EVALUATION OF LEANNESS, AGILITY AND LEAGILITY EXTENT IN INDUSTRIAL SUPPLY CHAIN

A Dissertation Submitted in Fulfillment of the Requirement for the Award of the Degree of

Doctor of Philosophy (Ph. D.)

IN

MECHANICAL ENGINEERING

BY

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This dissertation is dedicated to my

Late Grandfather

Mr. Ghasiram Matawale and

my younger brother

Dr. Virendra Kumar Matawale

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CERTIFICATE OF APPROVAL

Certified that the dissertation entitled **EVALUATION OF LEANNESS, AGILITY AND LEAGILITY EXTENT IN INDUSTRIAL SUPPLY CHAIN** submitted by **Chhabi Ram Matawale** has been carried out under my supervision in fulfillment of the requirement for the award of the degree of ***Doctor of Philosophy (Ph. D.)*** in ***Mechanical Engineering*** at **National Institute of Technology**, **Rourkela**, and this work has not been submitted to any university/institute anywhere before for any other academic degree/diploma.

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Acknowledgement

This dissertation is likely to be the final destination of my journey in obtaining my PhD. This has been kept on track and been seen through to completion with the support and encouragement of numerous people including my well-wishers, my friends, colleagues and faculties. At the verge of submission of my dissertation, I would like to thank all of them who made this journey possible through an unforgettable experience for me. It is a pleasant task to express my heartiest thanks to all those who contributed in many ways to the success of this endeavor and made it a cherished experience for me.

At this moment of accomplishment, first of all, I would like to pay honor to my supervisor, **Prof. Saurav Datta**, Assistant Professor, Department of Mechanical Engineering, National Institute of Technology, Rourkela. This work would have not been possible without his valuable guidance, moral support and continuous encouragement. Under his guidance I could successfully overcome many difficulties and really learnt a lot. Above all, his priceless and meticulous supervision at each and every phase of work inspired me in innumerable ways.

Besides my supervisor, I would like to express my heartiest thankfulness to the members of my Doctoral Scrutiny Committee (DSC): **Prof. Prabal Kumar Ray** (Chairman, DSC), Professor, Department of Mechanical Engineering, **Prof. Subash Chandra Mishra**, Professor and Head, Department of Metallurgical and Materials Engineering, **Prof. Chandan Kumar Sahoo**, Associate Professor and Head, School of Management, **Prof. Tarapada Roy**, Assistant Professor, Department of Mechanical Engineering of our institute, for their kind cooperation and insightful suggestions throughout period of my project work which has been proved extremely fruitful for the success of this dissertation.

I am also highly obliged to **Prof. Sunil Kumar Sarangi**, our Honorable Director, **Prof. Banshidhar Majhi**, Dean (Academic Affairs), **Prof. Siba Sankar Mahapatra**, Professor and Head, Department of Mechanical Engineering, National Institute of Technology, Rourkela, for their academic support and continuous motivation.

Special thanks with great pleasure goes to all the faculty and staff members of the Department of Mechanical Engineering for their vital association, kind and generous help during the progress of the work which forms the backbone of this work. **Mr. Prasanta Kumar Pal**, Technician (SG1), CAD/CAM Laboratory of our department deserves special thanks for his kind cooperation in every administrative affair during my research work. Besides this, certainly I would like to carry the fond memories of the company of research scholars associated with the CAD/CAM Laboratory, Department of Mechanical Engineering, National Institute of Technology, Rourkela, for their laudable help and cooperation to concentrate on my work all through.

I greatly appreciate and convey my heartfelt thanks to **Kumar Abhishek**, **Bijaya Bijeta Nayak**, **Chitrasen Samantra**, **Suman Chatterjee**, **Rajiv Kumar Yadav**, **Shruti Nigam**, **Anoop Kumar Sahu**, **Dilip Kumar Sen**, **Chinmaya Prasad Mohanty**, **Santosh Kumar Sahoo**, **Amit Kumar Mehar**, scholars associated with our department and all my well-wishers for their support and co-operation that seems difficult to express in words.

I gratefully acknowledge **Mr. Goutam Mandal** (Deputy Manager, NVH-pp, CAE1, RNTBCI, Mahindra World City, Chennai, Tamil Nadu, India) for providing necessary support and cooperation in conducting case studies which has been a part of my project work.

I owe a lot to my parents **Mr. Labha Ram Matawale** (Father) and **Mrs. Champa Devi** (Mother), for their inseparable support and encouragement at every stage of my academic and personal life and yearned to see this achievement come true. They are the people who show me the joy of intellectual pursuit ever since I was a child. I must thank them for sincerely bringing up me with immense care, in-depth love and affection.
I also feel pleased to strongly acknowledge the support received from my uncle **Dr. Anand Ram Matawale**, my younger brother **Dr. Virendra Kumar Matawale** and sisters **Mrs. Nirmala Narang**, **Mrs. Ahiman Ghritlahre** and **Mrs. Purnima Rai** in every possible way to see the completion of this doctoral work.

I am grateful to **Ministry of Human Resources Development (MHRD)**, **Government of India**, for the financial support provided during my tenure of staying at National Institute of Technology, Rourkela.

Finally, I would like to take this opportunity to express my sincere gratitude to all other individuals (not listed here) who have provided moral support and continuous encouragement. I am grateful for their kindness.

Above all, I bow to the **Devine Power** for granting me the wisdom, health and strength and led me all through.

CHHABI RAM MATAWALE

Abstract

The focus of Lean Manufacturing (LM) is the cost reduction by eliminating non value added activities (waste i.e. *muda*) and enabling continuous improvement; whereas, Agile Manufacturing (AM) is an approach which is mainly focused on satisfying the needs of customers while maintaining high standards of quality and controlling the overall costs involved in the production of a particular product. This approach has geared towards companies working in a highly turbulent as well as competitive business environment, where small variations in performance and product delivery can make a huge difference in the long term to a company's survival and reputation amongst the customers.

Leagility is basically the aggregation of lean and agile principles within a total supply chain strategy by effectively positioning the decoupling point, consequently to best suit the need for quick responding to a volatile demand downstream yet providing a level scheduling upstream from the marketplace. A leagile system adapts the characteristics of both lean and agile systems, acting together in order to exploit market opportunities in a cost-efficient way.

The present research aims to highlight how these lean, agile as well as leagile paradigms may be adapted according to particular marketplace requirements. Obviously, these strategies are distinctly different, since in the first case, the market winner is cost; whereas, in the second case, the market winner is the availability. Agile supply chains are required to be market sensitive and hence nimble. This means that the definition of waste is different from that appropriate to lean supply. The proper location of decoupling point for material flow and information flow enables a hybrid supply chain to be better engineered. This encourages lean (efficient) supply upstream and agile (effective) supply downstream, thus bringing together the best of both paradigms.

While implementing leanness/agility/leagility philosophy in industrial supply chain in appropriate situations, estimation of a unique quantitative performance metric (evaluation index) is felt indeed necessary. Such an index can help the industries to examine existing performance level of leanness/agility/leagility driven supply chain; to compare ongoing performance extent to the desired/expected one and to benchmark best practices of lean/agile/leagile manufacturing/supply chain, wherever applicable.

The present research attempts to assess the extent of leanness, agility as well as leagility, respectively, for an organizational supply chain using fuzzy/grey based Multi-Criteria Decision Making (MCDM) approaches. During this research, different leanness/agility/leagility appraisement models (evaluation index systems) by exploring the mathematics of fuzzy set/grey set theories have been proposed. This has followed by the substitution of the data gathered from a case manufacturing organization. After computing overall leanness/agility/leagility index; the ill-performing supply chain areas (obstacles or barriers of leanness/agility/leagility) have also been identified which require future improvement initiated by the managerial level in order to boost up overall organizational performance. Apart from this, the study has been extended to develop a suppliers' selection decision-making module (applicable in agile supply chain) by utilizing vague numbers set theory.

The outcome of the proposed Decision Support Systems (DSS) could be used as test kits for periodically assessing organizational supply chain lean/agile/leagile performance, along with facilitating effective suppliers' evaluation and selection.

Keywords: Lean Manufacturing (LM); Agile Manufacturing (AM); Leagility; Multi-Criteria Decision Making (MCDM); Fuzzy set; Grey set; Vague numbers set; Decision Support Systems (DSS)

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CHAPTER 1

RESEARCH BACKGROUND

1.1 Paradigm Shift in Manufacturing

Globalization in 21st century has imposed tough competitions amongst modern manufacturing enterprises (as well as service industries). The tremendous industrial growth in past few decades has completely revolutionized the older manufacturing strategies; giving emergence to the modern concepts. The competitive priority of manufacturing firms gradually shifted from 'cost' in 1960s to 'time' in the present days. During 1950s to 60s, the strategic trend in industries was cost reduction, but it was shifted to production in 1960s to 70s, quality in 1970s to 80s and the concept of Just-In-Time (JIT) and lean manufacturing came into existence from 1980s to 90s. But recently, in 21st century, manufacturing industries have become more concerned about time (specifically delivery time to the customer) than ever before. Manufacturing strategies/practices has undergone many evolutionary stages and paradigm shifts in the past. The paradigm shift has been observed from a craft industry to mass production then to Computer Integrated Manufacturing (CIM) towards lean manufacturing; and then to agile manufacturing; now-a-days, it's the leagile manufacturing.

The development in manufacturing technology as described by (Cheng et al., 1998) is presented below in Fig. 1.1.

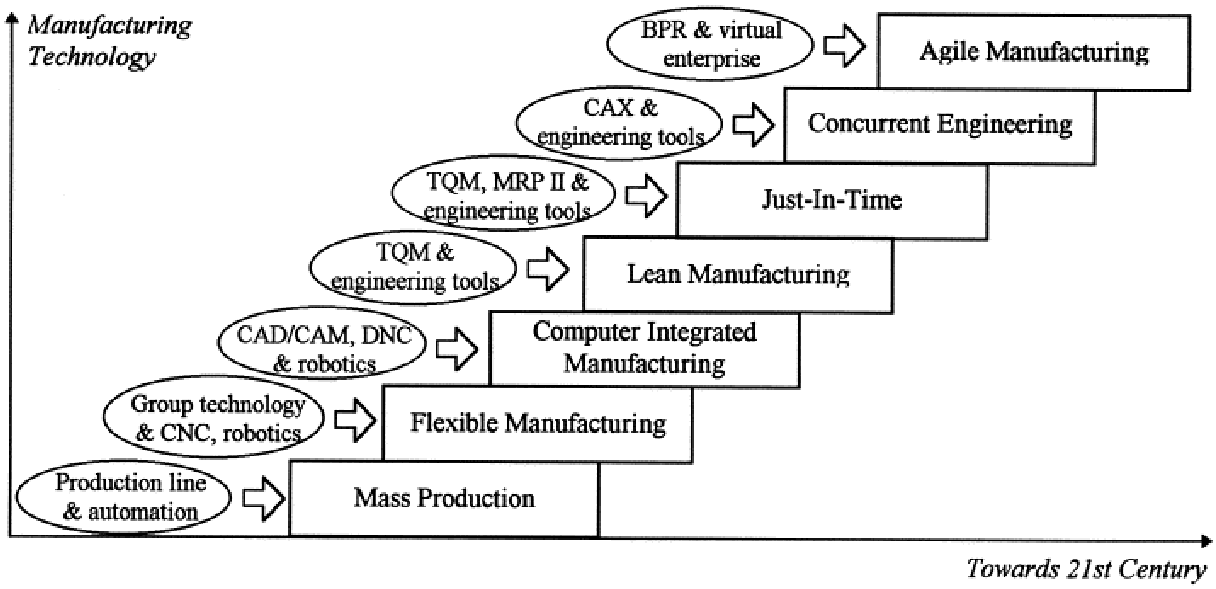

Fig. 1.1: Development in manufacturing technology [Source: Cheng et al., 1998]

1.1.1 Lean Manufacturing

Lean manufacturing, lean enterprise or lean production is basically a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful and thus a target for elimination. Lean manufacturing focuses on cost reduction by eliminating non-value-added activities so that several advantages can be obtained such as minimization/elimination of waste, increased business opportunities and more competitive organizations. Lean manufacturing can be adopted where there is a stable demand and to ensure a level schedule. The term 'lean manufacturing', which first appeared in 1990, when it was used to refer to the elimination of waste in the production process, has been announced as the production system of the 21st century. Historically, the concept of lean manufacturing was originated with Toyota Production Systems (TPS). Lean manufacturing is called lean as it uses less or the minimum, of everything required to produce a product or perform a service. Lean operations eliminate seven tedious wastes (*muda*), namely overproduction, over processing, waiting, motion, defects, inventory, and transportation.

The original seven *muda* are:

- Transport (moving products that are not actually required to perform the processing)
- Inventory (all components, work in process, and finished product not being processed)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Waiting (waiting for the next production step, interruptions of production during shift change)
- Overproduction (production ahead of demand)
- Over Processing (resulting from poor tool or product design creating activity)
- Defects (the effort involved in inspecting for and fixing defects)

Lean is all about achieving more value by utilizing fewer resources more effectively and efficiently through the continuous elimination of non-valued added activities or waste.

The technique often decreases the time between a customer order and shipment, and it is designed to radically improve profitability, customer satisfaction, throughput time, and employee morale. The benefits generally are lower costs, higher quality, and shorter lead times.

The characteristics of lean processes are:

- Single-piece production
- Repetitive order characteristics
- Just-In-Time materials/pull scheduling

- Short cycle times
- Quick changeover
- Continuous flow work cells
- Collocated machines, equipment/tools and people
- Compressed space
- Multi-skilled and empowered employees
- Flexible workforce
- High first-pass yields with major reductions in defects

In short, the fundamental philosophy behind lean manufacturing is to provide superior quality products for more customers at a significantly lower price and to contribute to a more prosperous society.

It is important to build a company production system based on this philosophy. Lean manufacturing has endeavored to rationalize production by:

- Completely eliminating waste in the production process
- To build quality into the process
- To reduce costs - productivity improvements
- To develop its own unique approach toward corporate management
- To create and develop integrated techniques that will contribute to corporate operation.

Essentially, lean is entered on *preserving value with less work*. Lean manufacturing is a management philosophy derived mostly from the Toyota Production System (TPS) (hence the term Toyotism is also prevalent) and identified as 'lean' only in the 1990s. TPS is renowned for its focus on reduction of the original Toyota *seven wastes* to improve overall customer value, but there are varying perspectives on how this is best achieved. The steady growth of Toyota, from a small company to the world's largest automaker, has focused attention on how it has achieved this success.

For many, lean is the set of 'tools' that assist in the identification and steady elimination of waste (*muda*). As waste is eliminated, quality improves while production time and cost are substantially reduced. A non-exhaustive list of such tools would include: Single Minute Exchange of Die (SMED), Value Stream Mapping, Five S, *Kanban* (pull systems), *poka-yoke* (error-proofing), Total Productive Maintenance (TPM), elimination of time batching, mixed model processing, Rank Order Clustering, single point scheduling, redesigning working cells, multi-process handling and control charts (for checking mura).

Additional S's are Safety, Security and Satisfaction. The list describes how to organize a work space for efficiency and effectiveness by identifying and storing the items used, maintaining the area and items, and sustaining the new order. The decision-making process usually comes from a dialogue about standardization, which builds understanding among employees of how they should do the work.

There is a second approach to lean manufacturing, which is promoted by Toyota, called The Toyota Way, in which the focus is upon improving the 'flow' or smoothness of work, thereby steadily eliminating *mura* (unevenness) through the system. Techniques to improve flow include production levelling, 'pull' production (by means of *kanban*) and the *Heijunka box*. This is a fundamentally different approach from most improvement methodologies, which may partially account for its lack of popularity.

The difference between these two approaches is not the goal itself, but rather the prime approach to achieving it. The implementation of smooth flow exposes quality problems that already existed, and thus waste reduction naturally happens as a consequence. The advantage claimed for this approach is that it naturally takes a system-wide perspective, whereas, a waste focuses sometimes wrongly assumes this perspective.

Both lean and TPS can be seen as a loosely connected set of potentially competing principles whose goal is cost reduction by the elimination of waste. These principles include: Pull processing, Perfect first-time quality, Waste minimization, Continuous improvement, Flexibility, Building and maintaining a long term relationship with suppliers, Autonomation, Load levelling and Production flow and Visual control.

Toyota's view is that the main method of lean is not the tools, but the reduction of three types of waste: *muda* ('non-value-adding work'), *muri* ('overburden'), and *mura* ('unevenness'), to expose problems systematically and to use the tools where the ideal cannot be achieved. From this perspective, the tools are workarounds adapted to different situations, which explains any apparent incoherence of the principles above.

[Source: Roos et al. 1991; Holweg, 2007; Krafcik, 1988; Ohno, 1988; Womack and Daniel, 2003; Hounshell, 1984; Pettersen, 2009; Gupta and Jain, 2013]

1.1.2 Agile Manufacturing

As we head into the race, the headwinds are strong. Commodity volatility is the highest in one hundred years. Materials are limited and the standards for social responsibility programs are rising. Product life cycles are shorter and customers have higher expectations. Global market opportunities are high, but require micro-segmentation and customization. As a result, supply chain complexity is increasing. So it is time to implement the supply chain agility and train to run the race. Supply chain agility is the capability of the supply chain associate organizations to adapt quickly with the rapid changes in these business environments. It requires an appropriate combination of coordination, communication and speed in procurement, inventory, assembly and delivery of products and services, as well as the return and re-use of materials and services. Supply chain agility also includes human, financial and information capital flows across organizations that facilitate effective and efficient fulfillment of orders.

Supply chain agility is an operational strategy focused on promoting adaptability, flexibility, and has the ability to respond and react quickly and effectively to changing markets in the supply chain. A supply chain is the process of moving goods from the customer order through the raw materials stage, supply, production, and distribution of products to the customer. All organizations have supply chains of varying levels, depending upon the size of the organization and the type of product manufactured. These networks obtain supplies and components, change these materials into finished products and then distribute them to the customer. Included in this supply chain process are customer orders, order processing, inventory, scheduling, transportation, storage, and customer service. A necessity in coordinating all these activities is the information service network. The difference between supply chain management and supply chain agility is the extent of capability that the organization possesses. Key to the success of an agile supply chain is the speed and flexibility with which these activities can be accomplished and the realization that customer needs and customer satisfaction are the very reasons for the network. Customer satisfaction is paramount. Achieving this capability requires all physical and logical events within the supply chain to be performed quickly, accurately, and effectively. The faster parts, information, and decisions flow through an organization, the faster it can respond to customer needs.

[Source: Shari and Zhang, 1999; Mason-Jones and Towill, 1999; Sanchez and Nagi, 2001; Gunasekaran and Yusuf, 2002; Arteta and Giachetti, 2004]

The definition of 'agility' as expressed by (Goldman et al. 1995) "Agility is dynamic, context specific, focused on aggressive changes and growth oriented. It is not about improving efficiency, cutting costs, or avoidance of competitiveness. It's about succeeding and about winning profits, market share and customers in the very center of competitive storms that many companies now fear".

The term `agile manufacturing' came into popular usage with the publication of the report by Lacocca Institute (USA) in 1991, entitled '21st Century Manufacturing Enterprise Strategy' (Nagel and Dove, 1991). The manufacturing agility they defined is the ability to thrive in a competitive environment with continuous and unanticipated change, to respond quickly to rapidly changing, fragmenting and globalizing markets which are driven by demands for high-quality, high-performance, low cost customer-oriented products and services. Manufacturing agility is accomplished by integrating all of the available resources including technology, people and organization into a naturally coordinated independent system which is capable of achieving short product development cycle times and responding quickly to any sudden market opportunities.

Typically, agile manufacturing has the following features (Cheng et al., 1998):

1. It implies breaking out of the mass production mold and producing much more highly customized products based on when and where the customer needs them in any quantity.
2. It amounts to striving for economies of scope rather than economies of scale, without the high cost traditionally associated with product customization.
3. Increased customer preference and anticipated customer needs are an integral part of the agile manufacturing process.
4. It requires an all-encompassing view rather than only being associated with the workshop or factory floor.
5. Agile manufacturing further embodies such concepts as rapid formation of a virtual company or enterprise based on multi-company merits alliance to rapidly introduce new products to the market.
6. It requires more transparent and richer information flow across product development cycles and virtual enterprises without any geographical and interpretational limitations.

Agile manufacturing is the ability to respond to and create new windows of opportunity in a turbulent market environment, driven by the individualization of customer requirements cost effectively, rapidly and continuously. Agile manufacturing is essentially the utilization of market knowledge and virtual corporation to exploit profitable opportunities in a volatile marketplace. It is a new expression that is used to represent the ability of a producer of goods and services to thrive in the face of continuous change. These changes can occur in markets, in technologies, in business relationships and in all facets of the business enterprise (Goldman et al., 1995).

Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of lean manufacturing. In lean manufacturing, the emphasis is on cost-cutting. The requirement for organizations and facilities to become more flexible and responsive to customers led to the concept of agile manufacturing as a differentiation from the lean organization. This requirement for manufacturing to be able to respond to unique demands moves the balance back to the situation prior to the introduction of lean production, where manufacturing had to respond to what-ever pressures were imposed on it, with the risks to cost and quality.

According to Martin Christopher, when companies have to decide what to be, they have to look at the Customer Order Cycle i.e. COC (the time the customers are willing to wait) and the lead time for getting supplies. If the supplier has a short lead time, lean production is possible. If the COC is short, agile production is beneficial. [Source: Goldman et al., 1995]

Comparison of lean and agile manufacturing principles has been depicted in Table 1.1.

Table 1.1: Comparison of lean and agile manufacturing principles [Dove, 1993]

Characteristics - Lean	**Characteristics - Agile**
- is a response to competitive pressures with limited resources,	- is a response to complexity brought by constant change,
- is bottom-up driven, incrementally transforming the mass-production model,	- is top down driven responding to large forces,
- is a collection of operational tactics focused on productive use of resources,	- is an overall strategy focused on succeeding in an unpredictable environment,
- brought flexibility with its alternate paths and multiuse work modules,	- brings reconfigurable work modules and work environments,
- is process focused.	- is boundary focused.

Agile manufacturing is a term applied to an organization that has created the processes, tools, and training to enable it to respond quickly to customer needs and market changes while still controlling costs and quality. An enabling factor in becoming an agile manufacturer has been the development of manufacturing support technology that allows the marketers, the designers and the production personnel to share a common database of parts and products, to share data on production capacities and problems - particularly where small initial problems may have larger downstream effects. It is a general proposition of manufacturing that the cost of correcting quality issues increases as the problem moves downstream, so that it is cheaper to correct quality problems at the earliest possible point in the process.

Agile innovative approaches to meet the main needs of industry are:

- Cost-effectiveness, with the adoption of standards in production and inspection equipment and massive use of lean approaches;
- Optimized consumption of resources, efficient use of energy and materials, processes and machines, and intelligent control of their consumption;
- Short periods of innovation in the market (from concept to market new products), made possible by information technology – it is necessary including ability to adapt IT systems to support new processes;
- Adaptability and reconfigurability of manufacturing systems to maximize the autonomy and capacity of machines and people with use of existing infrastructures;
- High productivity coupled with increased safety and ergonomics, the integration of technical and human factors.

[Source: Lean and Agile Management for Changing Business Environment, Kováčová L/ *http://rockfordconsulting.com/supply-chain-agility.htm*]

Characteristic feature of agility in production systems is linked to computer-aided technologies. Those tools enable to get very high speed of response to customer's demands and new market opportunities.

Agile organizations are market-driven, with more product research and short development and introduction cycles. The focus is on quickly satisfying the supply chain, the chain of events from a customer's order inquiry through complete satisfaction of that customer. All physical events are performed quickly and accurately. Achieving agility starts with the physical flow of parts, from the point of supply, through the factory, and shipment through agile distribution channels. It emphasizes closing the distance between each point in the flow. Within the factory successive operations in the work chain are physically coupled, removing non-value adding functions and inducing velocity. Parts move with high velocity through the work chain. Natural points of delay are eliminated and simplified. The information chain is streamlined and electronically linked at every point, so that information flow is direct- -without interruptions and delays. Business cycle times are to be reduced to the time it actually takes to effectively process information.

[Source: *http://rockfordconsulting.com/supply-chain-agility.htm*]

1.1.3 Leagile Manufacturing

The lean and agile paradigms, though distinctly different, can be combined within successfully designed and operated total supply chains. Combining agility and leanness in one supply chain via the strategic use of a decoupling point has been termed 'leagility' (Naylor et al., 1999; Naim and Gosling, 2011).

The following definitions relate the agile and lean manufacturing paradigms to supply chain strategies. They have been developed to emphasize the distinguishing features of leanness and agility as follows:

Agility means using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place.

Leanness means developing a value stream to eliminate all waste, including time, and to enable a level schedule.

In the case of agility the key point is that the marketplace demands are extremely volatile. The businesses in the supply chain must therefore not only come up with, but also exploit this volatility to their strategic advantage. Thus, it can be seen that customer service level, i.e. availability in the right place at the right time, is the market winner in serving a volatile marketplace. However, cost is an important market qualifier and this is usually reduced by leanness. The solution is therefore to utilize the concept of the leagile supply chain shown in Fig. 1.2. The definition of leagility also follows from (Naylor et al., 1999) as:

Leagility is the combination of the lean and agile paradigm within a total supply chain strategy by positioning the decoupling point so as to best suit the need for responding to a volatile demand downstream yet providing level scheduling upstream from the decoupling point.

[Source: Mason-Jones et al., 2000]

A leagile system has characteristics of both lean and agile systems, acting together in order to exploit market opportunities in a cost-efficient manner. The system being defined as leagile could be an entire supply chain or a single manufacturing plant with individual lean and agile sub groups contain a decoupling point, which separates the lean and agile portions of the system.

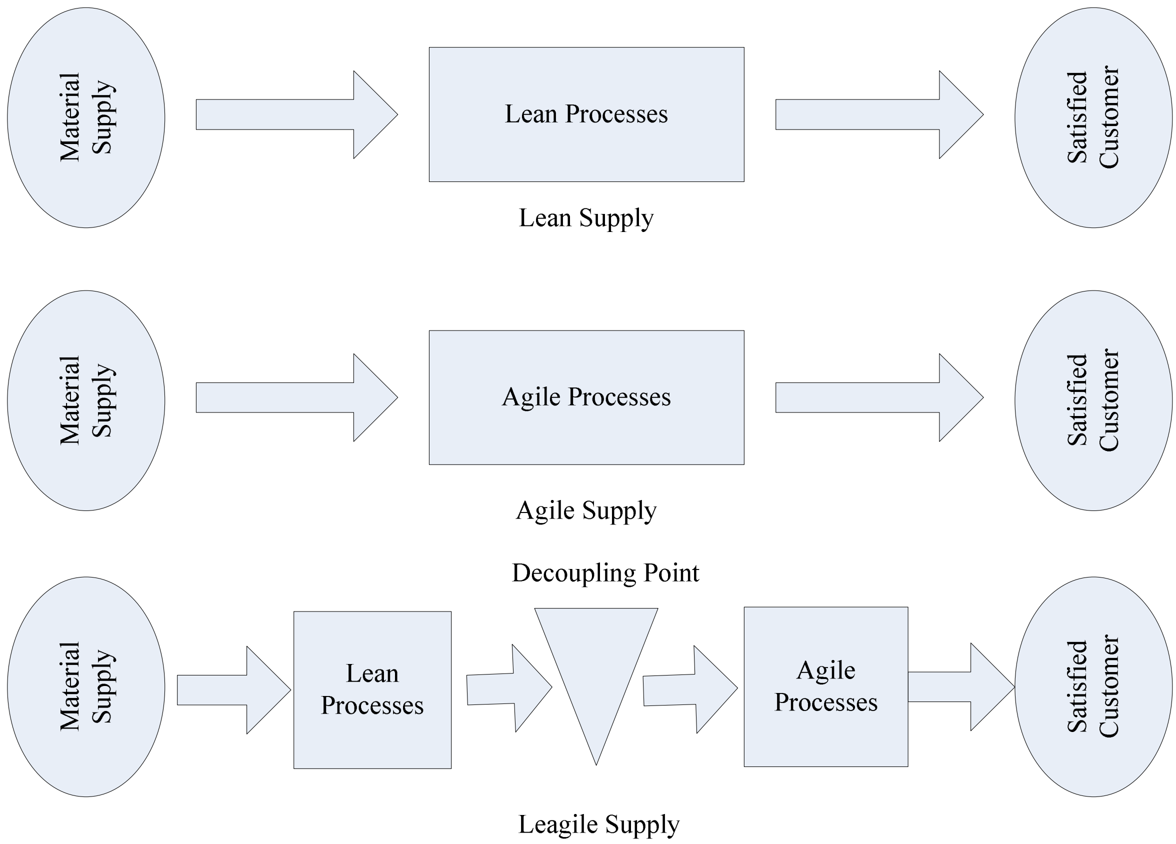

Fig. 1.2: Lean, agile and leagile supply

The decoupling point is the point in the material flow streams to which the customer's order penetrates. A decoupling point within a factory enables lean and agile practices to complement each other at the operational level to improve overall performance and profitability of the factory (Mason-Jones et al., 2000; Prince and Kay, 2003). It is the point where order driven and the forecast driven activities meet. As a rule, the decoupling point coincides with an important stock point in control terms a main stock point from which the customer has to be supplied. The lean processes are on the upstream side of the decoupling point, and the agile processes are on the downstream side. The decoupling point also acts as a strategic point for buffer stock, and its position changes depending on the variability in demand and product mix (Mason-Jones et al., 2000). Stratton and Warburton (2003) considered it is easy to produce deviations when the lean system makes forecast to the market demands, therefore, they proposed the combination of lean supply chain and agile supply chain to adjust to the uncertainty of market.

The most important reason behind combining these two concepts is to take advantages of both in a single unit; because, there is always a need for responding to volatile demand downstream and providing level scheduling upstream from the marketplace (Van Hoek et al., 2001). Naylor et al. (1999) believed that they can complement each other in the right operational conditions and should not be viewed as competitive, rather as mutually supportive. Agility is dynamic and context specific, aggressively change embracing and growth oriented (Goldman et al., 1995). Agile manufacturing promises not only improved manufacturing performance, but also the support of future business strategies designed to improve the way in which an enterprise competes in the market place. On a strategic level, agile manufacturing is seemed very attractive for its potential to cope up with future uncertainty and the prospect of producing a wide range of highly customized products at mass production prices.

Therefore, these two concepts can be combined within successfully designed and operated supply chains; where agile manufacturing concepts are applied to the part of the supply chain under the greatest pressure to operate in an environment of fluctuating demand in terms of volume and variety. Lean concepts can then be applied to the rest of the supply chain to create and encourage level demand necessary to achieve the cost benefits associated with this production strategy. The innovation being sought is the application of lean and agile concepts at different stages of the same manufacturing process route so that the benefits of both strategies can be maximized.

These new strategies enable the enterprises to survive in the existing environment of fierce competitions laid down by their competitors. The requirement of faster delivery within the due date, ability of being flexible to the fluctuation of demand, and to meet the customer expectations are some of the prime motivations that has provoked the manufacturing enterprises to look for the available best alternatives, and implement it in their daily manufacturing practices. The emerging concepts of lean, agile, and leagile are the outcomes of the difficulties faced by the enterprises during the last few decades.

Compared with traditional supply chain, leagile supply chain has the following advantages:

1. Sharing information
2. Shorten the length of supply chain
3. Order guidance
4. Close cooperation between enterprises

[Source: Bruce et al., 2004; Womack, 1991; Naylor et al., 1999; Mason-Jones et al., 2000; Stratton and Warburton, 2003; Yan and Chen, 2002; Zhang et al., 2012]

The modern supply chain aims towards full customer satisfaction, while simultaneously making sufficient profit for the enterprises. The lean, agile, and leagile principles play an important role in enhancing the performances of these supply chains. Lean and agile principles have been the prime source of motivation for these supply chains in past years. But day by day, due to increasing and fluctuating market demand, increase in product variety, and desire to make more profit (to the industries) led to the development of a new concept of leagility, which is an integration of the lean and agile principles. Recent advancements of operations management research have shown that leagile principle has immense potential to counteract the existing complexity of the market scenario. Therefore, leagile principles are now-a-days attracting the manufacturing enterprises, and researchers are aiming to find its obvious benefits in all industrial sectors.

1.2 State of Art: Leanness, Agility and Leagility in Manufacturing/ Supply Chain

Lean and agile principles have grown immense interest in the past few decades. The industrial sectors (manufacturing as well as service industries) throughout the globe are upgrading to these principles in order to enhance their performance, since they have proven to be efficient in handling supply chains. However, the present market trend demanded a more robust strategy inheriting the salient features of both lean and agile principles. Inspired by these, the leagility principle has been emerged encapsulating, features of leanness as well as agility. The present section exhibits state of art on understanding of different aspects of leanness, agility as well as leagility in manufacturing/supply chain.

Panizzolo (1998) dealt with the challenges posed by lean production principles for operations management. The author developed a research model which was able to accurately define and operationalize the lean production concept. The model represented a conceptualization of lean production as consisting of a number of improvement programmes or best practices characterizing different areas of the company (i.e. process and equipment, manufacturing planning and control, human resources, product design, supplier relationships, customer relationships). Arbós (2002) proposed a methodology for implementation of lean management in a services production system, as applied to the case of telecommunication services. Pavnaskar et al. (2003) proposed a classification scheme to serve as a link between manufacturing waste problems and lean manufacturing tools. Shah and Ward (2003) examined the effects of three contextual factors, plant size, plant age and unionization status, on the likelihood of implementing 22 manufacturing practices that were key facets of lean production systems. Furthermore, the authors postulated four ‘bundles’ of inter-related and internally consistent practices; these were just-in-time (JIT), total quality management (TQM), total preventive maintenance (TPM), and human resource management (HRM). They empirically validated these bundles and investigated their effects on operational performance.

Kainumaa and Tawara (2006) proposed the multiple attribute utility theory method for assessing a supply chain. The authors considered this approach to be one of the ‘the lean and green supply chain’ methods. Holweg (2007) investigated the evolution of the research at the MIT International Motor Vehicle Program (IMVP) that led to the conception of the term ‘lean production’. Furthermore, the paper investigated why – despite the pre-existing knowledge of (Just-In-Time) JIT – the program was so influential in promoting the lean production concept. Wan and Chen (2008) proposed a unit-invariant leanness measure with a self-contained benchmark to quantify the leanness level of manufacturing systems. Evolved from the concept of Data Envelopment Analysis (DEA), the leanness measure extracted the value-adding investments from a production process to determine the leanness frontier as a benchmark. A linear program based on slacks-based measure (SBM) derived the leanness score that indicated how lean the system was and how much waste existed. Using the score, impacts of various lean initiatives could be quantified as decision support information complementing the existing lean metrics.

Riezebos et al. (2009) presented reviews the role of Information Technology (IT) in achieving the principles of Lean Production (LP). Three important topics were reviewed: the use of IT in production logistics; computer-aided production management systems; and advanced plant maintenance. Saurin and Ferreira (2009) presented guidelines for assessing lean production impacts on working conditions either at a plant or departmental level, which were tested on a harvester assembly line in Brazil. The impacts detected in that line might provide insights for other companies concerned with balancing lean and good working conditions. Yang et al. (2011) explored the relationships between lean manufacturing practices, environmental management (e.g., environmental management practices and environmental performance) and business performance outcomes (e.g., market and financial performance). The hypothesized relationships of this model were tested with data collected from 309 international manufacturing firms (IMSS IV) by using AMOS. The findings suggested that prior lean manufacturing experiences were positively related to environmental management practices. Environmental management practices alone were negatively related to market and financial performance.

However, improved environmental performance substantially reduced the negative impact of environmental management practices on market and financial performance. The paper provided empirical evidences with large sample size that environmental management practices became an important mediating variable to resolve the conflicts between lean manufacturing and environmental performance.

Zarei et al. (2011) performed a research by linking Lean Attributes (LAs) and Lean Enablers (LEs), and used Quality Function Deployment (QFD) to identify viable LEs to be practically implemented in order to increase the leanness of the food chain. Furthermore, fuzzy logic was used to deal with linguistic judgments expressing relationships and correlations required in QFD. In order to illustrate the practical implications of the methodology, the approach was exemplified with the help of a case study in the canning industry. Demeter and Matyusz (2011) concentrated on how companies could improve their inventory turnover performance through the use of lean practices. The authors also investigated how various contingency factors (production systems, order types, product types) influenced the inventory turnover of lean manufacturers. The authors used cluster and correlation analysis to separate manufacturers based on the extent of their leanness and to examine the effect of contingencies.

Seyedhosseini et al. (2011) developed the concept of BSC approach for selecting the leanness criteria for auto part manufacturing organizations. For determining the lean performance measurement through the company's lean strategy map, a set of objectives should be driven based on the BSC concept. In order to determine the company's lean strategy map, the DEMATEL approach was used to identify the cause and effect relationships among objectives as well as their priorities. Saurin et al. (2011) introduced a framework for assessing the use of lean production (LP) practices in manufacturing cells (MCs). The development of the framework included four stages: (a) defining LP practices applicable to MC, based on criteria such as the inclusion of practices that workers could observe, interact with and use on a daily basis; (b) defining attributes for each practice, emphasizing the dimensions which were typical of their implementation in LP environments; (c) defining a set of evidence and sources of evidence for assessing the existence of each attribute – the sources of evidence included direct observations, analysis of documents, interviews and a feedback meeting to validate the assessment results with company representatives; (d) drawing up a model of the relationships among the LP practices, based on a survey with LP experts. This model supported the identification of improvement opportunities in MC performance based on the analysis of their interfaces.

Vinodh and Chintha (2011a) applied a fuzzy based quality function deployment (QFD) for enabling leanness in a manufacturing organization. A case study was carried out in an Indian electronics switches manufacturing organization. The approach was found very effective in the identification of lean competitive bases, lean decision domains, lean attributes and lean enablers for the organization. Ahmad et al. (2012) proposed relationship between Total Quality Management (TQM) practices and business performance with mediators of Statistical Process Control (SPC), Lean Production (LP) and Total Productive Maintenance (TPM). Study on TQM, Lean Production, TPM and SPC generally investigated the practices and business performance in isolation. The main contribution of this reporting was to identify the relationships among TQM, TPM, SPC and Lean Production practices as a conceptual model. The structural equation modeling (SEM) techniques were used to examine the relationships of the practices.

Bhasin (2012) investigated to decipher whether larger organizations embracing Lean as a philosophy were indeed more successful. Achievement was measured by the impact an organization's Lean journey had on its financial and operational efficiency levels. An adapted balance scorecard was utilized which embraced strategic, operational and indices focused towards the organization's future performance. Azevedo et al. (2012) proposed an index to assess the agility and leanness of individual companies and the corresponding supply chain. The index was named Agilean and was obtained from a set of agile and lean supply chain practices integrated in an assessment model. Hofer et al. (2012) empirically investigated the relationship between lean production implementation and financial performance. Marhani et al. (2012) provided the fundamental knowledge of Lean Construction (LC) and highlighted its implementation in the construction industry.

Salleh et al. (2012) presented the Integrated TQM and LM practices by a forming company. The integrated practices were an adaptation combination of four models award, ISO/TS16949 and lean manufacturing principles from Toyota Production System, SAEJ4000 and MAJAICO Lean Production System. A case study of the forming company in Selangor was conducted and simulation of the process was done by Delmia Quest Software. Deif (2012) proposed an approach to assess lean manufacturing based on system's variability. The assessment utilized a tool called variability source mapping (VSMII) which focused on capturing and reducing variability across the production system. The tool offered a metric called variability index to measure the overall variability level of the system. Based on the mapping and the metric, VSMII suggested a variability reduction plan guided by a recommendation list of both lean techniques as well as production control policies. An industrial application was used to demonstrate the aforesaid tool. Results showed that VSMII managed to reduce the overall variability level of the system as well as non-value added activities. Finally, the variability index was successfully applied as a leanness assessment metric.

Dombrowski et al. (2012) showed that a multitude of different knowledge flows could occur during the implementation of Lean Production Systems and that a decentralized, role-specific approach could help to identify adequate methods of knowledge management. Diaz-Elsayed et al. (2013) identified an approach for incorporating both lean and green strategies into a manufacturing system; from data collection to the valuation of a system. Furthermore, a case study was presented of part production in the automotive sector, in which the implementation of a tailored combination of lean and green strategies resulted in the reduction of approximately 10.8% of the production costs of a representative part. Powell et al. (2013) analyzed a typical lean and Enterprise Resource Planning (ERP) implementation processes contained within the scientific literature, and by further examining a concurrent implementation process in real-time, the authors developed and proposed a process for ERP-based lean implementations. The findings suggested that the implementation of a contemporary ERP system could act as a catalyst for the application of lean production practices.

Azadegan et al. (2013) investigated the effects of environmental complexity and dynamism on lean operations and lean purchasing practices. It empirically examined these relationships using archival and survey data from 126 manufacturers. The results showed that environmental complexity positively moderated the effects of lean operations and lean purchasing on performance. This research offered a more nuanced understanding of the effect of external environmental context on lean practices, and suggested that practitioners should carefully consider the external environment when implementing different types of lean practices. Dora et al. (2013) analyzed the application of lean manufacturing, its impact on operational performance and critical success factors in the food processing small and medium sized enterprises (SMEs). The respondents indicated improvement in operational performance, especially with overall productivity from the application of lean manufacturing. Skill of workforce, in-house expertise and organizational culture were found to be the critical factors for successful implementation of lean manufacturing practices. Chen et al. (2013) applied lean production and radio frequency identification (RFID) technologies to improve the efficiency and effectiveness of supply chain management. In this study, a three-tier spare parts supply chain with inefficient transportation, storage and retrieval operations was investigated. Value Stream Mapping (VSM) was used to draw current state mapping and future state mapping (with lean production and RFID) with material, information, and time flows.

Issa (2013) suggested and applied a technique for minimizing risk factors effect on time using lean construction principles. The lean construction was implemented in this study using the last planner system through execution of an industrial project in Egypt. Evaluating the effect of using the said tool was described in terms of two measurements: Percent Expected Time-overrun (PET) and Percent Plan Completed (PPC). The most important risk factors were identified and assessed, while PET was quantified at the project start and during the project execution using a model for time-overrun quantification. Matt and Rauch (2013) analyzed the role and potential of small enterprises – especially in Italy – and showed a preliminary study of the suitability of existing lean methods for the application in this type of organization. The research was combined with an industrial case study in a small enterprise to analyze the difficulties in the implementation stage and to identify the critical success factors. The results of this preliminary study could illustrate the existing hidden potential in small enterprises as well as a selection of suitable methods for productivity improvements. Mostafa et al. (2013) categorized the lean implementation initiatives as roadmap, conceptual/ implementation framework, descriptive and assessment checklist initiatives. Koukoulaki (2014) identified the effects of lean production (negative or positive) on occupational health and related risk factors. Almomani et al. (2014) proposed an integrated model of lean assessment and explored analytical hierarchy process (AHP) to define the route of lean implementation based on the perspective priorities for improvement.

Organizations are continuously having to cope with changing markets that are unpredictable and more diversified, increasing global competition and ever changing customer demands. As the product life cycle becomes shortened, high product quality becomes necessary for survival (Gunasekaran, 1998). Companies now have to be able to not only predict variations and changes within the market and socio-economic and political environments but must also be able to adapt and change in accordance with these environments. As a result, this demands that an organization develops and sustains an inherent ability to continuously change. Such a demand can be met by adopting the management philosophy of agile manufacturing (Sharp et al., 1999). Agile manufacturing is seen as the winning strategy to be adopted by manufacturers bracing themselves for dramatic performance enhancements to become national and international leaders in an increasingly competitive market of fast changing customer requirements (Yusuf et al., 1999). Agile manufacturing can be defined as the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services

(Gunasekaran, 1998; Szczerbicki and Williams, 2001). Agile manufacturing (AM) is a manufacturing paradigm that focuses on smaller scale, modular production facilities, and agile operations capable of dealing with turbulent and changing environments (Cao and Dowlatshahi, 2005). According to (Sherehiy et al., 2007), the global characteristics of agility can be applied to all aspects of enterprise: flexibility, responsiveness, speed, culture of change, integration and low complexity, high quality and customized products, and mobilization of core competencies.

Devo et al. (1997) discussed the genesis of several of the Agile Manufacturing Research Institutes (AMRI) and their on-going activities and results. A vision for agile manufacturing research was articulated and initial accomplishments identified in this reporting. Lee (1998) addressed on designs of components and manufacturing systems for agile manufacturing. In this paper, agile manufacturing was considered in the early design of components and manufacturing systems. A design for agility rule was formulated, proved, and substantiated by numerical results. The design rule reduced manufacturing lead times in consecutive changes of product models. Along with changes of product models, machines were relocated considering the overall costs of material handling and reconfiguration. A machine relocation problem was mathematically formulated and solved with a solution procedure developed.

Gunasekaran (1998) addressed the key concepts and enablers of agile manufacturing. The key enablers of agile manufacturing include: (i) virtual enterprise formation tools/metrics; (ii) physically distributed manufacturing architecture and teams; (iii) rapid partnership formation tools/metrics; (iv) concurrent engineering; (v) integrated product/production/business information system; (vi) rapid prototyping tools; and (vii) electronic commerce. The author presented a conceptual framework for the development of an agile manufacturing system. This framework took into account the customization and system integration with the help of business process redesign, legal issues, concurrent engineering, computer-integrated manufacturing, cost management, total quality management and information technology. Sharp et al. (1999) proposed a conceptual model which was developed to identify where UK's best practice companies were in their quest to become agile manufacturing organizations. In support of this, a questionnaire was developed and completed by best practitioners of manufacturing, to assess the model, and establish whether they were making progress to becoming agile manufacturing organizations.

Katayama and Bennett (1999) dealt with three concepts of concern to manufacturing management; agile manufacturing, adaptable production and lean production. These were described and compared within the context of the modern competitive situation in Japan. The results suggested that companies were trying to realize their cost adaptability through agility enhancement activities. Yusuf et al. (1999) identified the drivers of agility and discussed the portfolio of competitive advantages that emerged over time as a result of the changing requirements of manufacturing. Gunasekaran (1999) attempted to identify key strategies and techniques of AM, and developed a framework for the development of agile manufacturing systems (AMSs) along four key dimensions which include strategies, technologies, systems and people.

Meade and Sarkis (1999) introduced a decision methodology and structure for manufacturing (and organizational) agility improvement. The methodology allowed for the evaluation of alternatives (e.g. projects) to help organizations become more agile, with a specific objective of improving the manufacturing business processes. In order to evaluate alternatives that impact the business processes, a networked hierarchical analysis model based on the various characteristics of agility, was proposed. This evaluation model was based on the analytic network process methodology for solving complex and systemic decisions. Huang et al. (2000) viewed the agility of enterprises from two perspectives: business and organizational agility, and operational and logistics agility. In the business and organizational perspective of agility, the research developed an analytic method called distributed parallel integration evaluation model (DPIEM). Its purpose was organizing resources among distributed, networked organizations, based on the parallelism theory of computing and communication. In terms of operational and logistics agility in such distributed organizations, the research suggested that the connection between the autonomy functions and agility required significant functions of error detection and recovery (EDR), and conflict resolution (CR).

