ \dfrac{r-d}{r-Y} & (Y \leq d \leq Z) \\ 0 & (d<Z) \end{cases}$$

Definition 6: The α- cut of fuzzy set $\tilde{F}$ of the universe of discourse D is defined as

$F_{\alpha} = \{d \in D; U_{\tilde{F}} \geq \alpha\}$

Where $\alpha \in [0,1]$

Definition 7: Alternatively, by defining the interval of confidence level α, the triangular fuzzy number can be characterized using the following equation

$\forall \alpha[0,1] \quad \tilde{M}_{\alpha} = [X^{\alpha} , Z^{\alpha}] = [(Y-Z)\alpha + X, - (Z-Y)\alpha + Z]$

Definition 8: Suppose g = (g_1, g_2, g_3) and h = (h_1, h_2, h_3) are two triangular fuzzy numbers, then distance between them is calculated as:

$$d_p(\tilde{g}, \tilde{h}) = \sqrt{\frac{1}{3}[(g_1 - h_1)^2 + (g_2 - h_2)^2 + (g_3 - h_3)^2]}$$

5.3.2 Fuzzy AHP

AHP introduced by Satty (1980) is a quantitative technique that structures a multi-criteria, multi person, multi period problem hierarchically so that solutions are facilitated. The application of Satty's AHP has some limitation as follows:

(1) The AHP method mainly used in nearly crisp decision application.
(2) The AHP methods create and deal with the very unbalanced scale of judgment.
(3) The AHP method cannot handle the uncertainty and ambiguity associated with mapping of one's judgment to a number.
(4) Ranking of AHP method is rather imprecise.
(5) The subjective judgment, selection and preference of decision makers have great

Influence on the AHP results. Therefore Fuzzy AHP methodology Extends Satty's AHP by combining it with fuzzy set theory to solve hierarchical fuzzy problems. The fuzzy AHP method offer the number of benefits like, it can capture uncertain imprecise judgment of experts by handling linguistic variables. According to Ozdago-glu & Ozdagoglu, 2007; it is not completely captured the importance of qualitative aspects because its discrete scale couldn't reflect the human thinking style. Recently fuzzy AHP is widely used to solve multi-criteria decision problems in few other areas e.g. selection of thermal power plant by Choudhary & Shankar (2012), strategic analysis of electronic service quality by Buyukozkan & Cifci (2012), renewable energy planning by Kaya & Kahraman (2010).

Step 1: According to Chang's method (1996), for each level of the constructed hierarchy, the pair-wise linguistic judgments are converted in TFNs and organized in fuzzy comparison matrices as follows:

$$\tilde{D} = (\tilde{d}_{ij})_{n\times m} = \begin{pmatrix} (1, 1, 1) & \cdots & (X_{12}, Y_{12}, Z_{12}) & \cdots & (X_{1n}, Y_{1n}, Z_{1n}) \\ (X_{21}, Y_{21}, Z_{21}) & \cdots & (1, 1, 1) & \cdots & (X_{2n}, Y_{2n}, Z_{2n}) \\ . & & . & & . \\ . & & . & & . \\ (X_{n1}, Y_{n1}, Z_{n1}) & \cdots & (X_{n2}, Y_{n2}, Z_{n2}) & \cdots & (1, 1, 1) \end{pmatrix}$$

Where

$$\tilde{d}_{ij} = (X_{ij}, Y_{ij}, Z_{ij}) \qquad \ldots\ldots\ (1)$$

$$\tilde{d}_{ji}^{-1} = \left(\frac{1}{Z_{ji}}, \frac{1}{Y_{ji}}, \frac{1}{X_{ji}} \right) \qquad i, j = 1,2,\ldots\ldots n;\ i \neq j \qquad \ldots\ldots\ (2)$$

Represent the linguistic judgement for the items i and j; thus $\tilde{D}$ is a square and symmetrical matrix.

Table 5.3: Triangular fuzzy conversion scale (chang, 1996; Lee, 2010)

Linguistic Scale	Triangular Fuzzy Conversation scale	Triangular Fuzzy reciprocal scale
JUST EQUAL	(1,1,1)	(1,1,1)
EQUALLY IMPORTANCE	(2/3,1,3/2)	(2/3,1,3/2)
WEAKLY MORE IMPORTANCE	(1,3/2,2)	(1,3/2,2)
MODERATERLY MORE IMPORTANCE	(3/2,2,5/2)	(3/2,2,5/2)
STRONGLY MORE IMPORTANCE	(2,5/2,3)	(2,5/2,3)
EXTREMELY MORE IMPORTANCE	(5/2,3,7/2)	(5/2,3,7/2)

Step 2: Yager (1981) gives centroid defuzzification method which is also called center of gravity. This method converts the fuzzy comparison matrices into crisp comparison matrices. In case of triangular fuzzy number the translating formula is given by Wang & Elhag (2007). The translating formula is:

$$d_{ij}(\tilde{d}_{ij}) = \frac{X_{ij} + Y_{ij} + Z_{ij}}{3} \quad \ldots\ldots\ldots (3)$$

where

$\tilde{d}_{ij} = (X_{ij}, Y_{ij}, Z_{ij})$

Step 3: calculate the consistency of each comparison matrix by calculating the consistency index (CI) and also calculate consistency ratio (CR)

$$CI = \frac{(\lambda_{\max} - n)}{n-1} \quad \ldots\ldots\ldots (4)$$

$$CR = (CI / RI(n))100\% \quad \ldots\ldots\ldots (5)$$

Where largest eigen value of the comparison matrix is λ_{max} and dimension of matrix is n and random index is RI(n). Random index is depend upon the value of n which is shown in table 5.4.

Table 5.4: RI of random matrices

N	3	4	5	6	7	8	9
RI(n)	0.58	0.9	1.12	1.24	1.32	1.41	1.45

Source: Golden, Harker & Wasil, 1989.

The consistency of the matrix is acceptable only if CR is less than 10%. Nevertheless, the threshold of 10% can be increased or decreased depending on the tolerance of the decision makers. If a matrix gives result inconsistent then it is necessary to obtain new pair-wise comparison judgments. Then determining a new pair-wise fuzzy comparison matrix to analyze. The matrix review must be continuing until the consistency is obtained.

Step 4: we calculate the relative sum of each row of D̃ as:

$$\tilde{RS} = \sum_{j=1}^{n} d_{ij} = \sum_{j=1}^{n} X_{ij} , \sum_{j=1}^{n} Y_{ij} , \sum_{j=1}^{n} Z_{ij} \qquad i = 1,2,\ldots\ldots,n \qquad \ldots\ldots\ldots (6)$$

Step 5 : According to Wang and Elhag’s (2006), we normalized the row sum ($\tilde{S}_i$) as:

$$\tilde{S}_i = \frac{RS_i}{\sum_{j=1}^{n} RS_j}$$

$$= \frac{\sum_{j=1}^{n} X_{ij}}{\sum_{j=1}^{n} X_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} Z_{kj}} , \frac{\sum_{j=1}^{n} Y_{ij}}{\sum_{k=1,k\neq 1}^{n} \sum_{j=1}^{n} Y_{kj}} , \frac{\sum_{j=1}^{n} Z_{ij}}{\sum_{j=1}^{n} Z_{ij} + \sum_{k=1,k\neq i}^{n} \sum_{j=1}^{n} X_{kj}} \qquad \ldots\ldots\ldots.. (7)$$

Step 6 : calculate the local priority weight of each criterion and sub criterion.

$$A_i = S(\tilde{S}_i) = \frac{X_i + Y_i + Z_i}{3} \qquad \ldots\ldots\ldots (8)$$

Where

$\tilde{S}_i = (X_{ij}, Y_{ij}, Z_{ij})$

5.3.3 Fuzzy TOPSIS:

TOPSIS one of the classic multi-criteria decision making method which was developed by Hwang and Yoon (1981). It is based on the concept that we choose such alternative which has the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). In the traditional formulation of the TOPSIS method, personal judgments are done with crisp values. But in real life, measurement by using crisp values is not always possible so we go for better approach and use linguistic value rather than crisp value. Fuzzy set theory gives linguistic value. For this reason, we use fuzzy TOPSIS method to solve real life application problems under a fuzzy environment.

(Zeydan & Colpan, 2009,Aiello, Enea, Galante, & La Scalia, 2009; Onut, Kara, & Isık, 2009; Amiri, 2010; Baykasoglu, Kaplanoglu, Durmusoglu, & Sahin, 2013; Aydogan, 2012; Sadi-Nezhad & Damghani, 2010; Afshar, Marino, Saadatpour, & Afshar, 2011).

Step 1 : choose the linguistic rating values for the alternatives with respect to criteria.

Let us assume that there are m possible alternatives called S = {S_1, S_2, S_3 . . . . S_m} which are evaluated against the criteria, B = {B_1, B_2, B_3 . . . . B_n). The criteria weights are represented by w_j (j= 1,2,3………..n). The performance rating of each expert E_k (k = 1,2,3,…….. k) for each criteria B_j (j = 1,2,3,…………….n) with respect to alternative S_i (i = 1,2,3,……………….m) are denoted by $\tilde{R}_k$ = $\tilde{A}_{ijk}$ (i = 1,2,3,…………………m; j = 1,2,3,………………..n; k = 1,2,3,…………………….k) membership function $\mu\tilde{R}_k(x)$. Table shows the scale used for solution rating.

Table 5.5: Linguistic variables for solutions ratings

Linguistic variables	Corresponding TFN
Very poor	(1,1,3)
Poor	(1,3,5)
Medium	(3,5,7)
Good	(5,7,9)
Very good	(7,9,11)

Step 2 : Find out aggregate fuzzy ratings for alternatives.

All the experts gives fuzzy rating in triangular fuzzy number (TFN) $\tilde{R}_k$ = (lk, mk, nk), k = 1,2,3,…………………k. Then convert fuzzy rating of all experts into aggregate fuzzy rating $\tilde{R}$ = (l,m,n) k = 1,2,3,…………….k where

$$l = \min_k \{ l_k \}$$

$$m = \frac{1}{k} \sum_{k=1}^{k} m_k$$

$$n = \max_{k}\{ n_k \}$$

Fuzzy rating of Kth decision maker are $\tilde{X}_{ijk} = (l_{ijk}, m_{ijk}, n_{ijk})$, i = 1,2,3,……..m, j = 1,2,3……n, then aggregate fuzzy rating $\tilde{X}_{ij}(l_{ij}, m_{ij}, n_{ij})$ where

$$l_{ij} = \min_{k}\{ l_{ijk} \}$$

$$m_{ij} = \frac{1}{k}\sum_{k=1}^{k} m_{ijk}$$

$$n_{ij} = \max_{k}\{ n_{ijk} \} \qquad \text{……………} (9)$$

Step 3 : construct the fuzzy decision matrix

The fuzzy decision matrix for the alternatives ($\tilde{D}$) is constructed as follows :

$$\tilde{D} = \begin{array}{c|cccc|} & B_1 & B_2 & & B_n \\ S_1 & \tilde{x}_{11} & \tilde{x}_{12} & \ldots\ldots\ldots\ldots & \tilde{x}_{1n} \\ S_2 & \tilde{x}_{21} & \tilde{x}_{22} & \ldots\ldots\ldots\ldots & \tilde{x}_{2n} \\ S_3 & \tilde{x}_{31} & \tilde{x}_{32} & \ldots\ldots\ldots\ldots & \tilde{x}_{3n} \\ & . & . & \ldots\ldots\ldots\ldots.. & . \\ & . & . & \ldots\ldots\ldots\ldots.. & . \\ S_m & \tilde{x}_{m1} & \tilde{x}_{m2} & & \tilde{x}_{m3} \end{array} \qquad i = 1,2,3,\ldots..m;\ j = 1,2,3,\ldots.n$$

Step 4 : construct the normalized fuzzy decision matrix

We normalized the raw data with the help of linear scale transformation. So that various criteria scales is converted into comparable scale. The normalized fuzzy decision matrix $\tilde{N}$ is given by :

$\tilde{N} = [r_{ij}]_{m\times n}$, i = 1,2,3,…………m; j = 1,2,3,…………..n,

Where

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{n_j^*}, \frac{m_{ij}}{n_j^*}, \frac{n_{ij}}{n_j^*} \right) \quad \text{and} \quad n_j^* = \max_i \{ n_{ij} \} \quad \text{(benefit criteria)} \qquad \text{..……. (10)}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{n_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}} \right) \quad \text{and} \quad l_j^- = \min_i \{ l_{ij} \} \quad \text{(cost criteria)} \qquad \text{………. (11)}$$

Step 5 : construct the weighted normalized matrix

We multiply the weight (a_j) of evaluated criteria with normalized fuzzy decision matrix ($\tilde{r}_{ij}$) to get weighted normalized matrix ($\tilde{w}$).