Fujii et al. (2000) introduced an Activity Based Costing (ABC) method into the Distributed Virtual Factory (DVF) architecture to estimate the detailed cost analysis of the products. The methodology facilitated strategic enterprise management to prepare the request for the bids in the VE environment. The effectiveness of the proposed concept in agile manufacturing was discussed with simulation experiments. Chan and Zhang (2001) proposed an Object & Knowledge-based Interval Timed Petri-Net (OKITPN) approach which provided an object-oriented and modular method of modeling agile manufacturing activities. It included knowledge, interval time, modular and communication attributes. The features of object-oriented modeling allowed the AMS to be modeled with the properties of classes and objects, and made the concept of software IC possible for rapid modeling of complex AMSs.

Based on the characteristics of mass customization (MC) product manufacturing and the requirement of agile manufacturing, Yang and Li (2002) established an MC product manufacturing agility evaluation index system through studying MC enterprise’s organization management agility evaluation, MC products design agility evaluation, and MC manufacture agility evaluation. Also, with the Xi Dian Casting Limited Company as an example, the multi-grade fuzzy assessment method was used to evaluate its agility.

Yusuf and Adeleye (2002) carried out a comparative study of lean and agile manufacturing with a related survey of current practices in the UK. The paper explored the threats to lean and the drivers of agile manufacturing. Prince and Kay (2003) presented the background to why some manufacturing organizations require a combination of agile and lean characteristics in their manufacturing organizations. The paper also described the development of the virtual group (VG) concept (the application of virtual cells to functional layouts). VGs could enable the appropriate application of lean and agile concepts to different stages of production within a factory. The identification of VGs was achieved through the use of a methodology called enhanced production flow analysis (EPFA), which was described together with how it was different from Burbidge's PFA. Finally, the results of two case studies were presented which tested the ability of EFPA to identify VGs, and assess its usability.

Yao et al. (2003) studied a production system that implemented concepts inherent in MRP, JIT and TQM while recognizing the need for agility in a somewhat complex and demanding environment. For agile production it appeared essential that an on-line, real-time data capture system provided the status and location of production lots, components, subassemblies for schedule control. Current status of all material inventories and work in process was required to develop and adhere to schedules subject to frequent changes. For the large variety of styles and fabrics customers might order, the flexibility of small lots and a real-time, on-line communication system was seemed required. Such a system could provide timely, accurate and comprehensive information for intelligent decisions with respect to the product mix, effective use of production resources and customer requirements. Yusuf et al. (2004) reviewed emerging patterns in supply chain integration. It also explored the relationship between the emerging patterns and attainment of competitive objectives. The results reported in the paper were based on the data collected from a survey using the standard questionnaire. The survey involved 600 companies in the UK, as part of a larger study of agile manufacturing. The study was driven by a conceptual model, which related supply chain practices to competitive objectives. The study involved the use of factor analysis to reduce research variables to a few principal components. Subsequently, multiple regressions were conducted to study the relationship amongst the selected variables. The results validated the proposed conceptual model and lend credence to current thinking that supply chain integration could be a vital tool for competitive advantage.

Elkins et al. (2004) discussed decision models that provided initial insights and industry perspective into the business case for investment in agile manufacturing systems. The models were applied to study the hypothetical decision of whether to invest in a dedicated, agile, or flexible manufacturing system for engine and transmission parts machining. These decision models were a first step toward developing practical business case tools that might help industry to assess the value of agile manufacturing systems. Cao and Dowlatshahi (2005) addressed virtual enterprise and information technology as potential enablers of agile manufacturing. This empirical study explored the impact of the alignment between VE and IT on business performance in an AM setting. It was also established that the alignment between VE and IT had a positive impact on business performance. Further, it was shown that the impact of the alignment between VE and IT on business performance was more significant than the impact of VE and IT on business performance individually.

Zain et al. (2005) examined the influence of information technology acceptance on organizational agility. The study was based on the Technology Acceptance Model (TAM). The authors attempted to identify the relationships between IT acceptance and organizational agility in order to see how the acceptance of technology contributed to a firm's ability to be an agile competitor. Structural equation modeling techniques were used to analyze the data. Results from a survey involving 329 managers and executives in manufacturing firms in Malaysia showed that actual system or technology usage had the strongest direct effect on organizational agility. Meanwhile, perceived usefulness and perceived ease of use of IT influenced organizational agility indirectly through actual systems or technology use and attitudes towards using the technology. Deif and ElMaraghy (2006) presented a dynamic manufacturing planning and control (MPC) system that could maintain agility through the ability to dynamically switch between different policies due to varying market strategies. The dynamic behavior of the developed system was investigated by studying the effect of the time based parameters on responsiveness and cost effectiveness of the system reflected in the natural frequency and the damping of its different configurations. Results showed that the agility requirements were directly affected by the time based parameters of the MPC system: production lead time, capacity scalability delay, and shipment time. This resulted in a better understanding of the requirements for a well-designed agile MPC system.

Kim et al. (2006) suggested a framework for designing the agile and interoperable VEs. This modeling framework could be used for business managers or business domain experts to build an agile and interoperable VE quickly and systematically with insights. It also supported a coherent enterprise modeling in which various stakeholders having their own aspects and methodology, such as an IT manager and a business manager, could communicate effectively. Swafford et al. (2006) presented a framework of an organization's supply chain process flexibilities as an important antecedent of its supply chain agility. The authors established the key factors that determined the flexibility attributes of the three critical processes of the supply chain—procurement/sourcing, manufacturing, and distribution/logistics. Findings revealed that supply chain agility of a firm was directly and positively impacted by the degree of flexibility present in the manufacturing and procurement/sourcing processes of the supply chain; while it was indirectly impacted by the level of flexibility within its distribution/logistics process. The results also supported that a firm's supply chain agility was impacted by the synergy among the three process flexibilities in its internal supply chain.

Narasimhan et al. (2006) discussed leanness and agility in two ways: (1) as manufacturing paradigms and (2) as performance capabilities. The empirical study attempted to determine whether lean and agile forms occur with any degree of regularity in manufacturing plants. The results confirmed the existence of homogeneous groups that resembled lean and agile performing plants, and they identified important differences pertaining to their constituent performance dimensions. The results indicated that while the pursuit of agility might presume leanness, pursuit of leanness might not presume agility. Agarwal et al. (2006) presented a framework, which encapsulated the market sensitiveness, process integration, information driver and flexibility measures of supply chain performance. The paper explored the relationship among lead-time, cost, quality, and service level and the leanness and agility of a case supply chain in fast moving consumer goods business. The paper concluded with the justification of the framework, which analyzed the effect of market winning criteria and market qualifying criteria on the three types of supply chains: lean, agile and leagile.

Deif and ElMaraghy (2007) considered a dynamic control approach for linking manufacturing strategy with market strategy through a reconfigurable manufacturing planning and control (MPC) system to support agility in this context. The authors presented a comprehensive MPC model capable of adopting different MPC strategies through distributed controllers of inventory, capacity, and WIP. McAvoy et al. (2007) discussed the importance of adoption factors to the adoption of an agile method and the usefulness of a decision support tool to help determine the viability of such methods for specific software projects. It proposed the Adoption Assessment Matrix, could be used as a precursor to the selection and use of an agile method. The Adoption Assessment Matrix was used to assess the suitability of agile methods in software development projects in a series of workshops. Qumer and Henderson-Sellers (2008) provided a framework to support the evaluation, adoption and improvement of agile methods in practice. The Agile

Software Solution Framework (ASSF) provided an overall context for the exploration of agile methods, knowledge and governance and contains an Agile Toolkit for quantifying part of the agile process. This could link to the business aspects of software development so that the business value and agile process could be well aligned.

Swafford et al. (2008) focused on achieving supply chain agility through IT integration and flexibility. Results from this study indicated that IT integration enabled a firm to tap its supply chain flexibility which in turn results in higher supply chain agility and ultimately higher competitive business performance. Calvo et al. (2008) formulated a systemic criterion of sustainability in agile manufacturing and computed it through flexibility and complexity. It was defined as a ratio of utility and entropy as a sustainability measurement. Under a unified framework, utility allowed one to quantify the contributions to agility, in particular system flexibility. Complexity was measured by entropy. Thus, in this paper, an original complementary role of flexibility and the complexity of the system were proposed. Mafakheri et al. (2008) proposed a decision aid model using fuzzy set theory for agility assessment of projects. The applicability of the proposed model was demonstrated by a case study in software development project management.

Chan and Thong (2009) provided a critical review on the acceptance of traditional systems development methodologies (SDMs) and agile methodologies, and developed a conceptual framework for agile methodologies acceptance based on a knowledge management perspective. This framework could provide guidance for future research into acceptance of agile methodologies, and had implications for practitioners concerned with the effective deployment of agile methodologies. Braunscheidel and Suresh (2009) investigated the impact of two cultural antecedents, market orientation and learning orientation, and three organizational practices, all aimed at augmenting the supply chain agility of a firm. Kisperska-Moron and Swierczek (2009) explored the main agile capabilities of Polish companies in supply chains. The authors identified the variables, which had an impact on the inter-organizational agility in the supply chains. Bottani (2009) presented an original approach, which, by linking competitive bases, agile attributes and agile enablers, aimed at identifying the most appropriate enablers to be implemented by companies starting from competitive characteristics of the related market. The approach was based on the QFD methodology, and, in particular, on the house of quality (HOQ), which was successfully adopted in the new product development field. The whole scaffold exploited fuzzy logic, to translate linguistics judgments required for relationships and correlations matrixes into numerical values.

Lin et al. (2010) proposed two measures - network entropy and mutual information – in order to characterize the agility of networked organizational structure. Worley and Lawler (2010) described a comprehensive agility framework and then applied the framework to diagnose an organization's agility capability. Bottani et al. (2010) attempted to improve the existing knowledge on agility, by presenting the results of an empirical research in order to investigate both the profile of agile companies and the enablers practically adopted by those companies to achieve agility. Tseng and Lin (2011) suggested a new agility development method for dealing with the interface and alignment issues among the agility drivers, capabilities and providers using the QFD relationship matrix and fuzzy logic. A fuzzy agility index (FAI) for an enterprise composed of agility capability ratings and a total relation-weight with agility drivers was developed to measure the agility level of an enterprise. This report also described how this robust approach could be applied to develop agility in a Taiwanese information technology (IT) product and service enterprise.

Iivari and Iivari (2011) analyzed the relationship between organizational culture and the post adoption deployment of agile methods. Inman et al. (2011) theorized and tested a structural model incorporating agile manufacturing as the focal construct. The model included the primary components of JIT (JIT-purchasing and JIT-production) as antecedents and operational performance and firm performance as consequences to agile manufacturing. Zandi and Tavana (2011) presented a novel structured approach to evaluate and select the best agile e-CRM framework in a rapidly changing manufacturing environment. The e-CRM frameworks were evaluated with respect to their customer and financial oriented features to achieve manufacturing agility. Initially, the e-CRM frameworks were prioritized according to their financial oriented characteristics using a fuzzy group real options analysis (ROA) model. Next, the e-CRM frameworks were ranked according to their customer oriented characteristics using a hybrid fuzzy group permutation and a four-phase fuzzy quality function deployment (QFD) model with respect to three main perspectives of agile manufacturing (i.e., strategic, operational and functional agilities). Finally, the best agile e-CRM framework was selected using a technique for order preference by similarity to the ideal solution (TOPSIS) model.

Zhang (2011) developed a numerical taxonomy of agile manufacturing strategies based on a large scale questionnaire study of UK industry. The taxonomy suggested the existence of three basic types of agility strategies: quick, responsive, and proactive. A cross-case analysis found that the choice of agility strategies was related to the nature of markets and competition, the characteristics of products (life cycles and degrees of maturity), and market positions of individual companies. Ngai et al. (2011) explored the impact of the relationship between supply chain competence and supply chain agility on firm performance. This study articulated the relationship from the perspective of inter-organizational collaboration. The authors developed a conceptual model based on the resource-based view and employed a multi-case study method in this exploratory research. The findings highlighted the importance of distinguishing the difference between supply chain agility and supply chain competence and their impact on firm performance.

Roberts and Grover (2012) aimed to conceptually define and operationalize firm's customer agility. The authors proposed that agility comprises two distinct capabilities, sensing and responding, and addressed the issue of alignment between these capabilities and its impact on performance. Hasan et al. (2012) made a contribution by providing insights into a decision aid for evaluating production flow layouts that supported and enhanced the agile manufacture of products. This paper explored the Analytical Network Process (ANP) which captured interdependencies among different criteria, sub-criteria and dimensions, an evident characteristic of production flow layouts in complex agile manufacturing environments. An application case study exemplifying the practical usefulness of this type of model described how management, after implementation of the model, made a mid-course correction related to the production layout initially selected. Azevedo et al. (2012) proposed an index to assess the agility and leanness of individual companies and the corresponding supply chain. The index was named Agilean and was obtained from a set of agile and lean supply chain practices integrated in an assessment model. This index made it possible to assess the companies and corresponding supply chain agile and lean behavior, which was translated into an index score to compare competing companies and supply chains.

Costantino et al. (2012) addressed the configuration problem of Manufacturing Supply Chains (MSC) with reference to the supply planning issue. Assuming a multi-stage manufacturing system, the authors presented a technique for the strategic management of the chain addressing supply planning and allowing the improvement of the MSC agility in terms of ability in reconfiguration to meet performance. A case study was presented describing the optimal MSC configuration of an Italian manufacturing firm. The obtained results showed that the design method provided managers with key answers to issues related to the supply chain strategic configuration and agility, e.g., choosing the right location for distributors and retailers for enhanced MSC flexibility and performance.

Lim and Zhang (2012) introduced a currency-based iterative agent bidding mechanism to effectively and cost-efficiently integrate the activities associated with production planning and control, so as to achieve an optimized process plan and schedule. The aim was to enhance the agility of manufacturing systems to accommodate dynamic changes in the market and production. Sukati et al. (2012) investigated the relationship between organizational practices and supply chain agility. Vinodh et al. (2013) reported an ASC assessment model which was encompassed with agile supply chain attributes essential for assessing the overall ASC performance of the organization. The computation was performed using fuzzy logic approach. The working of this model was examined by conducting a case study in an Indian automotive components manufacturing organization. The experience gained by conducting this case study favored the use of a computerized system which ensured accuracy of computations involving fuzzy logic. Yusuf et al. (2014) assessed the link between dimensions of agile supply chain, competitive objectives and business performance in the UK North Sea upstream oil and gas industry. By examining the whole supply chain associated with agile practices in an important sector, the paper identified the most important dimensions and attributes of supply chain agility and provided a deeper insight into those characteristics of agility that were found most relevant within the oil and gas industry.

Manufacturing plant managers need to seek performance improvements by adhering to the guiding principles of leanness and agility. Lean manufacturing and agile manufacturing paradigms have also received considerable attention in operations management literature. Given the resource constraints within which most manufacturing firms have to operate today, it is very useful, if not critical, to develop a clear understanding of how these paradigms differs and what their constituent dimensions are. Such an understanding is indeed essential for developing and testing theories relating to leanness and agility (Narasimhan et al., 2006).

The latter part of the 20th century saw the lean production paradigm positively impact many market sectors ranging from automotive through to construction. In particular, there is much evidence to suggest that level scheduling combined with the elimination of '*muda*' has successfully delivered a wide range of products to those markets where cost is the primary order winning criteria. However, there are many other volatile markets where the order winner is availability, which has led to the emergence of the agile paradigm typified by 'quick response' and similar initiatives. Nevertheless, 'lean' and 'agile' are not mutually exclusive paradigms and may be married to offer advantage to the industry (Aitken et al. 2002).

Naylor et al. (1999) stated that the use of either paradigm (lean and agile) has to be combined with a total supply chain strategy particularly considering market knowledge and positioning of the decoupling point as agile manufacturing is best suited to satisfying a fluctuating demand and lean manufacturing requires a level schedule. Mason-Jones et al. (2000) considered the effect of the marketplace environment on 'leagile' strategy selection to ensure optimal supply chain performance. Real-world case studies in the mechanical precision products, carpet making, and electronic products market sectors demonstrated the leagile approach towards matching supply chain design to the actual needs of the marketplace. Towill and Christopher (2002) pointed out that there was a tendency recently to see 'lean' and 'agile' as two distinct models of business operations. The authors reconciled the two paradigms and through case study examples showed how they might successfully be combined. A fundamental requirement was observed that supply chain design should be linked to corporate strategy and the needs of the market-place. Lean and agile principles could then be juxtaposed according to the requisite business strategy via a time-space matrix. This could determine whether the lean-agile principles are separated by time, by space or by both space and time.

Banomyong et al. (2008) focused on one facet of reverse logistics, which involved the return of damaged products to be repaired by a manufacturer. The authors presented the application of the 'leagile' paradigm in the reverse logistics process and its expected outcome, in terms of costs and lead-time reduction to consumers and to the manufacturer itself. The case study of an electrical appliance manufacturer based in Bangkok, Thailand, was used as an example to illustrate the possible impact of the 'leagile' concept on its repair and replacement services. It was discovered, with the application of the 'leagile' concept in the reverse logistics process, that lead-time for product repairs and returns, as well as costs involved with reverse logistics, were found drastically reduced while customer satisfaction increased significantly. Chan et al. (2009) proposed an integrated process planning and scheduling model inheriting the salient features of outsourcing, and leagile principles to compete in the existing market scenario. The authors also proposed a hybrid Enhanced Swift Converging Simulated Annealing (ESCSA) algorithm, to solve the complex real-time scheduling problems. The proposed algorithm inherited the prominent features of the Genetic Algorithm (GA), Simulated Annealing (SA), and the Fuzzy Logic Controller (FLC).

Chan and Kumar (2009) proposed a leagile supply chain based model for manufacturing industries. The paper emphasized various aspects of leagile supply chain modeling and implementation and proposed a Hybrid Chaos-based Fast Genetic Tabu Simulated Annealing (CFGTSA) algorithm to solve the complex scheduling problem prevailing in the leagile environment. The proposed CFGTSA algorithm was also compared with the GA, SA, TS and Hybrid Tabu SA algorithms to demonstrate its efficacy in handling complex scheduling problems. Huang and Li (2010) illustrated how a personal computer (PC) original equipment manufacturer (OEM) in Taiwan achieved leagility through reengineering its supply chain. The case study showed how the company adjusted its production processes from build-to-order (BTO) to configuration-to-order (CTO) to achieve leagility.

Zhang et al. (2012) used the system engineering concept towards building the system dynamics models of traditional supply chain and leagile supply chain. Through comparing the simulation results of these two kinds of supply chain, the authors showed the advantages of leagile supply chain. The results hold that shorten the length of supply chain, share the information, cooperation and production delay could effectively weaken the bullwhip effect. By running the simulation model, the authors determined the relationship among effect factors of leagile supply chain and observed the visual dynamic changes of supply chain. Thus, this result provided decision supports to enterprises' leagile supply chain. Cabral et al. (2012) proposed an integrated (Lean, Agile, Resilient and Green) LARG analytic network process (ANP) model to support decision-making in choosing the most appropriate practices and KPIs (key performance indicators) to be implemented by companies in an SC.

Soni and Kodali (2012) addressed the issue of lack of standard constructs in frameworks of lean, agile and leagile supply chain. This objective was achieved by evaluating reliability and validity of lean, agile and leagile supply chain constructs in Indian manufacturing industry. Principle Component Analysis (PCA) was performed on these constructs to find out the pillars of each type of supply chain followed by evaluating reliability and validity of these pillars to establish the underlying constructs. Finally, using the results of the study, a framework for lean, agile and leagile supply chain was proposed. Mehrsai et al. (2014) covered a quick review on the lean and agility techniques and highlighted specific contributions of autonomous control to their targets. The purpose was to clarify the role of the autonomy in compliance with the lean and agility goals. This was inspected through development of a discrete event simulation with some scenarios in a supply network.

Aforesaid sections deal with state of art on different aspects of lean, agile and leagile concepts in manufacturing/service sectors. The concept, implementation framework, appropriate supply chain construct in relation to lean, agile as well as leagile manufacturing strategies have been found well documented in literature. The following sections provide glimpses of past research attempting to estimate leanness, agility as well as leagility extent in industrial context (organization/SC).

Vinodh and Balaji (2011) attempted to assess the leanness level of a manufacturing organization by designing a leanness measurement model. The authors thus computed a leanness index. Since the manual computation is time consuming and error-prone; the authors developed a computerized decision support system. This decision support system was designated as FLBLA-DSS (decision support system for fuzzy logic based leanness assessment). FLBLA-DSS computed the fuzzy leanness index, Euclidean distance and identified the weaker areas which needed improvement. The developed DSS was test implemented in an Indian modular switches manufacturing organization. Vinodh and Chintha (2011b) assessed the leanness extent of an organization using multi-grade fuzzy approach. This was followed by the substitution of the data gathered from a manufacturing organization. After the computation of leanness index, the areas for leanness improvement were identified. Vinodh et al. (2011) presented a study in which fuzzy association rules mining approach was used for leanness evaluation of an Indian modular switches manufacturing organization. The experiences gained as a result of the conduct of the study indicated that leanness evaluation could be performed by the decision makers without any constraints.

Vinodh and Vimal (2012) presented the 30 criteria based leanness assessment methodology using fuzzy logic. Fuzzy logic was used to overcome the disadvantages with scoring method such as impreciseness and vagueness. During this research, a conceptual model for leanness assessment was designed. Then the authors computed fuzzy leanness index which indicated the leanness level of the organization and fuzzy performance importance index which helped in identifying the obstacles for leanness. In another reporting, Vimal and Vinodh (2012) attempted the fuzzy logic-based inference method towards leanness evaluation. A conceptual model consisting of three levels namely enabler, criterion, and attributes was developed. Then the linguistic variables were assigned and the membership functions were defined. Leanness level was computed using IF–THEN rules based interface method. This was followed by gap analysis to identify the weaker criteria. Then suitable proposals were derived to overcome these obstacles towards leanness improvement of the organization.

Behrouzi and Wong (2013) developed an integrated stochastic-fuzzy model to evaluate supply chain leanness of small and medium enterprises in the automotive industry. This research was carried out to systematically quantify the leanness of a supply chain with regard to stochastic and fuzzy uncertainties in performance measures. Particularly, four performance categories (quality, cost, delivery and reliability, and flexibility) along with 28 related measures were selected as surrogates for leanness. The probability function of the total leanness was identified and different leanness situations were consequently predicted. A total leanness index was also provided and connected to fuzzy sets (linguistic terms) to evaluate the current leanness level. Lin et al. (2006a) developed a fuzzy agility index (FAI) based on agility providers using fuzzy logic. The FAI comprised attribute' ratings and corresponding weights, and was aggregated by a fuzzy weighted average. In order to illustrate the efficacy of the method, this study also evaluated the supply chain agility of a Taiwanese company. In another reporting, Lin et al. (2006b) developed an absolute agility index, a unique and unprecedented attempt in agility measurement, using fuzzy logic to address the ambiguity in agility evaluation. Jain et al. (2008) developed an approach based on Fuzzy Association Rule Mining to support the decision makers by enhancing the flexibility in making decisions for evaluating agility with both tangibles and intangibles attributes/criteria such as Flexibility, Profitability, Quality, Innovativeness, Pro-activity, Speed of response, Cost and Robustness. Dimitropoulos (2009) introduced an index for measuring the ability of a company to timely and profitably exploit windows of upcoming commercial opportunity and a model for calculating the long-term cost of software in agile production environments. The evaluation focused on the effects of the production infrastructure on the strategic and tactical ability of the company. Through the introduced index and software cost model, the impact of software on the agility of automatic production systems was explained, along with the benefits from reconfigurable production control software build upon open standards.

Wang (2009) developed an agility-based manufacturing system to catch on the traits involved in mass customization (MC). An MC manufacturing agility evaluation approach based on concepts of TOPSIS was proposed through analyzing the agility of organization management, product design, processing manufacture, partnership formation capability and integration of information system. Bottani (2009) explored the main issues arising when attempting to quantitatively assess the agility level of a company. More precisely, the key questions of this study concerned the suitability of available agility metrics to: (1) assess the agility level reached by companies; (2) assess the agility level of companies operating in different market segments; and (3) capture all aspects of agility. In order to answer those questions, two manufacturing companies, operating in the mechanical engineering and food processing industries, were examined through site visits and direct interviews, and detailed pieces of information were derived about their perception of agility drivers, attributes and enablers, and the corresponding degree of implementation. The results of the case studies showed that available metrics of agility suffered from several limitations and did not consider all aspects of agility. Based on these outcomes, gaps for further research were identified and suggested.

Vinodh and Prasanna (2011) developed a conceptual model for agility evaluation. This was followed by gathering single factor assessment vector and weights by experts. Then multi-grade fuzzy approach was used for the evaluation of agility in the supply chain. The evaluation exercise indicated that the case organization was agile; but still there existed chances for improving the agility level. Then the weaker areas were identified and the improvement proposals were implemented. The implementation result indicated that there was a significant improvement in the agility level of the case organization. Dahmardeh and Pourshahabi (2011) proposed a knowledge-based framework for the measurement and assessment of public sector agility using the A.T. Kearney model. In the paper, the authors used the absolute agility index together with fuzzy logic to address the ambiguity in agility evaluation in public sector in a case study. Vinodh and Devadasan (2011) reported a research carried out to assess the agility level of an organization using fuzzy logic approach. During this research, an agility index measurement model containing 20 criteria incorporated with fuzzy logic approach was designed. Subsequently, the data gathered from a manufacturing organization were substituted in this model and the agility index was determined. Using this model, the method of determining the obstacles for achieving agility in the organization was examined. It was found that the organization was required to concentrate on the activities leading to overcome obstacles so as to achieve agility.

Vinodh et al. (2012a) attempted the agility assessment of an Indian electric automotive car manufacturing organization using a scoring approach and validated using an effective multi-grade fuzzy method. The result indicated that the organization was agile to an extent of 84.1% using the scoring approach and 7.05 using the multi-grade fuzzy method, which implied the organization was agile. The gap analysis results indicated that the largest gap was observed in the case of 'nature of management' criterion followed by 'devolution of authority', 'customer response adoption' and 'employee involvement'. Necessary actions were taken for the improvement of these agility gaps. The improvement in agile performance measures was 7.7 to 9.7 (on a Likert scale of range 0–10) after the implementation of the suggested proposals. The statistical validation study indicated the feasibility of improvement in agility after the assessment exercise with a practical success rate of 90%. Vinodh and Aravindraj (2012) used the IF–THEN rules approach to evaluate the current agile position of the firm. The assessment was carried out in an Indian modular switches manufacturing company. The assessment revealed that the organization was fairly agile. Besides computing agility level, the gaps that impede agility were identified, and proposals for agility improvement were derived. The identified proposals were subjected to implementation in the case organization. Vinodh et al. (2012b) attempted to assess the agility of the manufacturing organization using a scoring approach. This paper presented a 30-criteria agility assessment model which could be utilized to measure agility and to identify the agile characteristics of organization. Thus, weak factors were identified, and proposals were suggested so as to enhance the agility of the organization.

Vinodh and Aravindraj (2013) presented the conceptual model of leagility imbibed with lean and agile principles. A fuzzy logic approach was used for the evaluation of leagility in supply chains. This article used to compute the performance of supply chains using both lean and agile concepts as leagility supply chains using a fuzzy logic approach.

1.3 Motivation and Objectives

While adapting lean, agile and leagile manufacturing concept (depending on requirements of the industry, its supply chain) in practice, the following questions definitely arise.

1. What precisely are leanness, agility as well as leagility? How these can be measured?
2. How can one adopt the appropriate lean, agile and leagile enablers to develop leanness, agility and leagility, respectively?
3. Which is the appropriate criteria-hierarchy (evaluation index system) comprising a set of capabilities/enablers, attributes as well as criterions to estimate overall organizational leanness, agility and leagility extent?
4. How can those lean, agile and leagile criterions (performance measures) be evaluated?
5. Is there any unique performance metric to infer current performance level of the candidate industry (its supply chain) from the viewpoint of leanness, agility and leagility?
6. How lean/agile and leagile barriers can be identified?
7. How can one effectively assist in achieving and enhancing leannnes/agility/leagility?

While seeking answers to these questions, the extent body of past research on various assessment modules (as exhibited in previous section) could be referred in which pioneers put tremendous effort in estimating overall performance index of lean, agile as well as leagile supply chains. It is clearly understood that the performances measures (lean, agile and leagile indices/metrics) are difficult to define in general, mainly due to the multidimensionality and vagueness associated with the concept of leanness/agility/leagility itself. Subjectivity of evaluation indices often creates conflict, incompleteness as well as imprecision while such decision-making relies on expert judgment. Since human judgment often carriers some sort of ambiguity and vagueness and thus creates decision-making more complex. Due to the ill-defined and vague evaluation indices which exist within leanness/agility/leagility assessment,

most of the indices are described subjectively by linguistic terminologies which are characterized by ambiguity and multi-possibility, and the conventional assessment approaches cannot fruitfully handle such measurement. However, fuzzy set theory provides a useful tool for dealing with decisions in which the phenomena are imprecise and vague in nature.
Literature depicts application of fuzzy set theory to some extent in formulating decision support tools towards estimation of organizational leanness as well as agility. However, limited work has been documented so far in addressing aspects of leagility assessment in an industrial context. The formation of an integrated criteria-hierarchy combining both lean as well as agile philosophies to suit a leagility inspired supply chain is definitely a challenging task. Therefore, it is believed that development and subsequently exploration feasibility of different decision support modules (towards computing a unique quantitative metric of leanness, agility and leagility, respectively) need to be attempted and examined. Apart from fuzzy set theory, grey numbers can also possess the capability of efficiently dealing with inconsistent, vague and unclear data set. Therefore, the possibility of exploring grey numbers set theory in course of estimating leanness, agility as well as leagility could be a unified direction of the present research. Literature also confirms that as compared to fuzzy numbers, 'vague numbers' can provide more accurate prediction results in decision-making. Therefore, apart from extending application of fuzzy set theory (as well as grey numbers theory); establishing decision support systems based on the concept of vague numbers set could be another challenging aspect of the present dissertation.

The objectives of the present dissertation have been pointed out below.

1. To study the interrelationship of main capabilities/enablers of lean, agile and leagile manufacturing, respectively.
2. Development and exploration of integrated criteria-hierarchy (evaluation index system) to assess organizational leanness/agility/leagility.
3. Exploration of fuzzy set theory towards developing decision support systems for estimating a unique measurement index highlighting organizational performance from the perspectives of lean, agile and leagile, respectively. Apart from Generalized Triangular Fuzzy Numbers Set (as applied immensely in literature), application potential of Generalized Trapezoidal Fuzzy Numbers Set and Generalized Interval-Valued Fuzzy Numbers Set is to be investigated.

4. Application of grey numbers set theory to develop a decision support system for evaluating a lean metric.
5. Identification of barriers of lean, agile and leagile manufacturing. Exploration of (i) the concept of 'Degree of Similarity' (DOS) (between two fuzzy numbers), and (ii) the concept of 'grey possibility degree' (between two grey numbers) in order to identify ill-performing supply chain entitles which are responsible for the supply chain to lag behind to become lean, agile or leagile, truly.
6. Performance appraisement and benchmarking of leagility inspired industries (alternatives) running under similar supply chain construct (criteria-hierarchy).
7. Development of a decision support system to facilitate suppliers' evaluation and selection in an agile supply chain. Exploration of vague numbers set theory to aid the said decision-making.

1.4 Organization of the Present Dissertation

The dissertation has been organized as follows:

Chapter 1 (Research Background) provides a brief introduction on paradigm shift in manufacturing/production strategies starting from craft manufacturing, followed by mass production, flexible manufacturing, Computer Integrated Manufacturing (CIM), lean manufacturing, Just-In-Time (JIT) manufacturing, concurrent engineering to agile manufacturing; and recent times the leagile (lean + agile) manufacturing have been illustrated in detail. The prior state of art on understanding of various aspects of lean, agile as well as leagile manufacturing strategies in industrial supply chains/service sectors have been thoroughly documented in this chapter; based on which existing research gaps have been identified and the specific objectives of the present dissertation have been articulated as well.

Chapter 2 (Interrelationship of Capabilities/Enablers of Lean, Agile and Leagile Manufacturing: An ISM Approach) aims at identifying major performance indices (dimensions or metrics), also called capabilities (drivers or enablers) towards achieving leanness, agility as well as leagility, separately, at an organizational level (supply chain). The functional relationships amongst various capabilities (of lean, agile or leagile strategies), and the extent with which these are function-wise interconnected have been examined in this chapter through exploration of ISM (Interpretive Structural Modeling) approach.

Chapter 3 (Leanness Metric Evaluation) attempts to develop efficient Decision Support Systems (DSS) towards estimating a unique quantitative leanness metric of organizational supply chain through some case empirical researchers. Subjectivity associated with vague and ill-defined lean measures and metrics has been effectively tackled by utilizing fuzzy as well as grey set theories. Theories of Generalized Fuzzy Numbers Set (GFNs), Generalized Interval-Valued Fuzzy Numbers Set (GIVFNs) and finally grey numbers set theory have been adapted in a logical manner on order to facilitate the said decision making.

Chapter 4 (Agility Appraisement and Suppliers' Selection in Agile Supply Chain) aims at establishing two decision support systems- (i) to derive a quantitative evaluation metric estimating the extent of overall organizational agile performance (agility index), and (ii) to facilitate suppliers' (vendors') evaluation and selection in an agile supply chain. Based on empirical research, the study exhibits application potential of the proposed agility appraisement module in fuzzy environment. The concept of vague numbers set theory has been fruitfully explored in developing an efficient DSS towards suppliers' selection in agile supply chain.

Chapter 5 (A Fuzzy Embedded Leagility Evaluation Module in Supply Chain) proposes an integrated criteria hierarchy (evaluation index system) towards estimating the leagility extent of the candidate industry (its supply chain). The multi-level hierarchy criteria consists of a number of leagile capabilities, attributes as well as criterions. A fuzzy embedded leagility evaluation module has been proposed in this chapter and case empirically studied.

Chapter 6 (Performance Appraisement and Benchmarking of Leagility Inspired Industries: A Fuzzy Based Decision Making Approach) attempts to develop a fuzzy based decision support system towards performance appraisement and benchmarking of candidate industries (alternatives) running under similar leagile supply chain model. Through performance benchmarking, leagile alternatives have been ranked and the best leagile alternative (industry) has been selected (benchmarked) as well. The theory of 'Degree of Similarity' (DOS) obtained from fuzzy numbers set theory in conjugation with the concept of 'closeness coefficient' adapted from TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) has been tactfully utilized to establish the said decision support tool.

Chapter 7 (Case Study: Estimation of Organizational Leanness, Agility and Leagility Degree) exhibits a real case study conducted at a famous automobile part manufacturing industry at Tamil Nadu, INDIA. Exploring three distinct criteria-hierarchies (lean, agile and leagile supply chain, respectively), organizational leanness, agility as well as leagility index have been computed and compared as well to check existing performance level of the said organization from the viewpoint of leanness, agility, and leagility, respectively. Ill-performing supply chain entitles (barriers of lean, agile as well as leagile supply chain) have been identified as well through performance ranking of various evaluation indices (lean, agile and leagile indices, respectively).

Chapter 8 (Contributions and Future Scope) provides executive summary of the present dissertation. Within scope and limitations of the present research, major contributions have been pointed out followed by highlighting future research directions.

Outline of the work carried out in this dissertation has been furnished in Fig. 1.3.

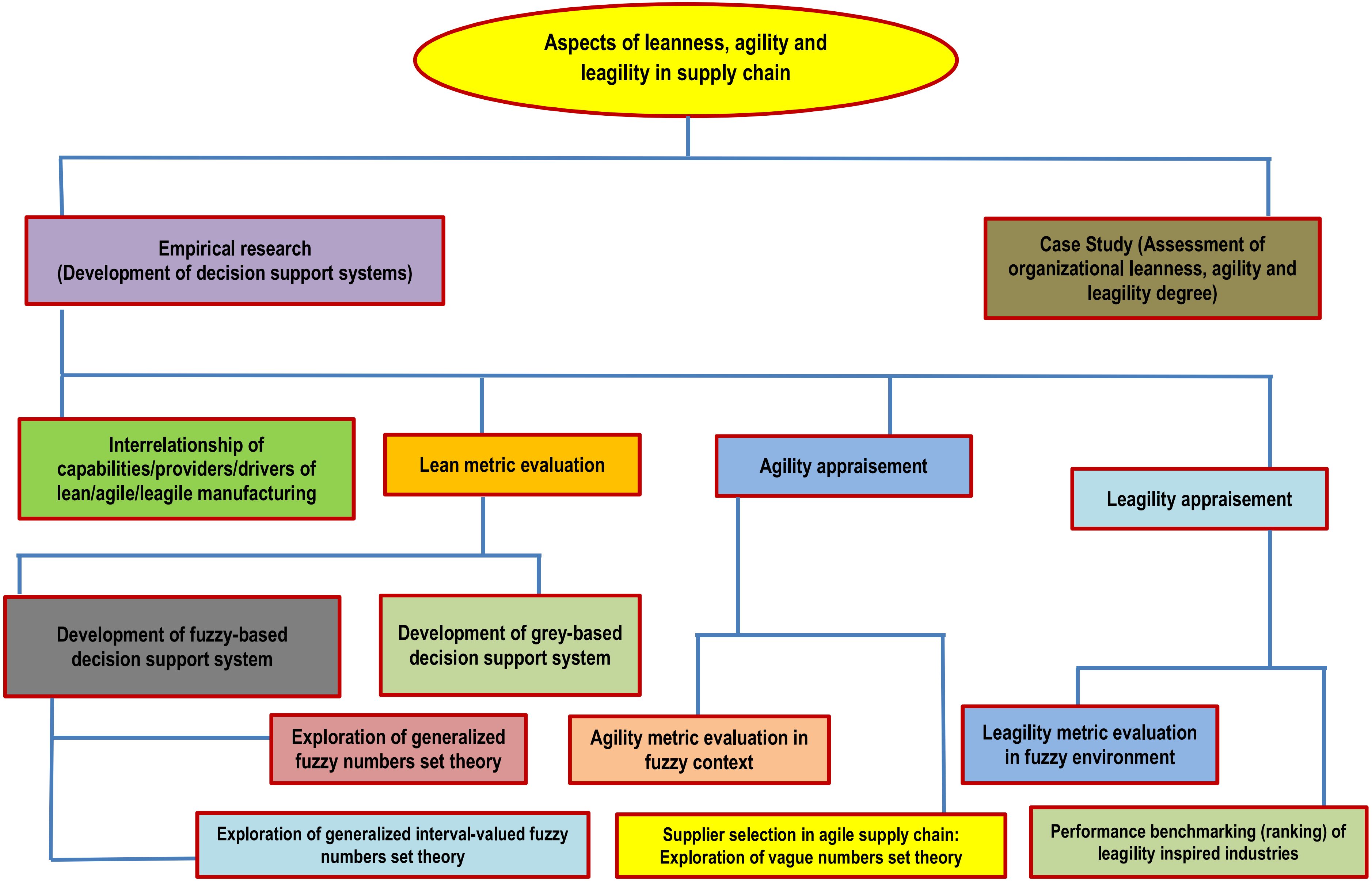

Fig. 1.3: Outline of the work carried out in this dissertation

CHAPTER 2

INTERRELATIONSHIP OF CAPABILITIES/ENABLERS OF LEAN, AGILE AND LEAGILE MANUFACTURING: AN ISM APPROACH

2.1 Coverage

The present work aims at pointing out the key success factors (enablers/capabilities) for lean, agile as well as leagile manufacturing in an organizational supply chain. The concise listing of the key enablers (of lean, agile and leagile manufacturing) has been taken from the extent body knowledge of past literature as well as experience of experts. An ISM (Interpretive Structural Modeling) based model has been developed to reveal the interrelationship among various drivers for individual lean, agile, and leagile manufacturing system, respectively.

2.2 Interpretive Structural Modeling (ISM): Concept and Mathematical Formulation

Interpretive Structural Modeling (ISM) is an interactive management method for developing hierarchy of system enablers to represent the system structure. The basic idea of ISM is to decompose a complicated system into several subsystems (elements) by using practical experience of experts and their knowledge. The method is interpretive as the judgment of the group decides whether and how the elements (enablers) are related. It is structural as on the basis of relationship, an overall structure is extracted from the complex set of enablers. It is called a modeling approach in the sense that the specific relationships and overall structure are portrayed in a graphical model. The ISM transforms unclear, poorly articulated mental models of systems into visible, well-defined models serving varied purposes (Mandal and Deshmukh, 1994; Faisal et al., 2007; Alawamleh and Popplewell, 2011).

It is a well-known methodology for identifying and summarizing relationships among specific elements, which define an issue or a problem, and provide a mean by which order can be imposed on the complexity of such elements (Mandal and Deshmukh 1994). Thus, a set of different directly and indirectly related elements are structured into a comprehensive systematic model.

Mandal and Deshmukh (1994) developed a model for vendor selection criteria; ISM was used to develop a hierarchy of criteria to be considered for selecting the vendors. Kumar and Ravikant (2013) presented an approach for supplier selection process by understanding the dynamics between the supplier selection process enablers (SSPE) and developed hierarchy based model and mutual relationships among SSPE using the ISM methodology. Faisal et al. (2007) employed ISM to present the classification of the enablers of information risks mitigation according to their driving power and dependence. The authors also presented a risk index to quantify information risks. Pfohl et al. (2011) identified inter-relationships among supply chain risks and classified the risks according to their driving and dependence power using the ISM method. The case study was performed to test the theoretical findings of the modeling and the applicability for practical use in two German industry and trade companies. Govindan et al. (2010) developed a framework to analyze the interactions among different criteria relating to the supplier development. Luthra et al. (2011) developed a structural model of the barriers to implement green supply chain management (GSCM) in Indian automobile industry using Interpretive Structural Modeling (ISM) technique. Khurana et al. (2010) provided a comprehensive framework for various important factors of information sharing system affecting the level of trust in supply chain management. ISM and Fuzzy MICMAC were deployed to identify and classify the key criterion of information sharing enablers that influenced trust based on their direct and indirect relationship.

Charan et al (2008) used the ISM technique to determine the key supply chain performance measurement systems implementation variables on which top management must focus to improve effectiveness and efficiency of supply chains. Ravi et al (2005)explored an ISM based approach to model the reverse logistics variables typically found in computer hardware supply chains. Thakkar et al. (2010) evaluated buyer-supplier relations by using integrated ISM and graph theoretic matrix. The case study of Indian automotive SMEs wasorganized. Jharkhariaand Shankar (2005) applied ISM methodology for understanding and establishing the relationship among the barriers for IT enabled supply chain management. This study was conducted for identifying the barriers for IT enabled supply chain for large industries like, Auto industries, FMCG and process industries. Mathiyazhagan and Haq (2013) identified the key pressures of motivation for adoption of green supply chain management (GSCM) in traditional supply chain management (TSCM). Influential pressure was determined with help of interpretive structural modeling technique.

The advantages as well as disadvantages of ISM approach have been pointed out below.

Advantages

(1) The process is systematic; the computer is programmed to consider all possible pair wise relations of system elements, either directly from the responses of the participants or by transitive inference.

(2) The process is efficient; depending on the context, the use of transitive inference may reduce the number of the required relational queries by from 50-80 percent.

(3) No knowledge of the underlying process is required of the participants; they simply must possess enough understanding of the object system to be able to respond to the series of relational queries generated by the computer.
(4) It guides and records the results of group deliberations on complex issues in an efficient and systematic manner.
(5) It produces a structured model or graphical representation of the original problem situation that can be communicated more effectively to others.
(6) It enhances the quality of interdisciplinary and interpersonal communication within the context of the problem situation by focusing the attention of the participants on one specific question at a time.
(7) It encourages issue analysis by allowing participants to explore the adequacy of a proposed list of systems elements or issue statements for illuminating a specified situation.
(8) It serves as a learning tool by forcing participants to develop a deeper understanding of the meaning and significance of a specified element list and relation.
(9) It permits action or policy analysis by assisting participants in identifying particular areas for policy action which offer advantages or leverage in pursuing specified objectives.

Disadvantages

(1) There may be many variable to a problem or issue. Increase in the number of variables to a problem or issue increases the complexity of the ISM methodology.
(2) It limits the number of variables to be considered for the development of ISM.
(3) Further experts help are to be taken in analysing the driving and dependence power of the variable of a problem or issue.
(4) ISM models are not statistically validated. Structural equation modelling (SEM), also commonly known as linear structural relationship approach has the capability of testing the validity of such hypothetical model.

Steps Involved in ISM Methodology

(1) Identification of the elements which are relevant to the problem or issue.
(2) From the elements identified in the first step, establishing the contextual relationship among them. This represents the relationship indicating whether or not one element leads to another.
(3) Developing a structural self-interaction matrix (SSIM) of enablers which indicates a pair wise relationship between enablers of the system under consideration.

(4) Developing a reachability matrix from the SSIM, and checking the matrix for transitivity. Transitivity of the contextual relation is basic assumption in ISM which states that if element A is related to element B and B is related to C, then A is necessarily related to C. The SSIM format is transformed in the reachability matrix format by transforming the information in each entry of the SSIM into 1s and 0s in the reachability matrix.
(5) The reachability matrix obtained in the fourth step is partitioned into different levels.
(6) Based on the relationships in the reachability matrix, removal of the transitive links and drawing a directed graph.
(7) Constructing the ISM model by replacing element nodes with statements.

2.3 Case Illustrations

The objective of this study is to investigate the relationships amongst different enablers/drivers of different manufacturing concept (lean, agile and leagile, respectively) using ISM. The model has been case empiricallystudied with reference to a famous automotive sector at eastern part of India; and the company's capability/enablers have been analyzed for successful adaptation as well as implementation of lean, agile and leagile practices by using the said ISM approach. Adopting the basic procedure of ISM, firstly the important elements (or enablers) with respect of lean, agile and leagile system (Vinodh et al., 2011; Vinodh and Chintha, 2011; Vinodh et al., 2010; Lin et al, 2006a, b), respectively have been identified. (Definitions of major enablers have been listed in Table 2.1).

Having decided on the element set and the contextual relation, a structural self-interaction matrix (SSIM) has been developed based on pair wise comparison of enablers. In the next step, the SSIM has been converted into a reachability matrix (RM) and its transitivity has been checked. Once transitivity embedding has been complete; a matrix model has thus been obtained. Then, the partitioning of the elements and an extraction of the structural model called ISM has been derived, and finally the MICMAC analysis has been organized. The detailed descriptions of procedure have been shown in subsequent sections.

2.3.1 The Structural Self-Interaction Matrix (SSIM)

Expert opinion has been explored towards developing the contextual relationship among lean enablers; similarly for agile as well as leagile enablers. Group of experts selected from the case industry have been consulted in identifying the nature of contextual relationships among the enablers. For analyzing the enablers following four symbols have been used to denote the direction of relationships between enablers (i and j):

V- Enablers i will help to achieve barrier j;

A- Enablers j will help to achieve barrier i;

X- Enablers i and j will help to achieve each other; and

O- Enablers i and j are unrelated

Based on the contextual relationships the SSIM has been developed for lean, agile and leagile system as shown in (Table 2.2, 2.3, 2.4), respectively.

2.3.2 Reachability Matrix

The SSIM (Table 2.2, 2.3, 2.4) has been transformed into a binary matrix for each system, called the initial reachability matrix as shown (Table 2.5, 2.6, 2.7) by substituting V, A, X and O by 1 and 0 as per the case.

The rules for the substitution of 1s and 0s are as follows:

- If the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0.
- If the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1.
- If the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry also becomes 1.
- If the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry also becomes 0.

After incorporating the transitivities as described in Step 4 of the ISM methodology, the final reachability matrix has been obtained, as in the present case, the final reachability matrix has appeared same as initial reachability matrix for agile and leagile manufacturing system, because, there has been no transitivity in both the case, but for lean system the final reachability matrix has been shown in Table 2.8.

In this table, the driving power of a particular enabler is the total number of enablers (including itself) that it influences. The dependences is the total number of enablers (including itself) that it may help in influencing its growth. These driving powers and dependency values will be used in classification of enablers into four groups, i.e. autonomous, dependent, linkage, and driver enablers. This part of analysis is called MICMAC analysis.

2.3.3 Level Partitions

The reachability and antecedent set for each enabler have been obtained from the final reachability matrix corresponding to individual lean, agile and leagile system, respectively. The reachability set for a particular enabler consists of the enabler itself and the other enabler, which it influences. The antecedent set consists of the enabler itself and the other enabler, which may influence it. Subsequently, the common enabler of the reachability and antecedent sets from the intersection sets are the same as assigned as the top-level element in the ISM hierarchy as it would not help achieve any other enabler above their own level. After the identification of the top-level enabler, it is discarded from further hierarchical analysis (i.e., removing that enabler from all the different sets).

For example, as seen in Table 2.9, the lean enablers (2, 3 and 5) have been found at level 1 due to similar reachability and intersection sets. Thus, it would be positioned at the top of the ISM hierarchy. Enablers (2, 3 and 5) have then been removed from all different sets for further analysis, as its level has been obtained. This iteration has been repeated until the levels of each enabler have been found out (Tables 2.9-2.11) as in lean system; and the same procedure has been adopted for both agile and leagile system to obtain the level as shown in Table 2.12 and Table 2.13, respectively. The identified levels aids in building the digraph and the final model of ISM.

2.3.4 Classification of Enablers (MICMAC Analysis)

MICMAC was developed by (Duperrin and Godet, 1973) to study the diffusion of impacts through reaction paths and loops for developing hierarchies for members of an element set. MICMAC analysis can be used to identify and analyze the elements in a complicated system (Warfield 1990). The objective of the MICMAC analysis is to analyze the driving power and the dependence of each of the elements under consideration. Based on driving power as well as dependence, these enablers can be classified into four categories:

(1) Autonomous enablers;
(2) Dependent enablers;
(3) Linkage enablers; and
(4) Independent enablers.

This classification is similar to that used by (Mandal and Deshmukh, 1994). In this classification, the first cluster includes autonomous enablers that have a weak driving power and weak dependence as shown in (Fig.2.1, 2.2, 2.3) for lean, agile and leagile system, respectively. These enablers are relatively disconnected from the system. In the present case, there is no autonomous enabler for all the system. The second cluster consists of the dependent variables that have weak driver power but strong dependence. In this case, enablers 2, 3, 5 for lean system, enabler 1, 4 for agile system and enabler 3 for leagile system have been found to occur in the category of dependent variables. The third cluster includes linkage variables that have strong driver power as well as strong dependence. Any action on these variables would have an effect on the others and also a feedback effect on themselves. In this case, no enabler for lean system as well as for agile system and enabler 1, 4, 5 for leagile system have been found to be in the linkage variable. The fourth cluster includes independent variables with strong driver power and weak dependence. In this case, enablers 1, 4 for lean system and enabler 2, 3 for agile and enabler 2 for leagile system have been found correspond in the category of driver enablers.

2.3.5 Formation of ISM Based Model

The structural model (Fig.2.4, 2.5, 2.6) has been generated from the final reachability matrix (Table 2.8, 2.6, 2.7) corresponding to individual lean, agile and leagile system, respectively, and thus the digraph has been drawn. Removing the transitivities as described in the ISM methodology, the digraph has been finally converted into the ISM. The contextual relationship in this structure is 'leads to'. This implies that each arrow is to be read as 'leads to'.

2.4 Discussions

The objective of the ISM model in this work has been to develop a logical hierarchy of interrelationship amongst various enablers of lean, agile and leagile system, respectively. Analyses of these manufacturing system enablers reveal that for a lean system, (i) manufacturing management leanness, (ii) work force leanness and (ii) manufacturing strategy leanness appears at higher level of the hierarchy; similarly, for agile system, (i) flexibility and for leagile system (i) the strategic management appear(s) the top level having weak driving power as well as strong dependency. Those enablers which can be placed at the bottom of the model with greater driving power appear (i) management responsibility and (ii) technology leanness in lean manufacturing system and (i) responsiveness in agile system and in leagile system it is (i) collaborative relationship. These enablers need greater attention from top managerial level.

The driver power-dependence diagram provides valuable insights on the relative importance and interdependencies of the enablers. Other managerial implication emerging from this study has been discussed as follows:

- The MICMAC analyses (Fig.2.1, 2.2, 2.3) indicate that there is no autonomous enabler in the process of successful lean, agile and leagile manufacturing system. Autonomous enablers are weak drivers and weak dependents. They do not have much influence in the supply chain under consideration. The absence of autonomous enabler in this study indicates that all the identified enablers influence the successful implementation of lean, agile and leagile system. Therefore, it is suggested that management should pay attention to all the enablers.

- It has been further observed that the enabler which have strong driving power and less dependency have been the key enablers of lean, agile and leagile manufacturing system.

ISM is a useful tool for exercising a logical thinking in approaching complex issues. Some of the major capabilities/enablers highlighted for enabling lean, agile as well as leagile manufacturing have been studied using ISM model to analyse the interaction between the capabilities. The driving power-dependence diagram gives some valuable insights about the relative importance and the interdependencies among the capabilities. The insights are very much useful for the managers so that they can proactively deal with these capabilities. The methodology proposed here structures the capabilities in a hierarchical form for ease of managing them. Thus the ISM based model proposed for identification of capabilities of lean, agile, leagile manufacturing can provide the decision-makers a realistic representation of the problem in the course of implementing aforesaid manufacturing concepts.

2.5 Concluding Remarks

In aforesaid work few important enablers of lean, agile and leagile system have been explored to develop ISM based models; an exhaustive list of enablers can also be utilized to develop the relationship among them using ISM methodology. The contextual relation amongst the enablers always depends on the user's knowledge and familiarity with the organization, and its operational strategy. Therefore, any biasing by the person (decision-maker) who is judging the enablers might influence the final result. However, this model has not been statistically validated. Further, Structural Equation Modeling (SEM) can be used for the statistical validation of developed hypothetical model. Hence, it has been suggested that future research may be directed to develop the initial model through ISM and then testing it using SEM.

Table 2.1:Definitions of major enablers/providers for lean, agile and leagile manufacturing

Lean Enablers

Lean Enablers	Definitions
Management responsibility	The major perspectives of management responsibility are organisational structure and nature of management which involves smooth flow of information, team management for decision making and inter-changeability of personnel.The management should clearly know the objectives and their involvement to ensure continued focus.The officers and executives representing broad functional areas are responsible for ensuring a strong, competitive supply base, and transparent information sharing. (Vinodh and Chintha 2011) (http://www.school-for-champions.com/iso9000/r401.htm)
Manufacturing management leanness	Manufacturing leanness is a strategy to incur less input to better achieve the organization's goals through producing better output. So the manufacturing management leanness is the management to adopt the continuous improvement culture, empowerment of personnel to resolve customer problem, change in business and technical processes, streamlining of processes and accept the JIT flow, cellular manufacturing and other manufacturing process depends on the market requirement. (Bayou and De Korvin, 2008;Vinodh and Chintha, 2011)
Work force leanness	Work force leanness is nothing but flexibility of employees to accept the new technologies adoption, multi-skilled personnel and implementation of job rotation system, and strong employee spirit and cooperation. (Vinodh and Chintha, 2011)
Technology leanness	The technology leanness is the ability of an organization to adopt new technology to be competitive, for flexible set-ups, less time for changing the machine set-ups, usage of automated tools used to enhance the production, active policy to help keep work areas clean, tidy and uncluttered, products designed for easy serviceability, service centres well equipped with spares. (Vinodh and Chintha, 2011;Vinodh et al., 2011)
Manufacturing strategy leanness	A manufacturing strategy is defined by a pattern of decisions, both structural and infrastructural, which determine the capability of a manufacturing system and specify how it will operate to meet a set of manufacturing objectives which are consistent with overall business objectives. It consists of status of quality, status of productivity, cost management, time management. (Vinodh and Chintha, 2011;Vinodh et al., 2011)

Agile Enablers

Agile Enablers	Definitions
Flexibility	Flexibility is the organization's ability to meet an increasing variety of customer expectations without excessive costs, time, organizational disruptions, or performance losses. In other words the ability of the system to quickly adjust to any change in relevant factors like product, process, loads and machine failure. (Beach et al., 2000; Zhang et al., 2003; Lin et al., 2006)
Responsiveness	Responsiveness is the ability to identify changes and respond quickly to them, reactively or proactively, and recover from them. In other words, ability to react purposefully and within an appropriate time-scale to customer demand or changes in the marketplace, to bring about or maintain competitive advantage. (Lin et al., 2006;Holweg, 2005)
Competency	Competency is the ability to efficiently and effectively reach enterprises' aims and goals. In other words competency is the measurable or observable knowledge, skills, abilities and behaviours critical to successful job performance. (Lin et al., 2006)
Cost	A cost is the value of money that has been used up to produce something. (http://en.wikipedia.org/wiki/Cost)

Leagile Enablers

Leagile Enablers	Definitions
Virtual enterprises	A virtual enterprise is a temporary alliance of businesses that come together to share skills or core competencies and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks. (http://en.wikipedia.org/wiki/Virtual_enterprise) (Zhou and Nagi, 2002;O'Brien and Al-Biqami, 1998)
Collaborative relationships	A relationship in which the capacity to act or effect change is shared by all persons in the relationship rather than being assigned to one person who is seen as the authority or expert. Collaborative relationships are characterized by commitment, cooperation, and connectedness in striving for a common goal. (Wagner et al., 2010; Thakkar et al., 2010)
Strategic management	Strategic management consists of the analysis, decisions, and actions an organization undertakes in order to create and sustain competitive advantages. Strategic management can be defined

	as the art and science of formulating, implementing, and evaluating cross-functional decisions that enable an organization to achieve its objectives. (David, 2011;Ketchen and Giunipero, 2004)
Knowledge and IT management	The knowledge and IT management refers to a multi-disciplined approach to achieve organizational objectives by making the best use of knowledge and resources related to information technology. As the Knowledge management focuses on processes such as acquiring, creating and sharing knowledge and the cultural and technical foundations and the aim of IT management is to generate value through the use of technology. (Raub and Wittich, 2004)
Customer and market sensitiveness	It is the consciousness of the customers to cost windows or range within which they make dealings. All the customers are always cost sensitive and concentrate basically to buy products on cheap rates. However, cost sensitivity of a customer substantially depends on condition of the market. In other words customer and marketing sensitivity as the mechanism of the supply chain, it includes the ability to read and respond to real customer requirements, and also to master change and uncertainty (Sharpe, 1972; Lin et al., 2006)

Table 2.2: Structural Self-Interaction Matrix (SSIM) for **lean system**

Sl. No.	Lean Enablers	5	4	3	2
1	Management responsibility	V	A	V	V
2	Manufacturing management leanness	V	A	X	
3	Work force leanness	X	O		
4	Technology leanness	V			
5	Manufacturing strategy leanness				

Table 2.3: Structural Self-Interaction Matrix (SSIM) for **agile system**

Sl. No.	Agile Enablers	4	3	2
1	Flexibility	A	A	A
2	Responsiveness	V	V	
3	Competency	V		
4	Cost			

Table 2.4: Structural Self-Interaction Matrix (SSIM) for **leagile system**

Sl. No.	Leagile Enablers	5	4	3	2
1	Virtual enterprises	X	X	V	A
2	Collaborative relationships	V	V	V	
3	Strategic management	A	A		
4	Knowledge and IT management	X			
5	Customer and market sensitiveness				

Table 2.5: Initial Reachability Matrix for lean system

Lean Enablers	1	2	3	4	5
1	1	1	1	0	1
2	0	1	1	0	1
3	0	1	1	0	1
4	1	1	0	1	1
5	0	0	1	0	1

Table 2.6: Initial Reachability Matrix for agile system
(There is no Transitivity so initial reachability matrixis the Final Reachability Matrix)

Agile Enablers	1	2	3	4	Driving Power
1	1	0	0	0	1
2	1	1	1	1	4
3	1	0	1	1	3
4	1	0	0	1	2
Dependence power	4	1	2	3	

Table 2.7: Initial Reachability Matrix for Leagile system
(There is no Transitivity so initial reachability matrix is the Final Reachability Matrix)

Leagile Enablers	1	2	3	4	5	Driving Power
1	1	0	1	1	1	4
2	1	1	1	1	1	5
3	0	0	1	0	0	1
4	1	0	1	1	1	4
5	1	0	1	1	1	4
Dependence power	4	1	5	4	4	

Table 2.8: Final Reachability matrix after incorporating the transitivity for lean system

Lean Enablers	1	2	3	4	5	Driving Power
1	1	1	1	0	1	4
2	0	1	1	0	1	3
3	0	1	1	0	1	3
4	1	1	1*	1	1	5
5	0	1*	1	0	1	3
Dependence power	2	5	5	1	5	

Table 2.9: Level partition of reachability matrix Iteration 1 for lean system

Lean Enablers	Reachability set	Antecedent set	Interaction set	level
1	1,2,3,5	1,4	1	-
2	2,3,5	1,2,3,4,5	2,3,5	I
3	2,3,5	1,2,3,4,5	2,3,5	I
4	1,2,3,4,5	1	1	
5	2,3,5	1,2,3,4,5	2,3,5	I

Table 2.10: Level partition reachability matrix Iteration 2 for lean system

Lean Enablers	Reachability set	Antecedent set	Interaction set	level
1	1	1,4	1	II
4	1,4	1	1	-

Table 2.11:Level partition reachability matrix Iteration 3 for lean system

Lean Enablers	Reachability set	Antecedent set	Interaction set	level
4	4	4	4	III

Table 2.12: Level partition of reachability matrix for agile system

Agile Enablers	Reachability set	Antecedent set	Interaction set	level
1	1	1,2,3,4	1	I
2	2,3	2	2	IV
3	3	2,3	3	III
4	4	2,3,4	4	II

Table 2.13: Level partition of reachability matrix for leagile system

Leagile Enablers	Reachability set	Antecedent set	Interaction set	level
1	1,4,5	1,2,4,5	1,4,5	II
2	1,2,4,5	2	2	III
3	3	1,2,3,4,5	3	I
4	1,4,5	1,2,4,5	1,4,5	II
5	1,4,5	1,2,4,5	1,4,5	II

Driving Power

5	[4]				
4	IV	[1]		III	
3					[2],[3],[5]
2					
1	I			II	
	1	2	3	4	5

Dependence Power

I – Autonomous, II – Dependent, III – Linkage, IV –Independent

Fig.2.1: Driving power and dependence diagram for enablers (MICMAC Analysis for lean system)

Driving Power

5	IV				III
4	[2]				
3		[3]			
2			[4]		
1	I			[1]	II
	1	2	3	4	5

Dependence Power

I – Autonomous, II – Dependent, III – Linkage, IV –Independent

Fig. 2.2: Driving power and dependence diagram for enablers (MICMAC Analysis for agile system)

Driving Power

5	[2]				
4				[1],[4],[5]	
3	IV			III	
2					
1	I			II	[3]
	1	2	3	4	5

Dependence Power

I – Autonomous, II – Dependent, III – Linkage, IV –Independent

Fig.2.3: Driving power and dependence diagram for enablers (MICMAC Analysis for leagile system)

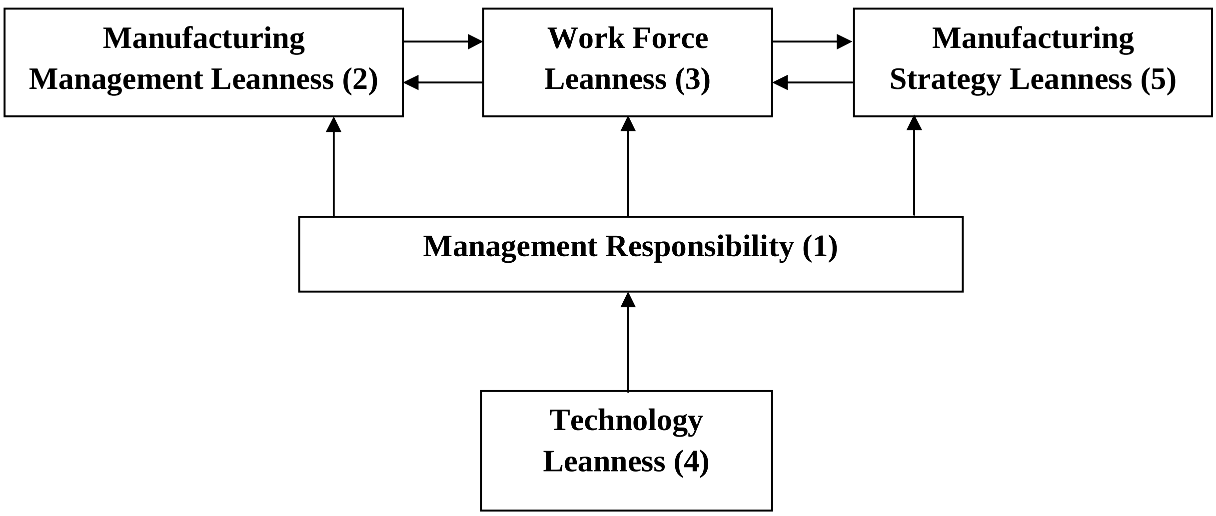

Fig.2.4: ISM Based Model for Lean System

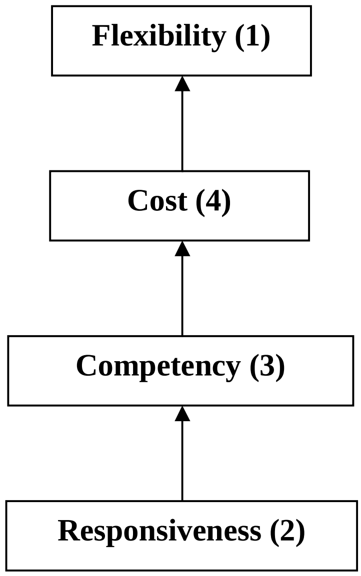

Fig.2.5: **ISM-based Model for Agile System**

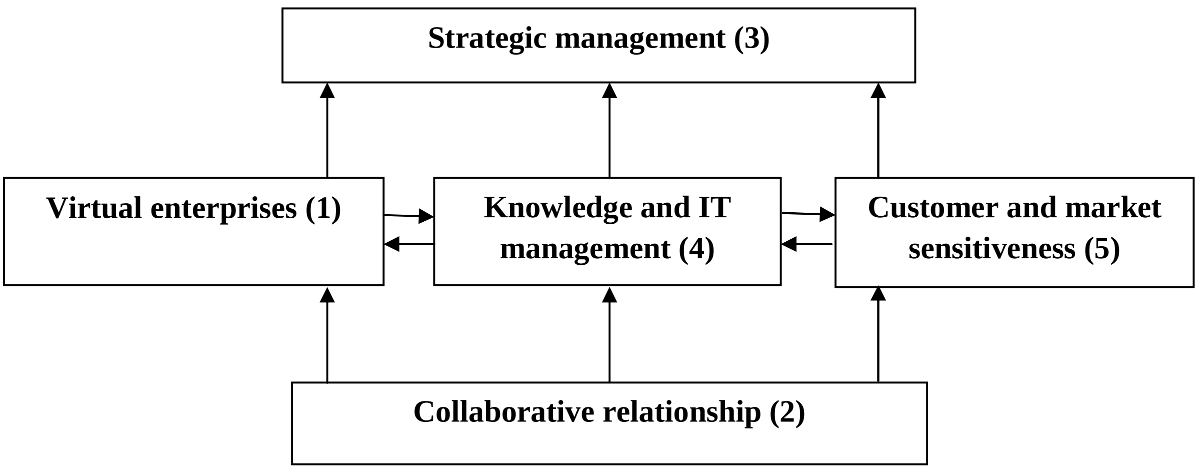

Fig.2.6: **ISM-based Model for Leagile System**

CHAPTER 3

LEANNESS METRIC EVALUATION

3.1 Leanness Metric Evaluation in Fuzzy Context

In this section, attempts have been made to establish leanness metric evaluation platform based on fuzzy numbers set theory. Decision makers' linguistic evaluation information has been converted into appropriate fuzzy numbers; and finally, operational rules of fuzzy mathematics have been utilized to estimate an overall quantitative leanness metric. This research has been conducted in two parts. In the first part, (Section 3.1.1) theory of Generalized Fuzzy Numbers Set (GFNS) has been explored. In the second part (Section 3.1.2) Generalized Interval-Valued Fuzzy Numbers Set (GIVFNS) theory has been used to facilitate the said lean metric appraisement modeling.

3.1.1 Leanness Metric Evaluation: Exploration of Generalized Fuzzy Numbers Set Theory

3.1.1.1 Coverage

In today's competitive global marketplace the concept of lean manufacturing has gained vital consciousness to all manufacturing sectors, their supply chains and hence a logical leanness measurement index system is indeed required in implementing leanness in practice. Such leanness estimation can help the enterprises to assess their existing leanness level; can compare different industries who are adapting this lean concept. Lean implementation requires quantitative measurement of overall 'leanness' followed by identification of obstacles towards enhancement of effective lean performance. In other words, it is felt that the quantitative methods can enhance some aspects of lean assessment.

To this end, the present work exhibits an efficient fuzzy-based leanness assessment system using generalized trapezoidal fuzzy numbers set theory.

Literature reveals that estimation of lean performance metric has been attempted to a remarkable extent by pioneer researchers in fuzzy environment. In most of the cases, they explored the concept of fuzzy numbers with triangular fuzzy membership function (MFs). Application of trapezoidal membership function has rarely been found. Therefore, present study has been formulated to develop a fuzzy-based leanness evaluation procedural hierarchy using fuzzy information (characterized by trapezoidal membership function) collected from a group of decision-makers (DMs). The proposed leanness measurement index system has been case empirically studied.

3.1.1.2 The Concept of Generalized Trapezoidal Fuzzy Numbers Set

By the definition given by (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, as shown in Fig. 3.1.

and the membership function $\mu_{\tilde{A}}(x): R \to [0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x - a_1}{a_2 - a_1} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \dfrac{x - a_4}{a_3 - a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty) \end{cases} \tag{3.1}$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in [0,1]$

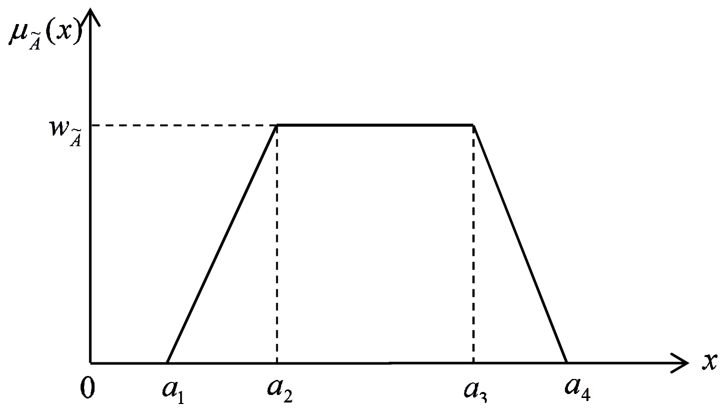

Fig. 3.1: Trapezoidal fuzzy number $\tilde{A}$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $\mu_{\tilde{A}}(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number (a_1, a_2, a_3, a_4); if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.2}$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.3}$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a, b, c, d; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.4}$$

Here,

$$a = \min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$
$$b = \min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$
$$c = \max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$
$$d = \max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = (a1 \times b1, a2 \times b2, a3 \times b3, a4 \times b4; \min(w_{\tilde{a}}, w_{\tilde{b}}))$$

$$\tilde{a} / \tilde{b} = {(a_1, a_2, a_3, a_4; w_{\tilde{a}})} \Big/ {(b_1, b_2, b_3, b_4; w_{\tilde{b}})}$$
$$= (a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{3.5}$$

Chen and Chen (2003) proposed the concept of COG point of generalized trapezoidal fuzzy numbers, and suppose that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ is $(x_{\tilde{a}}, y_{\tilde{a}})$, then:

$$y_{\tilde{a}} = \begin{cases} \dfrac{w_{\tilde{a}} \times \left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2 \right)}{6}, & if\ a_1 \neq a_4 \\ \dfrac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases} \quad (3.6)$$

$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times (a_2 + a_3) + (a_1 + a_4) \times (w_{\tilde{a}} - y_{\tilde{a}})}{2 \times w_{\tilde{a}}} \quad (3.7)$$

3.1.1.3 Revised Ranking Method of Generalized Trapezoidal Fuzzy Numbers

The ranking methodology adapted here has been described as follows (Chou et al., 2011). Considering n normal fuzzy numbers $A_i, (i = 1,2,...,n)$, each with a trapezoidal membership function $f_{A_i}(x)$. The revised method performs pair-wise comparisons on the n fuzzy numbers. For each pair of fuzzy numbers, say A_1 and A_2, the pair-wise comparison is preceded as follows. The maximizing set M and minimizing set G with membership function f_M is given as,

$$f_M(x) = \begin{cases} \left[(x - x_{\min}) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \leq x \leq x_{\max} \\ 0, & Otherwise. \end{cases} \quad (3.8)$$

The minimizing set G is a fuzzy subset with membership function f_G is given as,

$$f_G(x) = \begin{cases} \left[(x_{\max} - x) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \leq x \leq x_{\max} \\ 0, & Otherwise. \end{cases} \quad (3.9)$$

Here $x_{\min} = Inf\ S, x_{\max} = Sup\ S, S = U_{i=1}^{n} S_i, S_i = \{x / f_{A_i}(x) \succ 0\}$, and k is set to be 1. The revised ranking method defines the right utility values of each alternative A_i as:

$$u_{M_{i1}}(i) = \sup_x \left(f_M(x) \wedge f_{A_i^R}(x) \right), \ i = 1,2; \quad (3.10)$$

$$u_{G_{i2}}(i) = \sup_x \left(f_G(x) \wedge f_{A_i^R}(x) \right), \ i = 1,2. \quad (3.11)$$

The let utility values of each alternative A_i as:

$$u_{G_{i1}}(i) = \sup_x\left(f_G(x) \wedge f_{A_i^L}(x)\right), \ i = 1,2; \tag{3.12}$$

$$u_{M_{i2}}(i) = \sup_x\left(f_M(x) \wedge f_{A_i^L}(x)\right), \ i = 1,2. \tag{3.13}$$

The revised ranking method defines the total utility value of each fuzzy number A_i with index of optimism α as:

$$U_T^{\alpha}(i) = \frac{1}{2}\left[\alpha\{u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i)\} + (1-\alpha)\{u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i)\}\right], \ i = 1,2. \tag{3.14}$$

The index of optimism (α) represents the degree of optimism of a decision-maker (Kim and Park, 1990; Liou and Wang, 1992; Wang and Luo, 2009). A larger α indicates a higher degree of optimism. More specifically, when $\alpha = 0$, the total utility value $u_T^0(A_i)$ representing a pessimistic decision-maker's viewpoint is equal to the total left utility value of A_i. Conversely, for an optimistic decision-maker, i.e. $\alpha = 1$, the total utility value $u_T^1(A_i)$ is equal to the total right utility value of A_i. For a moderate (neutral) decision-maker, with $\alpha = 0.5$, the total utility value of each fuzzy number A_i become

$$U_T^{1/2}(i) = \frac{1}{2}\left[\frac{1}{2}\{u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i)\} + \frac{1}{2}\{u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i)\}\right], \ i = 1,2. \tag{3.15}$$

The greater the $u_T^{\alpha}(A_i)$, the bigger the fuzzy number A_i and the higher it's ranking order.

As described by (Chou et al., 2011), if A_i is a normal trapezoidal fuzzy number, i.e. $A_i = (a_i, b_i, c_i, d_i; 1)$, the total utility value of each fuzzy number A_i can be written as:

$$u_T^{\alpha}(i) = \frac{1}{2}\left(\begin{array}{l}\alpha\left[\dfrac{d_i - x_{\min}}{d_i - c_i + x_{\max} - x_{\min}} + \dfrac{c_i - x_{\min}}{c_i - d_i + x_{\max} - x_{\min}}\right] + \\ (1-\alpha)\left[\dfrac{a_i - x_{\min}}{a_i - b_i + x_{\max} - x_{\min}} + \dfrac{b_i - x_{\min}}{b_i - a_i + x_{\max} - x_{\min}}\right]\end{array}\right) \tag{3.16}$$

3.1.1.4 The Procedural Steps for Leanness Estimation

Procedural steps of proposed leanness assessment module have been highlighted below.

Step 1: Formation of a group of experts (Decision-Makers, DMs) for evaluating and appraising of performance extent as well as priority weight against various lean capabilities/attributes/criterions.

Step 2: Selection of appropriate linguistic scale to represent DMs' subjective judgment in relation to priority importance (weight) against evaluation attributes/criterions and at the same time to rate the performance extent of individual criterion.

Step 3: Assignment of performance ratings as well as importance weights of capabilities/attributes/criterions using linguistic terms.

Step 4: Approximation of DMs' subjective judgment (in linguistic terms) into Generalized Trapezoidal Fuzzy Numbers (GTFNs).

Step 5: Estimation of appraisement index.

Step 6: Identification of ill-performing areas which need future improvement.

3.1.1.5 Case Empirical Research

Leanness evaluation has been made by the procedural framework as described before. The evaluation framework is based on a lean capabler-attribute-criterion hierarchy adapted from the work by (Vinodh and Vimal, 2011). It is basically a 3-level evaluation index hierarchy comprising various leanness enablers (capabilities), leanness attributes as well as lean criterions (Table 3.1). Management responsibility, Manufacturing management leanness, Work force leanness, Technology leanness, Manufacturing strategy leanness have been considered as lean capabilities/enablers placed at 1st level of the evaluation index system hierarchy. Each enabler is further characterized by lean attributes (2nd level); and each lean attribute is further expanded with different lean criterions (3rd level). The purpose has been to examine lean aspects of the said organization (or its supply chain) from the base level instead of broad aspects.

Assuming that, in the primary stage, after extensive literature review and periodic discussions with the industries top management, an integrated hierarchy model towards leanness assessment has been constructed and made for ready to implement. The model encompasses of various lean capabilities/ attributes as well as lean criterions. An evaluation team consisting of five experts has been deployed to assign priority weights (importance extent) against different lean capabilities/ attributes as well as lean criterions considered in the proposed appraisement model. A questionnaire has been formed and circulated among the decision-makers (experts) to provide the required detail. The outcome of this research might be of enormous help to industries for improving productivity and profitability of companies; if lean could be implemented in reality.

Step 1 Determination of the appropriate linguistic scale for assessing the performance ratings and importance weights of lean attributes

The linguistic terms are used to assess the performance ratings and priority weights of lean attributes since vagueness is associated with individuals' subjective opinion; it is difficult for the decision-makers to determine the exact numeric score against an attribute. In order to assess the performance rating of the lean criterions from Table 3.1 (3rd level indices), the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} have been used (Table 3.2). Similarly, to assign importance weights (priority degree) of the lean capabilities-attributes and criterions, the linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been utilized (Table 3.2). The linguistic variables have been accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation.

Step 2 Measurement of performance ratings and importance weights of lean attributes using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of lean parameters has been accepted by the decision-makers (DMs), the decision-makers have been asked to use aforesaid linguistic scales to assess the performance rating as well as to assign importance weights (Tables 3.3-3.6 of APPENDIX-A).

Step 3 Approximation of the linguistic terms by generalized trapezoidal fuzzy numbers

Using the concept of generalized trapezoidal fuzzy numbers in fuzzy set theory (Chen and Chen, 2003; Chen and Chen, 2009), the linguistic variables have been be approximated by trapezoidal fuzzy numbers (shown in Table 3.2). Next, the aggregated decision-making cum evaluation matrix has been constructed. The aggregated fuzzy appropriateness rating against each lean criterions (3rd level indices) attribute has been shown in Table 3.7 with corresponding fuzzy importance weight. Aggregated fuzzy priority weight of lean attributes (2nd level indices) as well as enablers/capabilities (1st level indices) given by decision-makers has been furnished in Table 3.8-3.9.

The aggregated fuzzy rating as well as priority weight has been computed as follows.

Assume that there are 'N' decision-makers $\{\mathrm{DM}_1, \mathrm{DM}_2, \ldots\ldots, \mathrm{DM}_N\}$ with their linguistic ratings $P_n(n=1,\ 2,\ 3,\ \ldots\ldots,\ N)$ which can be represented as a positive generalized trapezoidal fuzzy number $\tilde{F}_n(n=1,\ 2,\ldots\ldots,\ N)$ with membership function $\mu_{\tilde{F}_n}\mu_{\tilde{F}_n}(x)$. A good aggregation method should be considered for the range of fuzzy ratings of each criterion. It means that the range of aggregated fuzzy rating must include the range of all the evaluator's fuzzy ratings. Let the fuzzy ratings of all evaluation experts or sortation specialists (DMs) are generalized trapezoidal fuzzy numbers $\tilde{F}_n = (a_n,\ b_n,\ c_n,\ d_n),\ n=1,\ 2,\ldots\ldots,\ N$; then the aggregated fuzzy rating can be defined as $\tilde{F} = (a,\ b,\ c,\ d)$

Here

$$a = \frac{1}{N}\sum_{n=1}^{N} a_n, \quad b = \frac{1}{N}\sum_{n=1}^{N} b_n$$

$$c = \frac{1}{N}\sum_{n=1}^{N} c_n, \quad d = \frac{1}{N}\sum_{n=1}^{N} d_n$$

Similarly, let the fuzzy weight against an attribute assigned by the decision-makers are generalized trapezoidal fuzzy numbers $\tilde{W}_n = (w_{1n},\ w_{2n},\ w_{3n},\ w_{4n}),\ n=1,\ 2,\ldots\ldots,\ N$; then the aggregated fuzzy weight can be defined as $\tilde{W} = (w_1,\ w_2,\ w_3,\ w_4)$

Here

$$w_1 = \frac{1}{N}\sum_{n=1}^{N} w_{1n}, \quad w_2 = \frac{1}{N}\sum_{n=1}^{N} w_{2n},$$

$$w_3 = \frac{1}{N}\sum_{n=1}^{N} w_{3n}, \quad w_4 = \frac{1}{N}\sum_{n=1}^{N} w_{4n}.$$

Step 4 Determination of FOPI

FOPI represents the *Fuzzy Overall Performance Index*. The fuzzy index has been calculated at the attribute level and then extended to enabler level. Fuzzy index system (at 2nd level) encompasses several lean attributes (Table 3.1).

The fuzzy index (appropriateness rating) of each lean attribute (at 2nd level) has been calculated as follows:

$$U_{i,j} = \frac{\sum_{k=1}^{n}\left(w_{i,j,k} \otimes U_{i,j,k}\right)}{\sum_{k=1}^{n} w_{i,j,k}} \qquad (3.17)$$

Here $U_{i,j,k}$ represents aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represents aggregated fuzzy weight corresponding to lean criterion $C_{i,j,k}$ which is under j_{th} lean attribute (at 2nd level) and i_{th} lean capability (at 1st level).

The fuzzy index of each lean capability/enabler (at 1st level) has been calculated as follows:

$$U_{i} = \frac{\sum_{j=1}^{n}\left(w_{i,j} \otimes U_{i,j}\right)}{\sum_{j=1}^{n} w_{i,j}} \qquad (3.18)$$

Here $U_{i,j}$ represents computed fuzzy performance measure (rating) obtained using Eq. 3.17 and $w_{i,j}$ represents aggregated fuzzy weight for priority importance corresponding to j_{th} lean attribute $C_{i,j}$ which is under i_{th} lean capability (at 1st level).

Thus, fuzzy overall performance index $U(FOPI)$ has been calculated as follows:

$$U(FOPI) = \frac{\sum_{i=1}^{n}\left(w_{i} \otimes U_{i}\right)}{\sum_{i=1}^{n} w_{i}} \qquad (3.19)$$

Here U_i = Computed fuzzy performance rating of i^{th} lean capability C_i (computed by Eq. 3.18); w_i = Aggregated fuzzy weight of i^{th} lean capability, and $i = 1, 2, 3, \ldots n$.

Computed fuzzy appropriateness ratings of different lean attributes (at 2nd level) as well as lean enablers (at 1st level) have been furnished in Table 3.8 and 3.9, respectively. Finally, Eq. 3.19 has been explored to calculate overall lean estimate.

Fuzzy Overall Performance Index (FOPI) becomes:

$$U = \frac{\sum (w_i \otimes U_i)}{\sum w_i}$$

= (2.23, 2.81, 4.46, 5.30; 1.00) / (4.10, 4.33, 4.75, 4.89; 1.00)

= (0.456, 0.592, 1.029, 1.293; 1.00)

After evaluating FOPI and the organizational existing leanness extent, simultaneously it is also felt indeed necessary to identify and analyze the obstacles (ill-performing areas) for leanness improvement. Fuzzy Performance Importance Index (FPII) may be used to identify these obstacles. FPII combines the performance rating and importance weight of lean criterions. The higher the FPII of a factor, the higher is the contribution. The FPII can be calculated as follows (Lin et al., 2006):

$$FPII_{i,j,k} = w'_{i,j,k} \otimes U_{i,j,k} \quad (3.20)$$

Here, $w'_{i,j,k} = \left[(1,1,1,1;1) - w_{i,j,k}\right]$ (3.21)

In this formulation, $U_{i,j,k}$ represent aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represent aggregated fuzzy weight corresponding to lean criterion $C_{i,j,k}$ which is under j_{th} lean attribute (at 2nd level) and i_{th} lean capability (at 1st level).

FPII need to be ranked to identify individual criterion performance level. Based on that poorly performing criterions are identified and in future, attention must be given to improve those criteria aspects in order to boost up overall leanness degree.

Computed FPII against each lean criterion has been tabulated (Table 3.10). Ranking scores based on u_T^{α} (of FPIIs) have been furnished in Table 3.11. In this computation, three types of DMs risk-bearing attitude (optimistic, neutral and pessimistic: $\alpha = 1, 0.5, 0$) have been considered for the decision-making process. The revised ranking method proposed by (Chou et al., 2011) has been explored in this computation. Ranking provides necessary information about comparative performance picture of existing lean criterions. By this way, ill-performing areas can be sorted out. Industry should find feasible means to improve performance in those areas to boost up overall degree of leanness in future.

3.1.1.6 Concluding Remarks

Lean paradigm has become an important avenue in recent times. Many organizations around the world have been attempting to implement lean concepts. The efficacy measure is an important indicator in lean performance measure. Aforesaid study aimed to develop a fuzzy based quantitative analysis framework and a simulation methodology to evaluate the efficacy of lean metrics. The procedural hierarchy presented here could help the industries to assess their existing lean performance extent, to compare and to identify week-performing areas towards lean implementation successfully.

Table 3.1: Conceptual model for leanness assessment

Goal	Leanness enablers (1st level Indices) C_i	Leanness attributes (2nd Level Indices) $C_{i,j}$	Leanness criterions (3rd Level Indices) $C_{i,j,k}$
Leanness Estimate C	Management responsibility C_1	Organizational structure $C_{1,1}$	Smooth information flow $C_{1,1,1}$
			Team management for decision-making $C_{1,1,2}$
			Interchange-ability personnel $C_{1,1,3}$
		Nature of management $C_{1,2}$	Clearly known management goals $C_{1,2,1}$
			Management involvement $C_{1,2,2}$
			Transparency in information sharing $C_{1,2,3}$
	Manufacturing management leanness C_2	Customer response adaptation $C_{2,1}$	Prevalence of continuous improvement culture $C_{2,1,1}$
			Empowerment of personnel to resolve customer problem $C_{2,1,2}$
		Change in business and technical processes $C_{2,2}$	Employee's attitude turned to accept the changes $C_{2,2,1}$
			Conduct of pilot study on new $C_{2,2,2}$
		JIT flow $C_{2,3}$	Produce small lot size $C_{2,3,1}$
			JIT delivery to customers $C_{2,3,2}$
			Optimization of processing sequence and flow in shop floor $C_{2,3,3}$
		Pull production $C_{2,4}$	Demand driven production $C_{2,4,1}$
			Limited WIP inventory $C_{2,4,2}$
			Minimum equipment idle time $C_{2,4,3}$
		Supplier development $C_{2,5}$	Providing technological assistance to the suppliers $C_{2,5,1}$
			Providing training in quality issues to the supplier personnel $C_{2,5,2}$

			Providing financial assistance to the suppliers $C_{2,5,3}$
		Streamlining of processes $C_{2,6}$	Adoption of value stream mapping $C_{2,6,1}$
			Quantification of seven deadly wastes $C_{2,6,2}$
			Focused factory production system $C_{2,6,3}$
		Cellular manufacturing $C_{2,7}$	Organization of manufacturing operation around similar product families $C_{2,7,1}$
			Utilization of manufacturing cells $C_{2,7,2}$
		Continuous improvement $C_{2,8}$	Mission driven strategy $C_{2,8,1}$
			Positive attitude of employees $C_{2,8,2}$
			Inclusion of employees suggestion scheme $C_{2,8,3}$
		Waste quantification $C_{2,9}$	Identification of wastes $C_{2,9,1}$
			Scope for waste elimination $C_{2,9,2}$
		Activity categorization $C_{2,10}$	Classification of activities $C_{2,10,1}$
			Conversion of non-value added (NVA) into necessary but non-value added (NNVA) $C_{2,10,2}$
	Work force leanness C_3	Employee status $C_{3,1}$	Flexible workforce to accept the adaptation of new technologies $C_{3,1,1}$
			Multi-skilled personnel $C_{3,1,2}$
			Implementation of job rotation system $C_{3,1,3}$
		Employee involvement $C_{3,2}$	Strong employee spirit and cooperation $C_{3,2,1}$
			Employee empowerment $C_{3,2,2}$
	Technology leanness C_4	Manufacturing set-ups $C_{4,1}$	Flexible set-ups $C_{4,1,1}$
			Less time to changing machine set-ups $C_{4,1,2}$
			Exploration of automated tools towards production

			enhancement $C_{4,1,3}$
			Activity policy to help and keep work areas clean, tidy and uncluttered $C_{4,1,4}$
		Maintenance management $C_{4,2}$	Identification and prioritization of critical machines $C_{4,2,1}$
			Implementation of TPM techniques $C_{4,2,2}$
			Maintenance of installed machines $C_{4,2,3}$
		Visual controls $C_{4,3}$	Implementation of Poka-Yoke $C_{4,3,1}$
			Using ANDON device $C_{4,3,2}$
			Introduction of card system $C_{4,3,3}$
		Product service $C_{4,4}$	Products designed for easy and serviceability $C_{4,4,1}$
			Service centers well equipped with spares $C_{4,4,2}$
			Usage of DFMA principles $C_{4,4,3}$
			Practice job rotation between design and manufacturing engineering $C_{4,4,4}$
		Integrated product design $C_{4,5}$	Usage of product data management (PDM) systems $C_{4,5,1}$
			New way of coordination of design and manufacturing issues $C_{4,5,2}$
		In-house technology $C_{4,6}$	Design and development of proprietary items for own use $C_{4,6,1}$
			Improve present equipment before considering new equipment $C_{4,6,2}$
			Develop dedicated technologies for specific product use $C_{4,6,3}$
		Production methodology $C_{4,7}$	Management interest towards investment on FMS

			concepts $C_{4,7,1}$
			Application of lean manufacturing principles for waste elimination $C_{4,7,2}$
			Exercise better vendor and supplier management $C_{4,7,3}$
		Workplace organization $C_{4,8}$	Elimination of unnecessary tools $C_{4,8,1}$
			Sustainability of improvements $C_{4,8,2}$
			Proper allocation of tools $C_{4,8,3}$
		Manufacturing planning $C_{4,9}$	Utilization of advanced MRP II systems $C_{4,9,1}$
			Use of ERP systems $C_{4,9,2}$
			Execution of short range planning $C_{4,9,3}$
			Company procurement policy based on time schedule $C_{4,9,4}$
			Strategic network in SCM to exercise zero inventory system $C_{4,9,5}$
	Manufacturing strategy leanness C_5	Standardization, systemization and simplification $C_{5,1}$	Standardization of components $C_{5,1,1}$
			Systemization of processes $C_{5,1,2}$
			Simplification of processes $C_{5,1,3}$
		Status of quality $C_{5,2}$	Products exceeding the customers expectation $C_{5,2,1}$
			Conduct of survey/studies to ensure quality status $C_{5,2,2}$
			Usage of TQM tools $C_{5,2,3}$
		Status of productivity $C_{5,3}$	Productivity linked to the personnel prosperity $C_{5,3,1}$
			Reduction of non-value adding cost $C_{5,3,2}$
			Quality is not infused at the cost of productivity $C_{5,3,3}$
			Application of totality concepts in achieving

			productivity $C_{5,3,4}$
		Cost management $C_{5,4}$	Kaizen method of product pricing $C_{5,4,1}$
			Costing system focusing on the identification of value adding and Non-value adding activities $C_{5,4,2}$
		Time management $C_{5,5}$	Scheduled activities $C_{5,5,1}$
			IT-based communication system $C_{5,5,2}$
		Resource utilization $C_{5,6}$	Planning of resources $C_{5,6,1}$
			Optimized utilization of tools $C_{5,6,2}$
			Retrofitting of machine tools $C_{5,6,3}$
		Flexible business practices $C_{5,7}$	Machine tool automation degree $C_{5,7,1}$
			Layout flexibility $C_{5,7,2}$

Table 3.2: Definitions of linguistic variables for assigning appropriateness rating and priority weight (A-9 member linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	(0, 0, 0, 0; 1.0)
Very Poor (VP)	Very Low (VL)	(0, 0, 0.02, 0.07; 1.0)
Poor (P)	Low (L)	(0.04, 0.1, 0.18, 0.23; 1.0)
Medium Poor (MP)	Medium Low (ML)	(0.17, 0.22, 0.36, 0.42; 1.0)
Medium (M)	Medium (M)	(0.32, 0.41, 0.58, 0.65; 1.0)
Medium Good (MG)	Medium High (MH)	(0.58, 0.63, 0.80, 0.86; 1.0)
Good (G)	High (H)	(0.72, 0.78, 0.92, 0.97; 1.0)
Very Good (VG)	Very High (VH)	(0.93, 0.98, 1.0, 1.0; 1.0)
Absolutely Good (AG)	Absolutely High (AH)	(1.0, 1.0, 1.0, 1.0; 1.0)

Table 3.7: Aggregated fuzzy priority weight as well as appropriateness rating of lean criterions