$\tilde{W} = [\tilde{w}_{ij}]_{m\times n}$ i = 1,2,3,…….……m; j = 1,2,3,……………..n ……….. (12)

Where

$$\tilde{w}_{ij} = (\tilde{r}_{ij})\times(a_j)$$

$\tilde{w}_{ij}$ is a triangular fuzzy number which is represented by ($\tilde{l}_{ijk}$, $\tilde{m}_{ijk}$, $\tilde{n}_{ijk}$)

Step 6: find out fuzzy ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

The FPIS and FNIS of the alternatives find out by:

$$A^* = (\tilde{p}_1^*, \tilde{p}_2^*, \tilde{p}_3^* \text{………….} \tilde{p}_n^*) \qquad \text{………. (13)}$$

Where

$$\tilde{p}_j^* = (\tilde{n}_j^*, \tilde{n}_j^*, \tilde{n}_j^*) \quad \text{and} \quad \tilde{n}_j^* = \max_i \{ \tilde{n}_{ij} \}$$

$$A^{-} = (\tilde{p}_1^{-}, \tilde{p}_2^{-}, \tilde{p}_3^{-} \ldots\ldots\ldots\ldots\ldots \tilde{p}_n^{-}) \qquad \ldots\ldots\ldots (14)$$

Where

$$\tilde{p}_j^{-} = (\tilde{l}_j^{*}, \tilde{l}_j^{*}, \tilde{l}_j^{*}) \quad \text{and} \quad \tilde{l}_j^{*} = \min_i \{ \tilde{l}_{ij} \}$$

i = 1,2,3,……………….m;   j = 1,2,3,………………..n

Step 7 : find out the distance of each alternative from fuzzy ideal solution (FPIS) and fuzzy negative ideal solution (FNIS)

We find out the distance (d_i^{+} , d_i^{-}) of each alternative i = 1,2,3,………m from FPIS and FNIS is computed as follows:

$$d_i^{+} = \sum_{j=1}^{n} dp\,(\tilde{w}_{ij}, \tilde{p}_j^{*}), \qquad i = 1,2,3,\ldots\ldots\ldots m \qquad \ldots\ldots\ldots (15)$$

$$d_i^{-} = \sum_{j=1}^{n} dp\,(\tilde{w}_{ij}, \tilde{p}_j^{-}), \qquad i = 1,2,3,\ldots\ldots\ldots m \qquad \ldots\ldots\ldots (16)$$

Step 8: find out the closeness coefficient (cc_i) of each alternative

The closeness coefficient shows the distance to the fuzzy ideal solution and fuzzy negative ideal solution simultaneously. We find closeness coefficient of each alternative by following formula:

$$cc_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \qquad \ldots\ldots\ldots (17)$$

Step 9 : give rank to the alternatives

We give the rank to the different alternatives according to decreasing order of closeness coefficient (cc_i).

5.4 Proposed fuzzy AHP TOPSIS framework to rank the solutions of Lean Manufacturing in industry:

In three phases, we overcome the barriers of lean manufacturing and find out the solutions.

Phase 1: Identification of the barriers and solutions of lean manufacturing in industry

In the first phase, we identify and evaluate the barriers with the help of expert panel which comprising senior managers, LM project representatives, IT representatives, and customers. Then the barriers of LM adoption in industry are determined through experts opinion and literature review. When we find out the barriers then another expert panel is formed for evaluation of solutions of LM adoption in industry. Then we make hierarchy structure such that objective is at the first level, main barriers in the second level, sub barriers at third level and solutions are in the fourth level.

Phase 2: find out the weight of barriers of LM with the help of fuzzy AHP.

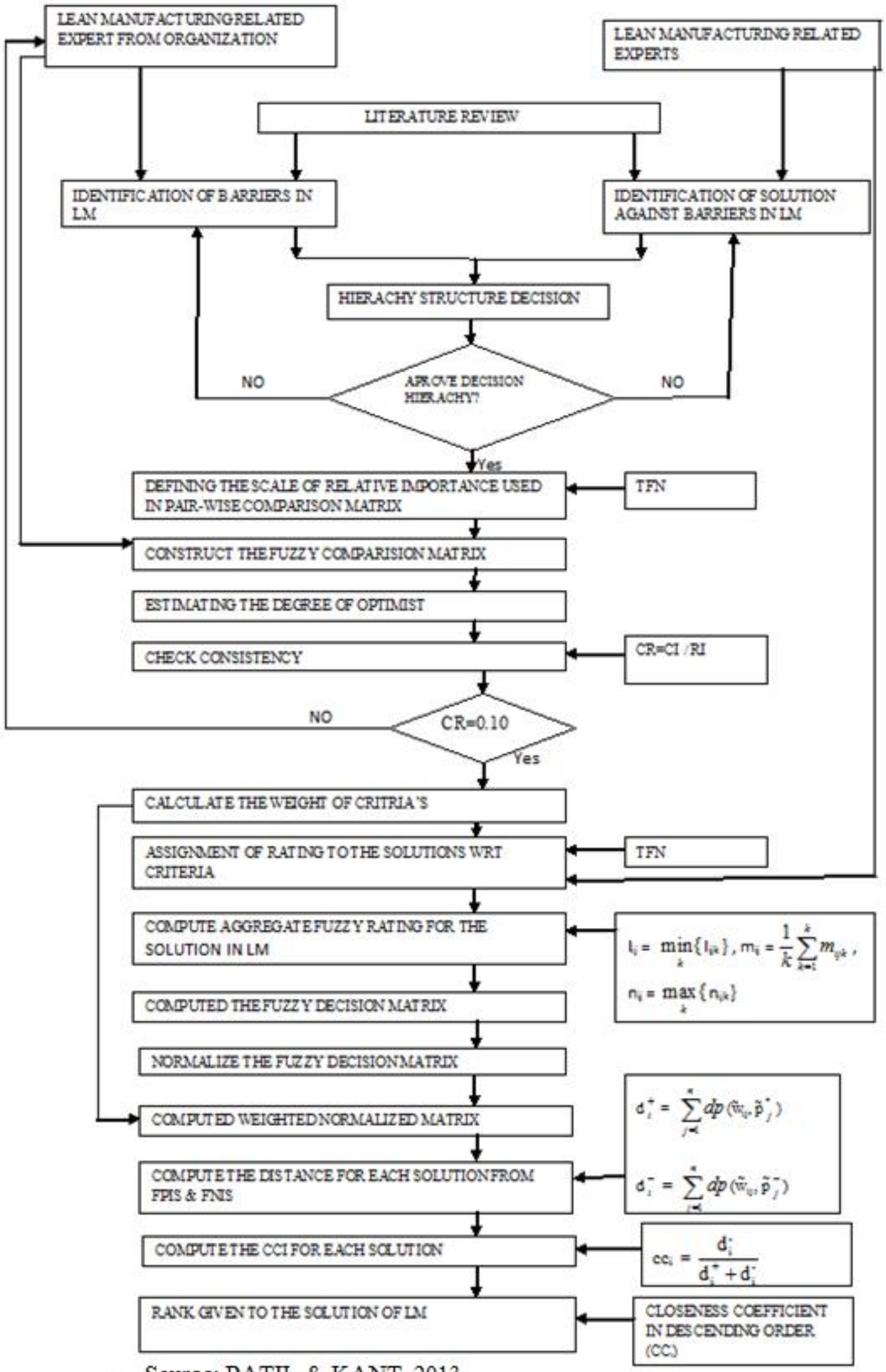
After forming a decision hierarchy, we find out the weights of the barriers of LM with the help of fuzzy AHP. We make Pair wise comparison matrixes of experts evaluations are constructed to acquire criteria weights by using the scale in Table 5.3. Then we check the consistency of matrix. Matrix is consistence when CI is less than 10%. Then we find out the row sum. Then we normalized the row sum. Then we find out the weights of barriers..

Phase 3: Evaluation of the solutions of lean manufacturing and determine of final rank with the help of Fuzzy TOPSIS

We use the Fuzzy TOPSIS to give the ranking to the solutions of alternatives. The rating of solutions towards the barriers will be done by linguistic scale. We finalized the ranking of solutions according to cc_i value. We give the ranking to the solutions in descending order of cc_i value.

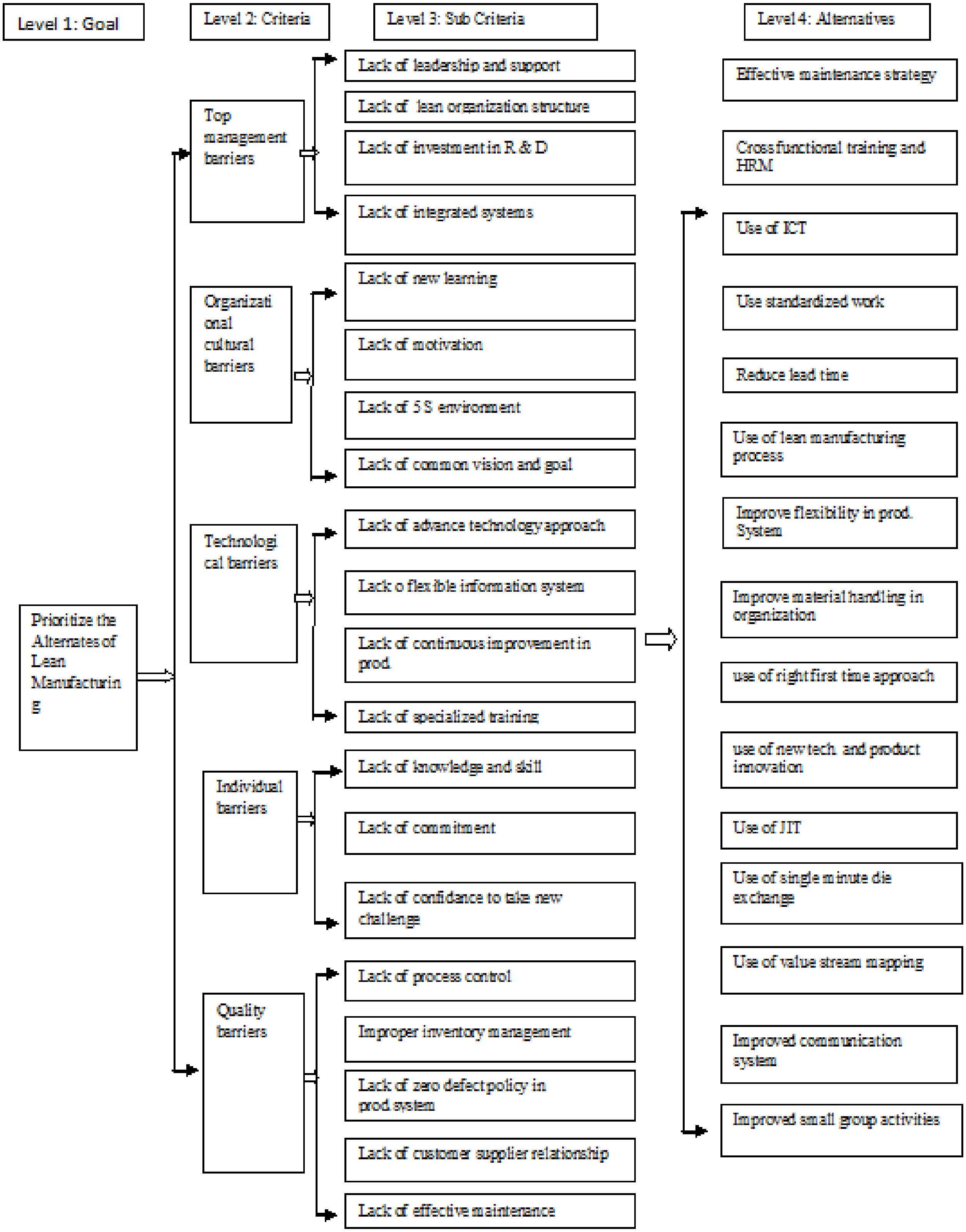
5.5 Application of the proposed framework

The proposed framework is used to find out the rank to the solutions of LM adoption in industry to overcome its barriers. The application is based on three phases which is provided in previous section and explained as following.



Source: PATIL & KANT, 2013

fig. 5.1 proposed fuzzy AHP-TOPSIS framework to prioritize the solutions of LM



Source: Modified based on PATIL & KANT, 2013

Fig. 5.2 Decision hierarchy for prioritizing solutions of LM

5.5.1 Problem description

Nowadays, more and more Indian organizations realize that lean manufacturing plays an important role in business success. Some Indian organizations have implemented lean manufacturing. But the success rate is not so good because due to barriers of lean manufacturing. So we identify the barriers and find out the solutions so that success rate increase. It is difficult to implement all the solutions at the same time. So it is essential to prioritize these solutions of lean manufacturing and implement them in a stepwise manner. The case organization Y wanted to implement lean manufacturing. Organization Y is an Indian firm with more than 800 crores gross turnover and 1500 employees. This organization engages in design, production and sales. This organization interested to identify and rank the solutions of lean manufacturing.

5.5.2 Case analysis

Phase 1: Identification of the barriers and solutions of lean manufacturing in industry

The decision group is composed of the 10 experts which comprising five senior managers, one IT representatives, four LM project representatives. In this study 20 qualitative and quantitative barriers (sub-criteria) of Lean manufacturing. This is identified through literature review and intensive discussion with decision group members.

Four expert of lean manufacturing find out the solutions against its barriers. Total 15 solutions identified through literature review and finalized it by discussion with the expert panel.

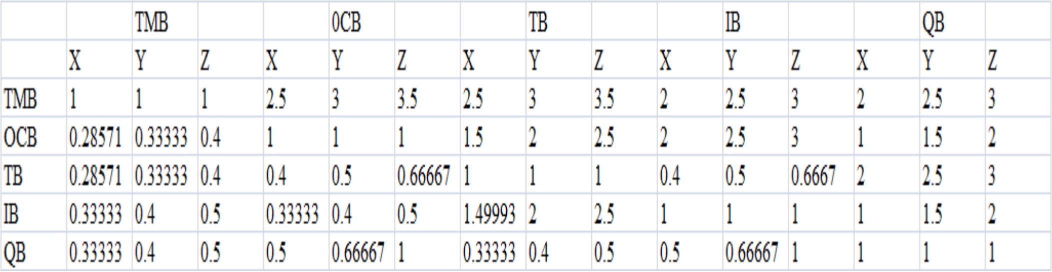
There are four levels in decision hierarchy structure for this problem. The overall goal of decision process determined as ‘‘ranking the solutions of lean manufacturing to overcome its barriers’’ is in the first level of hierarchy and the main Barriers on the second level, the sub barriers at third level and solutions at the fourth level of hierarchy.

Phase 2: find out the weight of barriers of LM with the help of fuzzy AHP.

In this phase the decision group is asked to make pair wise comparisons of five main barriers and 20 sub barriers by using linguistic variables. Then we check the consistency of matrix. Matrix is consistence when CI is less than 10%. Then we find out the row sum. Then we normalized the row sum. Then we find out the weights of barriers.