Criterions $C_{i,j,k}$	Aggregated Rating $U_{i,j,k}$	Aggregated Weight $w_{i,j,k}$
$C_{1,1,1}$	(0.96, 0.99, 1.00, 1.00; 1.00)	(0.97, 0.99, 1.00, 1.00; 1.00)
$C_{1,1,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{1,1,3}$	(0.85, 0.90, 0.97, 0.99; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{1,2,1}$	(0.61, 0.66, 0.82, 0.88; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{1,2,2}$	(0.37, 0.45, 0.62, 0.69; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{1,2,3}$	(0.89, 0.94, 0.98, 0.99; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,1,1}$	(0.66, 0.72, 0.87, 0.93; 1.00)	(0.64, 0.69, 0.85, 0.90; 1.00)
$C_{2,1,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(1.00, 1.00, 1.00, 1.00; 1.00)
$C_{2,2,1}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,2,2}$	(0.80, 0.86, 0.95, 0.98; 1.00)	(0.45, 0.50, 0.67, 0.73; 1.00)
$C_{2,3,1}$	(0.50, 0.57, 0.74, 0.80; 1.00)	(0.80, 0.86, 0.95, 0.98; 1.00)
$C_{2,3,2}$	(0.58, 0.63, 0.80, 0.86; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,3,3}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.86, 0.90, 0.97, 0.99; 1.00)
$C_{2,4,1}$	(0.97, 0.99, 1.00, 1.00; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{2,4,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.80, 0.86, 0.95, 0.98; 1.00)
$C_{2,4,3}$	(0.89, 0.94, 0.98, 0.99; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,5,1}$	(0.37, 0.45, 0.62, 0.69; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,5,2}$	(0.26, 0.33, 0.49, 0.56; 1.00)	(0.80, 0.86, 0.95, 0.98; 1.00)
$C_{2,5,3}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.64, 0.69, 0.85, 0.90; 1.00)
$C_{2,6,1}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,6,2}$	(0.99, 1.00, 1.00, 1.00; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,6,3}$	(0.80, 0.86, 0.95, 0.98; 1.00)	(0.86, 0.90, 0.97, 0.99; 1.00)
$C_{2,7,1}$	(0.76, 0.82, 0.94, 0.98; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{2,7,2}$	(0.86, 0.90, 0.97, 0.99; 1.00)	(0.85, 0.90, 0.97, 0.99; 1.00)
$C_{2,8,1}$	(0.48, 0.54, 0.71, 0.78; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{2,8,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{2,8,3}$	(0.66, 0.72, 0.87, 0.93; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{2,9,1}$	(0.76, 0.82, 0.94, 0.98; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{2,9,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.64, 0.69, 0.85, 0.90; 1.00)
$C_{2,10,1}$	(0.29, 0.37, 0.54, 0.60; 1.00)	(1.00, 1.00, 1.00, 1.00; 1.00)
$C_{2,10,2}$	(0.18, 0.25, 0.38, 0.44; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{3,1,1}$	(0.20, 0.26, 0.40, 0.47; 1.00)	(0.45, 0.50, 0.67, 0.73; 1.00)
$C_{3,1,2}$	(0.58, 0.63, 0.80, 0.86; 1.00)	(0.76, 0.82, 0.94, 0.98; 1.00)
$C_{3,1,3}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{3,2,1}$	(0.99, 1.00, 1.00, 1.00; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{3,2,2}$	(0.80, 0.86, 0.95, 0.98; 1.00)	(0.76, 0.82, 0.94, 0.98; 1.00)
$C_{4,1,1}$	(0.76, 0.82, 0.94, 0.98; 1.00)	(0.64, 0.69, 0.85, 0.90; 1.00)
$C_{4,1,2}$	(0.86, 0.90, 0.97, 0.99; 1.00)	(1.00, 1.00, 1.00, 1.00; 1.00)
$C_{4,1,3}$	(0.48, 0.54, 0.71, 0.78; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{4,1,4}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.45, 0.50, 0.67, 0.73; 1.00)
$C_{4,2,1}$	(0.97, 0.99, 1.00, 1.00; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{4,2,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.76, 0.82, 0.94, 0.98; 1.00)
$C_{4,2,3}$	(0.89, 0.94, 0.98, 0.99; 1.00)	(0.87, 0.91, 0.97, 0.99; 1.00)
$C_{4,3,1}$	(0.86, 0.90, 0.97, 0.99; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)

$C_{4,3,2}$	(0.48, 0.54, 0.71, 0.78; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{4,3,3}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{4,4,1}$	(0.66, 0.72, 0.87, 0.93; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{4,4,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{4,4,3}$	(0.29, 0.37, 0.54, 0.60; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{4,4,4}$	(0.18, 0.25, 0.38, 0.44; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{4,5,1}$	(0.20, 0.26, 0.40, 0.47; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{4,5,2}$	(0.93, 0.98, 1.00, 1.00; 1.00)	(0.89, 0.94, 0.98, 0.99; 1.00)
$C_{4,6,1}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.50, 0.57, 0.74, 0.80; 1.00)
$C_{4,6,2}$	(0.96, 0.99, 1.00, 1.00; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{4,6,3}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.89, 0.94, 0.98, 0.99; 1.00)
$C_{4,7,1}$	(0.85, 0.90, 0.97, 0.99; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{4,7,2}$	(0.61, 0.66, 0.82, 0.88; 1.00)	(0.29, 0.37, 0.54, 0.60; 1.00)
$C_{4,7,3}$	(0.64, 0.69, 0.85, 0.90; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{4,8,1}$	(0.37, 0.45, 0.62, 0.69; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{4,8,2}$	(0.61, 0.66, 0.82, 0.88; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{4,8,3}$	(0.86, 0.90, 0.97, 0.99; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{4,9,1}$	(0.48, 0.54, 0.71, 0.78; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{4,9,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{4,9,3}$	(0.66, 0.72, 0.87, 0.93; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{4,9,4}$	(0.82, 0.86, 0.95, 0.98; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{4,9,5}$	(0.69, 0.75, 0.90, 0.95; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{5,1,1}$	(0.96, 0.99, 1.00, 1.00; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{5,1,2}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{5,1,3}$	(0.85, 0.90, 0.97, 0.99; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{5,2,1}$	(0.61, 0.66, 0.82, 0.88; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{5,2,2}$	(0.18, 0.25, 0.38, 0.44; 1.00)	(0.76, 0.82, 0.94, 0.98; 1.00)
$C_{5,2,3}$	(0.20, 0.26, 0.40, 0.47; 1.00)	(0.80, 0.86, 0.95, 0.98; 1.00)
$C_{5,3,1}$	(0.93, 0.98, 1.00, 1.00; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{5,3,2}$	(0.76, 0.82, 0.94, 0.98; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{5,3,3}$	(0.86, 0.90, 0.97, 0.99; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{5,3,4}$	(0.48, 0.54, 0.71, 0.78; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{5,4,1}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{5,4,2}$	(0.66, 0.72, 0.87, 0.93; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{5,5,1}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.76, 0.82, 0.94, 0.98; 1.00)
$C_{5,5,2}$	(0.29, 0.37, 0.54, 0.60; 1.00)	(0.69, 0.75, 0.90, 0.95; 1.00)
$C_{5,6,1}$	(0.18, 0.25, 0.38, 0.44; 1.00)	(0.66, 0.72, 0.87, 0.93; 1.00)
$C_{5,6,2}$	(0.20, 0.26, 0.40, 0.47; 1.00)	(0.93, 0.98, 1.00, 1.00; 1.00)
$C_{5,6,3}$	(0.89, 0.94, 0.98, 0.99; 1.00)	(0.72, 0.78, 0.92, 0.97; 1.00)
$C_{5,7,1}$	(0.86, 0.90, 0.97, 0.99; 1.00)	(0.80, 0.86, 0.95, 0.98; 1.00)
$C_{5,7,2}$	(0.48, 0.54, 0.71, 0.78; 1.00)	(0.80, 0.86, 0.95, 0.98; 1.00)

Table 3.8: Aggregated fuzzy priority weight as well as computed appropriateness rating of lean attributes

Attribute $C_{i,j}$	Aggregated Weight $w_{i,j}$	Computed Rating $U_{i,j}$
$C_{1,1}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.70, 0.80, 1.08, 1.21; 1.00)
$C_{1,2}$	(0.83, 0.87, 0.95, 0.98; 1.00)	(0.48, 0.59, 0.91, 1.07; 1.00)
$C_{2,1}$	(0.61, 0.66, 0.82, 0.88; 1.00)	(0.60, 0.69, 0.98, 1.10; 1.00)
$C_{2,2}$	(0.82, 0.87, 0.94, 0.97; 1.00)	(0.52, 0.66, 1.15, 1.42; 1.00)
$C_{2,3}$	(0.83, 0.87, 0.95, 0.98; 1.00)	(0.49, 0.59, 0.91, 1.08; 1.00)
$C_{2,4}$	(0.56, 0.62, 0.78, 0.84; 1.00)	(0.65, 0.78, 1.12, 1.29; 1.00)
$C_{2,5}$	(0.89, 0.91, 0.97, 0.99; 1.00)	(0.33, 0.43, 0.78, 0.97; 1.00)
$C_{2,6}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.66, 0.77, 1.09, 1.25; 1.00)
$C_{2,7}$	(0.92, 0.95, 0.98, 0.99; 1.00)	(0.65, 0.77, 1.08, 1.24; 1.00)
$C_{2,8}$	(0.75, 0.80, 0.90, 0.94; 1.00)	(0.50, 0.60, 0.94, 1.12; 1.00)
$C_{2,9}$	(0.82, 0.86, 0.95, 0.98; 1.00)	(0.54, 0.67, 1.12, 1.34; 1.00)
$C_{2,10}$	(0.80, 0.86, 0.95, 0.98; 1.00)	(0.21, 0.29, 0.50, 0.60; 1.00)
$C_{3,1}$	(0.85, 0.90, 0.97, 0.99; 1.00)	(0.44, 0.54, 0.84, 1.01; 1.00)
$C_{3,2}$	(0.69, 0.75, 0.90, 0.95; 1.00)	(0.68, 0.80, 1.13, 1.30; 1.00)
$C_{4,1}$	(0.86, 0.90, 0.97, 0.99; 1.00)	(0.56, 0.67, 1.02, 1.19; 1.00)
$C_{4,2}$	(0.93, 0.98, 1.00, 1.00; 1.00)	(0.68, 0.80, 1.10, 1.24; 1.00)
$C_{4,3}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.55, 0.66, 0.98, 1.15; 1.00)
$C_{4,4}$	(0.80, 0.86, 0.95, 0.98; 1.00)	(0.35, 0.45, 0.76, 0.94; 1.00)
$C_{4,5}$	(0.85, 0.90, 0.97, 0.99; 1.00)	(0.49, 0.59, 0.79, 0.90; 1.00)
$C_{4,6}$	(0.89, 0.94, 0.98, 0.99; 1.00)	(0.60, 0.73, 1.10, 1.30; 1.00)
$C_{4,7}$	(0.78, 0.82, 0.94, 0.98; 1.00)	(0.48, 0.62, 1.11, 1.39; 1.00)
$C_{4,8}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.51, 0.61, 0.92, 1.08; 1.00)
$C_{4,9}$	(0.78, 0.83, 0.93, 0.96; 1.00)	(0.53, 0.64, 1.00, 1.19; 1.00)
$C_{5,1}$	(0.76, 0.82, 0.94, 0.98; 1.00)	(0.67, 0.79, 1.09, 1.24; 1.00)
$C_{5,2}$	(0.89, 0.94, 0.98, 0.99; 1.00)	(0.25, 0.33, 0.61, 0.76; 1.00)
$C_{5,3}$	(0.85, 0.90, 0.97, 0.99; 1.00)	(0.58, 0.69, 1.03, 1.19; 1.00)
$C_{5,4}$	(0.89, 0.91, 0.97, 0.99; 1.00)	(0.58, 0.68, 0.98, 1.13; 1.00)
$C_{5,5}$	(0.89, 0.94, 0.98, 0.99; 1.00)	(0.39, 0.50, 0.85, 1.04; 1.00)
$C_{5,6}$	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.33, 0.42, 0.66, 0.79; 1.00)
$C_{5,7}$	(0.80, 0.86, 0.95, 0.98; 1.00)	(0.55, 0.65, 0.93, 1.08; 1.00)

Table 3.9: Aggregated fuzzy priority weight as well as computed appropriateness rating of lean capabilities/enablers

Enablers C_i	Aggregated Weight w_i	Computed Rating U_i
C_1	(0.80, 0.86, 0.95, 0.98; 1.00)	(0.57, 0.68, 1.00, 1.16; 1.00)
C_2	(0.97, 0.99, 1.00, 1.00; 1.00)	(0.53, 0.63, 0.94, 1.09; 1.00)
C_3	(0.72, 0.78, 0.92, 0.97; 1.00)	(0.56, 0.67, 0.97, 1.12; 1.00)
C_4	(0.73, 0.79, 0.91, 0.95; 1.00)	(0.57, 0.67, 0.93, 1.07; 1.00)
C_5	(0.87, 0.91, 0.97, 0.99; 1.00)	(0.50, 0.60, 0.85, 0.98; 1.00)

Table 3.10: Computation of FPII against each of the lean criterions

Lean Criterions $C_{i,j,k}$	$w'_{i,j,k} = [(1,1,1,1;1) - w_{i,j,k}]$	Fuzzy Performance Importance Index (FPII) $w'_{i,j,k} \otimes U_{i,j,k}$
$C_{1,1,1}$	(0.0, 0.0, 0.01, 0.03; 1.00)	(0.0, 0.0, 0.008, 0.028; 1.00)
$C_{1,1,2}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.022, 0.062, 0.202, 0.272; 1.00)
$C_{1,1,3}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.044, 0.094, 0.242, 0.304; 1.00)
$C_{1,2,1}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.045, 0.084, 0.231, 0.296; 1.00)
$C_{1,2,2}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.012, 0.048; 1.00)
$C_{1,2,3}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.027, 0.075, 0.216, 0.278; 1.00)
$C_{2,1,1}$	(0.10, 0.15, 0.31, 0.36; 1.00)	(0.064, 0.109, 0.270, 0.337; 1.00)
$C_{2,1,2}$	(0.0, 0.0, 0.0, 0.0; 1.00)	(0.0, 0.0, 0.0, 0.0; 1.00)
$C_{2,2,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.022, 0.062, 0.202, 0.272; 1.00)
$C_{2,2,2}$	(0.27, 0.33, 0.50, 0.55; 1.00)	(0.217, 0.286, 0.472, 0.544; 1.00)
$C_{2,3,1}$	(0.02, 0.05, 0.14, 0.20; 1.00)	(0.009, 0.027, 0.103, 0.156; 1.00)
$C_{2,3,2}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.017, 0.050, 0.176, 0.241; 1.00)
$C_{2,3,3}$	(0.01, 0.03, 0.10, 0.14; 1.00)	(0.009, 0.025, 0.088, 0.136; 1.00)
$C_{2,4,1}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.051, 0.103, 0.250, 0.308; 1.00)
$C_{2,4,2}$	(0.02, 0.05, 0.14, 0.20; 1.00)	(0.013, 0.037, 0.129, 0.190; 1.00)
$C_{2,4,3}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.027, 0.075, 0.216, 0.278; 1.00)
$C_{2,5,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.011, 0.036, 0.137, 0.194; 1.00)
$C_{2,5,2}$	(0.02, 0.05, 0.14, 0.20; 1.00)	(0.005, 0.016, 0.069, 0.109; 1.00)
$C_{2,5,3}$	(0.10, 0.15, 0.31, 0.36; 1.00)	(0.069, 0.119, 0.285, 0.353; 1.00)
$C_{2,6,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.022, 0.062, 0.202, 0.272; 1.00)
$C_{2,6,2}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.030, 0.080, 0.220, 0.280; 1.00)
$C_{2,6,3}$	(0.01, 0.03, 0.10, 0.14; 1.00)	(0.010, 0.028, 0.091, 0.137; 1.00)
$C_{2,7,1}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.040, 0.085, 0.234, 0.301; 1.00)
$C_{2,7,2}$	(0.01, 0.03, 0.10, 0.15; 1.00)	(0.010, 0.029, 0.097, 0.152; 1.00)
$C_{2,8,1}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.025, 0.056, 0.178, 0.239; 1.00)
$C_{2,8,2}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.053, 0.100, 0.258, 0.326; 1.00)
$C_{2,8,3}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.017, 0.065; 1.00)
$C_{2,9,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.023, 0.066, 0.206, 0.273; 1.00)
$C_{2,9,2}$	(0.10, 0.15, 0.31, 0.36; 1.00)	(0.069, 0.119, 0.285, 0.353; 1.00)
$C_{2,10,1}$	(0.0,0.0, 0.0, 0.00; 1.00)	(0.0, 0.0, 0.0, 0.0; 1.00)
$C_{2,10,2}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.005, 0.020, 0.083, 0.122; 1.00)

$C_{3,1,1}$	(0.27, 0.33, 0.50, 0.55; 1.00)	(0.054, 0.086, 0.200, 0.258; 1.00)
$C_{3,1,2}$	(0.02, 0.06, 0.18, 0.24; 1.00)	(0.014, 0.040, 0.144, 0.205; 1.00)
$C_{3,1,3}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.018, 0.068; 1.00)
$C_{3,2,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.030, 0.080, 0.220, 0.280; 1.00)
$C_{3,2,2}$	(0.02, 0.06, 0.18, 0.24; 1.00)	(0.019, 0.055, 0.171, 0.234; 1.00)
$C_{4,1,1}$	(0.10, 0.15, 0.31, 0.36; 1.00)	(0.073, 0.125, 0.290, 0.355; 1.00)
$C_{4,1,2}$	(0.0, 0.0, 0.0, 0.0; 1.00)	(0.0, 0.0, 0.0, 0.0; 1.00)
$C_{4,1,3}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.014, 0.043, 0.157, 0.217; 1.00)
$C_{4,1,4}$	(0.27, 0.33, 0.50, 0.55; 1.00)	(0.194, 0.259, 0.456, 0.537; 1.00)
$C_{4,2,1}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.072, 0.127, 0.280, 0.336; 1.00)
$C_{4,2,2}$	(0.02, 0.06, 0.18, 0.24; 1.00)	(0.017, 0.050, 0.166, 0.231; 1.00)
$C_{4,2,3}$	(0.01, 0.03, 0.09, 0.13; 1.00)	(0.011, 0.030, 0.091, 0.125; 1.00)
$C_{4,3,1}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.045, 0.094, 0.242, 0.304; 1.00)
$C_{4,3,2}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.035, 0.069, 0.199, 0.261; 1.00)
$C_{4,3,3}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.018, 0.068; 1.00)
$C_{4,4,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.020, 0.058, 0.192, 0.259; 1.00)
$C_{4,4,2}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.037, 0.081, 0.230, 0.299; 1.00)
$C_{4,4,3}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.021, 0.048, 0.150, 0.203; 1.00)
$C_{4,4,4}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.008, 0.031; 1.00)
$C_{4,5,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.006, 0.021, 0.089, 0.130; 1.00)
$C_{4,5,2}$	(0.01, 0.02, 0.06, 0.11; 1.00)	(0.006, 0.016, 0.060, 0.112; 1.00)
$C_{4,6,1}$	(0.20, 0.26, 0.43, 0.50; 1.00)	(0.145, 0.206, 0.394, 0.481; 1.00)
$C_{4,6,2}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.071, 0.126, 0.280, 0.336; 1.00)
$C_{4,6,3}$	(0.01, 0.02, 0.06, 0.11; 1.00)	(0.004, 0.012, 0.055, 0.109; 1.00)
$C_{4,7,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.025, 0.072, 0.213, 0.277; 1.00)
$C_{4,7,2}$	(0.40, 0.46, 0.63, 0.71; 1.00)	(0.241, 0.306, 0.517, 0.626; 1.00)
$C_{4,7,3}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.047, 0.088, 0.237, 0.304; 1.00)
$C_{4,8,1}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.019, 0.047, 0.156, 0.213; 1.00)
$C_{4,8,2}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.045, 0.084, 0.231, 0.296; 1.00)
$C_{4,8,3}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.019, 0.069; 1.00)
$C_{4,9,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.014, 0.043, 0.157, 0.217; 1.00)
$C_{4,9,2}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.037, 0.081, 0.230, 0.299; 1.00)
$C_{4,9,3}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.049, 0.092, 0.244, 0.311; 1.00)
$C_{4,9,4}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.019, 0.069; 1.00)
$C_{4,9,5}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.021, 0.060, 0.197, 0.265; 1.00)
$C_{5,1,1}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.050, 0.103, 0.250, 0.308; 1.00)
$C_{5,1,2}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.053, 0.100, 0.258, 0.326; 1.00)
$C_{5,1,3}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.019, 0.069; 1.00)
$C_{5,2,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.018, 0.053, 0.181, 0.247; 1.00)
$C_{5,2,2}$	(0.02, 0.06, 0.18, 0.24; 1.00)	(0.004, 0.016, 0.068, 0.104; 1.00)
$C_{5,2,3}$	(0.02, 0.05, 0.14, 0.20; 1.00)	(0.004, 0.012, 0.057, 0.091; 1.00)
$C_{5,3,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.028, 0.078, 0.220, 0.280; 1.00)
$C_{5,3,2}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.040, 0.085, 0.234, 0.301; 1.00)
$C_{5,3,3}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.064, 0.116, 0.271, 0.332; 1.00)
$C_{5,3,4}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.014, 0.054; 1.00)
$C_{5,4,1}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.022, 0.062, 0.202, 0.272; 1.00)
$C_{5,4,2}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.017, 0.065; 1.00)

$C_{5,5,1}$	(0.02, 0.06, 0.18, 0.24; 1.00)	(0.017, 0.050, 0.166, 0.231; 1.00)
$C_{5,5,2}$	(0.05, 0.10, 0.25, 0.31; 1.00)	(0.015, 0.039, 0.134, 0.186; 1.00)
$C_{5,6,1}$	(0.07, 0.13, 0.28, 0.34; 1.00)	(0.013, 0.032, 0.105, 0.146; 1.00)
$C_{5,6,2}$	(0.0, 0.0, 0.02, 0.07; 1.00)	(0.0, 0.0, 0.008, 0.033; 1.00)
$C_{5,6,3}$	(0.03, 0.08, 0.22, 0.28; 1.00)	(0.027, 0.075, 0.216, 0.278; 1.00)
$C_{5,7,1}$	(0.02, 0.05, 0.14, 0.20; 1.00)	(0.015, 0.043, 0.136, 0.194; 1.00)
$C_{5,7,2}$	(0.02, 0.05, 0.14, 0.20; 1.00)	(0.009, 0.026, 0.100, 0.152; 1.00)

Table 3.11: Computation of total utility value of FPIIs and corresponding criteria ranking order

$C_{i,j,k}$	$u_T^{\alpha=0}$	Ranking order	$u_T^{\alpha=0.5}$	Ranking order	$u_T^{\alpha=1}$	Ranking order
$C_{1,1,1}$	0.0000	58	0.0141	66	0.0283	62
$C_{1,1,2}$	0.0652	28	0.2212	28	0.3771	22
$C_{1,1,3}$	0.1074	17	0.2716	16	0.4357	13
$C_{1,2,1}$	0.1018	19	0.2610	19	0.4201	17
$C_{1,2,2}$	0.0000	58	0.0236	63	0.0472	59
$C_{1,2,3}$	0.0788	25	0.2365	24	0.3942	19
$C_{2,1,1}$	0.1364	10	0.3107	10	0.4850	8
$C_{2,1,2}$	0.0000	58	0.0000	67	0.0000	63
$C_{2,2,1}$	0.0652	28	0.2212	28	0.3771	22
$C_{2,2,2}$	0.4002	2	0.6080	2	0.8158	2
$C_{2,3,1}$	0.0288	48	0.1169	45	0.2051	40
$C_{2,3,2}$	0.0529	35	0.1920	33	0.3311	29
$C_{2,3,3}$	0.0265	50	0.1018	49	0.1772	45
$C_{2,4,1}$	0.1201	12	0.2827	12	0.4452	11
$C_{2,4,2}$	0.0396	42	0.1460	43	0.2524	39
$C_{2,4,3}$	0.0788	25	0.2365	24	0.3942	19
$C_{2,5,1}$	0.0372	43	0.1498	41	0.2625	36
$C_{2,5,2}$	0.0164	54	0.0786	53	0.1409	49
$C_{2,5,3}$	0.1477	8	0.3288	6	0.5099	6
$C_{2,6,1}$	0.0652	28	0.2212	28	0.3771	22
$C_{2,6,2}$	0.0846	22	0.2415	21	0.3984	18
$C_{2,6,3}$	0.0293	47	0.1052	48	0.1811	44
$C_{2,7,1}$	0.0976	20	0.2619	18	0.4262	15
$C_{2,7,2}$	0.0309	46	0.1137	46	0.1965	43
$C_{2,8,1}$	0.0637	29	0.1976	32	0.3315	28

$C_{2,8,2}$	0.1202	11	0.2929	11	0.4657	10
$C_{2,8,3}$	0.0000	58	0.0316	61	0.0632	57
$C_{2,9,1}$	0.0686	27	0.2250	26	0.3814	21
$C_{2,9,2}$	0.1477	8	0.3288	6	0.5099	6
$C_{2,10,1}$	0.0000	58	0.0000	67	0.0000	63
$C_{2,10,2}$	0.0199	52	0.0910	52	0.1622	48
$C_{3,1,1}$	0.1106	15	0.2378	23	0.3651	25
$C_{3,1,2}$	0.0425	40	0.1595	39	0.2764	35
$C_{3,1,3}$	0.0000	58	0.0331	60	0.0662	56
$C_{3,2,1}$	0.0846	22	0.2415	21	0.3984	18
$C_{3,2,2}$	0.0579	32	0.1899	34	0.3218	30
$C_{4,1,1}$	0.1557	6	0.3357	5	0.5157	5
$C_{4,1,2}$	0.0000	58	0.0000	67	0.0000	63
$C_{4,1,3}$	0.0451	39	0.1709	37	0.2968	32
$C_{4,1,4}$	0.3606	3	0.5797	3	0.7987	3
$C_{4,2,1}$	0.1562	5	0.3241	7	0.4919	7
$C_{4,2,2}$	0.0525	36	0.1836	35	0.3146	31
$C_{4,2,3}$	0.0321	45	0.1017	50	0.1713	47
$C_{4,3,1}$	0.1084	16	0.2720	15	0.4357	13
$C_{4,3,2}$	0.0823	23	0.2243	27	0.3662	24
$C_{4,3,3}$	0.0000	58	0.0331	61	0.0662	56
$C_{4,4,1}$	0.0603	31	0.2095	30	0.3587	26
$C_{4,4,2}$	0.0927	21	0.2570	20	0.4214	16
$C_{4,4,3}$	0.0544	34	0.1674	38	0.2804	34
$C_{4,4,4}$	0.0000	58	0.0149	65	0.0297	61
$C_{4,5,1}$	0.0210	51	0.0974	51	0.1738	46
$C_{4,5,2}$	0.0169	53	0.0759	54	0.1349	51
$C_{4,6,1}$	0.2786	4	0.4907	4	0.7027	4
$C_{4,6,2}$	0.1549	7	0.3234	8	0.4919	7
$C_{4,6,3}$	0.0133	56	0.0707	56	0.1282	52
$C_{4,7,1}$	0.0754	26	0.2327	25	0.3899	20
$C_{4,7,2}$	0.4362	1	0.6813	1	0.9264	1
$C_{4,7,3}$	0.1064	18	0.2690	17	0.4315	14
$C_{4,8,1}$	0.0523	37	0.1727	36	0.2931	33
$C_{4,8,2}$	0.1018	19	0.2610	19	0.4201	17

$C_{4,8,3}$	0.0000	58	0.0340	58	0.0680	54
$C_{4,9,1}$	0.0451	39	0.1709	37	0.2968	32
$C_{4,9,2}$	0.0927	21	0.2570	20	0.4214	16
$C_{4,9,3}$	0.1110	14	0.2769	14	0.4429	12
$C_{4,9,4}$	0.0000	58	0.0337	59	0.0674	55
$C_{4,9,5}$	0.0628	30	0.2153	29	0.3679	23
$C_{5,1,1}$	0.1191	13	0.2822	13	0.4452	11
$C_{5,1,2}$	0.1202	11	0.2929	11	0.4657	10
$C_{5,1,3}$	0.0000	58	0.0340	58	0.0680	54
$C_{5,2,1}$	0.0554	33	0.1978	31	0.3403	27
$C_{5,2,2}$	0.0159	55	0.0758	55	0.1357	50
$C_{5,2,3}$	0.0127	57	0.0648	57	0.1169	53
$C_{5,3,1}$	0.0822	24	0.2403	22	0.3984	18
$C_{5,3,2}$	0.0976	20	0.2619	18	0.4262	15
$C_{5,3,3}$	0.1408	9	0.3111	9	0.4815	9
$C_{5,3,4}$	0.0000	58	0.0265	62	0.0529	58
$C_{5,4,1}$	0.0652	28	0.2212	28	0.3771	22
$C_{5,4,2}$	0.0000	58	0.0316	61	0.0632	57
$C_{5,5,1}$	0.0525	36	0.1836	35	0.3146	31
$C_{5,5,2}$	0.0423	41	0.1481	42	0.2539	38
$C_{5,6,1}$	0.0355	44	0.1176	44	0.1998	41
$C_{5,6,2}$	0.0000	58	0.0159	64	0.0318	60
$C_{5,6,3}$	0.0788	25	0.2365	24	0.3942	19
$C_{5,7,1}$	0.0461	38	0.1535	40	0.2609	37
$C_{5,7,2}$	0.0273	49	0.1131	47	0.1990	42

3.1.2 Leanness Metric Evaluation: Exploration of Generalized Interval-Valued Fuzzy Numbers Set Theory

3.1.2.1 Coverage

The present work exhibits an efficient fuzzy-based leanness assessment system using generalized Interval-Valued (IV) trapezoidal fuzzy numbers set. The concept of 'Degree of Similarity' between two IV fuzzy numbers has been explored here to identify ill-performing areas towards lean achievement. Apart from estimating overall lean performance metric, the model presented here can identify ill-performing areas towards lean achievement. Literature reveals that efforts were already made by pioneers towards estimation of lean performance index in fuzzy environment. In most of the cases, they explored the concept of generalized fuzzy numbers sets. Application of generalized Interval-Valued fuzzy membership function is seemed to yield more accurate evaluation as well as prediction results. Therefore, present study has been aimed to develop a fuzzy-based leanness evaluation module using fuzzy information data set (characterized by generalized positive Interval-Valued trapezoidal membership function) collected from a group of decision-makers (DMs). The proposed leanness measurement index system has been case empirically investigated as well.

3.1.2.2 The Concept of Generalized Interval-Valued Fuzzy Numbers (IVFNs) Set

In the following, some basic concepts of IVFNs and their arithmetic operations have been discussed.

Wang and Li (1998) defined IVFNs and presented their extended operational rules. From Chen (2006), the trapezoidal IVFN $\tilde{\tilde{A}}$, as shown in Fig. 3.2, can be represented by

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right],$$

Here $a_1^L \le a_2^L \le a_3^L \le a_4^L$, $a_1^U \le a_2^U \le a_3^U \le a_4^U$, $\tilde{\tilde{A}}^L$ denotes the lower IVFN, $\tilde{\tilde{A}}^U$ denotes the upper IVFN, and $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$.

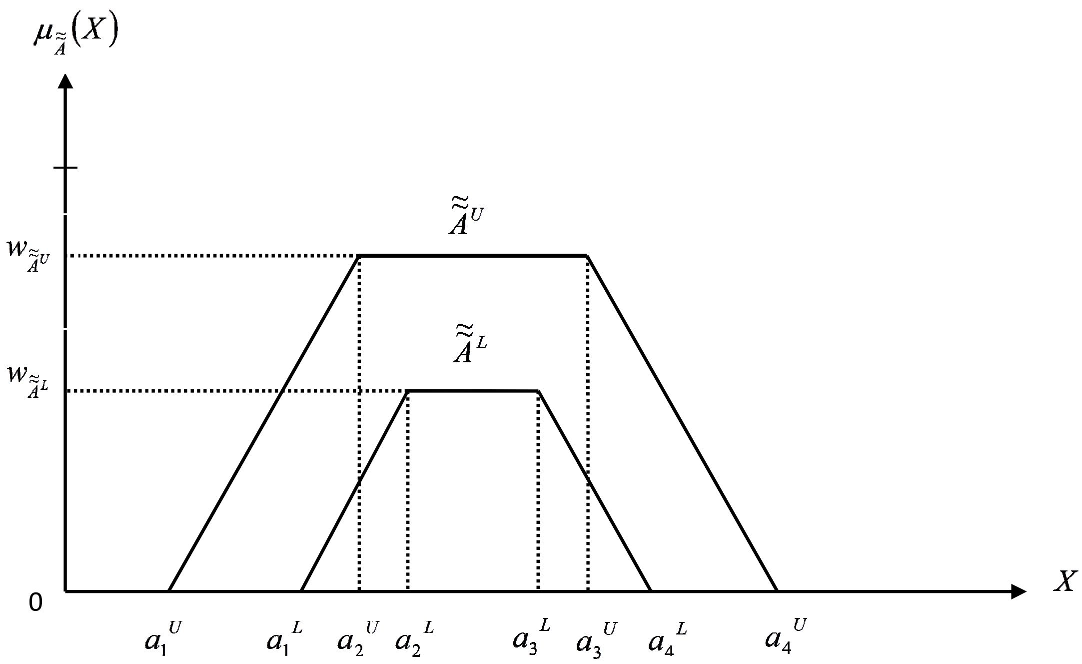

Fig. 3.2: An Interval-Valued (Trapezoidal) Fuzzy Number (IVFN)

Assume that there are two IVFNs $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$, where;

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right]$, and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right],$

$0 \le w_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1$, $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$, $0 \le w_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1$, and $\tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U$.

The arithmetic operations between IVFNs $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ as given by Chen (1995) and Wei and Chen (2009) have been reproduced as follows:

1. IVFNs addition $\oplus$

$$\tilde{\tilde{A}} \oplus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \oplus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$
$$= \left(a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L, a_4^L + b_4^L; \min\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \left(a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U, a_4^U + b_4^U; \min\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right)$$

(3.22)

2. IVFNs subtraction $\ominus$

$$\tilde{\tilde{A}} \ominus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \ominus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \left(a_1^L - b_1^L, a_2^L - b_2^L, a_3^L - b_3^L, a_4^L - b_4^L; \min\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \left(a_1^U - b_1^U, a_2^U - b_2^U, a_3^U - b_3^U, a_4^U - b_4^U; \min\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right)$$

(3.23)

3. IVFNs multiplication $\otimes$

$$\tilde{\tilde{A}} \otimes \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \otimes \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \left(a_1^L \times b_1^L, a_2^L \times b_2^L, a_3^L \times b_3^L, a_4^L \times b_4^L; \min\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \left(a_1^U \times b_1^U, a_2^U \times b_2^U, a_3^U \times b_3^U, a_4^U \times b_4^U; \min\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right)$$

(3.24)

4. IVFNs division

$$\tilde{\tilde{\mathrm{A}}}/\tilde{\tilde{\mathrm{B}}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] / \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \left[\left(\frac{a_1^L}{b_4^L}, \frac{a_2^L}{b_3^L}, \frac{a_3^L}{b_2^L}, \frac{a_4^L}{b_1^L}; \min\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \left(\frac{a_1^U}{b_4^U}, \frac{a_2^U}{b_3^U}, \frac{a_3^U}{b_2^U}, \frac{a_4^U}{b_1^U}; \min\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right)\right]$$

(3.25)

Here, $a_1^L, a_2^L, a_3^L, a_4^L, a_1^U, a_2^U, a_3^U, a_4^U, b_1^L, b_2^L, b_3^L, b_4^L, b_1^U, b_2^U, b_3^U, b_4^U$ are all non-zero positive real numbers or all non-zero negative real numbers, $0 < w_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1$ and $0 < w_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1$.

5. Similarity measures between IV-fuzzy numbers

The similarity measure presented by Wei and Chen (2009) has been presented here. Let $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ be two IVFNs, where $\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right]$ and $\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$,

$$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1, 0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1, 0 \le w_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1, \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U;$$

$$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1, 0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1, 0 \le w_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1, \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U.$$

First, the areas $A\left(\tilde{\tilde{A}}^L\right)$, $A\left(\tilde{\tilde{A}}^U\right)$, $A\left(\tilde{\tilde{B}}^L\right)$, and $A\left(\tilde{\tilde{B}}^U\right)$ of the lower trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{B}}^L$ and the upper trapezoidal fuzzy numbers $\tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^U$ are calculated, followed by the

COG points $\left(x^*_{\tilde{\tilde{A}}^L}, y^*_{\tilde{\tilde{A}}^L}\right)$, $\left(x^*_{\tilde{\tilde{A}}^U}, y^*_{\tilde{\tilde{A}}^U}\right)$, $\left(x^*_{\tilde{\tilde{B}}^L}, y^*_{\tilde{\tilde{B}}^L}\right)$, and $\left(x^*_{\tilde{\tilde{B}}^U}, y^*_{\tilde{\tilde{B}}^U}\right)$ of $A\left(\tilde{\tilde{A}}^L\right)$, $A\left(\tilde{\tilde{A}}^U\right)$, $A\left(\tilde{\tilde{B}}^L\right)$, and $A\left(\tilde{\tilde{B}}^U\right)$ respectively. Next, the COG points $\left(x^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{A}}}; x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{B}}}\right)$ of the IVFNs $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{B}}^L$ are calculated, followed by the degree of similarity, $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right)$ and $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)$, between the lower trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L$, $\tilde{\tilde{B}}^L$ and the upper trapezoidal fuzzy numbers $\tilde{\tilde{A}}^U$, $\tilde{\tilde{B}}^U$ respectively. Finally, the degree of similarity between IVFNs is calculated as follows:

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \left[\frac{S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) + S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)}{2} \times (1-\Delta x) \times (1-\Delta y)\right]^{\left(\frac{1}{1+2t}\right)} * \left(1-\left|w^U_{\tilde{\tilde{A}}} - w^U_{\tilde{\tilde{B}}} - w^L_{\tilde{\tilde{A}}} + w^L_{\tilde{\tilde{B}}}\right|\right)^{\frac{u}{2}} \tag{3.26}$$

Here,

$$t = \begin{cases} 1, if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0\ and\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, Otherwise, \end{cases} \tag{3.27}$$

$$u = \begin{cases} 1, if\ a_1^U = a_4^U\ and\ b_1^U = b_4^U, \\ 0, Otherwise. \end{cases} \tag{3.28}$$

$$S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) = \begin{cases} \left[1 - \frac{\sum_{i=1}^{4}\left|a_i^L - b_i^L\right|}{4}\right] \times \frac{\min\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)}{\max\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \max\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)}, if\ \min\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right) \neq 0, \\ 0, Otherwise. \end{cases} \tag{3.29}$$

$$S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right) = \begin{cases} \left[1 - \dfrac{\sum_{i=1}^{4}\left|a_i^U - b_i^U\right|}{4}\right] \times \dfrac{\min\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)}{\max\left(L\left(\tilde{\tilde{A}}^U\right), L\left(\tilde{\tilde{B}}^U\right)\right) + \max\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right)}, & if \ \min\left(w_{\tilde{\tilde{A}}^U}, w_{\tilde{\tilde{B}}^U}\right) \neq 0, \\ 0, Otherwise. \end{cases}$$

(3.30)

$$\Delta x = \begin{cases} \left|x^*_{\tilde{\tilde{A}}} - x^*_{\tilde{\tilde{B}}}\right|, if \ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0 \ and \ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, Otherwise, \end{cases}$$ (3.31)

$$\Delta y = \begin{cases} \left|y^*_{\tilde{\tilde{A}}} - y^*_{\tilde{\tilde{B}}}\right|, if \ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \neq 0 \ and \ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \neq 0, \\ 0, Otherwise. \end{cases}$$ (3.32)

$$L\left(\tilde{\tilde{A}}^L\right) = \sqrt{\left(a_1^L - a_2^L\right)^2 + w^2_{\tilde{\tilde{A}}^L}} + \sqrt{\left(a_3^L - a_4^L\right)^2 + w^2_{\tilde{\tilde{A}}^L}} + \left(a_3^L - a_2^L\right) + \left(a_4^L - a_1^L\right),$$ (3.33)

$$L\left(\tilde{\tilde{B}}^L\right) = \sqrt{\left(b_1^L - b_2^L\right)^2 + w^2_{\tilde{\tilde{B}}^L}} + \sqrt{\left(b_3^L - b_4^L\right)^2 + w^2_{\tilde{\tilde{B}}^L}} + \left(b_3^L - b_2^L\right) + \left(b_4^L - b_1^L\right),$$ (3.34)

$$L\left(\tilde{\tilde{A}}^U\right) = \sqrt{\left(a_1^U - a_2^U\right)^2 + w^2_{\tilde{\tilde{A}}^U}} + \sqrt{\left(a_3^U - a_4^U\right)^2 + w^2_{\tilde{\tilde{A}}^U}} + \left(a_3^U - a_2^U\right) + \left(a_4^U - a_1^U\right),$$ (3.35)

$$L\left(\tilde{\tilde{B}}^U\right) = \sqrt{\left(b_1^U - b_2^U\right)^2 + w^2_{\tilde{\tilde{B}}^U}} + \sqrt{\left(b_3^U - b_4^U\right)^2 + w^2_{\tilde{\tilde{B}}^U}} + \left(b_3^U - b_2^U\right) + \left(b_4^U - b_1^U\right).$$ (3.36)

3.1.2.3 Leanness Estimation Procedural Hierarchy: Case Empirical Illustration

Leanness evaluation has been made by the procedural framework as described as follows. The evaluation framework is based on a lean capabler-attribute-criterion hierarchy adapted from the work by (Vinodh and Vimal, 2011).

Step 1 Determination of the appropriate linguistic scale for assessing the performance ratings and importance weights of lean attributes

The linguistic terms are used to assess the performance ratings and priority weights of lean attributes since vagueness is associated with individuals' subjective opinion, it is difficult for the decision-makers to determine the exact numeric score against an attribute. In order to assess the performance rating of the lean criterions from Table 3.1 (already described in Section 3.1.1) (3^{rd} level indices), the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} have been used (Table 3.12).

Similarly, to assign importance weights (priority degree) of the lean capabilities-attributes and criterions, the linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been utilized (Table 3.12).

The linguistic variables have been accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation.

Step 2 Measurement of performance ratings and importance weights of lean attributes using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of lean parameters has been accepted by the decision-makers (DMs), the decision-makers have been asked to use aforesaid linguistic scales to assess the performance rating against each criterions as well as to assign importance weights towards each of the lean criterions, attributes as well as capabilities (Tables 3.13-3.16 of APPENDIX-A).

Step 3 Approximation of the linguistic terms by generalized IV-trapezoidal fuzzy numbers

Using the concept of generalized Interval-Valued (IV) trapezoidal fuzzy numbers in fuzzy set theory (Chen and Lai, 2011), the linguistic variables have been be approximated by Interval-

Valued (IV) trapezoidal fuzzy numbers (shown in Table 3.12). Next, the aggregated decision-making cum evaluation matrix has been constructed. The aggregated fuzzy appropriateness rating against each lean criterion (3rd level indices) has been shown in Table 3.17 with corresponding fuzzy importance weight. Aggregated fuzzy priority weight of lean attributes (2nd level indices) as well as enablers/capabilities (1st level indices) given by decision-makers has been furnished in Tables 3.18-3.19. The aggregated fuzzy rating as well as priority weight has been computed based on the method of averaging opinions of the decision-makers.

Step 4 Determination of FOPI

FOPI represents the *Fuzzy Overall Performance Index*. The fuzzy index has been calculated at the attribute level and then extended to enabler level. Fuzzy index system (at 2nd level) encompasses several lean attributes (Table 3.1).

The fuzzy index (appropriateness rating) of each lean attribute (at 2nd level) has been calculated as follows:

$$U_{i,j} = \frac{\sum_{k=1}^{n}\left(w_{i,j,k} \otimes U_{i,j,k}\right)}{\sum_{k=1}^{n} w_{i,j,k}} \qquad (3.37)$$

Here $U_{i,j,k}$ represents aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represents aggregated fuzzy weight corresponding to lean criterion $C_{i,j,k}$ which is under j_{th} lean attribute $C_{i,j}$ (at 2nd level) and i_{th} lean capability C_i (at 1st level).

The fuzzy index of each lean capability/enabler (at 1st level) has been calculated as follows:

$$U_i = \frac{\sum_{j=1}^{n}\left(w_{i,j} \otimes U_{i,j}\right)}{\sum_{j=1}^{n} w_{i,j}} \qquad (3.38)$$

Here $U_{i,j}$ represents computed fuzzy performance measure (rating) obtained using Eq. 3.37 and $w_{i,j}$ represents aggregated fuzzy weight for priority importance corresponding to j_{th} lean attribute $C_{i,j}$ which is under i_{th} lean capability C_i (at 1st level).

Thus, fuzzy overall performance index $U(FOPI)$ has been calculated as follows:

$$U(FOPI) = \frac{\sum_{i=1}^{n}(w_i \otimes U_i)}{\sum_{i=1}^{n} w_i} \quad (3.39)$$

Here U_i =Computed fuzzy performance rating of i^{th} lean capability C_i (computed by Eq. 3.38);

w_i =Aggregated fuzzy weight of i^{th} lean capability C_i, and $i = 1, 2, 3, ...n$.

Computed fuzzy appropriateness ratings of different lean attributes (at 2nd level) as well as lean enablers (at 1st level) have been furnished in Table 3.18 and 3.19, respectively. Finally, Eq. 3.39 has been explored to calculate overall lean estimate.

Fuzzy Overall Performance Index (FOPI) becomes:

[(0.36, 0.52, 1.17, 1.64, 0.80), (0.36, 0.52, 1.17, 1.64, 1.00)]

Step 5 Identifying Obstacles towards Lean Achievement

After evaluating FOPI and the organizational existing leanness extent, simultaneously it is also felt indeed necessary to identify and analyze the obstacles (ill-performing areas) for leanness improvement. *Fuzzy Performance Importance Index (FPII)* may be used to identify these obstacles. FPII combines the performance rating and importance weight of lean criterions. The higher the FPII of a factor, the higher is the contribution. The FPII can be calculated as follows (Lin et al., 2006):

$$FPII_{i,j,k} = w'_{i,j,k} \otimes U_{i,j,k} \quad (3.40)$$

Here, $w'_{i,j,k} = \left[\{(1,1,1,1;1),(1,1,1,1;1)\} - w_{i,j,k}\right]$ (3.41)

In this formulation, $U_{i,j,k}$ represent aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represent aggregated fuzzy weight corresponding to lean criterion $C_{i,j,k}$ which is under j_{th} lean attribute $C_{i,j}$ (at 2nd level) and i_{th} lean capability C_i (at 1st level).

FPII need to be ranked to identify individual criterion performance level. Based on that poorly performing criterions are identified and in future, attention must be given to improve those criteria aspects in order to boost up overall leanness degree.

Computed FPII against each lean criterions has been tabulated (Table 3.20) which has been compared with the '*ideal FPII*'. The value of the '*ideal FPII*' has been computed as:

[(0.251, 0.323, 0.517, 0.626; 0.800), (0.251, 0.323, 0.517, 0.626; 1.000)]

The concept of '*Degree of Similarity*' between two IVFNs has been explored towards lean criteria ranking. Degree of similarity between *ideal FPII* with corresponding criterion's FPII has thus been computed. Higher value of degree of similarity indicates high level of performance. Based on corresponding degree of similarity lean criterions have been ranked accordingly, Ranking order has been furnished in Table 3.21; and graphically presented in Fig. 3.3. Such a criteria ranking provides necessary information about comparative performance picture of existing lean criterions. By this way, ill-performing areas can be sorted out. Industry should find feasible means to improve performance in those areas to boost up overall degree of leanness in future. Lesser value of ranking order exhibits higher level of performance. The industry should categorically think the areas in which it should prosper.