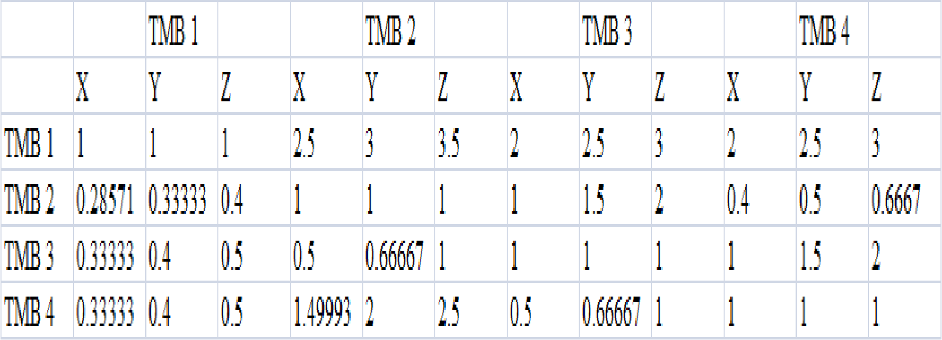
Pair wise comparison matrix of major criteria shown in table 5.6 and pair wise comparison matrix of its sub criteria shown in table 5.7 to 5.11.

Table 5.6: Pair wise comparison matrix of the major criteria



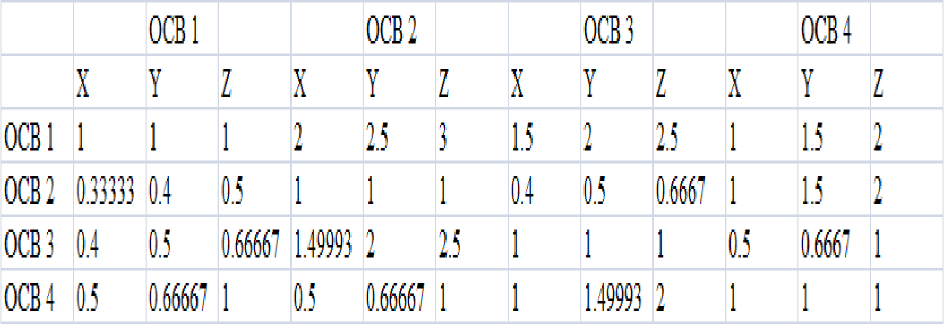
		TMB			0CB			TB			IB			QB	
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
TMB	1	1	1	2.5	3	3.5	2.5	3	3.5	2	2.5	3	2	2.5	3
OCB	0.28571	0.33333	0.4	1	1	1	1.5	2	2.5	2	2.5	3	1	1.5	2
TB	0.28571	0.33333	0.4	0.4	0.5	0.66667	1	1	1	0.4	0.5	0.6667	2	2.5	3
IB	0.33333	0.4	0.5	0.33333	0.4	0.5	1.49993	2	2.5	1	1	1	1	1.5	2
QB	0.33333	0.4	0.5	0.5	0.66667	1	0.33333	0.4	0.5	0.5	0.66667	1	1	1	1

Table 5.7: Pair wise comparison matrix of Top Management Barriers



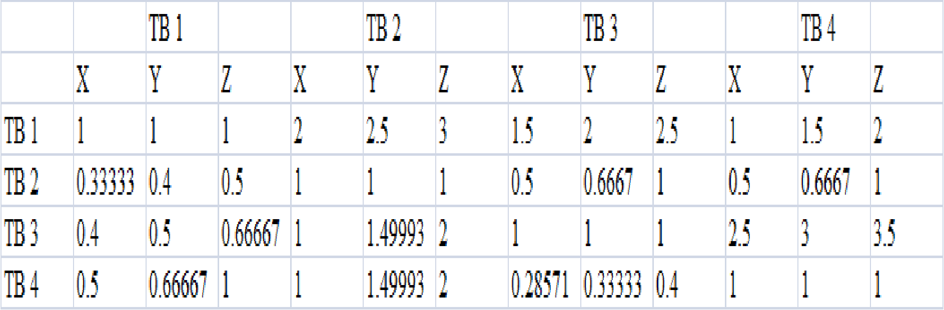
		TMB 1			TMB 2			TMB 3			TMB 4	
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
TMB 1	1	1	1	2.5	3	3.5	2	2.5	3	2	2.5	3
TMB 2	0.28571	0.33333	0.4	1	1	1	1	1.5	2	0.4	0.5	0.6667
TMB 3	0.33333	0.4	0.5	0.5	0.66667	1	1	1	1	1	1.5	2
TMB 4	0.33333	0.4	0.5	1.49993	2	2.5	0.5	0.66667	1	1	1	1

Table 5.8: Pair wise comparison matrix of Organizational Culture Barriers



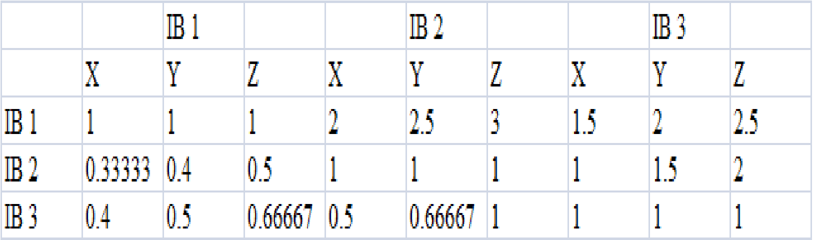
		OCB 1			OCB 2			OCB 3			OCB 4	
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
OCB 1	1	1	1	2	2.5	3	1.5	2	2.5	1	1.5	2
OCB 2	0.33333	0.4	0.5	1	1	1	0.4	0.5	0.6667	1	1.5	2
OCB 3	0.4	0.5	0.66667	1.49993	2	2.5	1	1	1	0.5	0.6667	1
OCB 4	0.5	0.66667	1	0.5	0.66667	1	1	1.49993	2	1	1	1

Table 5.9: Pair wise comparison matrix of Technological Barriers



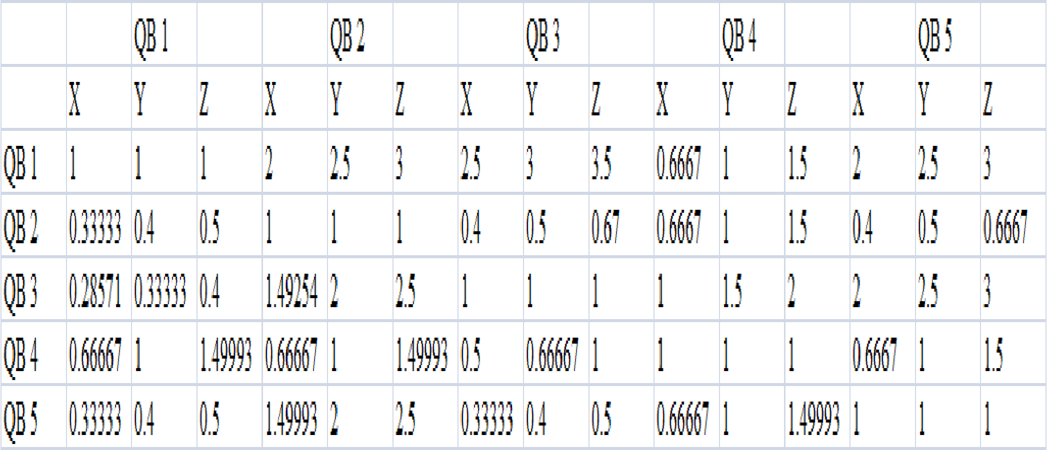
		TB 1			TB 2			TB 3			TB 4	
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
TB 1	1	1	1	2	2.5	3	1.5	2	2.5	1	1.5	2
TB 2	0.33333	0.4	0.5	1	1	1	0.5	0.6667	1	0.5	0.6667	1
TB 3	0.4	0.5	0.66667	1	1.49993	2	1	1	1	2.5	3	3.5
TB 4	0.5	0.66667	1	1	1.49993	2	0.28571	0.33333	0.4	1	1	1

Table 5.10: Pair wise comparison matrix of Individual Barriers



		IB 1			IB 2			IB 3	
	X	Y	Z	X	Y	Z	X	Y	Z
IB 1	1	1	1	2	2.5	3	1.5	2	2.5
IB 2	0.33333	0.4	0.5	1	1	1	1	1.5	2
IB 3	0.4	0.5	0.66667	0.5	0.66667	1	1	1	1

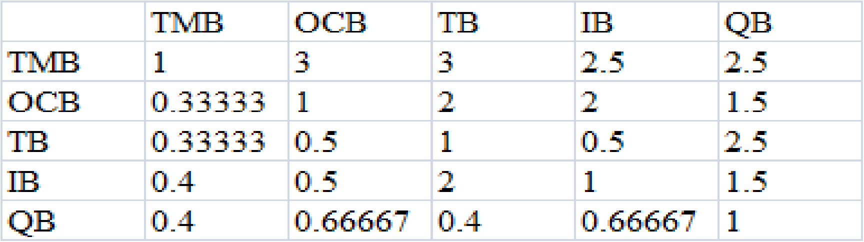
Table 5.11: Pair wise comparison matrix of Quality Barriers



		QB 1			QB 2			QB 3			QB 4			QB 5	
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
QB 1	1	1	1	2	2.5	3	2.5	3	3.5	0.6667	1	1.5	2	2.5	3
QB 2	0.33333	0.4	0.5	1	1	1	0.4	0.5	0.67	0.6667	1	1.5	0.4	0.5	0.6667
QB 3	0.28571	0.33333	0.4	1.49254	2	2.5	1	1	1	1	1.5	2	2	2.5	3
QB 4	0.66667	1	1.49993	0.66667	1	1.49993	0.5	0.66667	1	1	1	1	0.6667	1	1.5
QB 5	0.33333	0.4	0.5	1.49993	2	2.5	0.33333	0.4	0.5	0.66667	1	1.49993	1	1	1

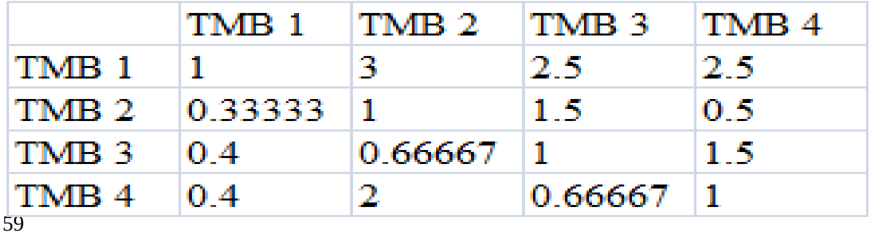
By using the equation 3, values of crisp comparison matrixes of major criterion and sub criterion have been calculated. Table 5.12 to 5.17 for crisp comparison matrixes of major criterion and sub criterion are as shown below:

Table 5.12: Crisp comparison matrix of major criteria



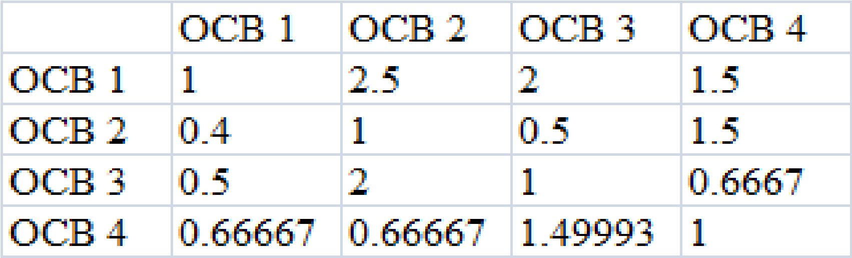
	TMB	OCB	TB	IB	QB
TMB	1	3	3	2.5	2.5
OCB	0.33333	1	2	2	1.5
TB	0.33333	0.5	1	0.5	2.5
IB	0.4	0.5	2	1	1.5
QB	0.4	0.66667	0.4	0.66667	1

Table 5.13: Crisp comparison matrix of Top Management Barriers



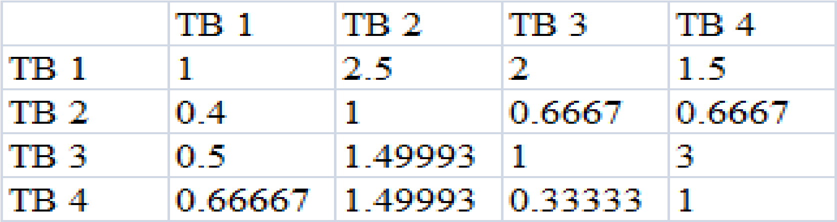
	TMB 1	TMB 2	TMB 3	TMB 4
TMB 1	1	3	2.5	2.5
TMB 2	0.33333	1	1.5	0.5
TMB 3	0.4	0.66667	1	1.5
TMB 4	0.4	2	0.66667	1

Table 5.14: Crisp comparison matrix of Organizational Culture Barriers



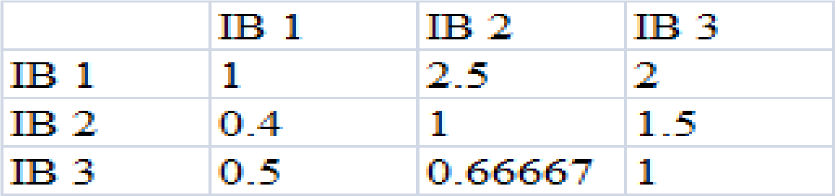
	OCB 1	OCB 2	OCB 3	OCB 4
OCB 1	1	2.5	2	1.5
OCB 2	0.4	1	0.5	1.5
OCB 3	0.5	2	1	0.6667
OCB 4	0.66667	0.66667	1.49993	1

Table 5.15: Crisp comparison matrix of Technology Barriers



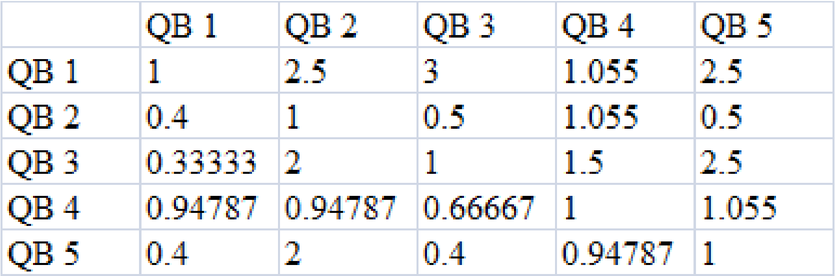
	TB 1	TB 2	TB 3	TB 4
TB 1	1	2.5	2	1.5
TB 2	0.4	1	0.6667	0.6667
TB 3	0.5	1.49993	1	3
TB 4	0.66667	1.49993	0.33333	1

Table 5.16: Crisp comparison matrix of Individual Barriers



	IB 1	IB 2	IB 3
IB 1	1	2.5	2
IB 2	0.4	1	1.5
IB 3	0.5	0.66667	1

Table 5.17: Crisp comparison matrix of Quality Barriers



	QB 1	QB 2	QB 3	QB 4	QB 5
QB 1	1	2.5	3	1.055	2.5
QB 2	0.4	1	0.5	1.055	0.5
QB 3	0.33333	2	1	1.5	2.5
QB 4	0.94787	0.94787	0.66667	1	1.055
QB 5	0.4	2	0.4	0.94787	1

Then i analysed the consistency index by using the equation 4 and consistency ratio by using equation 5 of above matrices. Values for CI and CR as given below:

CI= 0.07375 and CR= 0.06644 of major criteria matrix.

CI= 0.06554 and CR= 0.07364 of Top Management barriers matrix.

CI= 0.07243 and CR= 0.08139 of Organizational cultural barriers matrix.

CI= 0.06875 and CR= 0.07724 of Technological barriers matrix

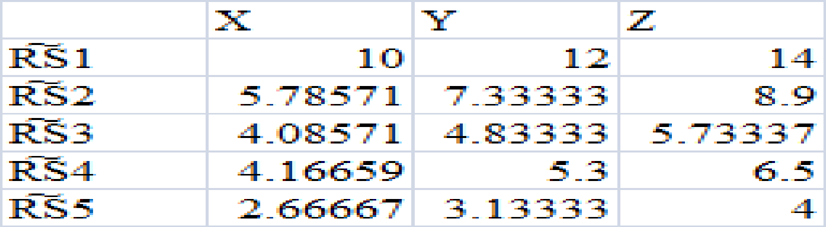
CI= 0.02209 and CR= 0.03808 of Individual behaviour barriers matrix

CI= 0.08086 and CR= 0.07284 of Quality barriers matrix

The results obtained from the calculations based on pair wise comparison matrixes provided CR values of all the matrixes are less than 0.1. Hence, these matrixes are consistent.

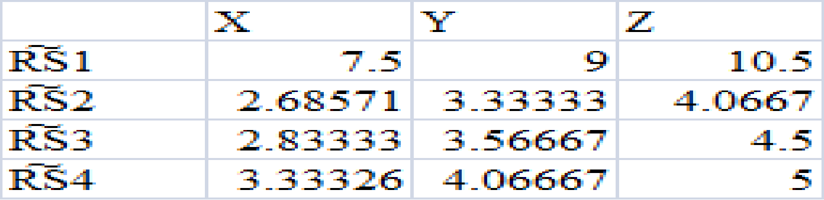
By using the equation 6, values of row sum of each criterion and sub criterion have been calculated. Table 5.19 to 5.23 for row sum of each criterion and sub criterion are as shown below:

Table 5.18: Row sum of each indicator with respect to major criteria



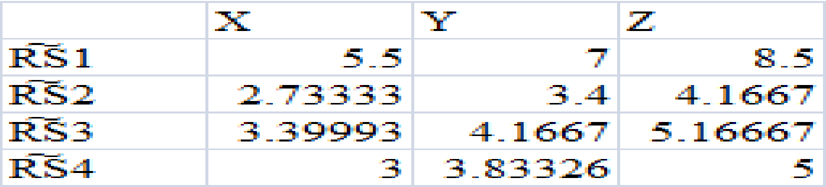
	X	Y	Z
$\widetilde{RS}1$	10	12	14
$\widetilde{RS}2$	5.78571	7.33333	8.9
$\widetilde{RS}3$	4.08571	4.83333	5.73337
$\widetilde{RS}4$	4.16659	5.3	6.5
$\widetilde{RS}5$	2.66667	3.13333	4

Table 5.19: Row sum of each indicator with respect to Top Management Barriers



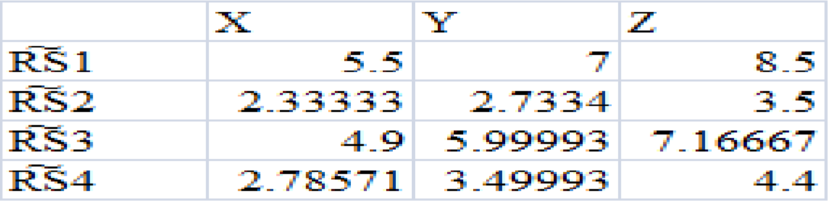
	X	Y	Z
$\widetilde{RS}1$	7.5	9	10.5
$\widetilde{RS}2$	2.68571	3.33333	4.0667
$\widetilde{RS}3$	2.83333	3.56667	4.5
$\widetilde{RS}4$	3.33326	4.06667	5

Table 5.20: Row sum of each indicator with respect to Organizational cultural barriers



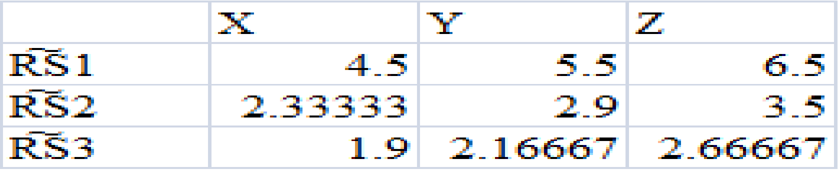
	X	Y	Z
$\widetilde{RS}1$	5.5	7	8.5
$\widetilde{RS}2$	2.73333	3.4	4.1667
$\widetilde{RS}3$	3.39993	4.1667	5.16667
$\widetilde{RS}4$	3	3.83326	5

Table 5.21: Row sum of each indicator with respect to technological barriers



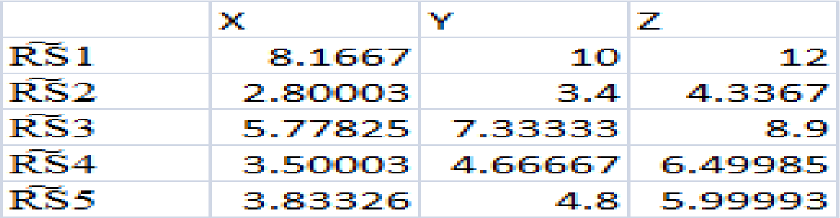
	X	Y	Z
R̃S̃1	5.5	7	8.5
R̃S̃2	2.33333	2.7334	3.5
R̃S̃3	4.9	5.99993	7.16667
R̃S̃4	2.78571	3.49993	4.4

Table 5.22: Row sum of each indicator with respect to Individual behaviour barriers



	X	Y	Z
R̃S̃1	4.5	5.5	6.5
R̃S̃2	2.33333	2.9	3.5
R̃S̃3	1.9	2.16667	2.66667

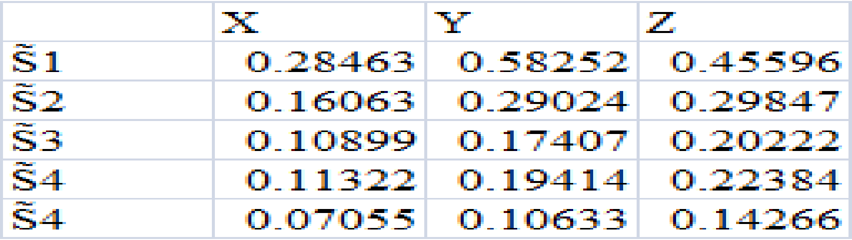
Table 5.23: Row sum of each indicator with respect to Quality barriers



	X	Y	Z
R̃S̃1	8.1667	10	12
R̃S̃2	2.80003	3.4	4.3367
R̃S̃3	5.77825	7.33333	8.9
R̃S̃4	3.50003	4.66667	6.49985
R̃S̃5	3.83326	4.8	5.99993

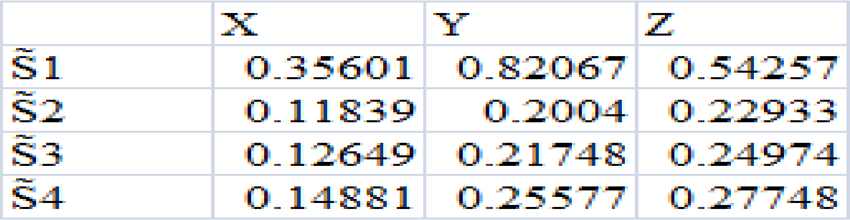
By using the equation 7, values of normalized row sum of each criterion and sub criterion have been calculated. Table 5.24 to 5.29 for normalized row sum of each criterion and sub criterion are as shown below:

Table 5.24: Normalized row sum of each indicator with respect to major criteria



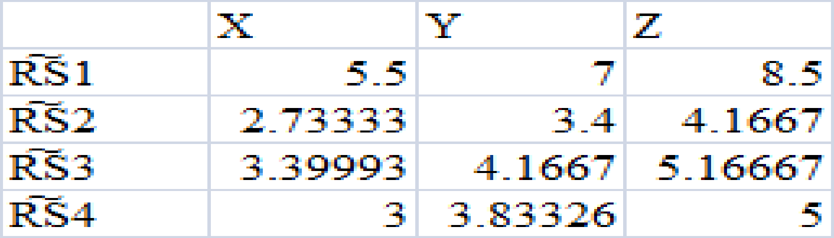
	X	Y	Z
S̃1	0.28463	0.58252	0.45596
S̃2	0.16063	0.29024	0.29847
S̃3	0.10899	0.17407	0.20222
S̃4	0.11322	0.19414	0.22384
S̃4	0.07055	0.10633	0.14266

Table 5.25: Normalized row sum of each indicator with respect to Top Management barriers



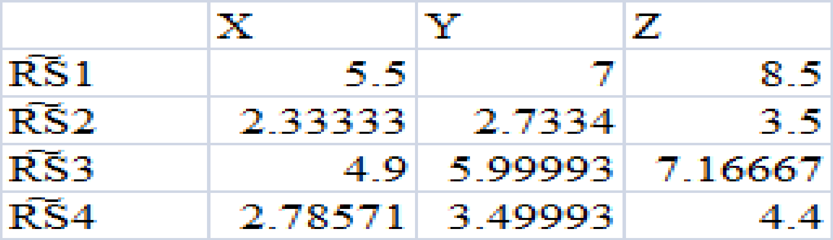
	X	Y	Z
S̃1	0.35601	0.82067	0.54257
S̃2	0.11839	0.2004	0.22933
S̃3	0.12649	0.21748	0.24974
S̃4	0.14881	0.25577	0.27748

Table 5.26: Normalized row sum of each indicator with respect to Organizational cultural barriers



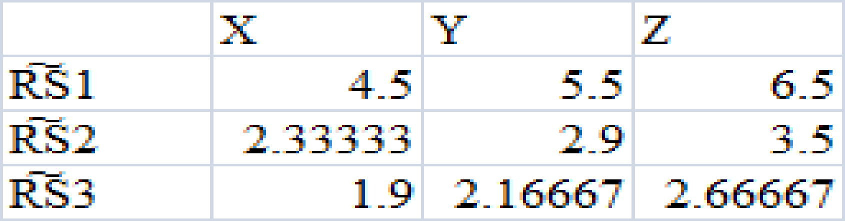
	X	Y	Z
R̃S̃1	5.5	7	8.5
R̃S̃2	2.73333	3.4	4.1667
R̃S̃3	3.39993	4.1667	5.16667
R̃S̃4	3	3.83326	5

Table 5.27: Normalized row sum of each indicator with respect to Technological barriers



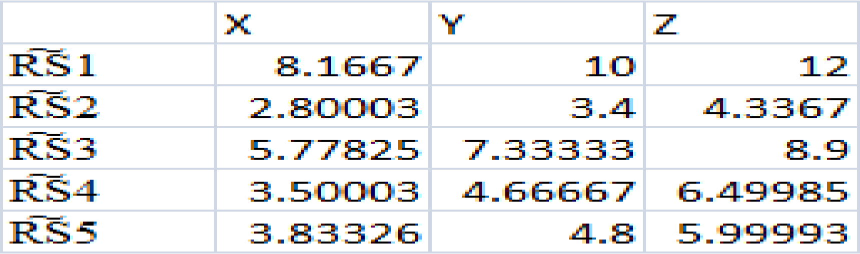
	X	Y	Z
R̃S̃1	5.5	7	8.5
R̃S̃2	2.33333	2.7334	3.5
R̃S̃3	4.9	5.99993	7.16667
R̃S̃4	2.78571	3.49993	4.4

Table 5.28: Normalized row sum of each indicator with respect to Individual barriers



	X	Y	Z
R̃S̃1	4.5	5.5	6.5
R̃S̃2	2.33333	2.9	3.5
R̃S̃3	1.9	2.16667	2.66667

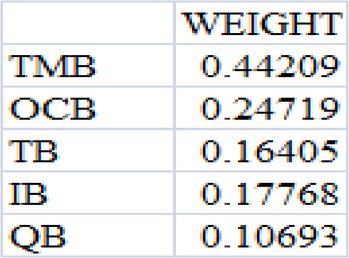
Table 5.29: Normalized row sum of each indicator with respect to Quality barriers



	X	Y	Z
$\widetilde{RS}$1	8.1667	10	12
$\widetilde{RS}$2	2.80003	3.4	4.3367
$\widetilde{RS}$3	5.77825	7.33333	8.9
$\widetilde{RS}$4	3.50003	4.66667	6.49985
$\widetilde{RS}$5	3.83326	4.8	5.99993