3.1.2.4 Concluding Remarks

Lean manufacturing strategy has become a major avenue for both academics and practitioners in recent era. Many organizations around the world have attempted to implement it but the lack of a clear understanding of lean performance and its measurement necessitates effective in-depth research while implementing lean practices. Literature addressed lean techniques and tools, but very few studies were found to focus systematically on evaluation of lean performance appraisement index. In order to fill the current gap, this paper presents a systematic and logical lean appraisement platform based on Interval-Valued Fuzzy Sets theory in order to estimate the lean performance of manufacturing systems.

The efficacy measure is indeed an important indicator in lean performance measure. The research aimed to develop a quantitative analysis framework and a simulation methodology to evaluate the efficacy of lean metrics in the production systems. Apart from estimating overall organizational leanness metric; the aforesaid research provides a scope for identifying ill-performing areas (obstacles/barriers for lean achievement) which require special emphasis to prosper in future.

The major contributions of this work have been summarized as follows:

1. Development and implementation of an efficient decision-making procedural hierarchy to support leanness extent evaluation.
2. An overall lean performance index evaluation platform has been introduced.
3. Concept of generalized Interval-Valued trapezoidal fuzzy numbers has been efficiently explored to facilitate this decision-making.
4. The appraisement index system has been extended with the capability to search ill-performing areas which require future progress.

Table 3.12: Definitions of linguistic variables for appropriateness rating and priority weight (A-9 member interval linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized interval-valued trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	[(0, 0, 0, 0; 0.8), (0, 0, 0, 0; 1)]
Very Poor (VP)	Very Low (VL)	[(0, 0, 0.02, 0.07; 0.8), (0, 0, 0.02, 0.07; 1)]
Poor (P)	Low (L)	[(0.04, 0.10, 0.18, 0.23; 0.8), (0.04, 0.10, 0.18, 0.23; 1)]
Medium Poor (MP)	Medium Low (ML)	[(0.17, 0.22, 0.36, 0.42; 0.8), (0.17, 0.22, 0.36, 0.42; 1)]
Medium (M)	Medium (M)	[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1)]
Medium Good (MG)	Medium High (MH)	[(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1)]
Good (G)	High (H)	[(0.72, 0.78, 0.92, 0.97; 0.8), (0.72, 0.78, 0.92, 0.97; 1)]
Very Good (VG)	Very High (VH)	[(0.93, 0.98, 1, 1; 0.8), (0.93, 0.98, 1, 1; 1)]
Absolutely Good (AG)	Absolutely High (AH)	[(1, 1, 1, 1; 0.8), (1, 1, 1, 1; 1)]

Table 3.17: Aggregated fuzzy rating as well as aggregated fuzzy priority weight of lean criterions

Leanness criterions ($C_{i,j,k}$)	Aggregated rating of lean criterions ($U_{i,j,k}$)	Aggregated weight of lean criterions ($W_{i,j,k}$)
$C_{1,1,1}$	[(0.90, 0.94, 0.98, 0.99; 0.80), (0.90, 0.94, 0.98, 0.99; 1.00)]	[(0.97, 0.99, 1.00, 1.00; 0.80), (0.97, 0.99, 1.00, 1.00; 1.00)]
$C_{1,1,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{1,1,3}$	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{1,2,1}$	[(0.61, 0.66, 0.82, 0.88; 0.80), (0.61, 0.66, 0.82, 0.88; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{1,2,2}$	[(0.40, 0.48, 0.65, 0.71; 0.80), (0.40, 0.48, 0.65, 0.71; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{1,2,3}$	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,1,1}$	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]	[(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)]
$C_{2,1,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(1.00, 1.00, 1.00, 1.00; 0.80), (1.00, 1.00, 1.00, 1.00; 1.00)]
$C_{2,2,1}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,2,2}$	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]	[(0.39, 0.46, 0.62, 0.69; 0.80), (0.39, 0.46, 0.62, 0.69; 1.00)]
$C_{2,3,1}$	[(0.53, 0.60, 0.76, 0.82; 0.80), (0.53, 0.60, 0.76, 0.82; 1.00)]	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]
$C_{2,3,2}$	[(0.58, 0.63, 0.80, 0.86; 0.80), (0.58, 0.63, 0.80, 0.86; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,3,3}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]
$C_{2,4,1}$	[(0.97, 0.99, 1.00, 1.00; 0.80), (0.97, 0.99, 1.00, 1.00; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{2,4,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]
$C_{2,4,3}$	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,5,1}$	[(0.37, 0.45, 0.62, 0.69; 0.80), (0.37, 0.45, 0.62, 0.69; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,5,2}$	[(0.26, 0.33, 0.49, 0.56; 0.80), (0.26, 0.33, 0.49, 0.56; 1.00)]	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]
$C_{2,5,3}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)]
$C_{2,6,1}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,6,2}$	[(0.99, 1.00, 1.00, 1.00; 0.80), (0.99, 1.00, 1.00, 1.00; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,6,3}$	[(0.80, 0.86, 0.95, 0.98, 0.80), (0.80, 0.86, 0.95, 0.98, 1.00)]	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]
$C_{2,7,1}$	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{2,7,2}$	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]
$C_{2,8,1}$	[(0.48, 0.54, 0.71, 0.78; 0.80), (0.48, 0.54, 0.71, 0.78; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{2,8,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{2,8,3}$	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{2,9,1}$	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{2,9,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)]
$C_{2,10,1}$	[(0.29, 0.37, 0.54, 0.60; 0.80), (0.29, 0.37, 0.54, 0.60; 1.00)]	[(1.00, 1.00, 1.00, 1.00; 0.80), (1.00, 1.00, 1.00, 1.00; 1.00)]

$C_{2,10,2}$	[(0.18, 0.25, 0.38, 0.44; 0.80), (0.18, 0.25, 0.38, 0.44; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{3,1,1}$	[(0.20, 0.26, 0.40, 0.47; 0.80), (0.20, 0.26, 0.40, 0.47; 1.00)]	[(0.39, 0.46, 0.62, 0.69; 0.80), (0.39, 0.46, 0.62, 0.69; 1.00)]
$C_{3,1,2}$	[(0.58, 0.63, 0.80, 0.86; 0.80), (0.58, 0.63, 0.80, 0.86; 1.00)]	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]
$C_{3,1,3}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{3,2,1}$	[(0.97, 0.99, 1.00, 1.00; 0.80), (0.97, 0.99, 1.00, 1.00; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{3,2,2}$	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]
$C_{4,1,1}$	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]	[(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)]
$C_{4,1,2}$	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]	[(1.00, 1.00, 1.00, 1.00; 0.80), (1.00, 1.00, 1.00, 1.00; 1.00)]
$C_{4,1,3}$	[(0.48, 0.54, 0.71, 0.78; 0.80), (0.48, 0.54, 0.71, 0.78; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{4,1,4}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.45, 0.50, 0.67, 0.73; 0.80), (0.45, 0.50, 0.67, 0.73; 1.00)]
$C_{4,2,1}$	[(0.97, 0.99, 1.00, 1.00; 0.80), (0.97, 0.99, 1.00, 1.00; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{4,2,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]
$C_{4,2,3}$	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]	[(0.92, 0.95, 0.98, 0.99; 0.80), (0.92, 0.95, 0.98, 0.99; 1.00)]
$C_{4,3,1}$	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{4,3,2}$	[(0.48, 0.54, 0.71, 0.78; 0.80), (0.48, 0.54, 0.71, 0.78; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{4,3,3}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{4,4,1}$	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{4,4,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{4,4,3}$	[(0.29, 0.37, 0.54, 0.60; 0.80), (0.29, 0.37, 0.54, 0.60; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{4,4,4}$	[(0.18, 0.25, 0.38, 0.44; 0.80), (0.18, 0.25, 0.38, 0.44; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{4,5,1}$	[(0.20, 0.26, 0.40, 0.47; 0.80), (0.20, 0.26, 0.40, 0.47; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{4,5,2}$	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]
$C_{4,6,1}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.50, 0.57, 0.74, 0.80; 0.80), (0.50, 0.57, 0.74, 0.80; 1.00)]
$C_{4,6,2}$	[(0.96, 0.99, 1.00, 1.00; 0.80), (0.96, 0.99, 1.00, 1.00; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{4,6,3}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]
$C_{4,7,1}$	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{4,7,2}$	[(0.61, 0.66, 0.82, 0.88; 0.80), (0.61, 0.66, 0.82, 0.88; 1.00)]	[(0.29, 0.37, 0.54, 0.60; 0.80), (0.29, 0.37, 0.54, 0.60; 1.00)]
$C_{4,7,3}$	[(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{4,8,1}$	[(0.37, 0.45, 0.62, 0.69; 0.80), (0.37, 0.45, 0.62, 0.69; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{4,8,2}$	[(0.64, 0.69, 0.85, 0.90; 0.80), (0.64, 0.69, 0.85, 0.90; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{4,8,3}$	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{4,9,1}$	[(0.48, 0.54, 0.71, 0.78; 0.80), (0.48, 0.54, 0.71, 0.78; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{4,9,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{4,9,3}$	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]

$C_{4,9,4}$	[(0.82, 0.86, 0.95, 0.98; 0.80), (0.82, 0.86, 0.95, 0.98; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{4,9,5}$	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{5,1,1}$	[(0.96, 0.99, 1.00, 1.00; 0.80), (0.96, 0.99, 1.00, 1.00; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{5,1,2}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{5,1,3}$	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{5,2,1}$	[(0.61, 0.66, 0.82, 0.88; 0.80), (0.61, 0.66, 0.82, 0.88; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{5,2,2}$	[(0.18, 0.25, 0.38, 0.44; 0.80), (0.18, 0.25, 0.38, 0.44; 1.00)]	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]
$C_{5,2,3}$	[(0.20, 0.26, 0.40, 0.47; 0.80), (0.20, 0.26, 0.40, 0.47; 1.00)]	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]
$C_{5,3,1}$	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{5,3,2}$	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{5,3,3}$	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{5,3,4}$	[(0.48, 0.54, 0.71, 0.78; 0.80), (0.48, 0.54, 0.71, 0.78; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{5,4,1}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{5,4,2}$	[(0.66, 0.72, 0.87, 0.93; 0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]
$C_{5,5,1}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]
$C_{5,5,2}$	[(0.29, 0.37, 0.54, 0.60; 0.80), (0.29, 0.37, 0.54, 0.60; 1.00)]	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]
$C_{5,6,1}$	[(0.15, 0.22, 0.34, 0.40; 0.80), (0.15, 0.22, 0.34, 0.40; 1.00)]	[(0.66, 0.72, 0.87, 0.93;0.80), (0.66, 0.72, 0.87, 0.93; 1.00)]
$C_{5,6,2}$	[(0.20, 0.26, 0.40, 0.47; 0.80), (0.20, 0.26, 0.40, 0.47; 1.00)]	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]
$C_{5,6,3}$	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]
$C_{5,7,1}$	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]
$C_{5,7,2}$	[(0.48, 0.54, 0.71, 0.78; 0.80), (0.48, 0.54, 0.71, 0.78; 1.00)]	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]

Table 3.18: Computed fuzzy rating and aggregated fuzzy priority weight of lean attributes

Leanness Attribute (C_{ij})	Aggregated weight of lean attributes ($W_{i,j}$)	Computed rating of lean attribute ($U_{i,i}$)
$C_{1,1}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.68, 0.79, 1.07, 1.20; 0.80), (0.68, 0.79, 1.07, 1.20; 1.00)]
$C_{1,2}$	[(0.83, 0.87, 0.95, 0.98, 0.80), (0.83, 0.87, 0.95, 0.98, 1.00)]	[(0.49, 0.60, 0.92, 1.08; 0.80), (0.49, 0.60, 0.92, 1.08; 1.00)]
$C_{2,1}$	[(0.61, 0.66, 0.82, 0.88; 0.80), (0.61, 0.66, 0.82, 0.88; 1.00)]	[(0.60, 0.69, 0.98, 1.10; 0.80), (0.60, 0.69, 0.98, 1.10; 1.00)]
$C_{2,2}$	[(0.82, 0.87, 0.94, 0.97; 0.80), (0.82, 0.87, 0.94, 0.97; 1.00)]	[(0.50, 0.65, 1.16, 1.45; 0.80), (0.50, 0.65, 1.16, 1.45; 1.00)]
$C_{2,3}$	[(0.78, 0.82, 0.94, 0.98; 0.80), (0.78, 0.82, 0.94, 0.98; 1.00)]	[(0.50, 0.60, 0.92, 1.09; 0.80), (0.50, 0.60, 0.92, 1.09; 1.00)]
$C_{2,4}$	[(0.56, 0.62, 0.78, 0.84; 0.80), (0.56, 0.62, 0.78, 0.84; 1.00)]	[(0.64, 0.76, 1.11, 1.29; 0.80), (0.64, 0.76, 1.11, 1.29; 1.00)]
$C_{2,5}$	[(0.89, 0.91, 0.97, 0.99; 0.80), (0.89, 0.91, 0.97, 0.99; 1.00)]	[(0.33, 0.43, 0.78, 0.97; 0.80), (0.33, 0.43, 0.78, 0.97; 1.00)]

$C_{2,6}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.66, 0.77, 1.09, 1.25; 0.80), (0.66, 0.77, 1.09, 1.25; 1.00)]
$C_{2,7}$	[(0.92, 0.95, 0.98, 0.99; 0.80), (0.92, 0.95, 0.98, 0.99; 1.00)]	[(0.65, 0.77, 1.08, 1.24; 0.80), (0.65, 0.77, 1.08, 1.24; 1.00)]
$C_{2,8}$	[(0.75, 0.80, 0.90, 0.94; 0.80), (0.75, 0.80, 0.90, 0.94; 1.00)]	[(0.50, 0.62, 0.95, 1.13; 0.80), (0.50, 0.62, 0.95, 1.13; 1.00)]
$C_{2,9}$	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]	[(0.54, 0.67, 1.12, 1.34; 0.80), (0.54, 0.67, 1.12, 1.34; 1.00)]
$C_{2,10}$	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]	[(0.21, 0.29, 0.50, 0.60; 0.80), (0.21, 0.29, 0.50, 0.60; 1.00)]
$C_{3,1}$	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.45, 0.55, 0.85, 1.02; 0.80), (0.45, 0.55, 0.85, 1.02; 1.00)]
$C_{3,2}$	[(0.69, 0.75, 0.90, 0.95; 0.80), (0.69, 0.75, 0.90, 0.95; 1.00)]	[(0.67, 0.80, 1.13, 1.30; 0.80), (0.67, 0.80, 1.13, 1.30; 1.00)]
$C_{4,1}$	[(0.86, 0.90, 0.97, 0.99; 0.80), (0.86, 0.90, 0.97, 0.99; 1.00)]	[(0.56, 0.67, 1.02, 1.19; 0.80), (0.56, 0.67, 1.02, 1.19; 1.00)]
$C_{4,2}$	[(0.93, 0.98, 1.00, 1.00; 0.80), (0.93, 0.98, 1.00, 1.00; 1.00)]	[(0.69, 0.80, 1.09, 1.22; 0.80), (0.69, 0.80, 1.09, 1.22; 1.00)]
$C_{4,3}$	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]	[(0.55, 0.66, 0.98, 1.15; 0.80), (0.55, 0.66, 0.98, 1.15; 1.00)]
$C_{4,4}$	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]	[(0.35, 0.45, 0.76, 0.94; 0.80), (0.35, 0.45, 0.76, 0.94; 1.00)]
$C_{4,5}$	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.47, 0.57, 0.78, 0.90; 0.80), (0.47, 0.57, 0.78, 0.90; 1.00)]
$C_{4,6}$	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]	[(0.60, 0.73, 1.10, 1.30; 0.80), (0.60, 0.73, 1.10, 1.30; 1.00)]
$C_{4,7}$	[(0.78, 0.82, 0.94, 0.98; 0.80), (0.78, 0.82, 0.94, 0.98; 1.00)]	[(0.48, 0.62, 1.11, 1.39; 0.80), (0.48, 0.62, 1.11, 1.39; 1.00)]
$C_{4,8}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.51, 0.62, 0.93, 1.09; 0.80), (0.51, 0.62, 0.93, 1.09; 1.00)]
$C_{4,9}$	[(0.78, 0.83, 0.93, 0.96; 0.80), (0.78, 0.83, 0.93, 0.96; 1.00)]	[(0.53, 0.64, 1.00, 1.19; 0.80), (0.53, 0.64, 1.00, 1.19; 1.00)]
$C_{5,1}$	[(0.76, 0.82, 0.94, 0.98; 0.80), (0.76, 0.82, 0.94, 0.98; 1.00)]	[(0.67, 0.79, 1.09, 1.24; 0.80), (0.67, 0.79, 1.09, 1.24; 1.00)]
$C_{5,2}$	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]	[(0.25, 0.33, 0.61, 0.76; 0.80), (0.25, 0.33, 0.61, 0.76; 1.00)]
$C_{5,3}$	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.58, 0.69, 1.03, 1.19; 0.80), (0.58, 0.69, 1.03, 1.19; 1.00)]
$C_{5,4}$	[(0.83, 0.87, 0.95, 0.98; 0.80), (0.83, 0.87, 0.95, 0.98; 1.00)]	[(0.58, 0.68, 0.98, 1.13; 0.80), (0.58, 0.68, 0.98, 1.13; 1.00)]
$C_{5,5}$	[(0.89, 0.94, 0.98, 0.99; 0.80), (0.89, 0.94, 0.98, 0.99; 1.00)]	[(0.39, 0.50, 0.85, 1.04; 0.80), (0.39, 0.50, 0.85, 1.04; 1.00)]
$C_{5,6}$	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.32, 0.41, 0.66, 0.79; 0.80), (0.32, 0.41, 0.66, 0.79; 1.00)]
$C_{5,7}$	[(0.80, 0.86, 0.95, 0.98; 0.80), (0.80, 0.86, 0.95, 0.98; 1.00)]	[(0.55, 0.65, 0.93, 1.08; 0.80), (0.55, 0.65, 0.93, 1.08; 1.00)]

Table 3.19: Computed fuzzy rating and aggregated fuzzy priority weight of lean capabilities

Lean Enablers (C_i)	Aggregate weight of lean enablers (W_i)	Computed rating of lean enablers (U_i)
C_1	[(0.85, 0.90, 0.97, 0.99; 0.80), (0.85, 0.90, 0.97, 0.99; 1.00)]	[(0.46, 0.61, 1.13, 1.44; 0.80), (0.46, 0.61, 1.13, 1.44; 1.00)]
C_2	[(0.99, 1.00, 1.00, 1.00; 0.80), (0.99, 1.00, 1.00, 1.00; 1.00)]	[(0.40, 0.55, 1.09, 1.43; 0.80), (0.40, 0.55, 1.09, 1.43; 1.00)]
C_3	[(0.72, 0.78, 0.92, 0.97; 0.80), (0.72, 0.78, 0.92, 0.97; 1.00)]	[(0.44, 0.58, 1.11, 1.46; 0.80), (0.44, 0.58, 1.11, 1.46; 1.00)]
C_4	[(0.71, 0.76, 0.89, 0.93; 0.80), (0.71, 0.76, 0.89, 0.93; 1.00)]	[(0.44, 0.59, 1.07, 1.38; 0.80), (0.44, 0.59, 1.07, 1.38; 1.00)]
C_5	[(0.87, 0.91, 0.97, 0.99; 0.80), (0.87, 0.91, 0.97, 0.99; 1.00)]	[(0.39, 0.53, 0.96, 1.24; 0.80), (0.39, 0.53, 0.96, 1.24; 1.00)]

Table 3.20: Computation of FPII of various lean criterions

Leanness Criterions $C_{i,j,k}$	$w'_{i,j,k} = [(1,1,1,1;1) - w_{i,j,k}]$	Fuzzy Performance Importance Index (FPII) $w'_{i,j,k} \otimes U_{i,j,k}$
$C_{1,1,1}$	[(0.000, 0.000, 0.008, 0.028; 0.800), (0.000, 0.000, 0.008, 0.028; 1.000)]	[(0.000, 0.000, 0.008, 0.028; 0.800), (0.000, 0.000, 0.008, 0.028; 1.000)]
$C_{1,1,2}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.022, 0.062, 0.202, 0.272; 0.800), (0.022, 0.062, 0.202, 0.272; 1.000)]
$C_{1,1,3}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.044, 0.094, 0.242, 0.304; 0.800), (0.044, 0.094, 0.242, 0.304; 1.000)]
$C_{1,2,1}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.045, 0.084, 0.231, 0.296; 0.800), (0.045, 0.084, 0.231, 0.296; 1.000)]
$C_{1,2,2}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.013, 0.050; 0.800), (0.000, 0.000, 0.013, 0.050; 1.000)]
$C_{1,2,3}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.027, 0.075, 0.216, 0.278; 0.800), (0.027, 0.075, 0.216, 0.278; 1.000)]
$C_{2,1,1}$	[(0.096, 0.152, 0.310, 0.364; 0.800), (0.096, 0.152, 0.310, 0.364; 1.000)]	[(0.064, 0.109, 0.270, 0.337; 0.800), (0.064, 0.109, 0.270, 0.337; 1.000)]
$C_{2,1,2}$	[(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)]	[(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)]
$C_{2,2,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.022, 0.062, 0.202, 0.272; 0.800), (0.022, 0.062, 0.202, 0.272; 1.000)]
$C_{2,2,2}$	[(0.312, 0.376, 0.540, 0.606; 0.800), (0.312, 0.376, 0.540, 0.606; 1.000)]	[(0.251, 0.323, 0.514, 0.595; 0.800), (0.251, 0.323, 0.514, 0.595; 1.000)]
$C_{2,3,1}$	[(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)]	[(0.010, 0.029, 0.106, 0.161; 0.800), (0.010, 0.029, 0.106, 0.161; 1.000)]
$C_{2,3,2}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.017, 0.050, 0.176, 0.241; 0.800), (0.017, 0.050, 0.176, 0.241; 1.000)]
$C_{2,3,3}$	[(0.012, 0.032, 0.096, 0.140; 0.800), (0.012, 0.032, 0.096, 0.140; 1.000)]	[(0.009, 0.025, 0.088, 0.136; 0.800), (0.009, 0.025, 0.088, 0.136; 1.000)]
$C_{2,4,1}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.051, 0.103, 0.250, 0.308; 0.800), (0.051, 0.103, 0.250, 0.308; 1.000)]
$C_{2,4,2}$	[(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)]	[(0.013, 0.037, 0.129, 0.190; 0.800), (0.013, 0.037, 0.129, 0.190; 1.000)]
$C_{2,4,3}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.025, 0.072, 0.213, 0.277; 0.800), (0.025, 0.072, 0.213, 0.277; 1.000)]
$C_{2,5,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.011, 0.036, 0.137, 0.194; 0.800), (0.011, 0.036, 0.137, 0.194; 1.000)]
$C_{2,5,2}$	[(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)]	[(0.005, 0.016, 0.069, 0.109; 0.800), (0.005, 0.016, 0.069, 0.109; 1.000)]
$C_{2,5,3}$	[(0.096, 0.152, 0.310, 0.364; 0.800), (0.096, 0.152, 0.310, 0.364; 1.000)]	[(0.069, 0.119, 0.285, 0.353; 0.800), (0.069, 0.119, 0.285, 0.353; 1.000)]
$C_{2,6,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.022, 0.062, 0.202, 0.272; 0.800), (0.022, 0.062, 0.202, 0.272; 1.000)]
$C_{2,6,2}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]
$C_{2,6,3}$	[(0.012, 0.032, 0.096, 0.140; 0.800), (0.012, 0.032, 0.096, 0.140; 1.000)]	[(0.010, 0.028, 0.091, 0.137; 0.800), (0.010, 0.028, 0.091, 0.137; 1.000)]
$C_{2,7,1}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.040, 0.085, 0.234, 0.301; 0.800), (0.040, 0.085, 0.234, 0.301; 1.000)]
$C_{2,7,2}$	[(0.012, 0.032, 0.100, 0.154; 0.800), (0.012, 0.032, 0.100, 0.154; 1.000)]	[(0.010, 0.029, 0.097, 0.152; 0.800), (0.010, 0.029, 0.097, 0.152; 1.000)]
$C_{2,8,1}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.025, 0.056, 0.178, 0.239; 0.800), (0.025, 0.056, 0.178, 0.239; 1.000)]
$C_{2,8,2}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.053, 0.100, 0.258, 0.326; 0.800), (0.053, 0.100, 0.258, 0.326; 1.000)]
$C_{2,8,3}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.018, 0.066; 0.800), (0.000, 0.000, 0.018, 0.066; 1.000)]
$C_{2,9,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.023, 0.066, 0.206, 0.273; 0.800), (0.023, 0.066, 0.206, 0.273; 1.000)]
$C_{2,9,2}$	[(0.096, 0.152, 0.310, 0.364; 0.800), (0.096, 0.152, 0.310, 0.364; 1.000)]	[(0.069, 0.119, 0.285, 0.353; 0.800), (0.069, 0.119, 0.285, 0.353; 1.000)]

$C_{2,10,1}$	[(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)]	[(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)]
$C_{2,10,2}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.005, 0.020, 0.083, 0.122; 0.800), (0.005, 0.020, 0.083, 0.122; 1.000)]
$C_{3,1,1}$	[(0.312, 0.376, 0.540, 0.606; 0.800), (0.312, 0.376, 0.540, 0.606; 1.000)]	[(0.062, 0.097, 0.218, 0.282; 0.800), (0.062, 0.097, 0.218, 0.282; 1.000)]
$C_{3,1,2}$	[(0.024, 0.064, 0.180, 0.238; 0.800), (0.024, 0.064, 0.180, 0.238; 1.000)]	[(0.014, 0.040, 0.144, 0.205; 0.800), (0.014, 0.040, 0.144, 0.205; 1.000)]
$C_{3,1,3}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.018, 0.068; 0.800), (0.000, 0.000, 0.018, 0.068; 1.000)]
$C_{3,2,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.029, 0.079, 0.220, 0.280; 0.800), (0.029, 0.079, 0.220, 0.280; 1.000)]
$C_{3,2,2}$	[(0.024, 0.064, 0.180, 0.238; 0.800), (0.024, 0.064, 0.180, 0.238; 1.000)]	[(0.019, 0.055, 0.171, 0.234; 0.800), (0.019, 0.055, 0.171, 0.234; 1.000)]
$C_{4,1,1}$	[(0.096, 0.152, 0.310, 0.364; 0.800), (0.096, 0.152, 0.310, 0.364; 1.000)]	[(0.073, 0.125, 0.290, 0.355; 0.800), (0.073, 0.125, 0.290, 0.355; 1.000)]
$C_{4,1,2}$	[(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)]	[(0.000, 0.000, 0.000, 0.000; 0.800), (0.000, 0.000, 0.000, 0.000; 1.000)]
$C_{4,1,3}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.014, 0.043, 0.157, 0.217; 0.800), (0.014, 0.043, 0.157, 0.217; 1.000)]
$C_{4,1,4}$	[(0.270, 0.332, 0.496, 0.554; 0.800), (0.270, 0.332, 0.496, 0.554; 1.000)]	[(0.194, 0.259, 0.456, 0.537; 0.800), (0.194, 0.259, 0.456, 0.537; 1.000)]
$C_{4,2,1}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.072, 0.127, 0.280, 0.336; 0.800), (0.072, 0.127, 0.280, 0.336; 1.000)]
$C_{4,2,2}$	[(0.024, 0.064, 0.180, 0.238; 0.800), (0.024, 0.064, 0.180, 0.238; 1.000)]	[(0.017, 0.050, 0.166, 0.231; 0.800), (0.017, 0.050, 0.166, 0.231; 1.000)]
$C_{4,2,3}$	[(0.006, 0.016, 0.052, 0.084; 0.800), (0.006, 0.016, 0.052, 0.084; 1.000)]	[(0.005, 0.015, 0.051, 0.083; 0.800), (0.005, 0.015, 0.051, 0.083; 1.000)]
$C_{4,3,1}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.045, 0.094, 0.242, 0.304; 0.800), (0.045, 0.094, 0.242, 0.304; 1.000)]
$C_{4,3,2}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.035, 0.069, 0.199, 0.261; 0.800), (0.035, 0.069, 0.199, 0.261; 1.000)]
$C_{4,3,3}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.018, 0.068; 0.800), (0.000, 0.000, 0.018, 0.068; 1.000)]
$C_{4,4,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.020, 0.058, 0.192, 0.259; 0.800), (0.020, 0.058, 0.192, 0.259; 1.000)]
$C_{4,4,2}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.037, 0.081, 0.230, 0.299; 0.800), (0.037, 0.081, 0.230, 0.299; 1.000)]
$C_{4,4,3}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.021, 0.048, 0.150, 0.203; 0.800), (0.021, 0.048, 0.150, 0.203; 1.000)]
$C_{4,4,4}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.008, 0.031; 0.800), (0.000, 0.000, 0.008, 0.031; 1.000)]
$C_{4,5,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.006, 0.021, 0.089, 0.130; 0.800), (0.006, 0.021, 0.089, 0.130; 1.000)]
$C_{4,5,2}$	[(0.006, 0.016, 0.060, 0.112; 0.800), (0.006, 0.016, 0.060, 0.112; 1.000)]	[(0.005, 0.015, 0.059, 0.111; 0.800), (0.005, 0.015, 0.059, 0.111; 1.000)]
$C_{4,6,1}$	[(0.202, 0.264, 0.428, 0.496; 0.800), (0.202, 0.264, 0.428, 0.496; 1.000)]	[(0.145, 0.206, 0.394, 0.481; 0.800), (0.145, 0.206, 0.394, 0.481; 1.000)]
$C_{4,6,2}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.071, 0.126, 0.280, 0.336; 0.800), (0.071, 0.126, 0.280, 0.336; 1.000)]
$C_{4,6,3}$	[(0.006, 0.016, 0.060, 0.112; 0.800), (0.006, 0.016, 0.060, 0.112; 1.000)]	[(0.004, 0.012, 0.055, 0.109; 0.800), (0.004, 0.012, 0.055, 0.109; 1.000)]
$C_{4,7,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.025, 0.072, 0.213, 0.277; 0.800), (0.025, 0.072, 0.213, 0.277; 1.000)]
$C_{4,7,2}$	[(0.396, 0.464, 0.628, 0.710; 0.800), (0.396, 0.464, 0.628, 0.710; 1.000)]	[(0.241, 0.306, 0.517, 0.626; 0.800), (0.241, 0.306, 0.517, 0.626; 1.000)]
$C_{4,7,3}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.047, 0.088, 0.237, 0.304; 0.800), (0.047, 0.088, 0.237, 0.304; 1.000)]
$C_{4,8,1}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.019, 0.047, 0.156, 0.213; 0.800), (0.019, 0.047, 0.156, 0.213; 1.000)]
$C_{4,8,2}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.047, 0.088, 0.237, 0.304; 0.800), (0.047, 0.088, 0.237, 0.304; 1.000)]
$C_{4,8,3}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.019, 0.069; 0.800), (0.000, 0.000, 0.019, 0.069; 1.000)]
$C_{4,9,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.014, 0.043, 0.157, 0.217; 0.800), (0.014, 0.043, 0.157, 0.217; 1.000)]
$C_{4,9,2}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.053, 0.100, 0.258, 0.326; 0.800), (0.053, 0.100, 0.258, 0.326; 1.000)]

$C_{4,9,3}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.049, 0.092, 0.244, 0.311; 0.800), (0.049, 0.092, 0.244, 0.311; 1.000)]
$C_{4,9,4}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.019, 0.069; 0.800), (0.000, 0.000, 0.019, 0.069; 1.000)]
$C_{4,9,5}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.021, 0.060, 0.197, 0.265; 0.800), (0.021, 0.060, 0.197, 0.265; 1.000)]
$C_{5,1,1}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.050, 0.103, 0.250, 0.308; 0.800), (0.050, 0.103, 0.250, 0.308; 1.000)]
$C_{5,1,2}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.053, 0.100, 0.258, 0.326; 0.800), (0.053, 0.100, 0.258, 0.326; 1.000)]
$C_{5,1,3}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.019, 0.069; 0.800), (0.000, 0.000, 0.019, 0.069; 1.000)]
$C_{5,2,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.018, 0.053, 0.181, 0.247; 0.800), (0.018, 0.053, 0.181, 0.247; 1.000)]
$C_{5,2,2}$	[(0.024, 0.064, 0.180, 0.238; 0.800), (0.024, 0.064, 0.180, 0.238; 1.000)]	[(0.004, 0.016, 0.068, 0.104; 0.800), (0.004, 0.016, 0.068, 0.104; 1.000)]
$C_{5,2,3}$	[(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)]	[(0.004, 0.012, 0.057, 0.091; 0.800), (0.004, 0.012, 0.057, 0.091; 1.000)]
$C_{5,3,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.028, 0.078, 0.220, 0.280; 0.800), (0.028, 0.078, 0.220, 0.280; 1.000)]
$C_{5,3,2}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.040, 0.085, 0.234, 0.301; 0.800), (0.040, 0.085, 0.234, 0.301; 1.000)]
$C_{5,3,3}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.064, 0.116, 0.271, 0.332; 0.800), (0.064, 0.116, 0.271, 0.332; 1.000)]
$C_{5,3,4}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.014, 0.054; 0.800), (0.000, 0.000, 0.014, 0.054; 1.000)]
$C_{5,4,1}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.022, 0.062, 0.202, 0.272; 0.800), (0.022, 0.062, 0.202, 0.272; 1.000)]
$C_{5,4,2}$	[(0.000, 0.000, 0.020, 0.070; 0.800), (0.000, 0.000, 0.020, 0.070; 1.000)]	[(0.000, 0.000, 0.017, 0.065; 0.800), (0.000, 0.000, 0.017, 0.065; 1.000)]
$C_{5,5,1}$	[(0.024, 0.064, 0.180, 0.238; 0.800), (0.024, 0.064, 0.180, 0.238; 1.000)]	[(0.017, 0.050, 0.166, 0.231; 0.800), (0.017, 0.050, 0.166, 0.231; 1.000)]
$C_{5,5,2}$	[(0.052, 0.104, 0.250, 0.308; 0.800), (0.052, 0.104, 0.250, 0.308; 1.000)]	[(0.015, 0.039, 0.134, 0.186; 0.800), (0.015, 0.039, 0.134, 0.186; 1.000)]
$C_{5,6,1}$	[(0.074, 0.128, 0.280, 0.336; 0.800), (0.074, 0.128, 0.280, 0.336; 1.000)]	[(0.011, 0.029, 0.095, 0.134; 0.800), (0.011, 0.029, 0.095, 0.134; 1.000)]
$C_{5,6,2}$	[(0.006, 0.016, 0.060, 0.112; 0.800), (0.006, 0.016, 0.060, 0.112; 1.000)]	[(0.001, 0.004, 0.024, 0.052; 0.800), (0.001, 0.004, 0.024, 0.052; 1.000)]
$C_{5,6,3}$	[(0.030, 0.080, 0.220, 0.280; 0.800), (0.030, 0.080, 0.220, 0.280; 1.000)]	[(0.027, 0.075, 0.216, 0.278; 0.800), (0.027, 0.075, 0.216, 0.278; 1.000)]
$C_{5,7,1}$	[(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)]	[(0.015, 0.043, 0.136, 0.194; 0.800), (0.015, 0.043, 0.136, 0.194; 0.800)]
$C_{5,7,2}$	[(0.018, 0.048, 0.140, 0.196; 0.800), (0.018, 0.048, 0.140, 0.196; 1.000)]	[(0.009, 0.026, 0.100, 0.152; 0.800), (0.009, 0.026, 0.100, 0.152; 1.000)]

Table 3.21: Lean criteria ranking based on 'Degree of Similarity' concept

Leanness Criterions ($C_{i,j,k}$)	Degree of Similarity with respect to ideal FPII	Ranking order
$C_{1,1,1}$	0.6382	66
$C_{1,1,2}$	0.7769	27
$C_{1,1,3}$	0.8003	15
$C_{1,2,1}$	0.7936	19
$C_{1,2,2}$	0.6441	65
$C_{1,2,3}$	0.7839	24
$C_{2,1,1}$	0.8184	10
$C_{2,1,2}$	0.4028	68
$C_{2,2,1}$	0.7769	27
$C_{2,2,2}$	0.9864	2
$C_{2,3,1}$	0.7199	44
$C_{2,3,2}$	0.7599	33
$C_{2,3,3}$	0.7068	49
$C_{2,4,1}$	0.8048	12
$C_{2,4,2}$	0.7353	42
$C_{2,4,3}$	0.7822	25
$C_{2,5,1}$	0.7356	41
$C_{2,5,2}$	0.6935	52
$C_{2,5,3}$	0.8281	6
$C_{2,6,1}$	0.7769	27
$C_{2,6,2}$	0.7860	21
$C_{2,6,3}$	0.7085	47
$C_{2,7,1}$	0.7962	17
$C_{2,7,2}$	0.7127	46
$C_{2,8,1}$	0.7608	32
$C_{2,8,2}$	0.8111	11
$C_{2,8,3}$	0.6507	62
$C_{2,9,1}$	0.7787	26
$C_{2,9,2}$	0.8281	6
$C_{2,10,1}$	0.4028	68

$C_{2,10,2}$	0.7004	51
$C_{3,1,1}$	0.7919	20
$C_{3,1,2}$	0.7418	39
$C_{3,1,3}$	0.6514	61
$C_{3,2,1}$	0.7859	22
$C_{3,2,2}$	0.7589	34
$C_{4,1,1}$	0.8308	5
$C_{4,1,2}$	0.4028	68
$C_{4,1,3}$	0.7477	36
$C_{4,1,4}$	0.9452	3
$C_{4,2,1}$	0.8235	7
$C_{4,2,2}$	0.7560	35
$C_{4,2,3}$	0.6788	57
$C_{4,3,1}$	0.8004	15
$C_{4,3,2}$	0.7738	28
$C_{4,3,3}$	0.6514	61
$C_{4,4,1}$	0.7701	30
$C_{4,4,2}$	0.7941	18
$C_{4,4,3}$	0.7427	38
$C_{4,4,4}$	0.6364	67
$C_{4,5,1}$	0.7038	50
$C_{4,5,2}$	0.6855	54
$C_{4,6,1}$	0.9076	4
$C_{4,6,2}$	0.8234	8
$C_{4,6,3}$	0.6830	56
$C_{4,7,1}$	0.7822	25
$C_{4,7,2}$	0.9951	1
$C_{4,7,3}$	0.7980	16
$C_{4,8,1}$	0.7470	37
$C_{4,8,2}$	0.7980	16
$C_{4,8,3}$	0.6526	59
$C_{4,9,1}$	0.7477	36
$C_{4,9,2}$	0.8111	11
$C_{4,9,3}$	0.8024	14

$C_{4,9,4}$	0.6522	60
$C_{4,9,5}$	0.7735	29
$C_{5,1,1}$	0.8047	13
$C_{5,1,2}$	0.8111	11
$C_{5,1,3}$	0.6526	59
$C_{5,2,1}$	0.7633	31
$C_{5,2,2}$	0.6922	53
$C_{5,2,3}$	0.6847	55
$C_{5,3,1}$	0.7856	23
$C_{5,3,2}$	0.7962	17
$C_{5,3,3}$	0.8185	9
$C_{5,3,4}$	0.6459	64
$C_{5,4,1}$	0.7769	27
$C_{5,4,2}$	0.6501	63
$C_{5,5,1}$	0.7560	35
$C_{5,5,2}$	0.7329	43
$C_{5,6,1}$	0.7080	48
$C_{5,6,2}$	0.6571	58
$C_{5,6,3}$	0.7839	24
$C_{5,7,1}$	0.7389	40
$C_{5,7,2}$	0.7154	45

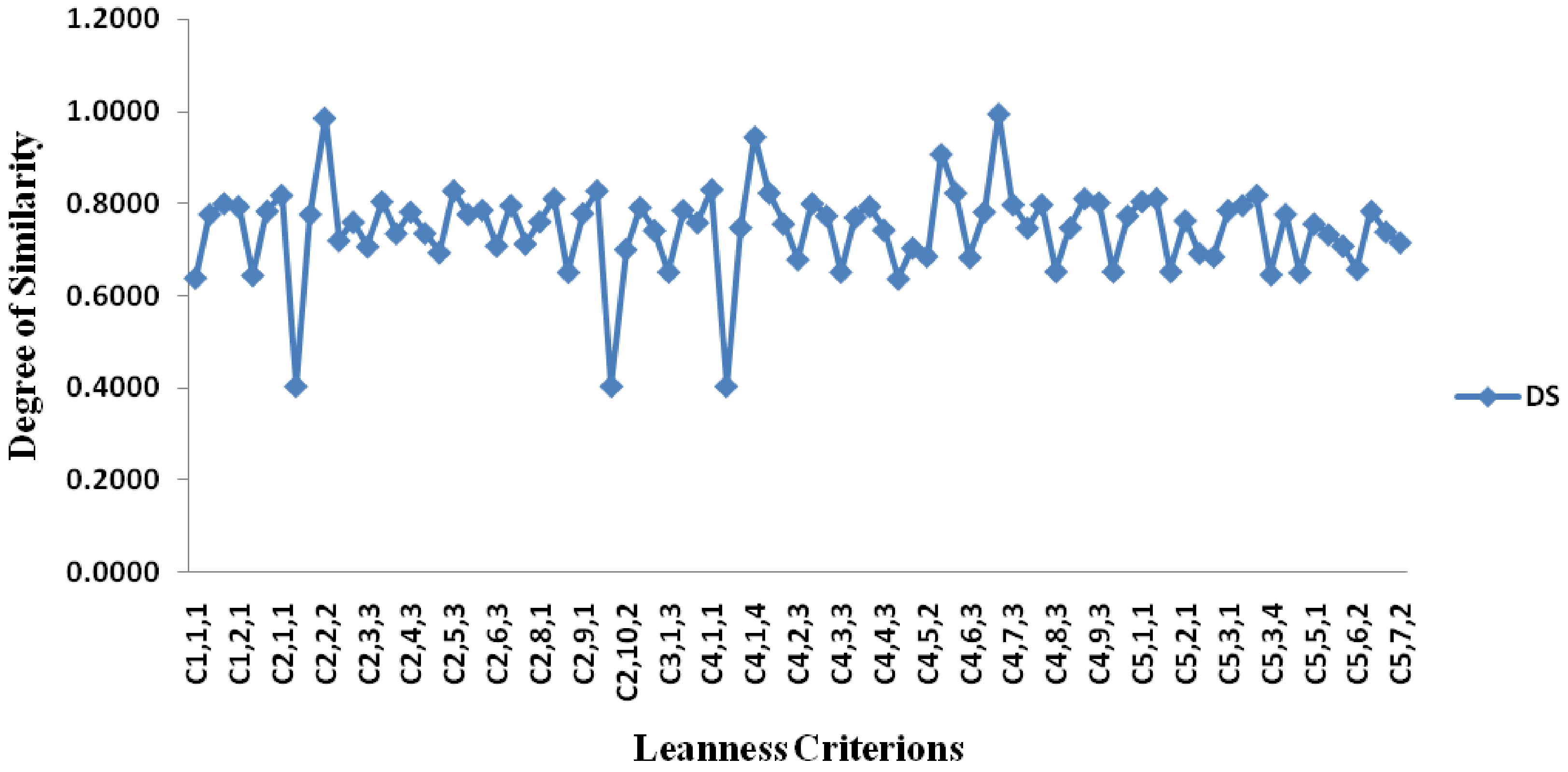

Fig. 3.3: Lean criteria ranking based on 'Degree of Similarity'

3.2 Leanness Metric Evaluation in Grey Context

3.2.1 Coverage

The present work exhibits an efficient grey-based leanness assessment system using concept of grey numbers theory. Such leanness estimation can help the enterprises to assess their existing leanness level; can compare different industries who are adapting this lean concept. Lean extent evaluation module (lean index appraisement system) exploring grey numbers theory is quite new and not documented in literature before.

The manufacturing organizations are recently witnessing a transition from mass manufacturing to lean manufacturing paradigm. Lean practices are mainly characterized by the elimination of obvious wastes generated in the manufacturing process, thereby, facilitating cost reduction. Lean implementation requires quantitative measurement of overall 'leanness extent' followed by identification of obstacles towards effective lean achievement.

An integrated structured evaluation model followed by an appraisement platform (methodological hierarchy) is seemed essential to quantify an equivalent lean performance index. The factors that enhance leanness can be categorized as lean enablers/capabilities, lean attributes followed by lean criterions. Elements of this hierarchical order are assumed to be correlated (interactive), thereby, influencing overall performance degree towards lean revolution. In general, most of the capabilities-attributes as well as criterions are subjective in nature and therefore, appropriateness rating (performance extent) and corresponding priority weights cannot be evaluated by exact numeric score. Therefore, assignment of priority weight as well as appropriateness rating seeks expert opinion of decision-makers (DMs). The situation may be viewed as a Multi-Criteria Group Decision-Making (MCGDM); linguistic variables are to be utilized to represent DMs subjective judgment towards qualitative evaluation criteria along with associated importance weights. Fuzzy logic has been found efficient in dealing with such types of subjective evaluation by representing linguistic variables into fuzzy numbers. Literature reveals that estimation of lean practices has been attempted to a remarkable extent by pioneer researchers mostly in fuzzy environment.

Apart from fuzzy logic, grey relation theory (Chen et al., 2008; Zhu et al., 2007; Huang, 2011; Fong and Wei, 2007; Guo et al., 2011) has the capability to deal with incomplete, inconsistent and vague information against subjective evaluation criteria. Successful application of grey theory (exploration of grey numbers) has been found in literature (Li et al., 2007; Li et al., 2008; Xu and Sasaki; 2004; Jadidi et al., 2008) in a variety of decision-making situations. Therefore, grey numbers theory has been adapted in this part of work to facilitate such a decision-modeling in lean manufacturing context. The grey based appraisement platform presented here yields an overall grey performance index towards lean manufacturing implementation in organizational supply chain and helps to identify week performing areas for future improvement. The proposed appraisement index system has been case empirically investigated.

3.2.2 The Concept of Grey Numbers

Grey theory (Deng, 1982), originally developed by *Prof. Deng* in 1982, has become a very effective method of solving uncertainty problems under discrete data and incomplete information. Grey theory is now being applied to various areas such as forecasting, system control, decision-making and computer graphics. Here, we give some basic definitions regarding relevant mathematical background of grey system, grey set and grey number in grey theory.

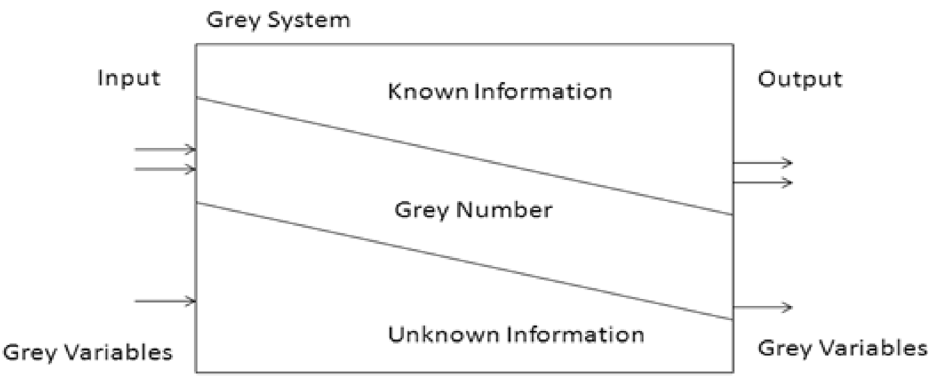

Fig. 3.4: Concept of grey system

Definition 1: A grey system (Xia, 2000) is defined as a system containing uncertain information presented by grey number and grey variables. The concept of grey system is shown in Fig. 3.4.