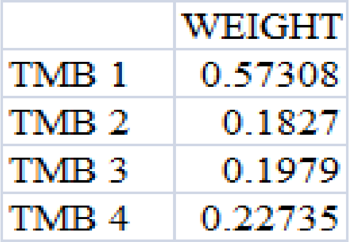
By using the equation 8, values of local priority weight of each criterion and sub criterion have been calculated. Table 5.30 to 5.36 for local priority weight of each criterion and sub criterion are as shown below:

Table 5.30: Weight of major criteria



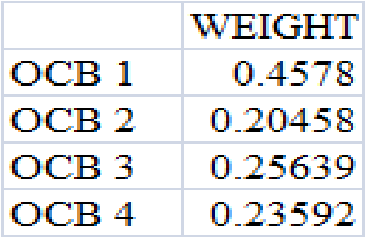
	WEIGHT
TMB	0.44209
OCB	0.24719
TB	0.16405
IB	0.17768
QB	0.10693

Table 5.31: Weight of Top Management barriers



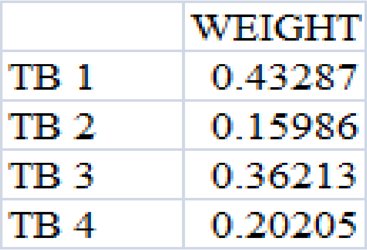
	WEIGHT
TMB 1	0.57308
TMB 2	0.1827
TMB 3	0.1979
TMB 4	0.22735

Table 5.32: Weight of Organizational cultural barriers



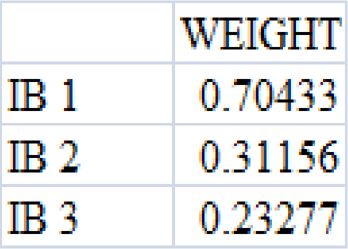
	WEIGHT
OCB 1	0.4578
OCB 2	0.20458
OCB 3	0.25639
OCB 4	0.23592

Table 5.33: Weight of Technology barriers



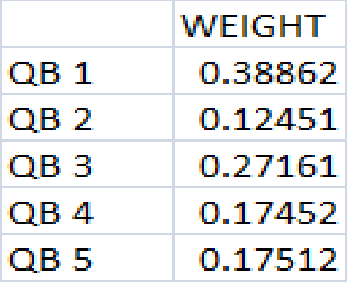
	WEIGHT
TB 1	0.43287
TB 2	0.15986
TB 3	0.36213
TB 4	0.20205

Table 5.34: Weight of Individual barriers



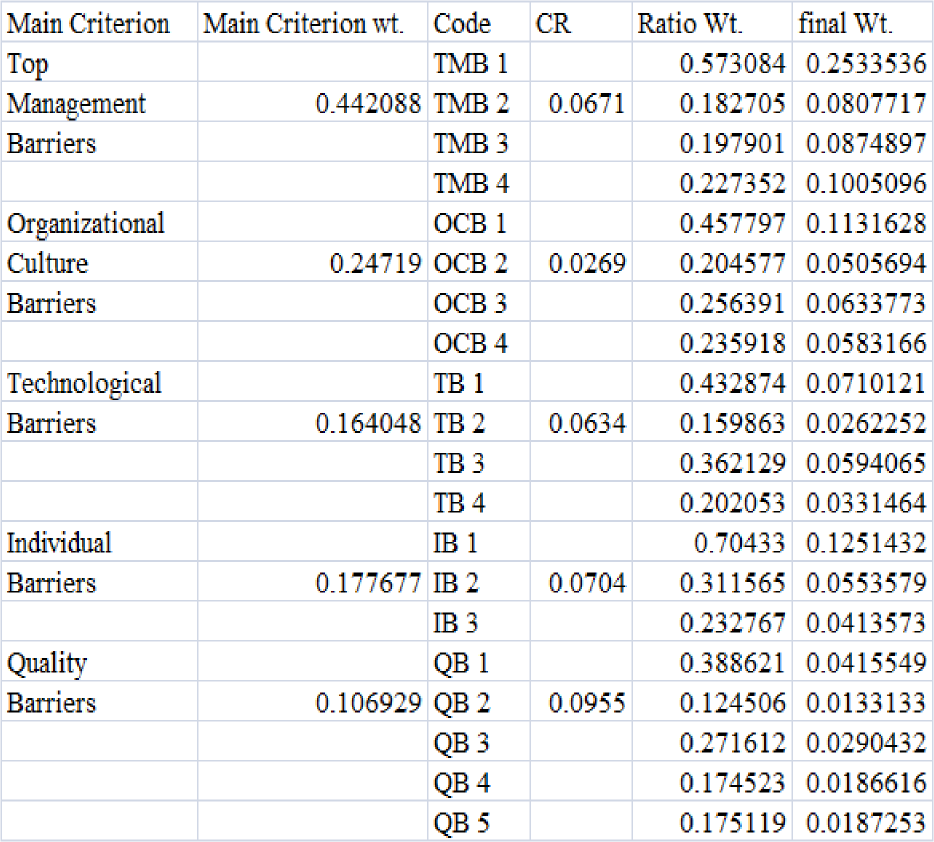
	WEIGHT
IB 1	0.70433
IB 2	0.31156
IB 3	0.23277

Table 5.35: Weight of Quality barriers



	WEIGHT
QB 1	0.38862
QB 2	0.12451
QB 3	0.27161
QB 4	0.17452
QB 5	0.17512

Table 5.36: Final weight of barriers



Main Criterion	Main Criterion wt.	Code	CR	Ratio Wt.	final Wt.
Top		TMB 1		0.573084	0.2533536
Management	0.442088	TMB 2	0.0671	0.182705	0.0807717
Barriers		TMB 3		0.197901	0.0874897
		TMB 4		0.227352	0.1005096
Organizational		OCB 1		0.457797	0.1131628
Culture	0.24719	OCB 2	0.0269	0.204577	0.0505694
Barriers		OCB 3		0.256391	0.0633773
		OCB 4		0.235918	0.0583166
Technological		TB 1		0.432874	0.0710121
Barriers	0.164048	TB 2	0.0634	0.159863	0.0262252
		TB 3		0.362129	0.0594065
		TB 4		0.202053	0.0331464
Individual		IB 1		0.70433	0.1251432
Barriers	0.177677	IB 2	0.0704	0.311565	0.0553579
		IB 3		0.232767	0.0413573
Quality		QB 1		0.388621	0.0415549
Barriers	0.106929	QB 2	0.0955	0.124506	0.0133133
		QB 3		0.271612	0.0290432
		QB 4		0.174523	0.0186616
		QB 5		0.175119	0.0187253

Phase 3: Evaluation of the solutions of lean manufacturing and determine of final rank with the help of Fuzzy TOPSIS

Expert’s panel gave fuzzy evaluation scale (very poor (VP), poor (P), fair (F), good (G), very good (VG)) and corresponding linguistic variables as shown in table 5.5. Linguistic scale evaluation matrixes were established by comparing solutions under each of the barriers separately. Table 5.37 to 5.39 for linguistic scale evaluation matrixes are as shown below:

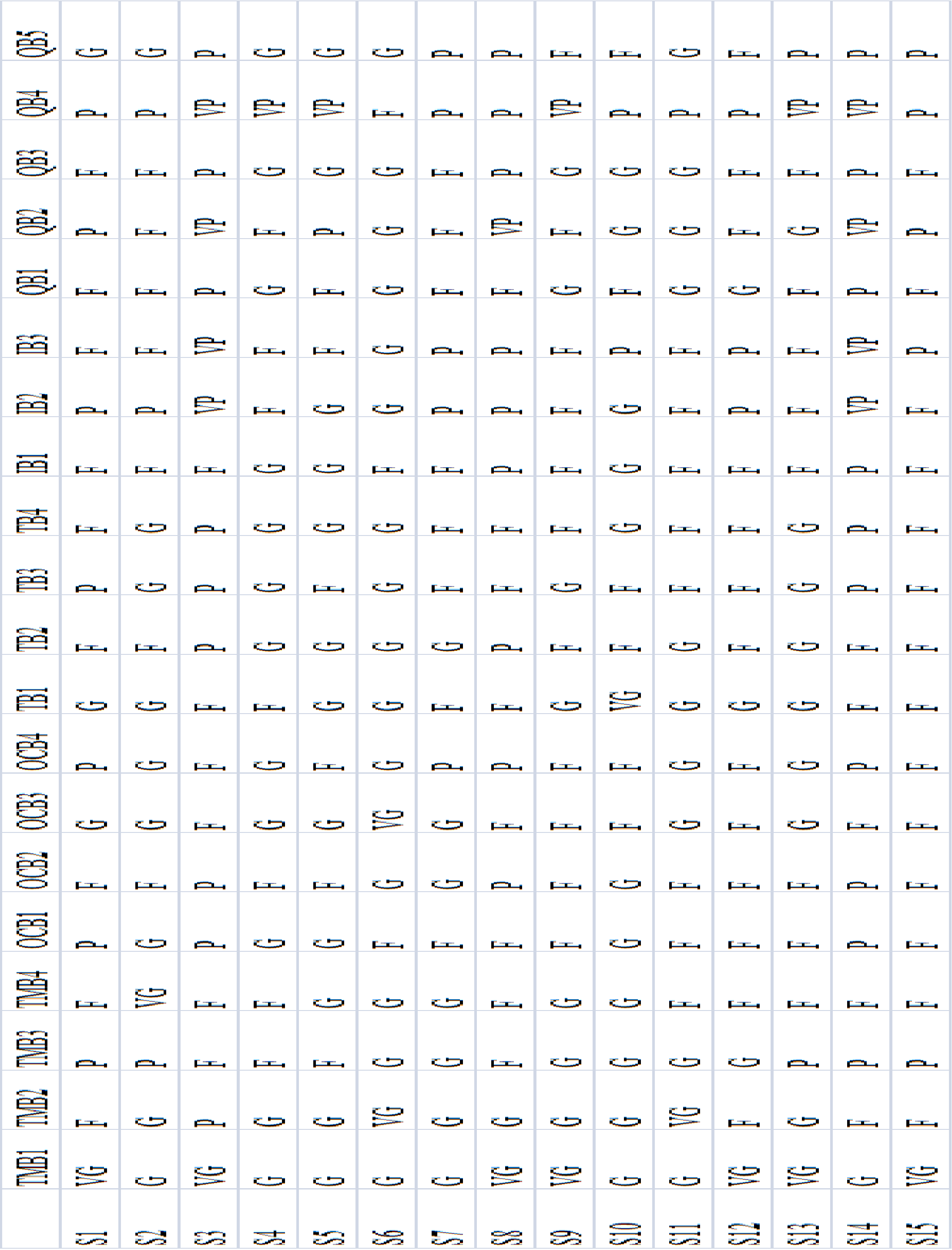
Table 5.37: Linguistic scale evaluation matrix for solution (expert 1)

	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2	TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
S1	VG	G	P	F	F	G	F	F	G	F	F	F	F	F	P	F	P	F	VP	VG
S2	VG	G	F	G	VG	G	G	F	F	F	G	G	G	F	G	P	P	F	VP	F
S3	G	F	P	G	F	VP	F	P	G	F	F	F	G	P	P	F	F	F	P	F
S4	VG	G	F	G	F	F	VG	F	G	G	F	G	G	P	P	G	F	G	P	F
S5	VG	VG	G	G	G	G	G	G	VG	G	G	F	F	F	P	G	F	F	P	G
S6	VG	G	G	VG	G	F	VG	F	G	G	F	F	G	F	F	G	F	F	P	VG
S7	G	G	F	F	G	F	F	F	G	G	G	P	G	F	P	F	G	G	VP	G
S8	VG	F	G	G	P	F	F	F	G	G	G	G	G	F	F	G	F	G	VP	F
S9	G	G	F	G	G	G	G	G	F	G	F	G	F	F	P	G	F	F	P	G
S10	VG	G	VG	F	G	F	G	P	G	G	G	G	F	G	F	G	F	VG	VP	G
S11	G	G	G	G	F	G	F	F	G	G	G	G	G	G	P	F	G	G	P	F
S12	G	G	G	F	F	F	G	F	F	G	F	G	G	P	P	G	F	G	VP	F
S13	G	G	F	G	G	F	G	F	G	G	G	G	G	F	P	G	F	G	P	F
S14	VG	G	P	G	F	P	F	P	F	F	P	F	P	P	VP	F	F	F	P	F
S15	G	G	P	F	G	G	G	G	G	G	F	F	G	G	F	G	P	G	VP	F

Table 5.38: Linguistic scale evaluation matrix for solution (expert 2)

	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2	TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
S1	G	G	F	G	F	F	G	F	F	G	F	G	G	F	P	G	P	P	VP	VG
S2	VG	F	P	G	G	G	F	G	G	P	F	VG	G	F	G	G	F	F	P	G
S3	G	F	F	VG	F	P	G	P	F	P	F	P	F	P	P	P	P	P	P	P
S4	G	VG	P	G	F	G	G	F	G	F	G	F	F	F	F	G	F	F	P	G
S5	VG	G	G	F	F	F	VG	F	G	F	G	G	G	G	F	G	F	G	P	F
S6	VG	VG	F	G	G	G	G	G	VG	G	G	G	G	F	G	F	F	G	P	G
S7	VG	F	G	G	F	F	G	F	G	VG	F	F	G	G	F	G	G	F	VP	F
S8	G	G	F	F	F	P	G	P	G	F	F	P	F	P	VP	F	P	P	VP	P
S9	VG	G	G	F	G	F	F	F	G	G	G	G	G	G	F	F	F	F	P	F
S10	VG	G	VG	G	F	G	G	F	G	G	G	F	G	F	F	G	F	G	P	F
S11	VG	G	F	G	G	F	G	P	F	G	G	G	G	F	F	G	F	F	P	F
S12	VG	G	F	P	G	P	G	P	G	G	G	G	G	F	F	F	F	F	P	P
S13	VG	F	F	F	G	G	F	F	VG	VG	F	F	G	F	F	G	F	G	P	F
S14	G	F	F	G	F	F	G	VP	P	P	F	F	F	P	P	P	VP	P	VP	P
S15	VG	G	F	P	F	F	F	F	G	F	P	P	G	F	P	F	P	F	P	P

Table 5.39: Linguistic scale evaluation matrix for solution (expert 3)



	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2	TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
S1	VG	F	P	F	P	F	G	P	G	F	P	F	F	P	F	F	P	F	P	G
S2	G	G	P	VG	G	F	G	G	G	F	G	G	F	P	F	F	F	F	P	G
S3	VG	P	F	F	P	P	F	F	F	P	P	P	F	VP	VP	P	VP	P	VP	P
S4	G	G	F	F	G	F	G	G	F	G	G	G	G	F	F	G	F	G	VP	G
S5	G	G	F	G	G	F	G	F	G	G	F	G	G	G	F	F	P	G	VP	G
S6	G	VG	G	G	F	G	VG	G	G	G	G	G	F	G	G	G	G	G	F	G
S7	G	G	G	G	F	G	G	P	F	G	F	F	F	P	P	F	F	F	P	P
S8	VG	G	F	F	F	P	F	P	F	P	F	F	P	P	P	F	VP	P	P	P
S9	VG	G	G	G	F	F	F	F	G	F	G	F	F	F	F	G	F	G	VP	F
S10	G	G	G	G	G	G	F	F	VG	F	F	G	G	G	P	F	G	G	P	F
S11	G	VG	G	F	F	F	G	G	G	G	F	F	F	F	F	G	G	G	P	G
S12	VG	F	G	F	F	F	F	F	G	F	F	F	F	P	P	G	F	F	P	F
S13	VG	G	P	F	F	F	G	G	G	G	G	G	F	F	F	F	G	F	VP	P
S14	G	F	P	F	P	P	F	P	F	F	P	P	P	VP	VP	P	VP	P	VP	P
S15	VG	F	P	F	F	F	F	F	F	F	F	F	F	F	P	F	P	F	P	P

Fuzzy evaluation matrixes for solution are designed between sub criterions and solutions.

By using the linguistic variables from table 4.5, values of fuzzy evaluation matrixes for solution have been taken. Table 5.40 to 5.42 for fuzzy evaluation matrixes are as shown below:

Table 5.40: Fuzzy evaluation matrix for solution (expert 1)

	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2	TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
S1	(7,9,11)	(5,7,9)	(1,3,5)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(1,1,3)	(7,9,11)
S2	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(1,3,5)	(3,5,7)	(1,1,3)	(3,5,7)
S3	(5,7,9)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(1,1,3)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)
S4	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(7,9,11)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)
S5	(7,9,11)	(7,9,11)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)
S6	(7,9,11)	(5,7,9)	(5,7,9)	(7,9,11)	(5,7,9)	(3,5,7)	(7,9,11)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(7,9,11)
S7	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(1,1,3)	(5,7,9)
S8	(7,9,11)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,1,3)	(3,5,7)
S9	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)
S10	(7,9,11)	(5,7,9)	(7,9,11)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(7,9,11)	(1,1,3)	(5,7,9)
S11	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)
S12	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(1,1,3)	(3,5,7)
S13	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)
S14	(7,9,11)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,3,5)	(1,1,3)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)
S15	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	(1,1,3)	(3,5,7)

Table 5.41: Fuzzy evaluation matrix for solution (expert 2)

	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2	TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
S1	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)	(1,3,5)	(1,1,3)	(7,9,11)
S2	(7,9,11)	(3,5,7)	(1,3,5)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)
S3	(5,7,9)	(3,5,7)	(3,5,7)	(7,9,11)	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)	(1,3,5)	(1,3,5)	(1,3,5)	(1,3,5)
S4	(5,7,9)	(7,9,11)	(1,3,5)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)
S5	(7,9,11)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(7,9,11)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)
S6	(7,9,11)	(7,9,11)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)
S7	(7,9,11)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,11)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(1,1,3)	(3,5,7)
S8	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,1,3)	(3,5,7)	(1,3,5)	(1,3,5)	(1,1,3)	(1,3,5)
S9	(7,9,11)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)
S10	(7,9,11)	(5,7,9)	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)
S11	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)
S12	(7,9,11)	(5,7,9)	(3,5,7)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)
S13	(7,9,11)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(7,9,11)	(7,9,11)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)
S14	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(1,1,3)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)	(1,1,3)	(1,3,5)	(1,1,3)	(1,3,5)
S15	(7,9,11)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(1,3,5)	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,3,5)

Table 5.42: Fuzzy evaluation matrix for solution (expert 3)

	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2	TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
S1	(7,9,11)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(5,7,9)	(1,3,5)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(5,7,9)
S2	(5,7,9)	(5,7,9)	(1,3,5)	(7,9,11)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)
S3	(7,9,11)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	(1,1,3)	(1,1,3)	(1,3,5)	(1,1,3)	(1,3,5)	(1,1,3)	(1,3,5)
S4	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,1,3)	(5,7,9)
S5	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(5,7,9)	(1,1,3)	(5,7,9)
S6	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(7,9,11)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)
S7	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)
S8	(7,9,11)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	(1,1,3)	(1,3,5)	(1,3,5)	(1,3,5)
S9	(7,9,11)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(5,7,9)	(1,1,3)	(3,5,7)
S10	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(7,9,11)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)	(3,5,7)
S11	(5,7,9)	(7,9,11)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(1,3,5)	(5,7,9)
S12	(7,9,11)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(5,7,9)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)
S13	(7,9,11)	(5,7,9)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(5,7,9)	(3,5,7)	(1,1,3)	(1,3,5)
S14	(5,7,9)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(1,3,5)	(1,3,5)	(1,3,5)	(1,1,3)	(1,1,3)	(1,3,5)	(1,1,3)	(1,3,5)	(1,1,3)	(1,3,5)
S15	(7,9,11)	(3,5,7)	(1,3,5)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)	(1,3,5)	(1,3,5)

By using the equation 9, values of aggregate fuzzy decision matrix for solution has been found out. Table 5.43 for aggregate fuzzy decision matrix is as shown below:

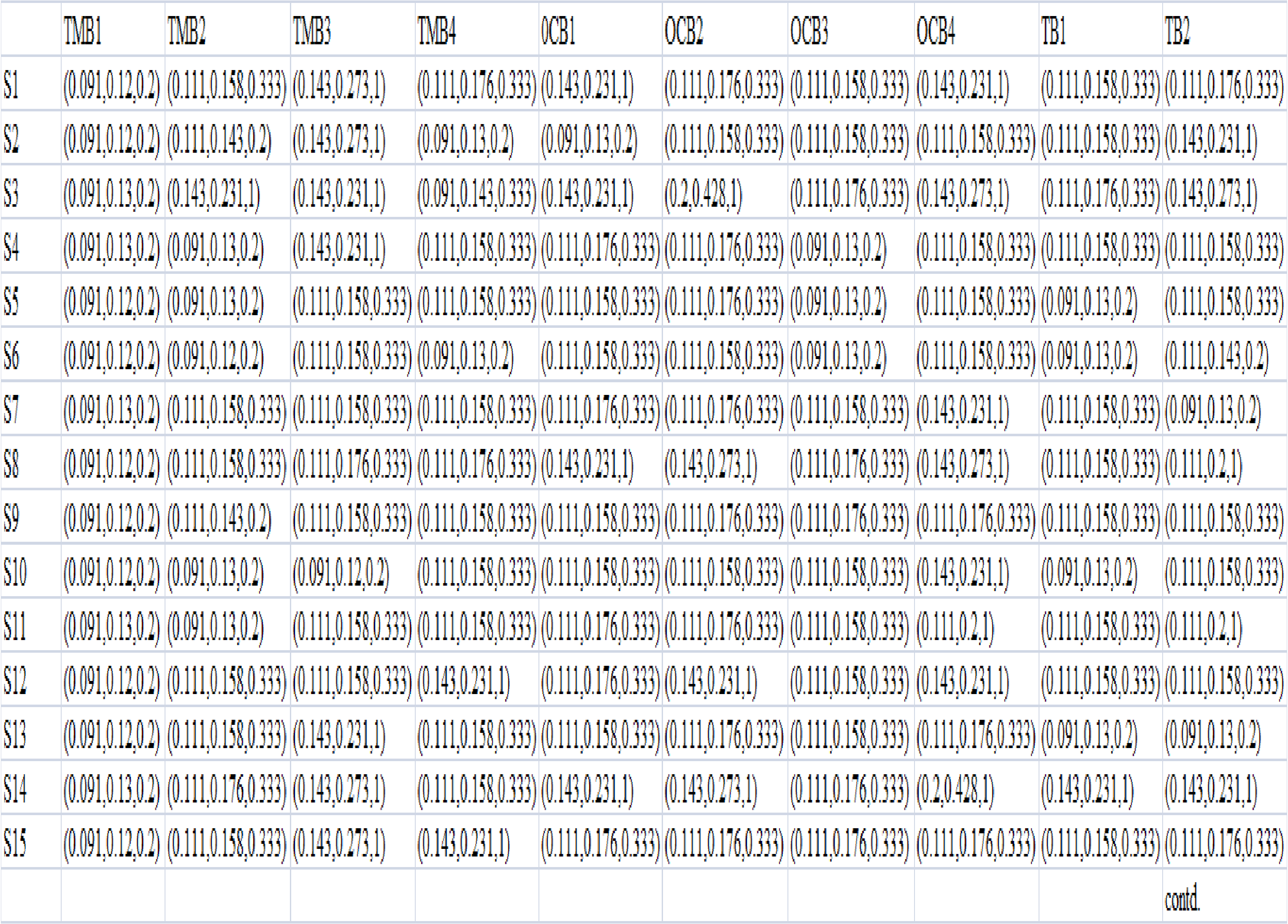
Table 5.43: Aggregate fuzzy decision matrix for solutions

	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2
S1	(5,8.333,11)	(3,6.333,9)	(1,3.667,7)	(3,5.667,9)	(1,4.333,7)	(3,5.667,9)	(3,6.333,9)	(1,4.333,7)	(3,6.333,9)	(3,5.667,9)
S2	(5,8.333,11)	(5,7,9)	(1,3.667,7)	(5,7.667,11)	(5,7.667,11)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)
S3	(5,7.667,11)	(1,4.333,7)	(1,4.333,7)	(3,7,11)	(1,4.333,7)	(1,2.333,5)	(3,5.667,9)	(1,3.667,7)	(3,5.667,9)	(1,4.333,7)
S4	(5,7.667,11)	(5,7.667,11)	(1,4.333,7)	(3,6.333,9)	(3,5.667,9)	(3,5.667,9)	(5,7.667,11)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)
S5	(5,8.333,11)	(5,7.667,11)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,5.667,9)	(5,7.667,11)	(3,5.667,9)	(5,7.667,11)	(3,6.333,9)
S6	(5,8.333,11)	(5,8.333,11)	(3,6.333,9)	(5,7.667,11)	(3,6.333,9)	(3,6.333,9)	(5,7.667,11)	(3,6.333,9)	(5,7.667,11)	(5,7,9)
S7	(5,7.667,11)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,5.667,9)	(3,5.667,9)	(3,6.333,9)	(1,4.333,7)	(3,6.333,9)	(5,7.667,11)
S8	(5,8.333,11)	(3,6.333,9)	(3,5.667,9)	(3,5.667,9)	(1,4.333,7)	(1,3.667,7)	(3,5.667,9)	(1,3.667,7)	(3,6.333,9)	(1,5,9)
S9	(5,8.333,11)	(5,7,9)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,5.667,9)	(3,5.667,9)	(3,5.667,9)	(3,6.333,9)	(3,6.333,9)
S10	(5,8.333,11)	(5,7.667,11)	(5,8.333,11)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)	(5,7.667,11)	(3,6.333,9)
S11	(5,7.667,11)	(5,7.667,11)	(3,6.333,9)	(3,6.333,9)	(3,5.667,9)	(3,5.667,9)	(3,6.333,9)	(1,5,9)	(3,6.333,9)	(5,7,9)
S12	(5,8.333,11)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)	(3,5.667,9)	(1,4.333,7)	(3,6.333,9)	(1,4.333,7)	(3,6.333,9)	(3,6.333,9)
S13	(5,8.333,11)	(3,6.333,9)	(1,4.333,7)	(3,5.667,9)	(3,6.333,9)	(3,5.667,9)	(3,6.333,9)	(3,5.667,9)	(5,7.667,11)	(5,7.667,11)
S14	(5,7.667,11)	(3,5.667,9)	(1,3.667,7)	(3,6.333,9)	(1,4.333,7)	(1,3.667,7)	(3,5.667,9)	(1,2.333,5)	(1,4.333,7)	(1,4.333,7)
S15	(5,8.333,11)	(3,6.333,9)	(1,3.667,7)	(1,4.333,7)	(3,5.667,9)	(3,5.667,9)	(3,5.667,9)	(3,5.667,9)	(3,6.333,9)	(3,5.667,9)
										contd.

TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
(1,4.333,7)	(3,5.667,9)	(3,5.667,9)	(1,4.333,7)	(1,3.667,7)	(3,5.667,9)	(1,2.333,5)	(1,4.333,7)	(1,1.667,5)	(5,8.333,11)
(3,6.333,9)	(5,7.667,11	(3,6.333,9)	(1,4.333,7)	(3,5.667,9)	(3,5.667,9)	(1,4.333,7)	(1,4.333,7)	(1,2.333,5)	(3,6.333,9)
(1,4.333,7)	(1,3.667,7)	(3,5.667,9)	(1,2.333,5)	(1,2.333,5)	(1,3.667,7)	(1,3,7)	(1,3.667,7)	(1,2.333,5)	(1,3.667,7)
(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)	(1,4.333,7)	(3,6.333,9)	(3,5,7)	(3,6.333,9)	(1,2.333,5)	(3,6.333,9)
(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)	(3,6.333,9)	(1,4.333,7)	(3,6.333,9)	(1,2.333,5)	(3,6.333,9)
(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,5.667,9)	(3,6.333,9)	(3,6.333,9)	(3,5.667,9)	(3,6.333,9)	(1,3.667,7)	(5,7.667,11)
(3,5.667,9)	(1,4.333,7)	(3,6.333,9)	(1,5,9)	(1,3.667,7)	(3,6.333,9)	(3,5.667,9)	(3,5.667,9)	(1,1.667,5)	(1,5,9)
(1,5,9)	(1,5,9)	(1,5,9)	(1,3.667,7)	(1,3,7)	(3,5.667,9)	(1,3,7)	(1,4.333,7)	(1,1.667,5)	(1,3.667,7)
(3,6.333,9)	(3,6.333,9)	(3,5.667,9)	(3,5,667,9)	(1,4.333,7)	(3,6.333,9)	(3,5,7)	(3,5.667,9)	(1,2.333,5)	(3,5.667,9)
(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)	(3,6.333,9)	(3,5.667,9)	(5,7.667,11	(1,2.333,5)	(3,5.667,9)
(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(3,5,667,9)	(1,4.333,7)	(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(1,2.333,5)	(3,5.667,9)
(3,5.667,9)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)	(1,3.667,7)	(3,6.333,9)	(3,5.667,9)	(3,5.667,9)	(1,2.333,5)	(1,4.333,7)
(3,6.333,9)	(3,6.333,9)	(3,6.333,9)	(1,4.333,7)	(1,4.333,7)	(3,6.333,9)	(3,5.667,9)	(3,6.333,9)	(1,2.333,5)	(1,4.333,7)
(1,3.667,7)	(1,4.333,7)	(1,3.667,7)	(1,2.333,5)	(1,1.667,5)	(1,3.667,7)	(1,2.333,7)	(1,3.667,7)	(1,1.667,5)	(1,3.667,7)
(1,4.333,7)	(1,4.333,7)	(3,6.333,9)	(3,5,667,9)	(1,3.667,7)	(3,5.667,9)	(1,3,5)	(3,5.667,9)	(1,2.333,5)	(1,3.667,7)

By using the equation 10 and 11, values of normalized fuzzy decision matrix for solution has been calculated. Table 5.44 for normalized fuzzy decision matrix is as shown below:

Table 5.44: Normalized fuzzy decision matrix for solutions

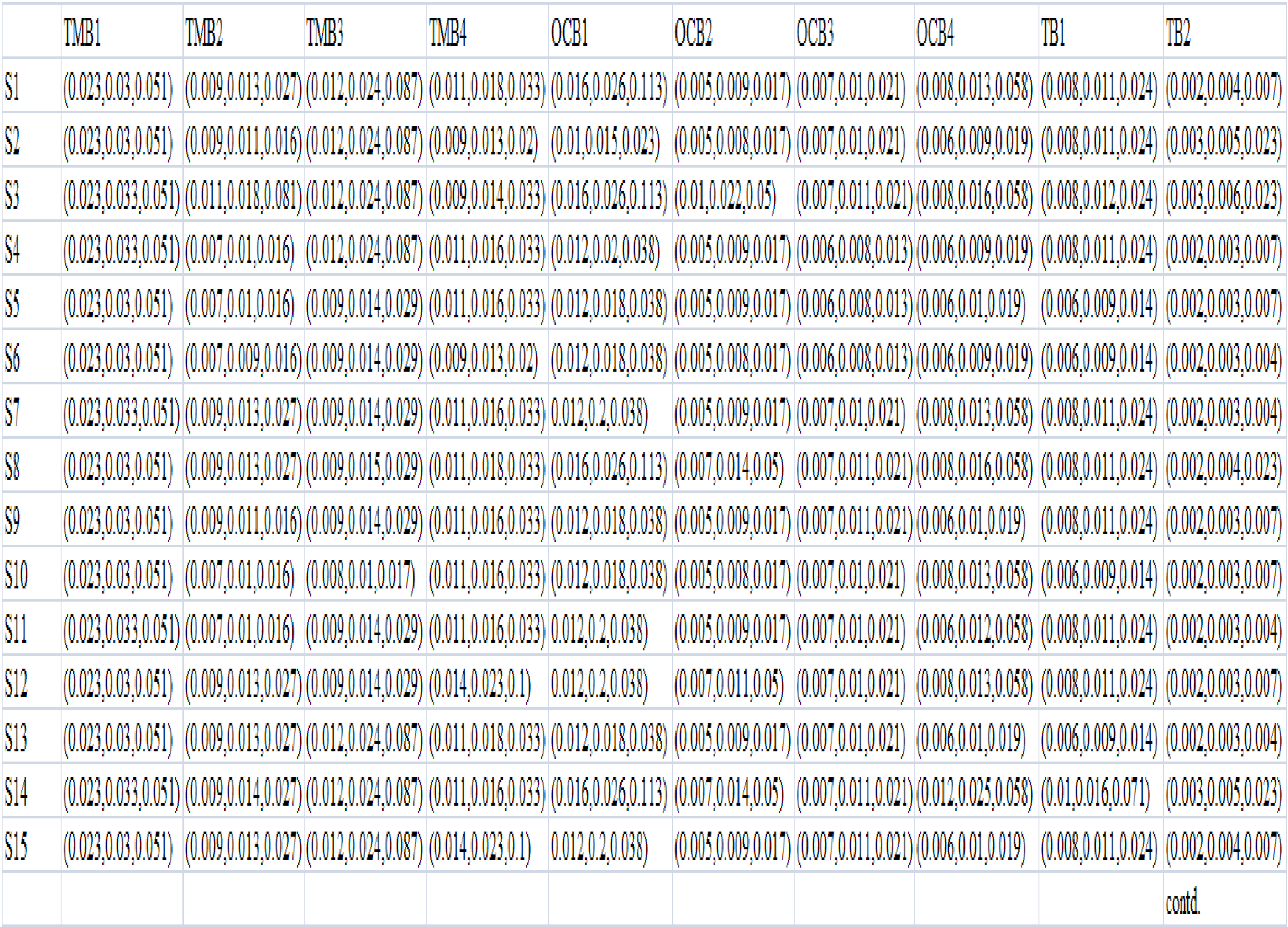


	TMB1	TMB2	TMB3	TMB4	0CB1	OCB2	OCB3	OCB4	TB1	TB2
S1	(0.091,0.12,0.2)	(0.111,0.158,0.333)	(0.143,0.273,1)	(0.111,0.176,0.333)	(0.143,0.231,1)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.176,0.333)
S2	(0.091,0.12,0.2)	(0.111,0.143,0.2)	(0.143,0.273,1)	(0.091,0.13,0.2)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)
S3	(0.091,0.13,0.2)	(0.143,0.231,1)	(0.143,0.231,1)	(0.091,0.143,0.333)	(0.143,0.231,1)	(0.2,0.428,1)	(0.111,0.176,0.333)	(0.143,0.273,1)	(0.111,0.176,0.333)	(0.143,0.273,1)
S4	(0.091,0.13,0.2)	(0.091,0.13,0.2)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)
S5	(0.091,0.12,0.2)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.091,0.13,0.2)	(0.111,0.158,0.333)
S6	(0.091,0.12,0.2)	(0.091,0.12,0.2)	(0.111,0.158,0.333)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.091,0.13,0.2)	(0.111,0.143,0.2)
S7	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.091,0.13,0.2)
S8	(0.091,0.12,0.2)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.143,0.231,1)	(0.143,0.273,1)	(0.111,0.176,0.333)	(0.143,0.273,1)	(0.111,0.158,0.333)	(0.111,0.2,1)
S9	(0.091,0.12,0.2)	(0.111,0.143,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)
S10	(0.091,0.12,0.2)	(0.091,0.13,0.2)	(0.091,0.12,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.091,0.13,0.2)	(0.111,0.158,0.333)
S11	(0.091,0.13,0.2)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.111,0.2,1)	(0.111,0.158,0.333)	(0.111,0.2,1)
S12	(0.091,0.12,0.2)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.176,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.158,0.333)
S13	(0.091,0.12,0.2)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.091,0.13,0.2)	(0.091,0.13,0.2)
S14	(0.091,0.13,0.2)	(0.111,0.176,0.333)	(0.143,0.273,1)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.143,0.273,1)	(0.111,0.176,0.333)	(0.2,0.428,1)	(0.143,0.231,1)	(0.143,0.231,1)
S15	(0.091,0.12,0.2)	(0.111,0.158,0.333)	(0.143,0.273,1)	(0.143,0.231,1)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)
										contd.

TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
(0.143,0.231,1)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.143,0.231,1)	(0.143,0.273,1)	(0.111,0.176,0.333)	(0.2,0.428,1)	(0.143,0.273,1)	(0.2,0.6,1)	(0.091,0.12,0.2)
(0.111,0.158,0.333)	(0.091,0.13,0.2)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.143,0.231,1)	(0.143,0.273,1)	(0.2,0.428,1)	(0.111,0.158,0.333)
(0.143,0.231,1)	(0.143,0.273,1)	(0.111,0.176,0.333)	(0.2,0.428,1)	(0.2,0.428,1)	(0.143,0.273,1)	(0.143,0.333,1)	(0.143,0.273,1)	(0.2,0.428,1)	(0.143,0.273,1)
(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.143,0.2,0.333)	(0.111,0.158,0.333)	(0.2,0.428,1)	(0.111,0.158,0.333)
(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.2,0.428,1)	(0.111,0.158,0.333)
(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.143,0.273,1)	(0.091,0.13,0.2)
(0.111,0.176,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.2,1)	(0.143,0.273,1)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.2,0.6,1)	(0.143,0.273,1)
(0.111,0.2,1)	(0.111,0.2,1)	(0.111,0.2,1)	(0.143,0.273,1)	(0.143,0.333,1)	(0.111,0.176,0.333)	(0.143,0.333,1)	(0.111,0.231,1)	(0.2,0.6,1)	(0.143,0.273,1)
(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.143,0.2,0.333)	(0.111,0.176,0.333)	(0.2,0.428,1)	(0.111,0.176,0.333)
(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.091,0.13,0.2)	(0.2,0.428,1)	(0.111,0.176,0.333)
(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.2,0.428,1)	(0.111,0.176,0.333)
(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.143,0.273,1)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.176,0.333)	(0.2,0.428,1)	(0.143,0.231,1)
(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.111,0.158,0.333)	(0.143,0.231,1)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.111,0.158,0.333)	(0.2,0.428,1)	(0.143,0.231,1)
(0.143,0.273,1)	(0.143,0.231,1)	(0.143,0.273,1)	(0.2,0.428,1)	(0.2,0.6,1)	(0.143,0.273,1)	(0.143,0.428,1)	(0.143,0.428,1)	(0.2,0.6,1)	(0.143,0.273,1)
(0.143,0.231,1)	(0.143,0.231,1)	(0.111,0.158,0.333)	(0.111,0.176,0.333)	(0.143,0.273,1)	(0.111,0.176,0.333)	(0.2,0.333,1)	(0.111,0.176,0.333)	(0.2,0.428,1)	(0.143,0.273,1)

By using the equation 12, values of weighted normalized fuzzy decision matrix for solution has been calculated. Table 5.45 for weighted normalized fuzzy decision matrix is as shown below:

Table 5.45: Weighted normalized fuzzy decision matrix for solutions



	TMB1	TMB2	TMB3	TMB4	OCB1	OCB2	OCB3	OCB4	TB1	TB2
S1	(0.023,0.03,0.051)	(0.009,0.013,0.027)	(0.012,0.024,0.087)	(0.011,0.018,0.033)	(0.016,0.026,0.113)	(0.005,0.009,0.017)	(0.007,0.01,0.021)	(0.008,0.013,0.058)	(0.008,0.011,0.024)	(0.002,0.004,0.007)
S2	(0.023,0.03,0.051)	(0.009,0.011,0.016)	(0.012,0.024,0.087)	(0.009,0.013,0.02)	(0.01,0.015,0.023)	(0.005,0.008,0.017)	(0.007,0.01,0.021)	(0.006,0.009,0.019)	(0.008,0.011,0.024)	(0.003,0.005,0.023)
S3	(0.023,0.033,0.051)	(0.011,0.018,0.081)	(0.012,0.024,0.087)	(0.009,0.014,0.033)	(0.016,0.026,0.113)	(0.01,0.022,0.05)	(0.007,0.011,0.021)	(0.008,0.016,0.058)	(0.008,0.012,0.024)	(0.003,0.006,0.023)
S4	(0.023,0.033,0.051)	(0.007,0.01,0.016)	(0.012,0.024,0.087)	(0.011,0.016,0.033)	(0.012,0.02,0.038)	(0.005,0.009,0.017)	(0.006,0.008,0.013)	(0.006,0.009,0.019)	(0.008,0.011,0.024)	(0.002,0.003,0.007)
S5	(0.023,0.03,0.051)	(0.007,0.01,0.016)	(0.009,0.014,0.029)	(0.011,0.016,0.033)	(0.012,0.018,0.038)	(0.005,0.009,0.017)	(0.006,0.008,0.013)	(0.006,0.01,0.019)	(0.006,0.009,0.014)	(0.002,0.003,0.007)
S6	(0.023,0.03,0.051)	(0.007,0.009,0.016)	(0.009,0.014,0.029)	(0.009,0.013,0.02)	(0.012,0.018,0.038)	(0.005,0.008,0.017)	(0.006,0.008,0.013)	(0.006,0.009,0.019)	(0.006,0.009,0.014)	(0.002,0.003,0.004)
S7	(0.023,0.033,0.051)	(0.009,0.013,0.027)	(0.009,0.014,0.029)	(0.011,0.016,0.033)	0.012,0.2,0.038)	(0.005,0.009,0.017)	(0.007,0.01,0.021)	(0.008,0.013,0.058)	(0.008,0.011,0.024)	(0.002,0.003,0.004)
S8	(0.023,0.03,0.051)	(0.009,0.013,0.027)	(0.009,0.015,0.029)	(0.011,0.018,0.033)	(0.016,0.026,0.113)	(0.007,0.014,0.05)	(0.007,0.011,0.021)	(0.008,0.016,0.058)	(0.008,0.011,0.024)	(0.002,0.004,0.023)
S9	(0.023,0.03,0.051)	(0.009,0.011,0.016)	(0.009,0.014,0.029)	(0.011,0.016,0.033)	(0.012,0.018,0.038)	(0.005,0.009,0.017)	(0.007,0.011,0.021)	(0.006,0.01,0.019)	(0.008,0.011,0.024)	(0.002,0.003,0.007)
S10	(0.023,0.03,0.051)	(0.007,0.01,0.016)	(0.008,0.01,0.017)	(0.011,0.016,0.033)	(0.012,0.018,0.038)	(0.005,0.008,0.017)	(0.007,0.01,0.021)	(0.008,0.013,0.058)	(0.006,0.009,0.014)	(0.002,0.003,0.007)
S11	(0.023,0.033,0.051)	(0.007,0.01,0.016)	(0.009,0.014,0.029)	(0.011,0.016,0.033)	0.012,0.2,0.038)	(0.005,0.009,0.017)	(0.007,0.01,0.021)	(0.006,0.012,0.058)	(0.008,0.011,0.024)	(0.002,0.003,0.004)
S12	(0.023,0.03,0.051)	(0.009,0.013,0.027)	(0.009,0.014,0.029)	(0.014,0.023,0.1)	0.012,0.2,0.038)	(0.007,0.011,0.05)	(0.007,0.01,0.021)	(0.008,0.013,0.058)	(0.008,0.011,0.024)	(0.002,0.003,0.007)
S13	(0.023,0.03,0.051)	(0.009,0.013,0.027)	(0.012,0.024,0.087)	(0.011,0.018,0.033)	(0.012,0.018,0.038)	(0.005,0.009,0.017)	(0.007,0.01,0.021)	(0.006,0.01,0.019)	(0.006,0.009,0.014)	(0.002,0.003,0.004)
S14	(0.023,0.033,0.051)	(0.009,0.014,0.027)	(0.012,0.024,0.087)	(0.011,0.016,0.033)	(0.016,0.026,0.113)	(0.007,0.014,0.05)	(0.007,0.011,0.021)	(0.012,0.025,0.058)	(0.01,0.016,0.071)	(0.003,0.005,0.023)
S15	(0.023,0.03,0.051)	(0.009,0.013,0.027)	(0.012,0.024,0.087)	(0.014,0.023,0.1)	0.012,0.2,0.038)	(0.005,0.009,0.017)	(0.007,0.011,0.021)	(0.006,0.01,0.019)	(0.008,0.011,0.024)	(0.002,0.004,0.007)
										contd.

TB3	TB4	IB1	IB2	IB3	QB1	QB2	QB3	QB4	QB5
(0.008,0.014,0.059)	(0.004,0.006,0.011)	(0.014,0.022,0.042)	(0.008,0.013,0.055)	(0.006,0.011,0.041)	(0.005,0.007,0.014)	(0.003,0.006,0.013)	(0.004,0.007,0.03)	(0.004,0.011,0.019)	(0.002,0.002,0.004)
(0.006,0.009,0.02)	(0.003,0.004,0.007)	(0.014,0.02,0.042)	(0.008,0.013,0.055)	(0.004,0.007,0.014)	(0.005,0.007,0.014)	(0.002,0.003,0.013)	(0.004,0.007,0.03)	(0.004,0.008,0.019)	(0.002,0.003,0.006)
(0.008,0.014,0.059)	(0.005,0.009,0.033	(0.014,0.022,0.042)	(0.011,0.024,0.055)	(0.008,0.018,0.041)	(0.006,0.011,0.041)	(0.002,0.004,0.013)	(0.004,0.008,0.03)	(0.004,0.008,0.019)	(0.003,0.005,0.019)
(0.006,0.009,0.02)	(0.004,0.005,0.011)	(0.014,0.02,0.042)	(0.008,0.013,0.055)	(0.006,0.01,0.041)	(0.005,0.006,0.014)	(0.002,0.003,0.004)	(0.003,0.004,0.01)	(0.004,0.008,0.019)	(0.002,0.003,0.006)
(0.006,0.009,0.02)	(0.004,0.005,0.011)	(0.014,0.02,0.042)	(0.006,0.009,0.018)	(0.006,0.01,0.041)	(0.005,0.006,0.014)	(0.002,0.003,0.013)	(0.003,0.004,0.01)	(0.004,0.008,0.019)	(0.002,0.003,0.006)
(0.006,0.009,0.02)	(0.004,0.005,0.011)	(0.014,0.02,0.042)	(0.006,0.011,0.055)	(0.004,0.006,0.014)	(0.005,0.006,0.014)	(0.001,0.002,0.004)	(0.003,0.004,0.01)	(0.003,0.005,0.019)	(0.002,0.002,0.004)
(0.006,0.01,0.02)	(0.005,0.008,0.033	(0.014,0.02,0.042)	(0.008,0.015,0.055)	(0.006,0.011,0.041)	(0.005,0.006,0.014)	(0.001,0.002,0.004)	(0.003,0.005,0.01)	(0.004,0.011,0.019)	(0.002,0.004,0.019)
(0.006,0.01,0.02)	(0.004,0.007,0.033)	(0.014,0.025,0.125)	(0.006,0.009,0.018)	(0.006,0.014,0.041)	(0.005,0.007,0.014)	(0.002,0.004,0.013)	(0.003,0.007,0.03)	(0.004,0.011,0.019)	(0.003,0.005,0.019)
(0.006,0.009,0.02)	(0.004,0.005,0.011)	(0.014,0.022,0.042)	(0.006,0.01,0.018)	(0.006,0.01,0.041)	(0.005,0.006,0.014)	(0.002,0.003,0.004)	(0.003,0.005,0.01)	(0.004,0.008,0.019)	(0.002,0.003,0.006)
(0.006,0.009,0.02)	(0.004,0.005,0.011)	(0.014,0.02,0.042)	(0.006,0.009,0.018)	(0.006,0.01,0.041)	(0.005,0.006,0.014)	(0.001,0.002,0.004)	(0.002,0.004,0.006	(0.004,0.008,0.019)	(0.002,0.003,0.006)
(0.006,0.009,0.02)	(0.004,0.005,0.011)	(0.014,0.02,0.042)	(0.006,0.01,0.018)	(0.006,0.01,0.041)	(0.005,0.006,0.014)	(0.001,0.002,0.004)	(0.003,0.004,0.01)	(0.004,0.008,0.019)	(0.002,0.003,0.006)
((0.006,0.01,0.02)	(0.004,0.005,0.011)	(0.014,0.02,0.042)	(0.008,0.013,0.055)	(0.006,0.011,0.041)	(0.005,0.006,0.014)	(0.001,0.002,0.004)	(0.003,0.005,0.01)	(0.004,0.008,0.019)	(0.003,0.004,0.019)
(0.006,0.009,0.02)	(0.004,0.005,0.011)	(0.014,0.02,0.042)	(0.008,0.013,0.055)	(0.006,0.01,0.041)	(0.005,0.006,0.014)	(0.001,0.002,0.004)	(0.003,0.004,0.01)	(0.004,0.008,0.019)	(0.003,0.004,0.019)
(0.008,0.016,0.059)	(0.005,0.008,0.033	(0.018,0.034,0.125)	(0.011,0.024,0.055)	(0.008,0.025,0.041)	(0.006,0.011,0.041)	(0.002,0.006,0.013)	(0.004,0.008,0.03)	(0.004,0.011,0.019)	(0.003,0.005,0.019)
(0.008,0.014,0.059)	(0.005,0.008,0.033	(0.014,0.02,0.042)	(0.006,0.01,0.018)	(0.006,0.011,0.041)	(0.005,0.007,0.014)	(0.002,0.004,0.013)	(0.003,0.005,0.01)	(0.004,0.008,0.019)	(0.003,0.005,0.019)

By using the equation 13, 14, 15 and 16, values of fuzzy positive ideal solution and fuzzy negative ideal solution of alternatives have been calculated. Table 5.46 for fuzzy positive ideal solution and fuzzy negative ideal solution of alternatives are as shown below:

Table 5.46: Fuzzy Positive Ideal Solution and Fuzzy Negative Ideal Solution of alternatives

Code	Solutions	d_i^+	d_i^-
S1	Effective maintenance strategy	0.45968	19.6215
S2	Cross functional training and HRM	0.3405	19.7063
S3	Use of ICT	0.55892	19.5467
S4	Use standardized work	0.34553	19.7018
S5	Reduce lead time	0.2903	19.7402
S6	Use of lean manufacturing process	0.25824	19.7642
S7	Improve flexibility in prod. System	0.52107	19.6881
S8	Improve material handling in organization	0.36404	19.5838
S9	Use of right first time approach	0.29759	19.7325
S10	Use of new tech. and product innovation	0.30262	19.7328
S11	Use of JIT	0.31677	19.7214
S12	Use of single minute die exchange	0.40868	19.6579
S13	Use of value stream mapping	0.35565	19.6948
S14	Improved communication system	0.60687	19.5101
S15	Improved small group activities	0.42154	19.6471

By using the equation 17, Cci value has been calculated against the solutions of barrier. Table 5.47 for closeness coefficient of alternatives are as shown below:

Table 5.47: Closeness coefficient of alternatives

Code	Solutions	Cci
S1	Effective maintenance strategy	0.97711
S2	Cross functional training and HRM	0.98302
S3	Use of ICT	0.9722

S4	Use standardized work	0.98276
S5	Reduce lead time	0.98551
S6	Use of lean manufacturing process	0.9871
S7	Improve flexibility in prod. System	0.98185
S8	Improve material handling in organization	0.97408
S9	Use of right first time approach	0.98514
S10	Use of new tech. and product innovation	0.9849
S11	Use of JIT	0.98419
S12	Use of single minute die exchange	0.97963
S13	Use of value stream mapping	0.98226
S14	Improved communication system	0.96983
S15	Improved small group activities	0.979

I gave the rank to the difference alternatives according to decreasing order of closeness coefficient (Cci). Table for ranking to alternatives are as shown below:

Table 5.48: Ranking to alternatives

Code	Solutions	cci	Rank
S1	Effective maintenance strategy	0.97711	12
S2	Cross functional training and HRM	0.98302	6
S3	Use of ICT	0.9722	14
S4	Use standardized work	0.98276	7
S5	Reduce lead time	0.98551	2
S6	Use of lean manufacturing process	0.9871	1
S7	Improve flexibility in prod. System	0.98185	9
S8	Improve material handling in organization	0.97408	13
S9	Use of right first time approach	0.98514	3
S10	Use of new tech. and product innovation	0.9849	4
S11	Use of JIT	0.98419	5
S12	Use of single minute die exchange	0.97963	10

S13	Use of value stream mapping	0.98226	8
S14	Improved communication system	0.96983	15
S15	Improved small group activities	0.979	11

5.6 Result and Dicussion

It is hard to say sure which solution of lean manufacturing overcome its barriers is more important, but with the help of ranking process by using fuzzy AHP TOPSIS approach make it more comprehensive and systematic. In this approach, we implement the solutions of lean manufacturing by step wise manner to overcome the barriers of lean manufacturing. Total 20 barriers and 15 solutions are found out from literature review and expert opinion. With the help of fuzzy AHP we calculate the barrier’s weight and with the help of Fuzzy TOPSIS we ranking the solutions of lean manufacturing. Final barrier’s weight shown in table 5.36 and ranking to the solutions shown in table 5.48. The solutions are S6-S5-S9-S10-S11-S2-S4-S13-S7-S12-S15-S1-S8-S3-S14 from most important to least important. Use of lean manufacturing process has highest rank and reduced lead time is ranked second. Improved communication system is lowest ranked.

5.7 Conclusion and Remarks

In this research, find out the barriers of lean manufacturing. Then find out the solutions to overcome these barriers. Fuzzy AHP is used to calculate the weight of barriers and fuzzy TOPSIS give rank to the solutions. Use of lean manufacturing process got highest rank and improved communication got lowest rank.

Chapter 6

Conclusion

In this research, it is observed that lean manufacturing is better than traditional manufacturing. Seven benefits of lean manufacturing have been discussed. Based on AHP comparative analysis for lean manufacturing and traditional manufacturing has been done. From this analysis it is observed that lead time reduction has highest global desirability index. Lead time reduction is followed by improvement in productivity, improvement in flexibility, improvement in quality, waste reduction, inventory reduction and net increased profit. Overall global score for lean manufacturing was

In next chapter, twelve critical success factors of lean manufacturing are identified. Ranking of these factors were done by TOPSIS approach. Top management commitment got highest rank. It means top management commitment is critical factor to successfully implement the lean manufacturing in organizations. Top management commitment is followed by process management, organization culture, employee training and team building, Just in time and lean practices, application of advanced technology and tools, product design and development, value stream mapping, total productive maintenance, inventory management, supplier development, and customer involvement.

The success rate of lean manufacturing in organizations is low due to its barriers. So in next chapters, barriers of lean manufacturing are identified. After that, solutions to overcome the barriers of lean manufacturing were analysed. In this study, scientific framework to rank the solutions of lean manufacturing in organization to overcome its barriers by using a multi criteria technique combining fuzzy AHP and fuzzy TOPSIS is proposed. Fuzzy AHP is used to get weights of the barriers of lean manufacturing. Fuzzy TOPSIS is utilized to rank the solutions. Use of lean manufacturing process got highest rank. It implies that organisations should apply different lean manufacturing processes very carefully. These findings will motivate organizations to implement lean manufacturing successfully for sustainable performance improvement.

This study can be further extended in form of different case studies as well as empirical study from manufacturing sectors.

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