Definition 2: Let X be the universal set. Then a grey set G of X is defined by its two mappings

$$\begin{cases} \overline{\mu}_G(x):\ x \rightarrow [0,1] \\ \underline{\mu}_G(x):\ x \rightarrow [0,1] \end{cases} \tag{3.42}$$

$\overline{\mu}_G(x) \geq \underline{\mu}_G(x), x \in X,\ X = R,\ \overline{\mu}_G(x)$ and $\underline{\mu}_G(x)$ are the upper and lower membership functions in G respectively. When $\overline{\mu}_G(x) = \underline{\mu}_G(x)$, the grey set G becomes a fuzzy set. It shows that grey theory considers the condition of fuzziness and can flexibly deal with the fuzziness situation.

Definition 3: A grey number is one of which the exact value is unknown, while the upper and/or the lower limits can be estimated. Generally grey number is written as $\left(\otimes G = G\big|_{\underline{\mu}}^{\overline{\mu}}\right)$.

Definition 4: If only the lower limit of G can be possibly estimated and G is defined as lower limit grey number.

$$\otimes G = \left[\underline{G}, \infty\right] \tag{3.43}$$

Definition 5: If only the upper limit of G can be possibly estimated and G is defined as lower limit grey number.

$$\otimes G = \left[-\infty, G\right] \tag{3.44}$$

Definition 6: If the lower and upper limits of G can be estimated and G is defined as interval grey number.

$$\otimes G = \left[\underline{G}, \overline{G}\right] \tag{3.45}$$

Definition 7: The basic operations of grey numbers $\otimes G_1 = \left[\underline{G}_1, \overline{G}_1\right]$ and $\otimes G_2 = \left[\underline{G}_2, \overline{G}_2\right]$ can be expressed as follows:

$$\otimes G_1 + \otimes G_2 = \left[\underline{G}_1 + \underline{G}_2, \overline{G}_1 + \overline{G}_2\right] \tag{3.46}$$

$$\otimes G_1 - \otimes G_2 = \left[\underline{G}_1 - \underline{G}_2, \overline{G}_1 - \overline{G}_2\right] \tag{3.47}$$

$$\begin{aligned} &\otimes G_1 \times \otimes G_2 = \left[\underline{G}_1, \overline{G}_1\right] \times \left[\underline{G}_2, \overline{G}_2\right] = \\ &\left[Min.\left(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\overline{G}_2\right), Max.\left(\underline{G}_1\underline{G}_2, \underline{G}_1\overline{G}_2, \overline{G}_1\underline{G}_2, \overline{G}_1\overline{G}_2\right)\right] \end{aligned} \tag{3.48}$$

$$\otimes G_1 \div \otimes G_2 = \left[\underline{G}_1, \overline{G}_1\right] \times \left[\frac{1}{\underline{G}_2}, \frac{1}{\overline{G}_2}\right] \tag{3.49}$$

Definition 8: The length of grey number $\otimes G$ is defined as:

$$L(\otimes G) = \left[\overline{G} - \underline{G}\right] \tag{3.50}$$

Grey possibility degree is utilized to compare the ranking of grey numbers.

Definition 9: For two grey numbers $\otimes G_1 = [\underline{G}_1, \overline{G}_1]$ and $\otimes G_2 = [\underline{G}_2, \overline{G}_2]$, the possibility degree of $\otimes G_1 \leq \otimes G_2$ can be expressed as follows (Shi et al., 2005):

$$P\{\otimes G_1 \leq \otimes G_2\} = \frac{Max.(0, \overline{G}_1 - \underline{G}_2)}{L^*} \tag{3.51}$$

Here, $L^* = L(\otimes G_1) + L(\otimes G_2)$.

For the position relationship between $\otimes G_1$ and $\otimes G_2$, there exists four possible cases on the real number axis. The relationship between $\otimes G_1$ and $\otimes G_2$ are determined as follows:

A. If $\underline{G}_1 = \underline{G}_2$ and $\overline{G}_1 = \overline{G}_2$, we say that $\otimes G_1 = \otimes G_2$ .Then $P\{\otimes G_1 \leq \otimes G_2\} = 0.5$.

B. If $\underline{G}_2 = \overline{G}_1$, we say that $\otimes G_2$ is larger than $\otimes G_1$, denoted as $\otimes G_2 > \otimes G_1$.
   Then $P\{\otimes G_1 \leq \otimes G_2\} = 1$.

C. If $\overline{G}_2 < \underline{G}_1$, we say that $\otimes G_2$ is smaller than $\otimes G_1$, denoted as $\otimes G_2 < \otimes G_1$,
   Then $P\{\otimes G_1 \leq \otimes G_2\} = 0$.

D. If there is an intercrossing part in them, when $P\{\otimes G_1 \leq \otimes G_2\} = 0.5$, we say that $\otimes G_2$ is larger than $\otimes G_1$ denoted as $(\otimes G_2 > \otimes G_1)$. When $P\{\otimes G_1 \leq \otimes G_2\} < 0.5$ we say that $\otimes G_2$ is smaller than $\otimes G_1$, denoted as $(\otimes G_2 < \otimes G_1)$.

3.2.3 Lean Metric Appraisement Platform: Case Empirical Research

Leanness evaluation has been made by the procedural framework as described below. The evaluation framework has been explored based on a lean capabler-attribute-criterion hierarchy adapted from the work by (Vinodh and Vimal, 2011).

The leanness evaluation index platform adapted in this paper has been shown in Table 3.1 (already described in Section 3.1.1). The 3-level hierarchical model consists of various lean enablers, following with lean attributes as well as lean criterions. Management responsibility, manufacturing management leanness, workforce leanness, technology leanness and manufacturing strategy leanness have been considered as lean enablers/capabilities at the 1st layer followed by 2nd layer which encompasses a number of lean attributes. The 3rd layer consists of various lean criterions. An approach based on the concept of grey numbers as well as grey possibility degree has been utilized to evaluate an overall leanness metric. In order to deal with subjective performance estimates as well as priority weights of various lean elements (parameters), linguistic variables have been utilized which have been represented further by transforming into grey numbers. Here, these linguistic variables corresponding to priority weight assignment $\otimes w$ have been expressed in grey numbers by 1-7 scale as shown in Table 3.22.1. The criterion ratings $\otimes G$ can be also expressed in grey numbers by 1-7 scale shown in Table 3.22.2. From previous literature it has been observed that grey number may vary in between either [0, 1] or in between [0, 10]. This interval selection depends on the discretion of the decision-making group. Similarly, the linguistic terminology and the total number of linguistic variables in the selected grey interval also depend on the decision-makers. Before exploring grey analysis and subsequent computations aforesaid two aspects must be predefined clearly.

The procedural steps of leanness estimation have been summarized as follows.

Step 1 Determination of the appropriate linguistic scale for assessing the performance ratings of lean criterions and importance weights of lean criterions-attributes-capabilities

The linguistic terms (Tables 3.22.1-3.22.2) have been used to assess the performance ratings and priority weights of lean criteria-attributes since vagueness is associated with individuals' subjective opinion, it is found difficult for the decision-makers to determine the exact numeric score against a vague attribute. In order to assess the performance rating of the lean criterions from Table 3.1 (3rd level indices), the seven linguistic variables {***Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG)***} have been used (Table 3.22.2). Similarly, to assign importance weights (priority degree) of the lean capabilities-attributes and criterions, the linguistic variables {***Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH)***} have been utilized (Table 3.22.1). The linguistic variables have been accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation.

Step 2 Measurement of performance ratings against each of the lean criterions and importance weights of lean capabilities-attributes-criterions using linguistic terms

After the linguistic variables for assessing the performance ratings and importance weights of lean parameters has been accepted by the decision-makers (DMs), the decision-makers have been asked to use aforesaid linguistic scales to assess the performance rating as well as to assign importance weights (Tables 3.23-3.26 in APPENDIX-A).

Step 3 Approximation of the linguistic terms by grey numbers

Decision-makers subjective judgment has been transformed into grey numbers. Assume that a decision-making group has K members; then the criterion weight of criterion Q_j can be calculated as:

$$\otimes w_j = \frac{1}{K}\left[\otimes w_j^1 + \otimes w_j^2 + ... + \otimes w_j^K\right] \tag{3.52}$$

Here $\otimes w_j^K \left(j = 1, 2, ..., n\right)$ is the attribute weight of k_{th} DM and can be described by grey number $\otimes w_j^K = \left[\underline{w}_j^K, \overline{w}_j^K\right]$.

Linguistic variables for the ratings to make attribute rating value have been converted into grey numbers. Then the rating value can be calculated as:

$$\otimes G_{ij} = \frac{1}{K}\left[\otimes G_{ij}^1 + \otimes G_{ij}^2 + ... + \otimes G_{ij}^K\right] \tag{3.53}$$

Here $\otimes G_{ij}^K \left(i = 1, 2, ..., m; j = 1, 2, ..., n\right)$ is the attribute rating value of K_{th} DM and can be described by grey number $\otimes G_{ij}^K = \left[\underline{G}_{ij}^K, \overline{G}_{ij}^K\right]$.

Step 4 Determination of OGPI

OGPI represents *Overall Grey Performance Index*. The grey index has been calculated at the criteria level; then extended to the attribute level and finally to the enabler (capabler) level. Grey index system at 2nd level encompasses several lean attributes.

The grey index of 2nd level green attributes can be calculated as follows:

$$U_{i,j} = \frac{\sum_{k=1}^{n}\left(w_{i,j,k} \otimes U_{i,j,k}\right)}{\sum_{k=1}^{n} w_{i,j,k}} \tag{3.54}$$

Here $U_{i,j,k}$ represents aggregated grey performance measure (rating) and $w_{i,j,k}$ represents aggregated grey weight corresponding to lean criterion $C_{i,j,k}$ which is under j_{th} lean attribute (at 2nd level) and i_{th} lean capability (at 1st level).

The grey index of each lean capability/enabler (at 1st level) has been calculated as follows:

$$U_i = \frac{\sum_{j=1}^{n}\left(w_{i,j} \otimes U_{i,j}\right)}{\sum_{j=1}^{n} w_{i,j}} \tag{3.55}$$

Here $U_{i,j}$ represents computed grey performance measure (rating) obtained using Eq. 3.54 and $w_{i,j}$ represents aggregated grey weight for priority importance corresponding to j_{th} lean attribute $C_{i,j}$ which is under i_{th} lean capability (at 1st level).

Thus, overall grey performance index $U(OGPI)$ has been calculated as follows:

$$U(OGPI) = \frac{\sum_{i=1}^{n}\left(w_i \otimes U_i\right)}{\sum_{i=1}^{n} w_i} \tag{3.56}$$

Here U_i =Computed grey performance rating of i^{th} lean capability C_i (computed by Eq. 3.55); w_i =Aggregated grey weight of i^{th} lean capability, and $i = 1,2,3,...n$.

Aggregated grey performance ratings as well as aggregated weight against each of the lean criterions (at 3rd level) have been shown in Table 3.27. Computed grey appropriateness ratings of different lean attributes (at 2nd level) with corresponding aggregated weight have been furnished in Table 3.28. Similarly computed grey appropriateness ratings of different lean capabilities (at 1st level) with corresponding aggregated weight have been furnished in Table 3.29. Finally, Eq. 3.56 has been explored to calculate overall lean estimate.

Thus, Overall Grey Performance Index (OGPI) becomes:

$$U = \frac{\sum\left(w_i \otimes U_i\right)}{\sum w_i} = [2.58, 18.63]$$

After evaluating OGPI and the organizational existing leanness extent, simultaneously it is also felt indeed necessary to identify and analyze the obstacles (ill-performing areas) for leanness improvement. Grey Performance Importance Index (GPII) may be used to identify these obstacles. GPII combines the performance rating and importance weight of lean criterions. The higher the GPII of a factor, the higher is the contribution. The GPII can be calculated as follows:

$$GPII_{i,j,k} = w'_{i,j,k} \otimes U_{i,j,k} \quad (3.57)$$

Here, $w'_{i,j,k} = \left[(1,1) - w_{i,j,k}\right]$ (3.58)

In this formulation, $U_{i,j,k}$ represent aggregated grey performance measure (rating) and $w_{i,j,k}$ represent aggregated grey weight corresponding to lean criterion $C_{i,j,k}$ which is under j_{th} lean attribute (at 2nd level) and i_{th} lean capability (at 1st level).

GPII need to be ranked to identify individual criterion performance level. Based on that poorly performing criterions are identified and in future, attention must be given to improve those criteria aspects in order to boost up overall leanness degree.

The GPII can be calculated as follows in Eqs. 3.57-3.58. The concept of GPII is similar to the FPII (Fuzzy Performance Importance Index) that was introduced by (Lin et al., 2006) for agility extent measurement in supply chain.

If used directly to calculate the GPII, the importance weights w_{ij} will neutralize the performance ratings in computing GPII; in this case it will become impossible to identify the actual weak areas (low performance rating and high importance). If w_{ij} is high, then the transformation $\left|(1,1) - w_{ij}\right|$ is low. Consequently, to elicit a factor with low performance rating and high importance, for each lean enable-attribute-criterion ijk (k_{th} criterion which is under j_{th} attribute which is included under i_{th} green capability), the grey performance importance index $GPII_{i,j,k}$, indicating the effect of each lean-enable-attribute-criterion that contributes to OGPI, has been defined as:

$$GPII_{i,j,k} = w'_{i,j,k} \otimes U_{i,j,k} \quad (3.59)$$

GPII need to be ranked to identify individual criterion's performance level. Based on that poorly performing attributes can be sorted out and in future, the particular case industry should pay attention towards improving those attribute aspects in order to boost up overall lean performance extent.

Grey Performance Importance Index (GPII) has been computed against each of the lean criterion and furnished in Table 3.30. The concept of 'grey possibility' degree has been explored to identify ill-performing areas towards successful lean implementation practices. Grey possibility degree between GPII of individual lean criterion has thus been computed with reference to the '*ideal GPII*' value [3.31, 5.26]. Lesser value of grey possibility degree corresponds to higher degree of performance. In other words, well performing attributes can be said to contribute more to the overall grey performance estimate. By this way, lean criterions have been ranked accordingly (Table 3.30) and thus, improvement opportunities have been verified.

3.2.4 Concluding Remarks

Lean paradigm has become an important avenue in recent times. Many organizations around the world have been attempting to implement lean concepts. The leanness metric is an important indicator in lean performance measure. Aforesaid study aimed to develop a quantitative analysis framework and a simulation methodology to evaluate the efficacy of lean practices by exploring the concept of grey numbers. The procedural hierarchy presented here could help the industries to assess their existing lean performance extent, to compare and to identify week (ill)-performing areas towards lean implementation successfully.

The proposed appraisement platform of grey numbers has been simulated in a case industry just to evaluate the overall leanness extent. The management should utilize predefined leanness estimate scale to compare with the OGPI thus obtained to check the existing lean performance level. If it is found unsatisfactory, industry should identify lean barriers and think of future improvement. This part is aimed to be examined in future work.

Table 3.22.1: A 7-member linguistic term set and corresponding grey numbers representation for capability/attribute/criteria weights

Scale	$\otimes w$
Very Low (VL)	[0.0, 0.1]
Low (L)	[0.1, 0.3]
Medium Low (ML)	[0.3, 0.4]
Medium (M)	[0.4, 0.5]
Medium High (MH)	[0.5, 0.6]
High (H)	[0.6, 0.9]
Very High (VH)	[0.9, 1.0]

Table 3.22.2: A 7-member linguistic term set and corresponding grey numbers representation for criteria ratings $\otimes$U

Scale	$\otimes$U
Very Poor (VP)	[0, 1]
Poor (P)	[1, 3]
Medium Poor (MP)	[3, 4]
Medium (M)	[4, 5]
Medium Good (MG)	[5, 6]
Good (G)	[6, 9]
Very Good (VG)	[9, 10]

Table 3.27: Aggregated grey priority weight and aggregated grey appropriateness rating of lean criterions

Leanness criterions $C_{i,j,k}$	Weight $w_{i,j,k}$	Aggregated weight expressed in grey numbers	Rating $U_{i,j,k}$	Aggregated rating expressed in grey numbers
$C_{1,1,1}$	$w_{1,1,1}$	(0.72, 0.94)	$U_{1,1,1}$	(9.00, 10.00)
$C_{1,1,2}$	$w_{1,1,2}$	(0.60, 0.90)	$U_{1,1,2}$	(6.00, 9.00)
$C_{1,1,3}$	$w_{1,1,3}$	(0.58, 0.84)	$U_{1,1,3}$	(7.80, 9.60)
$C_{1,2,1}$	$w_{1,2,1}$	(0.56, 0.78)	$U_{1,2,1}$	(5.20, 6.60)
$C_{1,2,2}$	$w_{1,2,2}$	(0.90, 1.00)	$U_{1,2,2}$	(4.20, 5.20)
$C_{1,2,3}$	$w_{1,2,3}$	(0.60, 0.90)	$U_{1,2,3}$	(8.40, 9.80)
$C_{2,1,1}$	$w_{2,1,1}$	(0.54, 0.72)	$U_{2,1,1}$	(5.60, 7.80)
$C_{2,1,2}$	$w_{2,1,2}$	(0.60, 0.90)	$U_{2,1,2}$	(6.00, 9.00)
$C_{2,2,1}$	$w_{2,2,1}$	(0.60, 0.90)	$U_{2,2,1}$	(6.00, 9.00)
$C_{2,2,2}$	$w_{2,2,2}$	(0.44, 0.54)	$U_{2,2,2}$	(7.20, 9.40)
$C_{2,3,1}$	$w_{2,3,1}$	(0.72, 0.94)	$U_{2,3,1}$	(4.80, 6.20)
$C_{2,3,2}$	$w_{2,3,2}$	(0.60, 0.90)	$U_{2,3,2}$	(5.00, 6.00)
$C_{2,3,3}$	$w_{2,3,3}$	(0.72, 0.94)	$U_{2,3,3}$	(6.00, 9.00)
$C_{2,4,1}$	$w_{2,4,1}$	(0.58, 0.84)	$U_{2,4,1}$	(9.00, 10.00)
$C_{2,4,2}$	$w_{2,4,2}$	(0.78, 0.96)	$U_{2,4,2}$	(6.00, 9.00)
$C_{2,4,3}$	$w_{2,4,3}$	(0.60, 0.90)	$U_{2,4,3}$	(8.40, 9.80)
$C_{2,5,1}$	$w_{2,5,1}$	(0.60, 0.90)	$U_{2,5,1}$	(4.20, 5.20)
$C_{2,5,2}$	$w_{2,5,2}$	(0.72, 0.94)	$U_{2,5,2}$	(3.60, 4.60)
$C_{2,5,3}$	$w_{2,5,3}$	(0.54, 0.72)	$U_{2,5,3}$	(6.00, 9.00)
$C_{2,6,1}$	$w_{2,6,1}$	(0.60, 0.90)	$U_{2,6,1}$	(6.00,9.00)
$C_{2,6,2}$	$w_{2,6,2}$	(0.60, 0.90)	$U_{2,6,2}$	(9.00, 10.00)
$C_{2,6,3}$	$w_{2,6,3}$	(0.72, 0.94)	$U_{2,6,3}$	(7.20, 9.40)
$C_{2,7,1}$	$w_{2,7,1}$	(0.58, 0.84)	$U_{2,7,1}$	(6.60, 9.20)
$C_{2,7,2}$	$w_{2,7,2}$	(0.78, 0.96)	$U_{2,7,2}$	(7.80, 9.60)
$C_{2,8,1}$	$w_{2,8,1}$	(0.58, 0.84)	$U_{2,8,1}$	(4.60, 5.60)
$C_{2,8,2}$	$w_{2,8,2}$	(0.56, 0.78)	$U_{2,8,2}$	(6.00, 9.00)
$C_{2,8,3}$	$w_{2,8,3}$	(0.90, 1.00)	$U_{2,8,3}$	(5.60, 7.80)
$C_{2,9,1}$	$w_{2,9,1}$	(0.60, 0.90)	$U_{2,9,1}$	(6.60, 9.20)
$C_{2,9,2}$	$w_{2,9,2}$	(0.54, 0.72)	$U_{2,9,2}$	(6.00, 9.00)
$C_{2,10,1}$	$w_{2,10,1}$	(0.60, 0.90)	$U_{2,10,1}$	(3.80, 4.80)
$C_{2,10,2}$	$w_{2,10,2}$	(0.60, 0.90)	$U_{2,10,2}$	(2.60, 4.00)
$C_{3,1,1}$	$w_{3,1,1}$	(0.44, 0.54)	$U_{3,1,1}$	(3.20, 4.20)
$C_{3,1,2}$	$w_{3,1,2}$	(0.66, 0.92)	$U_{3,1,2}$	(5.00, 6.00)
$C_{3,1,3}$	$w_{3,1,3}$	(0.90, 1.00)	$U_{3,1,3}$	(6.00, 9.00)

$C_{3,2,1}$	$w_{3,2,1}$	(0.60, 0.90)	$U_{3,2,1}$	(7.80, 9.60)
$C_{3,2,2}$	$w_{3,2,2}$	(0.66, 0.92)	$U_{3,2,2}$	(7.20, 9.40)
$C_{4,1,1}$	$w_{4,1,1}$	(0.54, 0.72)	$U_{4,1,1}$	(6.60, 9.20)
$C_{4,1,2}$	$w_{4,1,2}$	(0.66, 0.92)	$U_{4,1,2}$	(7.80, 9.60)
$C_{4,1,3}$	$w_{4,1,3}$	(0.60, 0.90)	$U_{4,1,3}$	(4.60, 5.60)
$C_{4,1,4}$	$w_{4,1,4}$	(0.44, 0.54)	$U_{4,1,4}$	(6.00, 9.00)
$C_{4,2,1}$	$w_{4,2,1}$	(0.56, 0.78)	$U_{4,2,1}$	(7.20, 9.40)
$C_{4,2,2}$	$w_{4,2,2}$	(0.66, 0.92)	$U_{4,2,2}$	(6.00, 9.00)
$C_{4,2,3}$	$w_{4,2,3}$	(0.66, 0.92)	$U_{4,2,3}$	(8.40, 9.80)
$C_{4,3,1}$	$w_{4,3,1}$	(0.58, 0.84)	$U_{4,3,1}$	(7.20, 9.40)
$C_{4,3,2}$	$w_{4,3,2}$	(0.56, 0.78)	$U_{4,3,2}$	(4.60, 5.60)
$C_{4,3,3}$	$w_{4,3,3}$	(0.90, 1.00)	$U_{4,3,3}$	(6.00, 9.00)
$C_{4,4,1}$	$w_{4,4,1}$	(0.60, 0.90)	$U_{4,4,1}$	(5.60, 7.80)
$C_{4,4,2}$	$w_{4,4,2}$	(0.58, 0.84)	$U_{4,4,2}$	(6.00, 9.00)
$C_{4,4,3}$	$w_{4,4,3}$	(0.56, 0.78)	$U_{4,4,3}$	(3.80, 4.80)
$C_{4,4,4}$	$w_{4,4,4}$	(0.90, 1.00)	$U_{4,4,4}$	(2.60, 4.00)
$C_{4,5,1}$	$w_{4,5,1}$	(0.60, 0.90)	$U_{4,5,1}$	(3.20, 4.20)
$C_{4,5,2}$	$w_{4,5,2}$	(0.84, 0.98)	$U_{4,5,2}$	(9.00, 10.00)
$C_{4,6,1}$	$w_{4,6,1}$	(0.48, 0.62)	$U_{4,6,1}$	(6.00, 9.00)
$C_{4,6,2}$	$w_{4,6,2}$	(0.56, 0.78)	$U_{4,6,2}$	(7.80, 9.60)
$C_{4,6,3}$	$w_{4,6,3}$	(0.84, 0.98)	$U_{4,6,3}$	(6.00, 9.00)
$C_{4,7,1}$	$w_{4,7,1}$	(0.60, 0.90)	$U_{4,7,1}$	(7.80, 9.60)
$C_{4,7,2}$	$w_{4,7,2}$	(0.38, 0.48)	$U_{4,7,2}$	(5.20, 6.60)
$C_{4,7,3}$	$w_{4,7,3}$	(0.56, 0.78)	$U_{4,7,3}$	(5.40, 7.20)
$C_{4,8,1}$	$w_{4,8,1}$	(0.58, 0.84)	$U_{4,8,1}$	(4.20, 5.20)
$C_{4,8,2}$	$w_{4,8,2}$	(0.56, 0.78)	$U_{4,8,2}$	(5.20, 6.60)
$C_{4,8,3}$	$w_{4,8,3}$	(0.90, 1.00)	$U_{4,8,3}$	(7.20, 9.40)
$C_{4,9,1}$	$w_{4,9,1}$	(0.60, 0.90)	$U_{4,9,1}$	(4.60, 5.60)
$C_{4,9,2}$	$w_{4,9,2}$	(0.58, 0.84)	$U_{4,9,2}$	(6.00, 9.00)
$C_{4,9,3}$	$w_{4,9,3}$	(0.56, 0.78)	$U_{4,9,3}$	(5.60, 7.80)
$C_{4,9,4}$	$w_{4,9,4}$	(0.90, 1.00)	$U_{4,9,4}$	(6.60, 9.20)
$C_{4,9,5}$	$w_{4,9,5}$	(0.60, 0.90)	$U_{4,9,5}$	(5.80, 8.40)
$C_{5,1,1}$	$w_{5,1,1}$	(0.58, 0.84,)	$U_{5,1,1}$	(7.80, 9.60)
$C_{5,1,2}$	$w_{5,1,2}$	(0.56, 0.78)	$U_{5,1,2}$	(6.00, 9.00)
$C_{5,1,3}$	$w_{5,1,3}$	(0.90, 1.00)	$U_{5,1,3}$	(7.80, 9.60)
$C_{5,2,1}$	$w_{5,2,1}$	(0.60, 0.90)	$U_{5,2,1}$	(5.20, 6.60)
$C_{5,2,2}$	$w_{5,2,2}$	(0.66, 0.92)	$U_{5,2,2}$	(2.60, 4.00)
$C_{5,2,3}$	$w_{5,2,3}$	(0.72, 0.94)	$U_{5,2,3}$	(3.20, 4.20)

$C_{5,3,1}$	$w_{5,3,1}$	(0.60, 0.90)	$U_{5,3,1}$	(9.00, 10.00)
$C_{5,3,2}$	$w_{5,3,2}$	(0.58, 0.84)	$U_{5,3,2}$	(6.60, 9.20)
$C_{5,3,3}$	$w_{5,3,3}$	(0.56, 0.78)	$U_{5,3,3}$	(7.20, 9.40)
$C_{5,3,4}$	$w_{5,3,4}$	(0.90, 1.00)	$U_{5,3,4}$	(4.60, 5.60)
$C_{5,4,1}$	$w_{5,4,1}$	(0.60, 0.90)	$U_{5,4,1}$	(6.00, 9.00)
$C_{5,4,2}$	$w_{5,4,2}$	(0.90, 1.00)	$U_{5,4,2}$	(5.60, 7.80)
$C_{5,5,1}$	$w_{5,5,1}$	(0.60, 0.90)	$U_{5,5,1}$	(6.00, 9.00)
$C_{5,5,2}$	$w_{5,5,2}$	(0.58, 0.84)	$U_{5,5,2}$	(3.80, 4.80)
$C_{5,6,1}$	$w_{5,6,1}$	(0.56, 0.78)	$U_{5,6,1}$	(2.60, 4.00)
$C_{5,6,2}$	$w_{5,6,2}$	(0.90, 1.00)	$U_{5,6,2}$	(3.20, 4.20)
$C_{5,6,3}$	$w_{5,6,3}$	(0.60, 0.90)	$U_{5,6,3}$	(8.40, 9.80)
$C_{5,7,1}$	$w_{5,7,1}$	(0.72, 0.94)	$U_{5,7,1}$	(7.20, 9.40)
$C_{5,7,2}$	$w_{5,7,2}$	(0.72, 0.94)	$U_{5,7,2}$	(4.60, 5.60)

Table 3.28: Aggregated grey priority weight and computed grey appropriateness rating of lean attributes

Leanness attributes $C_{i,j}$	Weight $w_{i,j}$	Aggregated weight expressed in grey numbers	Rating $U_{i,j}$	Computed rating expressed in grey numbers
$C_{1,1}$	$w_{1,1}$	(0.60, 0.90)	$U_{1,1}$	(5.45, 13.45)
$C_{1,2}$	$w_{1,2}$	(0.66, 0.92)	$U_{1,2}$	(4.38, 9.30)
$C_{2,1}$	$w_{2,1}$	(0.52, 0.66)	$U_{2,1}$	(4.09, 12.03)
$C_{2,2}$	$w_{2,2}$	(0.76, 0.90)	$U_{2,2}$	(4.70, 12.67)
$C_{2,3}$	$w_{2,3}$	(0.66, 0.92)	$U_{2,3}$	(3.88, 9.65)
$C_{2,4}$	$w_{2,4}$	(0.50, 0.64)	$U_{2,4}$	(5.53, 13.19)
$C_{2,5}$	$w_{2,5}$	(0.66, 0.92)	$U_{2,5}$	(3.26, 8.32)
$C_{2,6}$	$w_{2,6}$	(0.60, 0.90)	$U_{2,6}$	(5.18, 13.51)
$C_{2,7}$	$w_{2,7}$	(0.72, 0.94)	$U_{2,7}$	(5.51, 12.46)
$C_{2,8}$	$w_{2,8}$	(0.68, 0.82)	$U_{2,8}$	(4.22, 9.57)
$C_{2,9}$	$w_{2,9}$	(0.66, 0.92)	$U_{2,9}$	(4.44, 12.95)
$C_{2,10}$	$w_{2,10}$	(0.72, 0.94)	$U_{2,10}$	(2.13, 6.60)
$C_{3,1}$	$w_{3,1}$	(0.78, 0.96)	$U_{3,1}$	(4.11, 8.39)
$C_{3,2}$	$w_{3,2}$	(0.58, 0.84)	$U_{3,2}$	(5.18, 13.72)
$C_{4,1}$	$w_{4,1}$	(0.72, 0.94)	$U_{4,1}$	(4.58, 11.32)
$C_{4,2}$	$w_{4,2}$	(0.90, 1.00)	$U_{4,2}$	(5.17, 13.10)
$C_{4,3}$	$w_{4,3}$	(0.60, 0.90)	$U_{4,3}$	(4.64, 10.42)
$C_{4,4}$	$w_{4,4}$	(0.72, 0.94)	$U_{4,4}$	(3.21, 8.46)
$C_{4,5}$	$w_{4,5}$	(0.78, 0.96)	$U_{4,5}$	(5.04, 9.43)

$C_{4,6}$	$w_{4,6}$	(0.84, 0.98)	$U_{4,6}$	(5.16, 11.64)
$C_{4,7}$	$w_{4,7}$	(0.66, 0.92)	$U_{4,7}$	(4.48, 11.31)
$C_{4,8}$	$w_{4,8}$	(0.60, 0.90)	$U_{4,8}$	(4.51, 9.27)
$C_{4,9}$	$w_{4,9}$	(0.70, 0.88)	$U_{4,9}$	(4.25, 10.94)
$C_{5,1}$	$w_{5,1}$	(0.66, 0.92)	$U_{5,1}$	(5.69, 12.10)
$C_{5,2}$	$w_{5,2}$	(0.84, 0.98)	$U_{5,2}$	(2.59, 6.85)
$C_{5,3}$	$w_{5,3}$	(0.78, 0.96)	$U_{5,3}$	(4.94, 11.23)
$C_{5,4}$	$w_{5,4}$	(0.66, 0 .92)	$U_{5,4}$	(4.55, 10.60)
$C_{5,5}$	$w_{5,5}$	(0.84, 0.98)	$U_{5,5}$	(3.34, 10.28)
$C_{5,6}$	$w_{5,6}$	(0.60, 0.90)	$U_{5,6}$	(3.50, 7.83)
$C_{5,7}$	$w_{5,7}$	(0.72, 0.94)	$U_{5,7}$	(4.52, 9.79)

Table 3.29: Aggregated grey priority weight and computed grey appropriateness rating of lean capabilities

Lean enablers C_i	Weight w_i	Aggregated weight expressed in grey numbers	Rating U_1	Computed rating expressed in grey numbers
C_1	w_1	(0.72, 0.94)	C_1	(3.38, 16.40)
C_2	w_2	(0.90, 1.00)	C_2	(3.22, 14.53)
C_3	w_3	(0.60, 0.90)	C_3	(3.45, 14.40)
C_4	w_4	(0.64, 0.86)	C_4	(3.56, 13.79)
C_5	w_5	(0.72, 0.94)	C_5	(3.17, 12.69)

Table 3.30: Computation of GPII and corresponding criteria ranking

Leanness criterions $C_{i,j,k}$	Rating $U_{i,j,k}$	Weight $w_{i,j,k}$	$[(1,1) - w_{i,j,k}] = w_{i,j,k}$	$[w'_{i,j,k} \otimes U_{i,j,k}]$ = GPII	Grey possibility degree	Criteria ranking order
$C_{1,1,1}$	(9.00, 10.00)	(0.72, 0.94)	(0.06, 0.28)	(0.54, 2.80)	1.000	24
$C_{1,1,2}$	(6.00, 9.00)	(0.60, 0.90)	(0.10, 0.40)	(0.60, 3.60)	0.941	20
$C_{1,1,3}$	(7.80, 9.60)	(0.58, 0.84)	(0.16, 0.42)	(1.25, 4.03)	0.847	10
$C_{1,2,1}$	(5.20, 6.60)	(0.56, 0.78)	(0.22, 0.44)	(1.14, 2.90)	1.000	24
$C_{1,2,2}$	(4.20, 5.20)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.52)	1.000	24
$C_{1,2,3}$	(8.40, 9.80)	(0.60, 0.90)	(0.10, 0.40)	(0.84, 3.92)	0.879	14
$C_{2,1,1}$	(5.60, 7.80)	(0.54, 0.72)	(0.28, 0.46)	(1.57, 3.59)	0.930	19
$C_{2,1,2}$	(6.00, 9.00)	(0.60, 0.90)	(0.10, 0.40)	(0.60, 3.60)	0.941	20
$C_{2,2,1}$	(6.00, 9.00)	(0.60, 0.90)	(0.10, 0.40)	(0.60, 3.60)	0.941	20
$C_{2,2,2}$	(7.20, 9.40)	(0.44, 0.54)	(0.46, 0.56)	(3.31, 5.26)	0.499	1

$C_{2,3,1}$	(4.80, 6.20)	(0.72, 0.94)	(0.06, 0.28)	(0.29, 1.74)	1.000	24
$C_{2,3,2}$	(5.00, 6.00)	(0.60, 0.90)	(0.10, 0.40)	(0.50, 2.40)	1.000	24
$C_{2,3,3}$	(6.00, 9.00)	(0.72, 0.94)	(0.06, 0.28)	(0.36, 2.52)	1.000	24
$C_{2,4,1}$	(9.00, 10.00)	(0.58, 0.84)	(0.16, 0.42)	(1.44, 4.20)	0.811	7
$C_{2,4,2}$	(6.00, 9.00)	(0.78, 0.96)	(0.04, 0.22)	(0.24, 1.98)	1.000	24
$C_{2,4,3}$	(8.40, 9.80)	(0.60, 0.90)	(0.10, 0.40)	(0.84, 3.92)	0.879	14
$C_{2,5,1}$	(4.20, 5.20)	(0.60, 0.90)	(0.10, 0.40)	(0.42, 2.08)	1.000	24
$C_{2,5,2}$	(3.60, 4.60)	(0.72, 0.94)	(0.06, 0.28)	(0.22, 1.29)	1.000	24
$C_{2,5,3}$	(6.00, 9.00)	(0.54, 0.72)	(0.28, 0.46)	(1.68, 4.14)	0.812	8
$C_{2,6,1}$	(6.00,9.00)	(0.60, 0.90)	(0.10, 0.40)	(0.60, 3.60)	0.941	20
$C_{2,6,2}$	(9.00, 10.00)	(0.60, 0.90)	(0.10, 0.40)	(0.90, 4.00)	0.863	12
$C_{2,6,3}$	(7.20, 9.40)	(0.72, 0.94)	(0.06, 0.28)	(0.43, 2.63)	1.000	24
$C_{2,7,1}$	(6.60, 9.20)	(0.58, 0.84)	(0.16, 0.42)	(1.06, 3.86)	0.884	15
$C_{2,7,2}$	(7.80, 9.60)	(0.78, 0.96)	(0.04, 0.22)	(0.31, 2.11)	1.000	24
$C_{2,8,1}$	(4.60, 5.60)	(0.58, 0.84)	(0.16, 0.42)	(0.74, 2.35)	1.000	24
$C_{2,8,2}$	(6.00, 9.00)	(0.56, 0.78)	(0.22, 0.44)	(1.32, 3.96)	0.858	11
$C_{2,8,3}$	(5.60, 7.80)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.78)	1.000	24
$C_{2,9,1}$	(6.60, 9.20)	(0.60, 0.90)	(0.10, 0.40)	(0.66, 3.68)	0.926	18
$C_{2,9,2}$	(6.00, 9.00)	(0.54, 0.72)	(0.28, 0.46)	(1.68, 4.14)	0.812	8
$C_{2,10,1}$	(3.80, 4.80)	(0.60, 0.90)	(0.10, 0.40)	(0.38, 1.92)	1.000	24
$C_{2,10,2}$	(2.60, 4.00)	(0.60, 0.90)	(0.10, 0.40)	(0.26, 1.60)	1.000	24
$C_{3,1,1}$	(3.20, 4.20)	(0.44, 0.54)	(0.46, 0.56)	(1.47, 2.35)	1.000	24
$C_{3,1,2}$	(5.00, 6.00)	(0.66, 0.92)	(0.08, 0.34)	(0.40, 2.04)	1.000	24
$C_{3,1,3}$	(6.00, 9.00)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.90)	1.000	24
$C_{3,2,1}$	(7.80, 9.60)	(0.60, 0.90)	(0.10, 0.40)	(0.78, 3.84)	0.894	16
$C_{3,2,2}$	(7.20, 9.40)	(0.66, 0.92)	(0.08, 0.34)	(0.58, 3.20)	1.000	24
$C_{4,1,1}$	(6.60, 9.20)	(0.54, 0.72)	(0.28, 0.46)	(1.85, 4.23)	0.787	5
$C_{4,1,2}$	(7.80, 9.60)	(0.66, 0.92)	(0.08, 0.34)	(0.62, 3.26)	1.000	24
$C_{4,1,3}$	(4.60, 5.60)	(0.60, 0.90)	(0.10, 0.40)	(0.46, 2.24)	1.000	24
$C_{4,1,4}$	(6.00, 9.00)	(0.44, 0.54)	(0.46, 0.56)	(2.76, 5.04)	0.591	2
$C_{4,2,1}$	(7.20, 9.40)	(0.56, 0.78)	(0.22, 0.44)	(1.58, 4.14)	0.817	9
$C_{4,2,2}$	(6.00, 9.00)	(0.66, 0.92)	(0.08, 0.34)	(0.48, 3.06)	1.000	24
$C_{4,2,3}$	(8.40, 9.80)	(0.66, 0.92)	(0.08, 0.34)	(0.67, 3.33)	0.995	23
$C_{4,3,1}$	(7.20, 9.40)	(0.58, 0.84)	(0.16, 0.42)	(1.15, 3.95)	0.866	13
$C_{4,3,2}$	(4.60, 5.60)	(0.56, 0.78)	(0.22, 0.44)	(1.01, 2.46)	1.000	24
$C_{4,3,3}$	(6.00, 9.00)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.90)	1.000	24
$C_{4,4,1}$	(5.60, 7.80)	(0.60, 0.90)	(0.10, 0.40)	(0.56, 3.12)	1.000	24
$C_{4,4,2}$	(6.00, 9.00)	(0.58, 0.84)	(0.16, 0.42)	(0.96, 3.78)	0.901	17
$C_{4,4,3}$	(3.80, 4.80)	(0.56, 0.78)	(0.22, 0.44)	(0.84, 2.11)	1.000	24
$C_{4,4,4}$	(2.60, 4.00)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.40)	1.000	24
$C_{4,5,1}$	(3.20, 4.20)	(0.60, 0.90)	(0.10, 0.40)	(0.32, 1.68)	1.000	24
$C_{4,5,2}$	(9.00, 10.00)	(0.84, 0.98)	(0.02, 0.16)	(0.18, 1.60)	1.000	24
$C_{4,6,1}$	(6.00, 9.00)	(0.48, 0.62)	(0.38, 0.52)	(2.28, 4.68)	0.685	3

$C_{4,6,2}$	(7.80, 9.60)	(0.56, 0.78)	(0.22, 0.44)	(1.72, 4.22)	0.795	6
$C_{4,6,3}$	(6.00, 9.00)	(0.84, 0.98)	(0.02, 0.16)	(0.12, 1.44)	1.000	24
$C_{4,7,1}$	(7.80, 9.60)	(0.60, 0.90)	(0.10, 0.40)	(0.78, 3.84)	0.894	16
$C_{4,7,2}$	(5.20, 6.60)	(0.38, 0.48)	(0.52, 0.62)	(2.70, 4.09)	0.766	4
$C_{4,7,3}$	(5.40, 7.20)	(0.56, 0.78)	(0.22, 0.44)	(1.19, 3.17)	1.000	24
$C_{4,8,1}$	(4.20, 5.20)	(0.58, 0.84)	(0.16, 0.42)	(0.67, 2.18)	1.000	24
$C_{4,8,2}$	(5.20, 6.60)	(0.56, 0.78)	(0.22, 0.44)	(1.14, 2.90)	1.000	24
$C_{4,8,3}$	(7.20, 9.40)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.94)	1.000	24
$C_{4,9,1}$	(4.60, 5.60)	(0.60, 0.90)	(0.10, 0.40)	(0.46, 2.24)	1.000	24
$C_{4,9,2}$	(6.00, 9.00)	(0.58, 0.84)	(0.16, 0.42)	(0.96, 3.78)	0.901	17
$C_{4,9,3}$	(5.60, 7.80)	(0.56, 0.78)	(0.22, 0.44)	(1.23, 3.43)	0.971	21
$C_{4,9,4}$	(6.60, 9.20)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.92)	1.000	24
$C_{4,9,5}$	(5.80, 8.40)	(0.60, 0.90)	(0.10, 0.40)	(0.58, 3.36)	0.989	22
$C_{5,1,1}$	(7.80, 9.60)	(0.58, 0.84,)	(0.16, 0.42)	(1.25, 4.03)	0.847	10
$C_{5,1,2}$	(6.00, 9.00)	(0.56, 0.78)	(0.22, 0.44)	(1.32, 3.96)	0.858	11
$C_{5,1,3}$	(7.80, 9.60)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.96)	1.000	24
$C_{5,2,1}$	(5.20, 6.60)	(0.60, 0.90)	(0.10, 0.40)	(0.52, 2.64)	1.000	24
$C_{5,2,2}$	(2.60, 4.00)	(0.66, 0.92)	(0.08, 0.34)	(0.21, 1.36)	1.000	24
$C_{5,2,3}$	(3.20, 4.20)	(0.72, 0.94)	(0.06, 0.28)	(0.19, 1.18)	1.000	24
$C_{5,3,1}$	(9.00, 10.00)	(0.60, 0.90)	(0.10, 0.40)	(0.90, 4.00)	0.863	12
$C_{5,3,2}$	(6.60, 9.20)	(0.58, 0.84)	(0.16, 0.42)	(1.06, 3.86)	0.884	15
$C_{5,3,3}$	(7.20, 9.40)	(0.56, 0.78)	(0.22, 0.44)	(1.58, 4.14)	0.817	9
$C_{5,3,4}$	(4.60, 5.60)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.56)	1.000	24
$C_{5,4,1}$	(6.00, 9.00)	(0.60, 0.90)	(0.10, 0.40)	(0.60, 3.60)	0.941	20
$C_{5,4,2}$	(5.60, 7.80)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.78)	1.000	24
$C_{5,5,1}$	(6.00, 9.00)	(0.60, 0.90)	(0.10, 0.40)	(0.60, 3.60)	0.941	20
$C_{5,5,2}$	(3.80, 4.80)	(0.58, 0.84)	(0.16, 0.42)	(0.61, 2.02)	1.000	24
$C_{5,6,1}$	(2.60, 4.00)	(0.56, 0.78)	(0.22, 0.44)	(0.57, 1.76)	1.000	24
$C_{5,6,2}$	(3.20, 4.20)	(0.90, 1.00)	(0.00, 0.10)	(0.00, 0.42)	1.000	24
$C_{5,6,3}$	(8.40, 9.80)	(0.60, 0.90)	(0.10, 0.40)	(0.84, 3.92)	0.879	14
$C_{5,7,1}$	(7.20, 9.40)	(0.72, 0.94)	(0.06, 0.28)	(0.43, 2.63)	1.000	24
$C_{5,7,2}$	(4.60, 5.60)	(0.72, 0.94)	(0.06, 0.28)	(0.28, 1.57)	1.000	24

CHAPTER 4

AGILITY APPRAISEMENT AND SUPPLIERS' SELECTION IN AGILE SUPPLY CHAIN

4.1 Agility Appraisement and Identification of Agile Barriers in Supply Chain

4.1.1 Coverage

Nowadays, in turbulent and volatile global marketplaces, agility has been viewed as a key strategic consideration of a supply chain needed for survival. To achieve the competitive edge, industries must align with suppliers as well as their customers to streamline operations. Consequently, Agile Supply Chain (ASC) is considered as a dominant competitive advantage (Jassbi et al., 2010). In this context, the present work attempts to develop a procedural hierarchy towards estimating an overall performance metric for an agile supply chain. The theories behind generalized trapezoidal fuzzy numbers have been utilized in this appraisement cum decision-modeling. Apart from estimating supply chains' overall agility extent, the study has been extended towards identifying ill-performing areas (called agile barriers) which require future improvement. The concepts of (i) '*Maximizing set and Minimizing set*' and the concept (ii) 'Degree of Similarity' (for comparing two fuzzy numbers) have been explored to rank various agile criterions in accordance with their performance extent. This evaluation might be helpful for the industry managers to perform gap analysis between existent agility level and the desired one and also provides more informative, accurate and reliable information towards decision making.

Literature reveals that considerable amount of work has been carried out by pioneer researchers towards developing agility appraisement module in Agile Supply Chain Management (ASCM). Most of the agile parameters (agile enablers/capabilities, agile attributes and agile criterions) being subjective in nature, fuzzy analysis of expert opinion is indeed logical. Apart from agility assessment, another important aspect is the need for identifying agile barriers. It has been found that in analyzing agility in fuzzy context, previous researchers used the concept of '*maximizing set and minimizing set*' for comparing fuzzy numbers based on their individual utility values. Thus, agile criterions were ranked accordingly. It is felt that apart from utilizing the concept of fuzzy numbers ranking using '*maximizing set and minimizing set*'; the concept of 'Degree of Similarity' between two fuzzy numbers may be suitable to sort out various agile barriers. Motivated by this, present work aims to develop a fuzzy integrated agility assessment module to estimate an overall supply chain's agility index in ASCM. The work proposes an alternative approach towards identifying agile barriers as well.

4.1.2 Mathematical Base

Managerial decision-making process often experience uncertain-vague data which is really difficult to analyze. Fuzzy logic has the capability to overcome such imprecise linguistic human judgment. Fuzzy logic is an efficient tool to capture human perception to correlate with a mathematical base. Agility, as a whole, is a conceptual philosophy difficult to model and to estimate an overall agility index quantitatively. In this paper an effort has been made to establish a scientific mathematical background to assess overall agility degree for a given case application and to assess the extent of successful performance of the key indices that stimulate agility. The fuzzy based evaluation model presented here can be effectively implemented in industries supply chain to attain competitive advantage in the market. The appraisement module has been used by a single industry. The same model can be applied in different sectors to compare their degree of agility. Before discussing the proposed fuzzy based agility appraisement module; some preliminary knowledge about fuzzy logic; the theory of fuzzy numbers, their operational rules is indeed essential. This section deals with basics of fuzzy logic and related aspects to be explored in course of the present work.

4.1.2.1 Generalized Trapezoidal Fuzzy Numbers (GTFNs)

By the definition given by (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, as shown in Fig. 4.1.

and the membership function $\mu_{\tilde{A}}(x): R \to [0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1} \times w_{\tilde{A}}, & x \in (a_1, a_2) \\ w_{\tilde{A}}, & x \in (a_2, a_3) \\ \dfrac{x-a_4}{a_3-a_4} \times w_{\tilde{A}}, & x \in (a_3, a_4) \\ 0, & x \in (-\infty, a_1) \cup (a_4, \infty) \end{cases} \quad (4.1)$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in [0,1]$

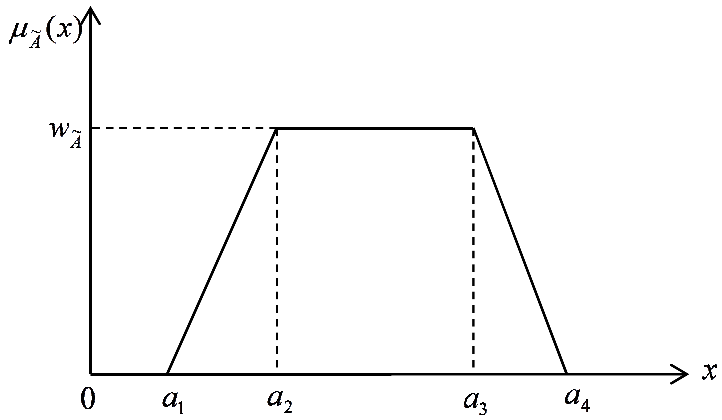

Fig. 4.1: Trapezoidal fuzzy number $\tilde{A}$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $\mu_{\tilde{A}}(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number (a_1, a_2, a_3, a_4); if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (4.2)$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) = (a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (4.3)$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$
$$(a, b, c, d; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{4.4}$$

Here,

$$a = \min(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$
$$b = \min(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$
$$c = \max(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3)$$
$$d = \max(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = (a1 \times b1, a2 \times b2, a3 \times b3, a4 \times b4; \min(w_{\tilde{a}}, w_{\tilde{b}}))$$

$$\tilde{a} / \tilde{b} = \frac{(a_1, a_2, a_3, a_4; w_{\tilde{a}})}{(b_1, b_2, b_3, b_4; w_{\tilde{b}})}$$
$$= (a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \tag{4.5}$$

4.1.2.2 Degree of Similarity between Two GTFNs

For any two generalized trapezoidal fuzzy numbers,

$\tilde{\tilde{A}} = (a_1, a_2, a_3, a_4)$ and $\tilde{\tilde{B}} = (b_1, b_2, b_3, b_4)$

1. The similarity measure (Chen, 1996)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = 1 - \frac{\sum_{i=1}^{4} |a_i - b_i|}{4} \tag{4.6}$$

2. In (Hsieh and Chen, 1999)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{1 + d\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right)} \tag{4.7}$$

Here $d\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=\left|P\left(\tilde{\tilde{A}}\right)-P\left(\tilde{\tilde{B}}\right)\right|$

$$P\left(\tilde{\tilde{A}}\right)=\frac{a_1+2a_2+2a_3+a_4}{6},\ P\left(\tilde{\tilde{B}}\right)=\frac{b_1+2b_2+2b_3+b_4}{6} \qquad (4.8)$$

3. Simple centre of gravity method (Chen and Chen, 2003)

The SCGM is based on the concept of medium curve (Subasic and Hirota, 1998). The SCGM method integrates the concepts of geometric distance and the COG distance of GFN's. If the GFN's are $\tilde{\tilde{A}}=\left(a_1,a_2,a_3,a_4;w_{\tilde{\tilde{A}}}\right)$ and $\tilde{\tilde{B}}=\left(b_1,b_2,b_3,b_4;w_{\tilde{\tilde{B}}}\right)$ and $0\le a_1\le a_2\le a_3\le a_4\le 1$ and $0\le b_1\le b_2\le b_3\le b_4\le 1.$

$COG\left(\tilde{\tilde{A}}\right)=\left(x^*_{\tilde{\tilde{A}}},y^*_{\tilde{\tilde{A}}}\right)$, $COG\left(\tilde{\tilde{B}}\right)=\left(x^*_{\tilde{\tilde{B}}},y^*_{\tilde{\tilde{B}}}\right)$ then

$$S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=1-\frac{\sum_{i=1}^{4}\left|a_i-b_i\right|}{4}\left(1-\left|x^*_{\tilde{\tilde{A}}}-x^*_{\tilde{\tilde{B}}}\right|\right)^{B\left(S_{\tilde{\tilde{A}}},S_{\tilde{\tilde{B}}}\right)}\frac{\min\left(y^*_{\tilde{\tilde{A}}},y^*_{\tilde{\tilde{B}}}\right)}{\max\left(y^*_{\tilde{\tilde{A}}},y^*_{\tilde{\tilde{B}}}\right)} \qquad (4.9)$$

Here

$$y^*_A=\begin{cases}\dfrac{w_{\tilde{\tilde{A}}}\left(\dfrac{a_3-a_2}{a_4-a_1}+2\right)}{6}, & if\ a_1\ne a_4,\\[2ex] \dfrac{w_{\tilde{\tilde{A}}}}{2}, & if\ a_1=a_4.\end{cases} \qquad (4.10)$$

$$x^*_{\tilde{\tilde{A}}}=\frac{y^*_{\tilde{\tilde{A}}}\left(a_3+a_2\right)+\left(a_4+a_1\right)\left(w_{\tilde{\tilde{A}}}-y^*_{\tilde{\tilde{A}}}\right)}{2w_{\tilde{\tilde{A}}}} \qquad (4.11)$$

$$B\left(S_{\tilde{\tilde{A}}},S_{\tilde{\tilde{B}}}\right)=\begin{cases}1 & if\ S_A+S_B>0\\ 0 & if\ S_A+S_B=0\end{cases} \qquad (4.12)$$

$$S_A=a_4-a_1;\ S_B=b_4-b_1 \qquad (4.13)$$

4. The radius of gyration based similarity measure (Yong et al., 2004)

$$S\left(\tilde{\tilde{A}},\tilde{\tilde{B}}\right)=1-\frac{\sum_{i=1}^{4}\left|a_i-b_i\right|}{4}\left(1-\left|r_x^{\tilde{\tilde{A}}}-r_x^{\tilde{\tilde{B}}}\right|\right)^{B\left(S_{\tilde{\tilde{A}}},S_{\tilde{\tilde{B}}}\right)}\frac{\min\left(r_y^{\tilde{\tilde{A}}},r_y^{\tilde{\tilde{B}}}\right)}{\max\left(r_y^{\tilde{\tilde{A}}},r_y^{\tilde{\tilde{B}}}\right)} \qquad (4.14)$$

Here

$$r_x^{\tilde{\tilde{A}}} = \sqrt{\frac{(I_x)_1 + (I_x)_2 + (I_x)_3}{\{(a_3 - a_2) + (a_4 - a_1)\}\frac{w_{\tilde{\tilde{A}}}}{2}}} \quad (4.15)$$

$$r_y^{\tilde{\tilde{A}}} = \sqrt{\frac{(I_y)_1 + (I_y)_2 + (I_y)_3}{\{(a_3 - a_2) + (a_4 - a_1)\}\frac{w_{\tilde{\tilde{A}}}}{2}}} \quad (4.16)$$

$$(I_x)_1 = \frac{(a_2 - a_1)w_{\tilde{\tilde{A}}}^3}{12} \quad (4.17)$$

$$(I_x)_2 = \frac{(a_3 - a_2)w_{\tilde{\tilde{A}}}^3}{3} \quad (4.18)$$

$$(I_x)_3 = \frac{(a_4 - a_3)w_{\tilde{\tilde{A}}}^3}{12} \quad (4.19)$$

$$(I_y)_1 = \frac{(a_2 - a_1)^3 w_{\tilde{\tilde{A}}}}{4} + \frac{(a_2 - a_1)a_1^2 w_{\tilde{\tilde{A}}}}{2} + \frac{2(a_2 - a_1)^2 a_1 w_{\tilde{\tilde{A}}}}{3} \quad (4.20)$$

$$(I_y)_2 = \frac{(a_3 - a_2)^3 w_{\tilde{\tilde{A}}}}{3} + \frac{(a_3 - a_2)a_2^2 w_{\tilde{\tilde{A}}}}{1} + \frac{2(a_3 - a_2)^2 a_2 w_{\tilde{\tilde{A}}}}{1} \quad (4.21)$$

$$(I_y)_3 = \frac{(a_4 - a_3)^3 w_{\tilde{\tilde{A}}}}{12} + \frac{(a_4 - a_3)a_3^2 w_{\tilde{\tilde{A}}}}{2} + \frac{2(a_4 - a_3)^2 a_1 w_{\tilde{\tilde{A}}}}{3} \quad (4.22)$$

5. Similarity measure based on geometric mean averaging operator (Chen, 2006)

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \left[\sqrt[4]{\prod_{i=1}^{4}\left(2 - |a_i - b_i|\right)} - 1\right] \times \frac{\min\left(y_{\tilde{\tilde{A}}}^*, y_{\tilde{\tilde{B}}}^*\right)}{\max\left(y_{\tilde{\tilde{A}}}^*, y_{\tilde{\tilde{B}}}^*\right)} \quad (4.23)$$

Here $y_{\tilde{\tilde{A}}}^*, y_{\tilde{\tilde{B}}}^*$ are given by Eq. 4.10.

6. Fuzzy similarity measure proposed by (Sridevi and Nadarajan, 2009)

(Sridevi and Nadarajan, 2009) presented a new similarity measure based on fuzzy difference of distance of points of fuzzy numbers rather than geometric distances used by the existing methods.

The membership function to measure the difference in distance of points of two GFN's is defined as

$$\mu_d(x) = \begin{cases} 1 - \frac{x}{d}, 0 \le x \le d \\ 0, Otherwise. \end{cases} \quad (4.24)$$

Here $0 < d \le 1$ and $x = |a_i - b_i|$. The degree of similarity of two GFN's $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ is defined as

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \frac{1}{4}\sum_{i=1}^{4} \mu_d(x)\left(1 - \left|x^*_{\tilde{\tilde{A}}} - x^*_{\tilde{\tilde{B}}}\right|\right)^{B\left(S_{\tilde{\tilde{A}}}, S_{\tilde{\tilde{B}}}\right)} \frac{\min\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)}{\max\left(y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}\right)} \quad (4.25)$$

$B\left(S_{\tilde{\tilde{A}}}, S_{\tilde{\tilde{B}}}\right)$ is 0 or 1 according as COG point is considered or not and $x^*_{\tilde{\tilde{A}}}, x^*_{\tilde{\tilde{B}}}, y^*_{\tilde{\tilde{A}}}, y^*_{\tilde{\tilde{B}}}$ are given in Eqs. 4.10-4.11.

4.1.2.3 Ranking of GTFNs using Maximizing Set and Minimizing Set

The ranking methodology adapted here has been described as follows (Chou et al., 2011). Considering n normal fuzzy numbers $A_i, (i = 1,2,...,n)$, each with a trapezoidal membership function $f_{A_i}(x)$. The revised method performs pair-wise comparisons on the n fuzzy numbers. For each pair of fuzzy numbers, say A_1 and A_2, the pair-wise comparison is preceded as follows. The maximizing set M and minimizing set G with membership function f_M is given as,

$$f_M(x) = \begin{cases} \left[(x - x_{\min}) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \le x \le x_{\max} \\ 0, & Otherwise. \end{cases} \quad (4.26)$$

The minimizing set G is a fuzzy subset with membership function f_G is given as,

$$f_G(x) = \begin{cases} \left[(x_{\max} - x) \big/ (x_{\max} - x_{\min}) \right]^k, & x_{\min} \le x \le x_{\max} \\ 0, & Otherwise. \end{cases} \quad (4.27)$$

Here $x_{\min} = Inf\ S, x_{\max} = Sup\ S, S = U_{i=1}^{n} S_i, S_i = \{x / f_{A_i}(x) \succ 0\}$, and k is set to be 1. The revised ranking method defines the right utility values of each alternative A_i as:

$$u_{M_{i1}}(i) = \sup_x \left(f_M(x) \wedge f_{A_i^R}(x)\right), \ i = 1,2; \tag{4.28}$$

$$u_{G_{i2}}(i) = \sup_x \left(f_G(x) \wedge f_{A_i^R}(x)\right), \ i = 1,2. \tag{4.29}$$

The let utility values of each alternative A_i as:

$$u_{G_{i1}}(i) = \sup_x \left(f_G(x) \wedge f_{A_i^L}(x)\right), \ i = 1,2; \tag{4.30}$$

$$u_{M_{i2}}(i) = \sup_x \left(f_M(x) \wedge f_{A_i^L}(x)\right), \ i = 1,2. \tag{4.31}$$

The revised ranking method defines the total utility value of each fuzzy number A_i with index of optimism α as:

$$U_T^{\alpha}(i) = \frac{1}{2}\left[\alpha\{u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i)\} + (1-\alpha)\{u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i)\}\right], \ i = 1,2. \tag{4.32}$$

The index of optimism (α) represents the degree of optimism of a decision-maker (Kim and Park, 1990; Liou and Wang, 1992; Wang and Luo, 2009). A larger α indicates a higher degree of optimism. More specifically, when $\alpha = 0$, the total utility value $u_T^0(A_i)$ representing a pessimistic decision-maker's viewpoint is equal to the total left utility value of A_i. Conversely, for an optimistic decision-maker, i.e. $\alpha = 1$, the total utility value $u_T^1(A_i)$ is equal to the total right utility value of A_i. For a moderate (neutral) decision-maker, with $\alpha = 0.5$, the total utility value of each fuzzy number A_i become

$$U_T^{1/2}(i) = \frac{1}{2}\left[\frac{1}{2}\{u_{M_{i1}}(i) + 1 - u_{G_{i2}}(i)\} + \frac{1}{2}\{u_{M_{i2}}(i) + 1 - u_{G_{i1}}(i)\}\right], \ i = 1,2. \tag{4.33}$$

The greater the $u_T^{\alpha}(A_i)$, the bigger the fuzzy number A_i and the higher it's ranking order.

As described by (Chou et al., 2011), if A_i is a normal trapezoidal fuzzy number, i.e. $A_i = (a_i, b_i, c_i, d_i; 1)$, the total utility value of each fuzzy number A_i can be written as:

$$u_T^{\alpha}(i)=\frac{1}{2}\left(\begin{array}{l}\alpha\left[\frac{d_i - x_{\min}}{d_i - c_i + x_{\max} - x_{\min}}+\frac{c_i - x_{\min}}{c_i - d_i + x_{\max} - x_{\min}}\right]+\\(1-\alpha)\left[\frac{a_i - x_{\min}}{a_i - b_i + x_{\max} - x_{\min}}+\frac{b_i - x_{\min}}{b_i - a_i + x_{\max} - x_{\min}}\right]\end{array}\right) \quad (4.34)$$

4.1.3 Agility Appraisement Modeling: Case Empirical Research

The procedural framework (Table 4.1) of the supply chain agility assessment has been made that illustrated as follows. The assessment framework is based on an agile capabilities-attribute-criterion hierarchy partially adapted from the work by (Jassbi et al., 2010). It consists of three-level indices. The first level indices comprise examining business operation environments, measuring agile drives and identifying of agile supply chain capabilities. The second level indices of the framework assesses the agile enabled attributes and synthesizes fuzzy ratings and weights to obtain the fuzzy agility index of a supply chain and the fuzzy performance importance index for each agile supply chain criterions. The third level indices of the aforesaid framework finds a fuzzy degree of similarity for each agile criterion with respect to that of ideal agile criteria using different degree of similarity measurement method and then finally ranks different agile criterions, higher the value of degree of similarity; higher be the ranking score. Procedural steps along with data analysis have been summarized below.

Step 1 Determination of Preference scale system

Due to existence of imprecise and incomplete information regarding agility evaluation, a fuzzy based evaluation module seems to be practical. Thus, for the subjective assessment against evaluation criterions as well as priority weights, linguistic terms are advisable to explore because it is difficult for the decision-makers to determine the exact numeric score of subjective criterions. There are many various linguistic judgment terminologies and corresponding membership functions those have been proposed in literature. In order to assess the performance rating of the agile criterion from Table 4.1 (3^{rd} level indices), the nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} have been used (Table 4.2). Such type of linguistic assessment represents the limits of human absolute discrimination. Similarly, in order to assign importance weights (priority degree) of various agile criterions/attributes as well as capabilities, the linguistic variables such as {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} have been employed (Table 4.2). The linguistic variables have been accepted among the DMs of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive market scenario.

Step 2 Obtaining performance ratings of agile enabled criterions and importance weights of different agile criterions/attributes and capabilities using linguistic terms

Once the linguistic variables for assessing the performance ratings and importance weights of agile indices have been accepted by the decision-makers (DMs), the decision-makers have been asked to use above mentioned linguistic scales to assess the performance rating (Table 4.3 in APPENDIX-B) as well as to assign corresponding importance weights (Tables 4.4-4.6 in APPENDIX-B) of various agile indices.

Step 3 Approximation of the linguistic ratings and weights with generalized trapezoidal fuzzy numbers

Using the concept of generalized trapezoidal fuzzy numbers in fuzzy set theory (as discussed in Section 4.1.2.1), the linguistic choices have been be approximated by generalized trapezoidal fuzzy numbers (representation shown in Table 4.2). Furthermore, *mean operator* has been used to obtain pulled opinion of the decision-making group by aggregating individual DM's fuzzy ratings and fuzzy weights against different agile indices. The aggregated fuzzy appropriateness rating (along with priority weights) against each agile criterion has been shown in Table 4.7. Aggregated fuzzy priority weight of various agile attributes as well as enablers has been furnished in Tables 4.8-4.9.

Step 4 Determination of fuzzy performance index (FPI)

Firstly, the fuzzy performance index has been calculated at the attribute level and finally extended to enabler level. Fuzzy index system (at 2nd level) encompasses several agile attributes (Table 4.1).

The fuzzy index (appropriateness rating) of each agile attribute (at 2nd level) has been calculated as follows:

$$U_{i,j}=\frac{\sum_{k=1}^{n}\left(w_{i,j,k}\otimes U_{i,j,k}\right)}{\sum_{k=1}^{n}w_{i,j,k}} \tag{4.35}$$

Here $U_{i,j,k}$ represent aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represent aggregated fuzzy weight corresponding to agile criterion $C_{i,j,k}$ which is under j_{th} agile attribute (at 2nd level) and i_{th} agile capability (at 1st level).

The fuzzy index of each agile capability/enabler (at 1st level) has been calculated as follows:

$$U_{i}=\frac{\sum_{j=1}^{n}\left(w_{i,j}\otimes U_{i,j}\right)}{\sum_{j=1}^{n}w_{i,j}} \tag{4.36}$$

Here $U_{i,j}$ represent computed fuzzy performance measure (rating) obtained using Eq. 4.35 and $w_{i,j}$ represent aggregated fuzzy weight for priority importance corresponding to j_{th} lean attribute $C_{i,j}$ which is under i_{th} agile capability (at 1st level).

Thus, overall fuzzy performance index $U(FPI)$ has been calculated as follows:

$$U(FPI)=\frac{\sum_{i=1}^{n}\left(w_{i}\otimes U_{i}\right)}{\sum_{i=1}^{n}w_{i}} \tag{4.37}$$

Here U_i = Computed fuzzy performance rating of i^{th} agile capability C_i (computed by Eq. 4.36); w_i = Aggregated fuzzy weight of i^{th} agile capability, and $i=1,2,3,...n$.

Computed fuzzy appropriateness ratings of different agile attributes (at 2nd level) as well as agile enablers (at 1st level) have been furnished in Table 4.8 and 4.9, respectively. Finally, Eq. 4.37 has been explored to calculate overall agile estimate.

Fuzzy Performance Index (FPI) becomes: (0.2986, 0.5313, 0.9411, 1.6434; 1.000)

4.1.4 Identification of Agile Barriers

After obtaining FPI for organizational existing agility extent; simultaneously, it is also felt necessary to identify and analyze the obstacles (ill-performing areas), also called agile barriers for supply chain agility improvement because agility evaluation not only determines supply chain agility but also helps managers to identify the main adverse factors involved in implementing an appropriate action plan to improve the agility level. In order the identify the principal obstacles for improving agility level a Fuzzy Performance Importance Index (FPII) used, which combines the performance rating and importance weight of each agile criterions. The higher the FPII of a factor, the higher is the contribution. The FPII can be calculated as follows.

$$FPII_{i,j,k} = w'_{i,j,k} \otimes U_{i,j,k} \qquad (4.38)$$

Here, $w'_{i,j,k} = [(1,1,1,1;1) - w_{i,j,k}]$ (4.39)

In this formulation, $U_{i,j,k}$ represent aggregated fuzzy performance measure (rating) and $w_{i,j,k}$ represent aggregated fuzzy weight corresponding to agile criterion $C_{i,j,k}$ which is under j_{th} agile attribute (at 2nd level) and i_{th} agile capability (at 1st level).

Since fuzzy numbers do not always yield a totally ordered set in the manner of real numbers therefore, FPII need to be ranked accordingly to identify individual criterion performance level. Based on that poorly performing criterions can be identified and in future, attention must be given to improve those criteria aspects in order to boost up overall agility degree.

Computed FPII against each agile criterions has been tabulated (Table 4.10). In order to rank FPIIs, the concept of 'maximizing set and minimizing set' towards comparison of fuzzy numbers has been used. Ranking scores (corresponding to each criterion's FPII) based on u_T^{α} have been shown in Table 4.11 and graphically presented in Fig. 4.2. In this computation, three types of DMs risk-bearing attitude (optimistic, neutral and pessimistic: $\alpha = 1,\ 0.5,\ 0$) have been considered for the decision-making process. The revised ranking method proposed by (Chou et al., 2011) has been explored in this computation. Ranking provides necessary information about comparative performance picture of existing agile criterions.

Apart from aforesaid ranking procedure, this paper demonstrates application feasibility towards exploration of the concept of 'Degree of Similarity' (between two fuzzy numbers) for agile criteria ranking. The DOS between individual FPIIs (of corresponding criterions) and the ideal FPII thus computed (0.2700, 0.3411, 0.4000, 0.4852; 1.0000) has been used to evaluate ranking order of agile attributes. Tables 4.12-4.17 represent agile criteria ranking using different similarity measurement method as proposed by various researchers. Graphical representation has also been furnished in Fig. 4.3. As compared to the existing ranking method (Fig. 4.2) (based on overall utility score) the ranking order appears to be almost similar for the proposed DOS based ranking method (Fig. 4.3). Therefore, DOS concept can also be used towards identification of agile barriers. By this way, ill-performing areas can be sorted out. Industry should find feasible means to improve performance in those areas to boost up overall degree of agility in future.

4.1.5 Concluding Remarks

Agile paradigm has become an important avenue in recent times. Many organizations around the world have been attempting to implement agile concepts in their supply chain. The agility metric is an important indicator in agile performance measure. Aforesaid study aimed to develop a quantitative analysis framework and a simulation methodology to evaluate the efficacy of agile practices by exploring the concept of Generalized Trapezoidal Fuzzy Numbers (GTFNs). The procedural hierarchy presented here could help the industries to assess their existing agile performance extent, to compare and to identify week-performing areas towards implementing agility successfully. The specific contributions of this research have been summarized below.

1. Development of fuzzy-based agility appraisement module for ASCM.
2. Identification of agile barriers.
3. Application feasibility of the concept of DOS towards ranking of agile criterions.

Aforesaid study is based on the information obtained from a particular industry/sector; the same model can be explored to evaluate overall agility degree of different agile organizations. By this way, agile enterprises can be compared and ranked accordingly (benchmarking).

Table 4.1: The conceptual model for agility appraisement

Goal	1st Grade (Agile capabilities)	2nd Grade (Agile attributes)	3rd Grade (Agile criterions)
Supply Chain Agility C	Flexibility C_1	Sourcing Flexibility C_{11}	Numerous available suppliers C_{111}
			Flexibility in volume C_{112}
			Flexibility in variety C_{113}
		Manufacturing Flexibility C_{12}	Flexible manufacturing system C_{121}
			CAM based manufacturing C_{122}
			Variety and volume of productions C_{123}
		Delivery Flexibility C_{13}	Variety of supply schedules for meeting customers' needs C_{131}
			Flexibility in volume of product C_{132}
			Provision of after-sales service C_{133}
	Responsiveness C_2	Sourcing Responsiveness C_{21}	Adaptability of delivery time by suppliers C_{211}
			Suppliers' delivery time C_{212}
			Supplier relation management C_{213}
		Manufacturing Responsiveness C_{22}	Time of establishment and changing parts C_{221}
			Responsiveness level to the market changes C_{222}
		Delivery Responsiveness C_{23}	Achievement of advised delivery C_{231}
			New product-to-market time C_{232}
			Customer service C_{233}
	Competency C_3	Cooperation and Internal-External Balance C_{31}	Cooperation and Internal-External Balance C_{311}
		Manufacturing Competency C_{32}	New product introduce C_{321}
			Quality of products and services C_{322}
			Integration C_{323}
			Time of new product development C_{324}
		Capabilities of human resources C_{33}	Capabilities of human resources C_{331}
	Cost C_4	Sourcing Cost C_{41}	Sourcing Cost C_{411}
		Manufacturing Cost C_{42}	Production cost C_{421}
			Establishment cost C_{4222}
			The cost of changing parts C_{423}
		Delivery Cost C_{43}	Delivery Cost C_{431}

Table 4.2: Definitions of linguistic variables and corresponding fuzzy representation for assigning appropriateness ratings and priority weights (A-9 member linguistic term set)

Linguistic terms (Attribute/criteria ratings)	Linguistic terms (Priority weights)	Generalized trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	(0, 0, 0.0625, 0.125; 1.0)
Very Poor (VP)	Very Low (VL)	(0.0625, 0.125, 0.1875, 0.25; 1.0)
Poor (P)	Low (L)	(0.1875, 0.25, 0.3125, 0.375; 1.0)
Medium Poor (MP)	Medium Low (ML)	(0.3125, 0.375, 0.4375, 0.5; 1.0)
Medium (M)	Medium (M)	(0.4375, 0.5, 0.5, 0.5625; 1.0)
Medium Good (MG)	Medium High (MH)	(0.5, 0.5625, 0.625, 0.6875; 1.0)
Good (G)	High (H)	(0.625, 0.6875, 0.75, 0.8125; 1.0)
Very Good (VG)	Very High (VH)	(0.75, 0.8125, 0.875, 0.9375; 1.0)
Absolutely Good (AG)	Absolutely High (AH)	(0.875, 0.9375, 1, 1; 1.0)

Table 4.7: Aggregated rating and aggregated priority weight of agile criterions

Agile criterions C_{ijk}	Aggregated fuzzy rating of agile criterions	Aggregated fuzzy weight of agile criterions
C_{111}	(0.7500, 0.8125, 0.8750, 0.9250; 1.0000)	(0.8250, 0.8875, 0.9500, 0.9750; 1.0000)
C_{112}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{113}	(0.7000, 0.7625, 0.8250, 0.8875; 1.0000)	(0.6000, 0.6625, 0.7250, 0.7875; 1.0000)
C_{121}	(0.5250, 0.5875, 0.6500, 0.7125; 1.0000)	(0.5750, 0.6375, 0.7000, 0.7625; 1.0000)
C_{122}	(0.4750, 0.5375, 0.5500, 0.6125; 1.0000)	(0.7500, 0.8125, 0.8750, 0.9375; 1.0000)
C_{123}	(0.7250, 0.7875, 0.8500, 0.9125; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{131}	(0.5750, 0.6375, 0.7000, 0.7625; 1.0000)	(0.5500, 0.6125, 0.6750, 0.7375; 1.0000)
C_{132}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.8750, 0.9375, 1.0000, 1.0000; 1.0000)
C_{133}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{211}	(0.6750, 0.7375, 0.8000, 0.8625; 1.0000)	(0.4375, 0.5000, 0.5375, 0.6000; 1.0000)
C_{212}	(0.5250, 0.5875, 0.6250, 0.6875; 1.0000)	(0.6750, 0.7375, 0.8000, 0.8625; 1.0000)
C_{213}	(0.5000, 0.5625, 0.6250, 0.6875; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{221}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.7250, 0.7875, 0.8500, 0.9000; 1.0000)
C_{222}	(0.8250, 0.8875, 0.9500, 0.9750; 1.0000)	(0.6000, 0.6625, 0.7250, 0.7875; 1.0000)
C_{231}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.7000, 0.7625, 0.8250, 0.8875; 1.0000)
C_{232}	(0.7000, 0.7625, 0.8250, 0.8875; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{233}	(0.4500, 0.5125, 0.5250, 0.5875; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{311}	(0.3875, 0.4500, 0.4750, 0.5375; 1.0000)	(0.6750, 0.7375, 0.8000, 0.8625; 1.0000)
C_{321}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.5500, 0.6125, 0.6750, 0.7375; 1.0000)
C_{322}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{323}	(0.8500, 0.9125, 0.9750, 0.9875; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)
C_{324}	(0.6750, 0.7375, 0.8000, 0.8625; 1.0000)	(0.7250, 0.7875, 0.8500, 0.9000; 1.0000)
C_{331}	(0.6500, 0.7125, 0.7750, 0.8375; 1.0000)	(0.6000, 0.6625, 0.7250, 0.7875; 1.0000)
C_{411}	(0.7250, 0.7875, 0.8500, 0.9000; 1.0000)	(0.7000, 0.7625, 0.8250, 0.8875; 1.0000)
C_{421}	(0.4750, 0.5375, 0.5750, 0.6375; 1.0000)	(0.6000, 0.6625, 0.7250, 0.7875; 1.0000)
C_{4222}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.5750, 0.6375, 0.7000, 0.7625; 1.0000)
C_{423}	(0.6000, 0.6625, 0.7250, 0.7875; 1.0000)	(0.7500, 0.8125, 0.8750, 0.9375; 1.0000)
C_{431}	(0.6500, 0.7125, 0.7750, 0.8375; 1.0000)	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)

Table 4.8: Aggregated priority weight and computed rating of agile attributes

Agile attributes C_{ij}	Aggregated fuzzy weight of agile attributes	Computed fuzzy rating of agile attributes
C_{11}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.5551, 0.7006, 0.8902, 1.1029; 1.0000)
C_{12}	(0.7250, 0.7875, 0.8500, 0.8875; 1.0000)	(0.4423, 0.5818, 0.7363, 0.9533; 1.0000)
C_{13}	(0.5250, 0.5875, 0.6500, 0.7125; 1.0000)	(0.4917, 0.6217, 0.7978, 0.9927; 1.0000)
C_{21}	(0.6750, 0.7375, 0.8000, 0.8625; 1.0000)	(0.4229, 0.5695, 0.7266, 0.9606; 1.0000)
C_{22}	(0.6750, 0.7375, 0.8000, 0.8500; 1.0000)	(0.5619, 0.7171, 0.9147, 1.1314; 1.0000)
C_{23}	(0.5125, 0.5750, 0.6250, 0.6875; 1.0000)	(0.4602, 0.6025, 0.7632, 0.9844; 1.0000)
C_{31}	(0.6750, 0.7375, 0.8000, 0.8625; 1.0000)	(0.3033, 0.4148, 0.5153, 0.6868; 1.0000)
C_{32}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.5379, 0.6948, 0.8937, 1.1239; 1.0000)
C_{33}	(0.6000, 0.6625, 0.7250, 0.7875; 1.0000)	(0.4952, 0.6511, 0.8481, 1.0992; 1.0000)
C_{41}	(0.7000, 0.7625, 0.8250, 0.8875; 1.0000)	(0.5718, 0.7278, 0.9197, 1.1411; 1.0000)
C_{42}	(0.6500, 0.7125, 0.7750, 0.8375; 1.0000)	(0.4399, 0.5794, 0.7462, 0.9662; 1.0000)
C_{43}	(0.6250, 0.6875, 0.7500, 0.8125; 1.0000)	(0.5000, 0.6531, 0.8455, 1.0888; 1.0000)

Table 4.9: Aggregated priority weight and computed rating of agile enablers

Agile enablers C_i	Aggregated fuzzy weight of agile capabilities	Computed fuzzy rating of agile capabilities
C_1	(0.7000,0.7625,0.8250,0.8875;1.0000)	(0.3837,0.5800,0.8786,1.3064;1.0000)
C_2	(0.8500,0.9125,0.9750,0.9875;1.0000)	(0.3752,0.5821,0.8732,1.3245;1.0000)
C_3	(0.6250,0.6875,0.7500,0.8125; 1.0000)	(0.3403,0.5341,0.8131,1.2480;1.0000)
C_4	(0.6000,0.6625,0.7250,0.7875;1.0000)	(0.3936,0.6029,0.9115,1.3704;1.0000)

Table 4.10: Computation of FPII

$C_{i,j,k}$	$w'_{i,j,k} = [(1,1,1,1;1) - w_{i,j,k}]$	Fuzzy Performance Importance Index (FPII) $w'_{i,j,k} \otimes U_{i,j,k}$
$C_{1,1,1}$	(0.0250, 0.0500, 0.1125, 0.1750; 1.0000)	(0.0188, 0.0406, 0.0984, 0.1619; 1.0000)
$C_{1,1,2}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.1172, 0.1719, 0.2344, 0.3047; 1.0000)
$C_{1,1,3}$	(0.2125, 0.2750, 0.3375, 0.4000; 1.0000)	(0.1488, 0.2097, 0.2784, 0.3550; 1.0000)
$C_{1,2,1}$	(0.2375, 0.3000, 0.3625, 0.4250; 1.0000)	(0.1247, 0.1763, 0.2356, 0.3028; 1.0000)
$C_{1,2,2}$	(0.0625, 0.1250, 0.1875, 0.2500; 1.0000)	(0.0297, 0.0672, 0.1031, 0.1531; 1.0000)
$C_{1,2,3}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.1359, 0.1969, 0.2656, 0.3422; 1.0000)
$C_{1,3,1}$	(0.2625, 0.3250, 0.3875, 0.4500; 1.0000)	(0.1509, 0.2072, 0.2713, 0.3431; 1.0000)
$C_{1,3,2}$	(0.0000, 0.0000, 0.0625, 0.1250; 1.0000)	(0.0000, 0.0000, 0.0469, 0.1016; 1.0000)
$C_{1,3,3}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.1172, 0.1719, 0.2344, 0.3047; 1.0000)
$C_{2,1,1}$	(0.4000, 0.4625, 0.5000, 0.5625; 1.0000)	(0.2700, 0.3411, 0.4000, 0.4852; 1.0000)
$C_{2,1,2}$	(0.1375, 0.2000, 0.2625, 0.3250; 1.0000)	(0.0722, 0.1175, 0.1641, 0.2234; 1.0000)
$C_{2,1,3}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.0938, 0.1406, 0.1953, 0.2578; 1.0000)
$C_{2,2,1}$	(0.1000, 0.1500, 0.2125, 0.2750; 1.0000)	(0.0625, 0.1031, 0.1594, 0.2234; 1.0000)
$C_{2,2,2}$	(0.2125, 0.2750, 0.3375, 0.4000; 1.0000)	(0.1753, 0.2441, 0.3206, 0.3900; 1.0000)
$C_{2,3,1}$	(0.1125, 0.1750, 0.2375, 0.3000; 1.0000)	(0.0703, 0.1203, 0.1781, 0.2438; 1.0000)
$C_{2,3,2}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.1313, 0.1906, 0.2578, 0.3328; 1.0000)
$C_{2,3,3}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.0844, 0.1281, 0.1641, 0.2203; 1.0000)
$C_{3,1,1}$	(0.1375, 0.2000, 0.2625, 0.3250; 1.0000)	(0.0533, 0.0900, 0.1247, 0.1747; 1.0000)
$C_{3,2,1}$	(0.2625, 0.3250, 0.3875, 0.4500; 1.0000)	(0.1641, 0.2234, 0.2906, 0.3656; 1.0000)
$C_{3,2,2}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.1172, 0.1719, 0.2344, 0.3047; 1.0000)
$C_{3,2,3}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.1594, 0.2281, 0.3047, 0.3703; 1.0000)
$C_{3,2,4}$	(0.1000, 0.1500, 0.2125, 0.2750; 1.0000)	(0.0675, 0.1106, 0.1700, 0.2372; 1.0000)
$C_{3,3,1}$	(0.2125, 0.2750, 0.3375, 0.4000; 1.0000)	(0.1381, 0.1959, 0.2616, 0.3350; 1.0000)
$C_{4,1,1}$	(0.1125, 0.1750, 0.2375, 0.3000; 1.0000)	(0.0816, 0.1378, 0.2019, 0.2700; 1.0000)
$C_{4,2,1}$	(0.2125, 0.2750, 0.3375, 0.4000; 1.0000)	(0.1009, 0.1478, 0.1941, 0.2550; 1.0000)
$C_{4,2,2}$	(0.2375, 0.3000, 0.3625, 0.4250; 1.0000)	(0.1484, 0.2063, 0.2719, 0.3453; 1.0000)
$C_{4,2,3}$	(0.0625, 0.1250, 0.1875, 0.2500; 1.0000)	(0.0375, 0.0828, 0.1359, 0.1969; 1.0000)
$C_{4,3,1}$	(0.1875, 0.2500, 0.3125, 0.3750; 1.0000)	(0.1219, 0.1781, 0.2422, 0.3141; 1.0000)

Table 4.11: Agile criteria ranking (using the concept of comparing fuzzy numbers using '*Maximizing set and Minimizing set*')

Agility Criterions $C_{i,j,k}$	Total utility scores and corresponding criteria ranking order					
	Utility value (α=0)	Ranking order	Utility value (α=0.5)	Ranking order	Utility value (α=1)	Ranking order
$C_{1,1,1}$	0.0603	24	0.1623	25	0.2643	24
$C_{1,1,2}$	0.2954	12	0.4262	13	0.5569	12
$C_{1,1,3}$	0.3674	5	0.5122	5	0.6569	5
$C_{1,2,1}$	0.3081	10	0.4321	12	0.5562	13
$C_{1,2,2}$	0.0975	23	0.1796	24	0.2616	25
$C_{1,2,3}$	0.3406	8	0.4852	8	0.6298	8
$C_{1,3,1}$	0.3674	5	0.5019	6	0.6364	7
$C_{1,3,2}$	0.0000	25	0.0743	26	0.1486	26
$C_{1,3,3}$	0.2954	12	0.4262	13	0.5569	12
$C_{2,1,1}$	0.6328	1	0.7793	1	0.9257	1
$C_{2,1,2}$	0.1929	18	0.2954	20	0.3980	19
$C_{2,1,3}$	0.2392	14	0.3529	16	0.4666	15
$C_{2,2,1}$	0.1684	20	0.2806	21	0.3928	21
$C_{2,2,2}$	0.4310	2	0.5842	2	0.7375	2
$C_{2,3,1}$	0.1933	17	0.3135	17	0.4337	17
$C_{2,3,2}$	0.3293	9	0.4704	10	0.6116	10
$C_{2,3,3}$	0.2168	16	0.3058	18	0.3948	20
$C_{3,1,1}$	0.1457	21	0.2261	23	0.3066	23
$C_{3,2,1}$	0.3980	3	0.5394	4	0.6809	4
$C_{3,2,2}$	0.2954	12	0.4262	13	0.5569	12
$C_{3,2,3}$	0.3974	4	0.5485	3	0.6995	3
$C_{3,2,4}$	0.1811	19	0.2997	19	0.4182	18
$C_{3,3,1}$	0.3422	7	0.4799	9	0.6177	9
$C_{4,1,1}$	0.2224	15	0.3543	15	0.4862	14
$C_{4,2,1}$	0.2541	13	0.3583	14	0.4624	16
$C_{4,2,2}$	0.3637	6	0.5016	7	0.6395	6
$C_{4,2,3}$	0.1207	22	0.2307	22	0.3406	22
$C_{4,3,1}$	0.3067	11	0.4409	11	0.5751	11

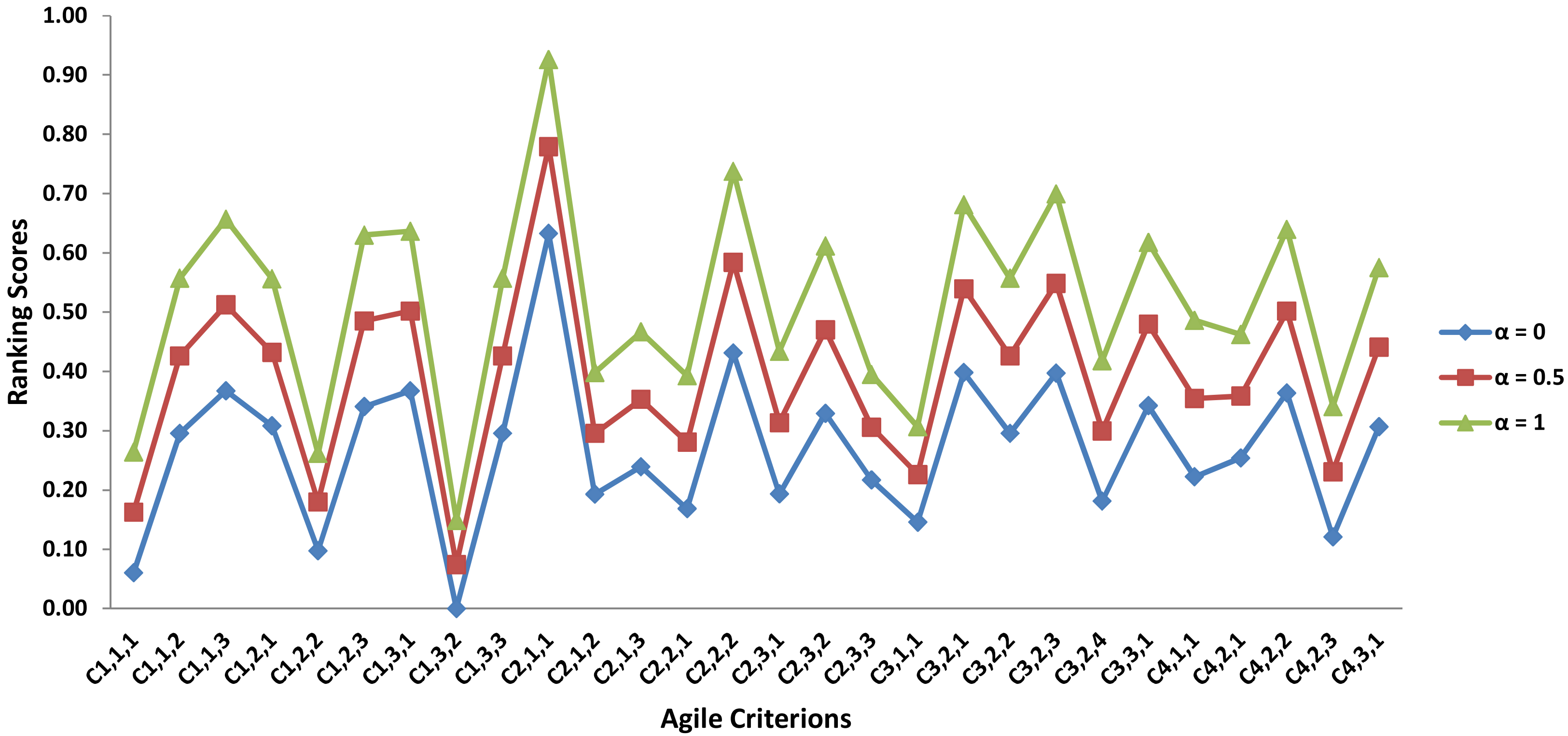

Fig. 4.2: Agile criteria ranking (Chou et al., 2011)

Table 4.12: Agile criteria ranking (using the concept of DOS by Chen, 1996)

Agility Criterions $C_{i,j,k}$	Degree of Similarity with respect to ideal FPII	Ranking order
$C_{1,1,1}$	0.70586	25
$C_{1,1,2}$	0.83297	13
$C_{1,1,3}$	0.87391	5
$C_{1,2,1}$	0.83578	12
$C_{1,2,2}$	0.71422	24
$C_{1,2,3}$	0.86109	8
$C_{1,3,1}$	0.86906	6
$C_{1,3,2}$	0.66305	26
$C_{1,3,3}$	0.83297	13
$C_{2,1,1}$	1.00000	1
$C_{2,1,2}$	0.77023	20
$C_{2,1,3}$	0.79781	16
$C_{2,2,1}$	0.76305	21
$C_{2,2,2}$	0.90844	2
$C_{2,3,1}$	0.77906	17
$C_{2,3,2}$	0.85406	10
$C_{2,3,3}$	0.77516	18
$C_{3,1,1}$	0.73660	23
$C_{3,2,1}$	0.88688	4
$C_{3,2,2}$	0.83297	13
$C_{3,2,3}$	0.89156	3
$C_{3,2,4}$	0.77227	19
$C_{3,3,1}$	0.85859	9
$C_{4,1,1}$	0.79875	15
$C_{4,2,1}$	0.80039	14
$C_{4,2,2}$	0.86891	7
$C_{4,2,3}$	0.73922	22
$C_{4,3,1}$	0.84000	11

Table 4.13: Agile criteria ranking (using the concept of DOS by Hsieh and Chen, 1999)

Agility Criterions $C_{i,j,k}$	Degree of Similarity with respect to ideal FPII	Ranking order
$C_{1,1,1}$	0.77135	25
$C_{1,1,2}$	0.85678	13
$C_{1,1,3}$	0.88792	5
$C_{1,2,1}$	0.85885	12
$C_{1,2,2}$	0.77782	24
$C_{1,2,3}$	0.87794	8
$C_{1,3,1}$	0.88412	6
$C_{1,3,2}$	0.74608	26
$C_{1,3,3}$	0.85678	13
$C_{2,1,1}$	1.00000	1
$C_{2,1,2}$	0.81316	20
$C_{2,1,3}$	0.83173	16
$C_{2,2,1}$	0.80793	21
$C_{2,2,2}$	0.91706	2
$C_{2,3,1}$	0.81896	17
$C_{2,3,2}$	0.87255	10
$C_{2,3,3}$	0.81652	18
$C_{3,1,1}$	0.79156	23
$C_{3,2,1}$	0.89827	4
$C_{3,2,2}$	0.85678	13
$C_{3,2,3}$	0.90334	3
$C_{3,2,4}$	0.81396	19
$C_{3,3,1}$	0.87601	9
$C_{4,1,1}$	0.83259	15
$C_{4,2,1}$	0.83360	14
$C_{4,2,2}$	0.88400	7
$C_{4,2,3}$	0.79308	22
$C_{4,3,1}$	0.86197	11

Table 4.14: Agile criteria ranking (using the concept of DOS by Chen and Chen, 2003)

Agility Criterions $C_{i,j,k}$	Degree of Similarity with respect to ideal FPII	Ranking order
$C_{1,1,1}$	0.47207	25
$C_{1,1,2}$	0.67614	13
$C_{1,1,3}$	0.74424	5
$C_{1,2,1}$	0.68072	12
$C_{1,2,2}$	0.50616	24
$C_{1,2,3}$	0.72257	8
$C_{1,3,1}$	0.73601	6
$C_{1,3,2}$	0.40708	26
$C_{1,3,3}$	0.67614	13
$C_{2,1,1}$	1.00000	1
$C_{2,1,2}$	0.58447	19
$C_{2,1,3}$	0.62027	15
$C_{2,2,1}$	0.56378	21
$C_{2,2,2}$	0.79553	2
$C_{2,3,1}$	0.59146	18
$C_{2,3,2}$	0.71082	10
$C_{2,3,3}$	0.59831	17
$C_{3,1,1}$	0.53971	22
$C_{3,2,1}$	0.76649	3
$C_{3,2,2}$	0.67614	13
$C_{3,2,3}$	0.76401	4
$C_{3,2,4}$	0.57741	20
$C_{3,3,1}$	0.71838	9
$C_{4,1,1}$	0.61980	16
$C_{4,2,1}$	0.63324	14
$C_{4,2,2}$	0.73574	7
$C_{4,2,3}$	0.53251	23
$C_{4,3,1}$	0.68761	11

Table 4.15: Agile criteria ranking (using the concept of DOS by Yong, 2004)

Agility Criterions $C_{i,j,k}$	Degree of Similarity with respect to ideal FPII	Ranking order
$C_{1,1,1}$	0.14958	25
$C_{1,1,2}$	0.45739	13
$C_{1,1,3}$	0.57404	5
$C_{1,2,1}$	0.46500	12
$C_{1,2,2}$	0.16852	24
$C_{1,2,3}$	0.53668	8
$C_{1,3,1}$	0.55959	6
$C_{1,3,2}$	0.06423	26
$C_{1,3,3}$	0.45739	13
$C_{2,1,1}$	1.00000	1
$C_{2,1,2}$	0.29671	20
$C_{2,1,3}$	0.36411	16
$C_{2,2,1}$	0.27815	21
$C_{2,2,2}$	0.67352	2
$C_{2,3,1}$	0.31699	17
$C_{2,3,2}$	0.51647	10
$C_{2,3,3}$	0.31160	18
$C_{3,1,1}$	0.21882	23
$C_{3,2,1}$	0.61262	4
$C_{3,2,2}$	0.45739	13
$C_{3,2,3}$	0.62062	3
$C_{3,2,4}$	0.30033	19
$C_{3,3,1}$	0.52935	9
$C_{4,1,1}$	0.36578	15
$C_{4,2,1}$	0.37303	14
$C_{4,2,2}$	0.55921	7
$C_{4,2,3}$	0.22251	22
$C_{4,3,1}$	0.47682	11

Table 4.16: Agile criteria ranking (using the concept of DOS by Chen, 2006)

Agility Criterions $C_{i,j,k}$	Degree of Similarity with respect to ideal FPII	Ranking order
$C_{1,1,1}$	0.66745	25
$C_{1,1,2}$	0.81168	13
$C_{1,1,3}$	0.85160	5
$C_{1,2,1}$	0.81441	12
$C_{1,2,2}$	0.70848	24
$C_{1,2,3}$	0.83911	8
$C_{1,3,1}$	0.84686	6
$C_{1,3,2}$	0.61200	26
$C_{1,3,3}$	0.81168	13
$C_{2,1,1}$	1.00000	1
$C_{2,1,2}$	0.75872	19
$C_{2,1,3}$	0.77736	15
$C_{2,2,1}$	0.73835	21
$C_{2,2,2}$	0.87649	2
$C_{2,3,1}$	0.75912	18
$C_{2,3,2}$	0.83226	10
$C_{2,3,3}$	0.77171	17
$C_{3,1,1}$	0.73242	22
$C_{3,2,1}$	0.86423	3
$C_{3,2,2}$	0.81168	13
$C_{3,2,3}$	0.85790	4
$C_{3,2,4}$	0.74718	20
$C_{3,3,1}$	0.83667	9
$C_{4,1,1}$	0.77613	16
$C_{4,2,1}$	0.79106	14
$C_{4,2,2}$	0.84672	7
$C_{4,2,3}$	0.72024	23
$C_{4,3,1}$	0.81854	11

Table 4.17: Agile criteria ranking (using the concept of DOS by Shridevi and Nadarajan, 2009)

Agility Criterions $C_{i,j,k}$	Degree of Similarity with respect to ideal FPII	Ranking order
$C_{1,1,1}$	0.27535	25
$C_{1,1,2}$	0.54056	13
$C_{1,1,3}$	0.63685	5
$C_{1,2,1}$	0.54697	12
$C_{1,2,2}$	0.30363	24
$C_{1,2,3}$	0.60601	8
$C_{1,3,1}$	0.62512	6
$C_{1,3,2}$	0.20021	26
$C_{1,3,3}$	0.54056	13
$C_{2,1,1}$	1.00000	1
$C_{2,1,2}$	0.41012	19
$C_{2,1,3}$	0.46308	16
$C_{2,2,1}$	0.38871	21
$C_{2,2,2}$	0.71535	2
$C_{2,3,1}$	0.42373	18
$C_{2,3,2}$	0.58936	10
$C_{2,3,3}$	0.42477	17
$C_{3,1,1}$	0.34671	22
$C_{3,2,1}$	0.66872	4
$C_{3,2,2}$	0.54056	13
$C_{3,2,3}$	0.67109	3
$C_{3,2,4}$	0.40714	20
$C_{3,3,1}$	0.60007	9
$C_{4,1,1}$	0.46364	15
$C_{4,2,1}$	0.47532	14
$C_{4,2,2}$	0.62474	7
$C_{4,2,3}$	0.34465	23
$C_{4,3,1}$	0.55663	11

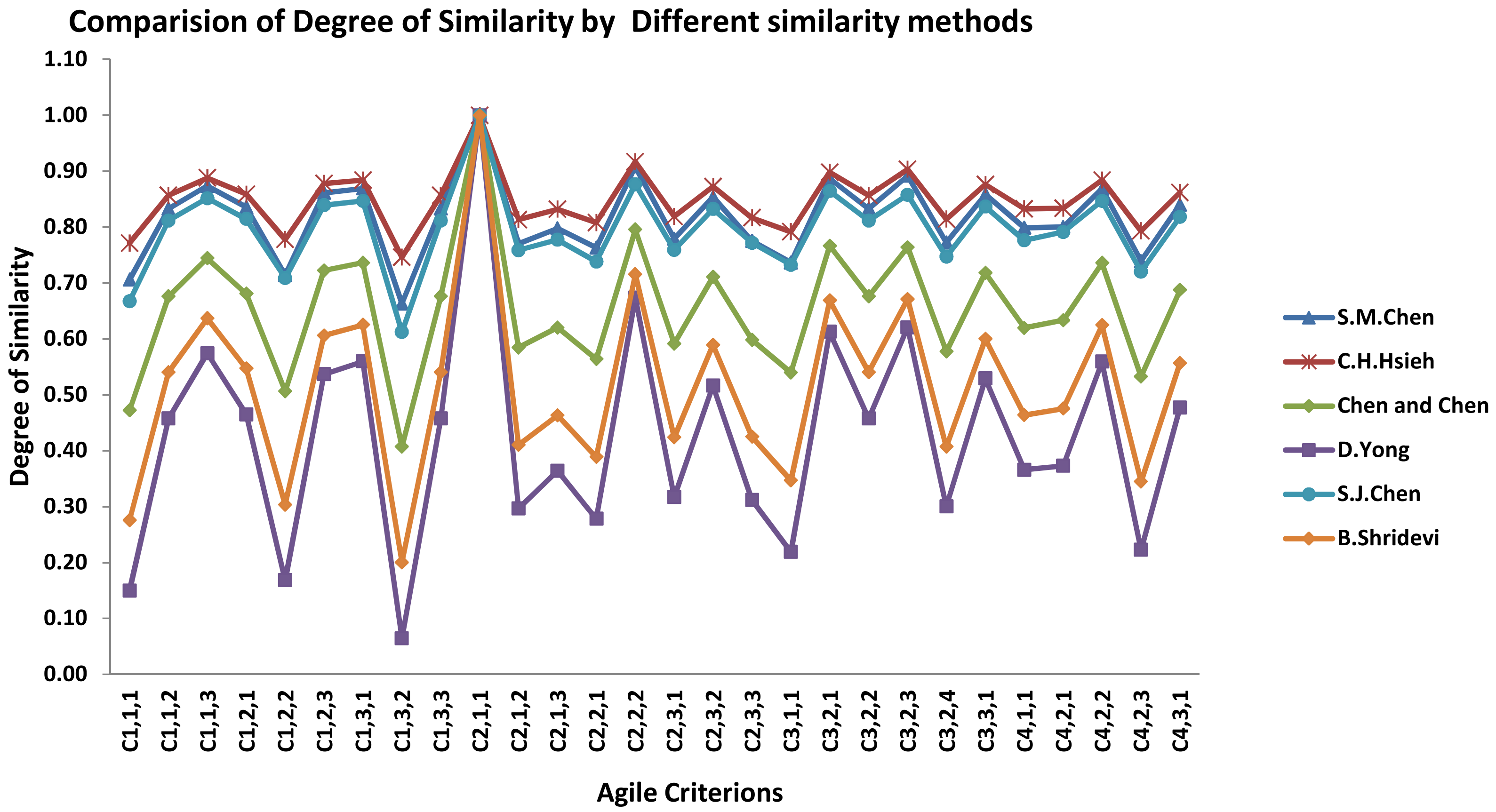

Fig. 4.3: Agile criteria ranking using degree of similarity measure (DOS)

4.2 Supplier /Partner Selection in Agile Supply Chain (ASC): Application of Vague Numbers Set

4.2.1 Coverage

The recent global market trend is seemed enforcing the manufacturing organizations (as well as service sectors) to improve existing supply chain systems or to take up/adapt advanced manufacturing strategies for being competitive. The concept of agile supply chain (ASC) has become increasingly important as means of achieving a competitive edge in turbulent business environments. An ASC is a dynamic alliance of member enterprises, the adaptation of which is likely to introduce velocity, responsiveness and flexibility into the manufacturing system. In ASC management, supplier/partner selection is a key strategic concern; influenced by various agility related criteria/attributes. Therefore, evaluation and selection of potential supplier in an ASC has become an important Multi-Criteria Decision Making (MCDM) problem. In this work, a supplier selection procedure (module) has been reported in the context of agile supply chain.

During supplier selection, subjectivity of evaluation information (human judgment) often creates conflict and bears some kind of uncertainty. To overcome this, the present work attempts to explore vague set theory to deal with uncertainties in the supplier selection decision making process. Since, vague sets can provide more accurate information as compared to fuzzy sets. It considers true membership function as well as false membership function which give more superior results for uncertain information. In this procedure, firstly, linguistic variables have been used to assess appropriateness rating (performance extent) as well as priority weights for individual quantitative or qualitative criterions. Secondly, the concept of degree of similarity and probability of vague sets has been used to determine appropriate ranking order of the potential supplier alternatives. A case empirical example has also been provided.

4.2.2 Introduction and State of Art

Competitive advantages associated with supply chain management (SCM) philosophy can be achieved by strategic collaboration with suppliers and service providers. The success of a supply chain is highly dependent on selection of good suppliers (Ng, 2008). Recently, supply chain management and the supplier (vendor) selection process have received considerable attention in the business-management literature.

During the 1990s, many manufacturers seek to collaborate with their suppliers in order to upgrade their management performance and competitiveness (Ittner et al., 1999; Shin et al., 2000; Chen et al., 2006). Simply looking for vendors offering the lowest prices is not ‘‘efficient sourcing’’ any more. Multiple criteria need to be taken into account when selecting suppliers to meet various business needs (Ng, 2008). This process is essentially considered as a multiple criteria decision-making (MCDM) problem which is affected by different tangible and intangible criteria including price, quality, performance, technical capability, delivery, etc. (Önüt et al., 2009). For any manufacturing or service business, selecting the right upstream suppliers is a key success factor that will significantly reduce purchasing cost, increase downstream customer satisfaction, and improve competitive ability (Liao and Kao, 2010).

A number of alternative approaches have been proposed in literature to solve such suppliers' selection problems: mathematical programming models, multiple attribute decision aid methods, cost-based methods, statistical and probabilistic methods, combined methodologies and many others (Önüt et al., 2009).

Pi and Low (2005) developed an evaluation and selection system of suppliers using Taguchi loss functions based on four attributes: quality, on-time delivery, price and service. These four attributes were transferred into the quality loss and combined to one decision variable for decision making. In another reporting, Pi and Low (2006) provided another method for quantifying the supplier's attributes to quality-loss using a Taguchi loss function, and these quality losses were also transferred into a variable for decision-making by an analytical hierarchy process (AHP). Chen et al. (2006) presented a fuzzy decision-making approach to deal with the supplier selection problem in supply chain system. A hierarchy multiple criteria decision-making (MCDM) model based on fuzzy-sets theory was proposed to deal with the supplier selection problems in the supply chain system. According to the concept of the TOPSIS, a closeness coefficient was defined to determine the ranking order of all suppliers by calculating the distances to the both fuzzy positive-ideal solution (FPIS) and fuzzy negative-ideal solution (FNIS) simultaneously. Bevilacqua et al. (2006) suggested a method that transferred the house of quality (HOQ) approach typical of quality function deployment (QFD) problems to the supplier selection process.

Jadidi et al. (2008) applied improved grey based method for supplier selection problem. Li et al. (2008) proposed a grey-based rough set approach to deal with supplier selection problem in supply chain management. The proposed approach took advantage of mathematical analysis power of grey system theory whilst at the same time utilizing data mining and knowledge discovery power of rough set theory. The said method was suitable to the decision-making under more uncertain environments. Demirtas and Ustun (2008) proposed an integrated approach of analytic network process (ANP) and multi-objective mixed integer linear programming (MOMILP) to consider both tangible and intangible factors in choosing the best suppliers and thereby, defining the optimum quantities among selected suppliers to maximize the total value of purchasing and to minimize the budget and defect rate. Ng (2008) proposed a weighted linear program for the multi-criteria supplier selection problem. Chou and Chang (2008) presented a strategy-aligned fuzzy simple multi-attribute rating technique (SMART) for solving the supplier/vendor selection problem from the perspective of strategic management of the supply chain (SC).

Amid et al. (2009) developed a weighted additive fuzzy multi-objective model for the supplier selection problem under price breaks in a supply chain. Wu (2009) presented a hybrid model using data envelopment analysis (DEA), decision trees (DT) and neural networks (NNs) to assess supplier performance. Wu et al. (2009) presented an integrated multi-objective decision-making process by using analytic network process (ANP) and mixed integer programming (MIP) to optimize the selection of supplier. Lee (2009) proposed an analytical approach to facilitate suppliers under fuzzy environment. A fuzzy analytic hierarchy process (FAHP) model, which incorporated the benefits, opportunities, costs and risks (BOCR) concept was constructed to evaluate various aspects of suppliers. Önüt et al. (2009) developed a fuzzy embedded supplier evaluation approach based on the analytic network process (ANP) and the technique for order performance by similarity to ideal solution (TOPSIS) methods to help a telecommunication company in the GSM sector in Turkey. Zhang et al. (2009) proposed an approach based on vague sets group decision to deal with the supplier selection problem in supply chain systems.

(Dash) Wu (2009) used grey related analysis and Dempster–Shafer theory to deal with supplier selection-fuzzy group decision making problem. First, in the individual aggregation, grey related analysis was employed as a means to reflect uncertainty in multi-attribute models through interval numbers. Secondly, in the group aggregation, the Dempster–Shafer (D–S) rule of combination was used to aggregate individual preferences into a collective preference, by which the candidate alternatives were ranked and the best alternative(s) were obtained. The proposed approach used both quantitative and qualitative data for international supplier selection. Guneri et al. (2009) aimed to present an integrated fuzzy and linear programming approach to the supplier selection problem.

Shen and Yu (2009) considered the strategic and operational factors simultaneously to secure the efficacy of supplier selection (VS) on initial stage of new product development (NPD). Wang and Yang (2009) introduced Analytical Hierarchy Process (AHP) and fuzzy compromise programming to obtain a reasonable compromise solution for allocating order quantities among suppliers with their quantity discount rate offered. Boran et al. (2009) proposed application of

TOPSIS method combined with intuitionistic fuzzy set to select appropriate supplier in group decision making environment. Ebrahim et al. (2009) proposed the scatter search algorithm for supplier selection and order lot sizing under multiple price discount environment.

Sanayei et al. (2010) reported a research on group decision making process for supplier selection with VIKOR under fuzzy environment. Chamodrakas et al. (2010) suggested an approach for decision support system enabling effective supplier selection processes in electronic marketplaces. The authors introduced an evaluation method with two stages: initial screening of the suppliers through the enforcement of hard constraints on the selection criteria and final supplier evaluation through the application of a modified variant of the Fuzzy Preference Programming (FPP) method. Keskin et al. (2010) applied Fuzzy Adaptive Resonance Theory (ART)'s classification ability to the supplier evaluation and selection area. Liao and Kao (2010) integrated the Taguchi loss function, analytical hierarchy process (AHP) and multi-choice goal programming (MCGP) model for solving the supplier selection problem. Awasthi et al. (2010) presented a fuzzy multi-criteria approach for evaluating environmental performance of suppliers. Büyüközkan and Çifçi (2011) examined the problem of identifying an effective model based on sustainability principles for supplier selection operations in supply chains. The paper developed an approach based on fuzzy analytic network process within multi-person decision-making schema under incomplete preference relations. Yucel and Guneri (2011) investigated on supplier section problem by using a weighted additive fuzzy programming approach. Dalalah et al. (2011) presented a hybrid fuzzy model for group Multi-Criteria Decision Making (MCDM) in relation to supplier selection. A modified fuzzy DEMATEL model was presented to deal with the influential relationship between the evaluations criteria. Liao and Kao (2011) proposed integrated fuzzy techniques for order preference by similarity to ideal solution (TOPSIS) and multi-choice goal programming (MCGP) approach to solve the supplier selection problem. Ertay et al. (2011) proposed a methodology, which was capable of evaluating and monitoring suppliers' performance, was constructed, using fuzzy analytic hierarchy process (AHP) to weight the established decision criteria and ELECTRE III to evaluate, rank and classify performance of suppliers regarding relative criteria. The proposed methodology was applied to a real-life supplier-selection and classification problem of a pharmaceutical company.

Zouggari and Benyoucef (2012) presented an efficient decision making approach for group multi-criteria supplier selection problem, which clubbed supplier selection process with order allocation for dynamic supply chains to cope market variations. Fuzzy-AHP method was used first for supplier selection through four classes (CLASS I: Performance strategy, CLASS II:

Quality of service, CLASS III: Innovation and CLASS IV: Risk), which were qualitatively meaningful. Thereafter, using simulation based fuzzy TOPSIS technique, the criteria application was quantitatively evaluated for order allocation among the selected suppliers. Büyüközkan (2012) proposed a decision model for supplier performance evaluation by considering various environmental performance criteria. An integrated, fuzzy group decision making approach was adopted to evaluate green supplier alternatives. More precisely, a fuzzy analytic hierarchy process (AHP) was applied to determine the relative weights of the evaluation criteria and an axiomatic design (AD)-based fuzzy group decision-making approach was applied to rank the green suppliers. Pitchipoo et al. (2012) developed an appropriate hybrid model by integrating the analytical hierarchy process (AHP) and grey relational analysis (GRA) for supplier evaluation and selection, which comprises three stages. In Stage I, the most influential criteria were selected by mutual-information-based feature selection. Stage II focused on the determination of the weights of the attributes using AHP, while Stage III was used for the determination of the best supplier using GRA.

Parthiban and Zubar (2013) selected the best performing supplier among the group according to the prioritization of performance criterion through the application of techniques like MISM (modified interpretive structural modeling), MICMAC (impact matrix cross-reference multiplication applied to a classification), and AHP (analytical hierarchy process). Pitchipoo et al. (2013) proposed a structured, integrated decision model for evaluating suppliers by combining the fuzzy analytical hierarchy process (FAHP) and grey relational analysis (GRA). Ghorbani et al. (2013) proposed a three-phase approach for supplier selection based on the Kano model and fuzzy Multi Criteria Decision-Making. Initially, the importance weight of the criteria was calculated using a fuzzy Kano questionnaire and fuzzy analytic hierarchy process. In the second phase, the Fuzzy TOPSIS technique was used to screen out in capable suppliers. Finally, in the third phase, the filtered suppliers which were qualified, once again would be evaluated by the same approach for the final ranking. Huang and Hu (2013) developed a systematic process for automotive industry supplier selection: a two-stage solution approach for supplier selection using Fuzzy Analytic Network Process-Goal Programming (FANP-GP) and De Novo Programming (DNP). The first stage was the FANP method integrated with the GP model to select the best supplier and to decide the optimal order quantity. In the second stage, the selected suppliers were evaluated based on the DNP method by adjusting their resource constraints and increase their capacity to achieve the minimum total procurement budget. Haldar et al. (2014) developed a quantitative approach for strategic supplier selection under a fuzzy environment in a disaster scenario (unwanted disturbances).

Aforesaid section exhibits the importance of supplier selection in the context of traditional supply chain management. An exhaustive literature survey has been conducted covering articles published in between 2006 to 2014. Several decision support tools and techniques have been attempted by pioneers to facilitate evaluation and selection of potential suppliers. The voluminous documentation provides an impression on the extent of importance of suppliers' selection issues, even in recent business management scenario. Agile supply chain management is also supported by effective supplier selection process; however, while selecting a supplier in agile supply chain; apart from traditional supplier selection criteria (cost, quality and performance), agility related criterions must be considered as well. The following sections provide an in-depth understanding of agile supply chain management as well as supplier selection issues in ASC. Limited works could be found in literature in addressing supplier/partner selection in ASC. Based on the above, research gap has been identified and finally, objectives of the present work have been chalked out.

Recently, the concept of the agile supply chain (ASC) has become increasingly important as means of achieving a competitive edge in rapidly changing (turbulent) business environments (Lin et al., 2006; Christopher and Towill, 2000). It has been realized that today's dynamic business environment experiences the need for greater agility in supply chains, which increases both the importance and frequency of partner selection decision-making (Wu and Barnes, 2010). In ASCs, companies must align with their supply partners to streamline their operations, as well as working together to achieve the necessary levels of agility throughout the entire supply chain and not just within an individual company (Christopher and Towill, 2000; Lin et al., 2006; Wu and Barnes, 2011; Wu et al., 1999; Luo et al., 2009).

Ren et al. (2005) proposed a decision-making methodology and a hierarchical model for the selection of agile partners. Sarkis et al. (2007) provided a practical model usable by organizations to help form agile virtual enterprises. The model helped to integrate a variety of factors, tangible and intangible, strategic and operational, for decision-making purposes. Luo et al. (2009) developed an agile supplier selection model that helped to overcome the information-processing difficulties inherent in screening a large number of potential suppliers in the early stages of the selection process. Based on radial basis function artificial neural network (RBF-ANN), the model enabled potential suppliers to be assessed against multiple criteria using both quantitative and qualitative measures. Its efficacy was illustrated using empirical data from the Chinese electrical appliance and equipment manufacturing industries.

Supplier/Partner selection is, therefore, considered as a fundamental issue in supply chain management as it contributes significantly to overall supply chain performance. However, such decision-making is problematic due to the need to consider both tangible and intangible factors, which cause vagueness, ambiguity and complexity (Yucel and Guneri 2011; Wu and Barnes, 2011; 2014). At the same time, the vagueness of the information in this type of problem makes decision-making more complicated (Amid et al. 2006; Yang 2010). Consequently, many researchers have realized the application potential of fuzzy set theory (FST) as offering an efficient means of handling this uncertainty effectively and of converting human judgments into meaningful results (Wu and Barnes, 2014; Yang, 2010; Yucel and Guneri, 2011; Zadeh, 1965; Amid et al., 2006). As an example, Wu and Barnes (2014) proposed a fuzzy intelligent approach for partner selection in agile supply chains by using fuzzy set theory in combination with radial basis function artificial neural network. The work included an empirical application of the model with data from 84 representative companies within the Chinese electrical components and equipment industry, to demonstrate its suitability for helping organizational decision-makers in partner selection.

Agility in supply chains is the capability to effectively and efficiently respond to the dynamic as well as turbulent market expectations. An agile supply chain (ASC) needs to be highly flexible and to be able to be reconfigured quickly in response to changes in the volatile business environment. The successful operation of an ASC largely depends upon the firm's ability to select the most appropriate potential partners/suppliers in any given situation (Wu and Barnes, 2010; Christopher, 2000; Wu and Barnes, 2014).

Literature depicts that application of fuzzy set theory has been immensely popularized in analyzing different aspects of agile supply chain management followed by supplier/partner selection. However, it has been found that exploration of vague set offers additional advantage with respect to fuzzy set. Vague sets are basically an extension of fuzzy sets. In a fuzzy set, each object is assigned a single value in the interval $[0,1]$, which represents the grade of membership in particular fuzzy set. This single value does not reveal the relation between membership and non-membership in a fuzzy set. In vague sets, each object is characterized by two different membership functions: a true membership function and a false membership function. This kind of interpretation is also called interval membership or an extension to the fuzzy membership function, contrasting to point membership in the context of fuzzy sets. In vague set the uncertainty within set is difference between the upper and lower bounds of the membership interval. Therefore, in the context of uncertain information and vagueness situation, vague set can provide more accurate information and gives better results than fuzzy sets (Hong and Choi, 2000; Ye, 2007; Zhang at al., 2009). Motivated by this, present work attempts to exhibit a decision support module for agile supplier selection under uncertain environments. The module is based on vague sets group decisions (Gau and Buehrer, 1993).

In supplier selection process, the degree of uncertainty of the attributes must be taken into account (Chen at al., 2006). Considering fuzziness in the decision data (information), in the group decision making process, linguistic variables that could be expressed in vague values are to be used, in order to assess the weights of all criteria and the ratings of each alternative with respect to each criterion. Linguistic variables are also to be used to determine weights of the importance of different decision-makers. These weights are then adjusted by considering the similarities and the differences amongst them. After that, the judgments of all decision-makers (DMs) are integrated into a final decision matrix. Using probability degree to compare the vague sets of the evaluation object, the ranking order of candidate suppliers could easily be determined.

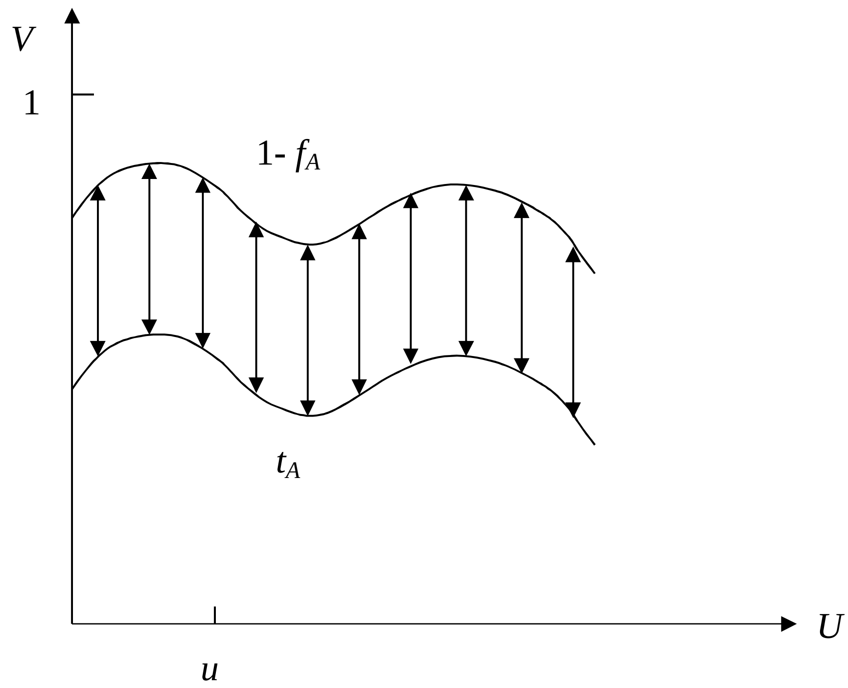

Fig. 4.4: Vague set

4.2.3 Vague Set Theory

Let U is the universe of discourse, with a generic element of U denoted by u. A vague set A is characterized by a truth-membership function t_A and a false-membership function f_A, where, $t_A(u)$ is a lower bound on the grade of membership of u, derived from the evidence for u; $f_A(u)$ is a lower bound on the negation of u, derived from the evidence against u and $t_A(u)+f_A(u)\leq 1$. The grade of membership of u in the vague set A is bound to a sub interval $[t_A(u),1-f_A(u)]$ of $[0,1]$. The vague value $[t_A(u),1-f_A(u)]$ indicates that the exact grade of membership $\mu_A(u)$ of u may be unknown, but it is bound by $t_A(u)\leq\mu_A(u)\leq 1-f_A(u)$, where $t_A(u)+f_A(u)\leq 1$. For example, Fig. 4.4 shows a vague set in the universe of discourse U.

When the universe of discourse U is continuous, a vague set A can be written as:

$$A=\int_U [t_A(u),1-f_A(u)]/u \qquad (u\in U) \tag{4.40}$$

When the universe of discourse U is discrete, a vague set A can be written as:

$$A=\sum_{i=l}^{n}[t_A(u_i),1-f_A(u_i)]/u_i \qquad (u\in U) \tag{4.41}$$

4.2.3.1 Operational Definitions between Two Vague Sets

Let x, y are two vague values in the universe of discourse U, $x=[t_x,1-f_x]$, $y=[t_y,1-f_y]$ where, $t_x,f_x,t_y,f_y\in[0,1]$ and $t_x+f_x\leq 1, t_y+f_y\leq 1$; the operation and relationship between vague values is illustrated as follows:

Definition 1: The minimum operation of vague values x and y is defined by

$$x\wedge y=[\min(t_x,t_y),\min(1-f_x,1-f_y)]=[\min(t_x,t_y),1-\max(f_x,f_y)] \tag{4.42}$$

Definition 2: The maximum operation of vague values x and y is defined by

$$x\vee y=[\max(t_x,t_y),\max(1-f_x,1-f_y)]=[\min(t_x,t_y),1-\max(f_x,f_y)] \tag{4.43}$$

Definition 3: The complement of vague value x is defined by

$$\overline{x}=[f_x,1-t_x] \tag{4.44}$$

Let A, B is two vague sets in the universe of discourse $U=\{u_1, u_2, \ldots u_n\}$,

$$A=\sum_{i=1}^{n}[t_A(u_i), 1-f_A(u_i)]/u_i\,,\quad B=\sum_{i=1}^{n}[t_B(u_i), 1-f_B(u_i)]/u_i$$

then the operations between vague are defined as follows:

Definition 4: The intersection of vague sets A and B is defined by

$$A \cap B=\sum_{i=1}^{n}\{[\,t_A(u_i), 1-f_A(u_i)\,] \wedge [\,t_B(u_i), 1-f_B(u_i)\,]\}/u_i \qquad (4.45)$$

Definition 5: The union of vague sets A and B is defined by

$$A \cup B=\sum_{i=1}^{n}\{[\,t_A(u_i), 1-f_A(u_i)\,] \vee [\,t_B(u_i), 1-f_B(u_i)\,]\}/u_i \qquad (4.46)$$

Definition 6: The complement of vague set A is defined by

$$\overline{A}=\sum_{i=1}^{n}[\,f_A(u_i),\ 1-t_A(u_i)]/u_i \qquad (4.47)$$

4.2.3.2 Similarity Measure between Two Vague Sets

Similarity measure between two vague values, $x=[t_x, 1-f_x]$, $y=[t_y, 1-f_y]$: reported in (Zhang at al., 2004) is calculated as:

$$S(x, y)=1-\frac{d(x, y)}{\sqrt{2}} \qquad (4.48)$$

Here, $d(x, y)=\sqrt{(t_x-t_y)^2+(1-f_x-(1-f_y))^2}=\sqrt{(t_x-t_y)^2+(f_x-f_y)^2}$ (4.49)

$d(x, y)$ is the distance between vague value x and y.

Definition 7: Let A, B are two vague sets in the universe of discourse $U=\{u_1, u_2, \ldots u_n\}$, $A=\sum_{i=1}^{n}[t_A(u_i), 1-f_A(u_i)]/u_i$, $B=\sum_{i=1}^{n}[t_B(u_i), 1-f_B(u_i)]/u_i$, the similarity measure between vague sets A and B is defined by:

$$S(A, B)=\frac{1}{n}\sum_{i=1}^{n}S(\mu_A(u_i), \mu_B(u_i)) \qquad (4.50)$$

4.2.3.3 Comparison between Vague Sets

In vague sets-based multiple criteria fuzzy decision making, the vague sets of the evaluation object are compared. Formally, a vague value is also an interval-value. Therefore, according to interval-value, the definition of comparison between vague sets is:

Definition 8: For vague value $x=[t_x,1-f_x]$, $y=[t_y,1-f_y]$, the probability of $x \geq y$ is defined by

$$P(x \geq y)=\frac{\text{Max}(0, L(x)+L(y)-\text{Max}(0, 1-f_x-t_x))}{L(x)+L(y)}, \quad (4.51)$$

where, $L(x)=1-f_x-t_x$, $L(y)=1-f_y-t_x$ is the length of vague value x, y.

With the above definition, we can easily get the property as follows:

Property 1: $0 \leq P(x \geq y) \leq 1$

Property 2: If $P(x \geq y)=P(y \geq x)$, then $P(x \geq y)=P(y \geq x)=0.5$

Property 3: $P(x \geq y)+P(y \geq x)=1$

Property 4: For any three vague values x, y, z, if $P(x \geq y) \geq 0.5$, $P(y \geq z) \geq 0.5$, then $P(x \geq z) \geq 0.5$

Definition 9: Let A, B is two vague sets in the universe of discourse $U=\{u_1, u_2, \ldots u_n\}$, $A=\sum_{i=1}^{n}[t_A(u_i), 1-f_A(u_i)]/u_i$, $B=\sum_{i=1}^{n}[t_B(u_i), 1-f_B(u_i)]/u_i$, the probability of $A \geq B$ is defined by

$$P(A \geq B)=\frac{1}{n}\sum_{i=1}^{n} P(\mu_A(u_i) \geq \mu_B(u_i)) \quad (4.52)$$

4.2.3.4 Defuzzification of Vague Value and Weighted Sum of Vague Values

Definition 10: For vague value $x=[t_x, 1-f_x]$, we define the defuzzification function to get the precise value as follows:

$$\text{Dfzz}(x)=t_x/(t_x+f_x). \quad (4.53)$$

Definition 11: For n Vague values $x_i=[t_{x_i}, 1-f_{x_i}]$, whose weights vector $w=(w_1, w_2, \ldots, w_n)$ are n precise values; the weighted sum of $x_i (i=1, \ldots, n)$ is defined as follows:

$$\bar{x} = \sum_{i=1}^{n} w_i \times x_i = \left[\sum_{i=1}^{n} w_i \times t_i , 1 - \sum_{i=1}^{n} w_i \times f_i \right], \quad (4.54)$$

where, $\sum_{i=1}^{n} w_i = 1$.

4.2.4 Agile Supplier/Partner Selection Module: Exploration of Vague Set Theory

A group multi-criteria decision making approach exploring vague sets theory as proposed by (Zhang et al., 2009) has been utilized here to rank potential supplier alternatives in ASC. It not only considers the relative importance of different decision-makers, but also includes the accordance and difference in the decision group. After all, it integrates the judgments of all the decision-makers into a decision matrix, from which we can get the ranking order (vector) of all supplier alternatives.

Assuming that $A = \{A1, A2, \ldots, Am\}$ is a discrete set of m possible supplier alternatives, and $C = \{C_1, C_2, \ldots, C_n\}$ is a set of n attributes of suppliers. The attributes are additively independent. Let $W = \{W_1, W_2, \ldots, W_n\}$ is the attribute weight vector. The attribute weights as well as performance extent (rating) of candidate suppliers is denoted in terms of linguistic variables. These linguistic variables can be further transformed into vague values. The procedural steps of the proposed supplier selection module are as follows:

Step 1: Formation of committee with a group of decision-makers and identify the importance weight vector of the decision-makers. Assume that a committee has K decision maker, weight vector $D = (D^1, D^2, \ldots, D^K)$ can be obtained by professional knowledge and experience of experts, which is the subjective weight vector of the decision-makers. Let, $D^k (k = 1, \ldots, K)$ is the importance degree of the k^{th} DM, and $D^k = (t_{D^k}, 1 - f_{D^k})$ is the vague variable.

Step 2: Using linguistic variables to identify the attribute weights and attribute ratings of alternatives suppliers.

For every DMs in the decision making group, we can get a vector of attribute weights and a preference matrix of supplier alternatives. Namely, $W^k = \{W_1^k, W_2^k, \ldots, W_n^k\}$ $(k = 1, \ldots, K)$ is the vector of attribute weights given by k^{th} DM, where, $W_j^k = \left(t_{W_j^k}, 1 - f_{W_j^k}\right)$ $(j = 1, \ldots, n)$ is a vague variable. The preference matrix given by k^{th} DM is written as:

$$R^k = \begin{bmatrix} R_{11}^k & R_{12}^k & \cdots & R_{1n}^k \\ R_{21}^k & R_{22}^k & \cdots & R_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ R_{m1}^k & R_{m2}^k & \cdots & R_{mn}^k \end{bmatrix},$$

Here, $R_{ij}^k \left(i = 1, \ldots, m;\ j = 1, \ldots, n\right)$ is the attribute rating of supplier alternative A_i on attribute C_j given by k^{th} DM, and $R_{ij}^k = \left[t_{R_{ij}^k}, 1 - f_{R_{ij}^k}\right]$ is a linguistic variable.

Step 3: Calculate weighted decision matrix of k^{th} DM.

Considering the different importance of each attribute, the weighted decision matrix can be expressed as:

$$M^k = \begin{bmatrix} M_{11}^k & M_{12}^k & \cdots & M_{1n}^k \\ M_{21}^k & M_{22}^k & \cdots & M_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ M_{m1}^k & M_{m2}^k & \cdots & M_{mn}^k \end{bmatrix},$$

where, $M_{ij}^k = W_j^k \wedge R_{ij}^k \quad \left(i = 1, \ldots, m;\ j = 1, \ldots, n\right).$ (4.55)

Each line $M_i^k = \sum_{j=1}^n M_{ij}^k / C_i$ represents the evaluation of k^{th} DM vis-a-vis alternative A_i on attributes set $C = \{C_1, C_2, \ldots, C_n\}$. It is also a vague set.

Step 4: Adjust the importance degree of decision-makers according to the preference accordance in the decision group.

Since the final decision must be close to the preference of most DMs, it is reasonable for us to increase the weight of DMs whose preference is close to the group preference. According to **Definition 7**, calculate the similarity between the p^{th} DM and q^{th} DM as follows:

$$S_{pq} = S\left(M^p, M^q\right) = \frac{1}{m}\sum_{i=1}^{m} S\left(M_i^p, M_i^q\right). \tag{4.56}$$

Thus, we can get the preference accordance matrix of all DMs:

$$S = [S_{pq}] = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1K} \\ S_{11} & S_{22} & \cdots & S_{2K} \\ \vdots & \vdots & \ddots & \vdots \\ S_{K1} & S_{K2} & \cdots & S_{KK} \end{bmatrix}.$$

Obviously, S is found to be a symmetric matrix. Using the line sum of S get the similarity weights vector,

$h = \{h^1, h^2, \ldots, h^K\}$, where

$$h^k = \frac{\sum_{q=1, q \neq k}^{K} S_{kq}}{\sum_{p=1}^{K} \sum_{q=1, q \neq p}^{K} S_{pq}} = \frac{\sum_{q=1}^{K} S_{kq} - 1}{\sum_{p=1}^{K} \sum_{q=1}^{K} S_{pq} - K}. \quad (4.57)$$

Since h is derived from the preference matrix given by all DMs, it is called the objective weights vector.

Step 5: Adjust the weights vectors of the decision-makers' by both subjective and objective weights vectors. Use Eq. (4.53) to get the precise value $w = \{w^1, w^2, \ldots, w^K\}$ of the subjective weights vector $D = (D^1, D^2, \ldots, D^K)$,

where, $w^k = t_{D^k} / (t_{D^k} + f_{D^k})$. (4.58)

Normalize w to get the final subjective weight vector, which is still said w with no confusion in the case. So, there is one h_k and one w_k corresponding to k^{th} DM. Calculate the adjusted weights vector $d = (d^1, d^2, \ldots, d^K)$ as follows:

$$d^k = a \times w^k + (1 - a) \times h^k, \qquad k = 1, 2, \ldots, K. \quad (4.59)$$

Here, $a \in [0,1]$ represents the preference to subjective weights against objective weights. The larger a is, the more is the attention of DMs to subjective weights. Contrarily, the more is the attention of DMs to objective weights.

Step 6: Integrate all DMs' preference matrix to generate the whole decision matrix.

$$G = \begin{bmatrix} G_{11} & G_{12} & \cdots & G_{1n} \\ G_{21} & G_{22} & \cdots & G_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ G_{m1} & G_{m2} & \cdots & G_{mn} \end{bmatrix},$$

Here, $G_{ij} = \sum_{k=1}^{K} d^k \times M_{ij}^k = \left[\sum_{k=1}^{k} d^k \times t_{M_{ij}^k}, 1 - \sum_{k=1}^{k} d^k \times f_{M_{ij}^k} \right],$ (4.60)

which is obtained by **Definition 11**.

Each line G_i in matrix G represents the evaluation of alternative A_i, by the whole decision group. Obviously G_i is a vague set.

Step 7: Calculate the probability matrix of all supplier alternatives.

$$P = \begin{bmatrix} P_{11} & P_{12} & \cdots & P_{1m} \\ P_{21} & P_{22} & \cdots & P_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ P_{m1} & P_{m2} & \cdots & P_{mm} \end{bmatrix},$$

Here, $P_{il} = P(G_i \geq G_l) = \frac{1}{n} \sum_{j=1}^{n} P(G_{ij} \geq G_{lj}),$ (4.61)

which is obtained by **Definition 9**.

Step 8: Calculate the order vector of all supplier alternatives.

By **Definition 8**, we have $p_{ii} = 0.5$, $p_{il} + p_{li} = 1$. so, P is a fuzzy complementary judgment matrix. According to the algorithm proposed by (Xu, 2001), order vector $e = (e_1, e_2, \ldots, e_m)$ for all supplier alternatives can be obtained by

$$e_i = \frac{\sum_{l=1}^{m} P_{il} + \frac{m}{2} - 1}{m(m-1)} \qquad (4.62)$$

When e_i is bigger, the ranking order of A_i is better. Otherwise, the ranking order is worse. According to the above procedure, appropriate ranking order of all supplier alternatives can be determined and the best one can easily be selected from amongst a set of feasible supplier alternatives.

4.2.5 Case Illustration

In this section, a case empirical research has been illustrated in which an appropriate agile supplier alternative has been selected for an automobile part manufacturing company located in southern part of India. A proposal was given to the industry management to conduct such a case study of academic interest. It was also assured that the method as well as outcome of the case study would be reported only for the benefit of academic community only. The industry if it is interested it can adapt the decision making module. We have provided a set of suppliers' selection criteria list, two-sets of linguistic variable (for assessing criteria weight as well as performance rating) and corresponding vague numbers representations. Also the detailed evaluation procedure was communicated to them. The industry was requested to invite our research team while such supplier selection situation would incur. While called by the industry, our team visited there and took part in that decision-making process. Based on brainstorming the team as well as industry management initially identified potential members of the expert group (decision-makers'). Decision-makers were instructed to interview the candidate suppliers individually. They were also instructed to visit suppliers' firms (if needed) for rational judgment as well as evaluation. Linguistic evaluation judgment as collected by the decision-making group was analyzed by the proposed vague set based decision support module. It was found that the result was satisfactory for the industry itself and also compatible with the past supplier selection record.

The step by step evaluation schemes have been presented below.

A set of supplier selection criteria in relation to ASC (as shown in Table 4.18) has been adapted here. The hierarchy-model consists of different suppliers evaluation criterions/indices as reported by (Luo et al., 2009). Assume that there are five suppliers $A1, A2, \ldots, A5$ selected as potential alternatives to be evaluated against various evaluation indices (performance indicators) from three broad aspects: such as management and technology capability, financial quality, and company resources and quality. A total of 31 performance indicators (indices) have been considered (refer Table 4.18) from aforesaid three broad aspects for evaluation and selection of potential suppliers in ASC. All indices have been considered as beneficial in nature (whose higher values are preferred) except cost (lover value is preferred). The selection procedure as per chronology in the methodology described as follows:

Step 1: A committee of five decision makers DMs (DM_1, DM_2, DM_3, DM_4, and DM_5) has been formed to make the selection decision.

Step 2: For collection of decision makers' opinion (or judgment); linguistic variables have been utilized in order to express suitability of performance as well as priority importance (weight) against individual evaluation criterions. Since human judgment consists of imprecision, ambiguity and vagueness in decision making information; linguistic data needs to be transformed into a mathematic base; here, it is represented by vague numbers. The linguistic variable as shown in Table 4.19 has been used for collecting expert judgment. Two-sets of linguistic variable have been used. The first set {Very Poor (VP), Poor (P), Medium Poor (MP), Fair (F), Medium Good (MG), Good (G) and Very Good (VG)} is for assessing criteria rating and the another set {Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H) and Very High (VH)} is used to express importance weights of various evaluation criteria (and also to assign weight of the decision-makers'). Table 4.19 also exhibits equivalent vague representation of each linguistic variable. The decision maker's importance weight has been shown in Table 4.20; as set by the industry top management. It is mainly based on experience as well as expertise of the decision-makers' chosen who is continuously associated with several decision-making situations in the said industry.

Step 3: This step is to collect expert opinion against criteria weights as well as criteria ratings in relation to supplier alternatives. The attribute weights and appropriateness ratings against individual criterions as given by decision makers have been shown in Table 4.21 and Table 4.22, respectively. Next, linguistic data have been transformed into appropriate vague numbers (with reference to Table 4.19) to construct the preference matrix.

Step 4: Weighted decision matrix has then been calculated for all candidate suppliers. According to Eq. (4.55), the obtained weighted decision matrix which has been shown in Table 4.23.

Step 5: In this step, the importance degree of decision makers needs to be adjusted. According to Eq. (4.56), the preference accordance matrix corresponding to five DMs have been computed as follows:

$$S = \begin{bmatrix} 1.0000 & 0.7764 & 0.7764 & 1.0000 & 0.7764 \\ 0.7764 & 1.0000 & 1.0000 & 0.7764 & 0.6000 \\ 0.7764 & 1.0000 & 1.0000 & 0.7764 & 0.6000 \\ 1.0000 & 0.7764 & 0.7764 & 1.0000 & 0.7764 \\ 0.7764 & 0.6000 & 0.6000 & 0.7764 & 1.0000 \end{bmatrix}$$

According to Eq. (4.57), the similarity weights vector of four DMs has been obtained, which appears as: $h = \{0.2090 \quad 0.2005 \quad 0.2005 \quad 0.2090 \quad 0.1811\}$ It is also called objective weights vector.

Step 6: The weight vector of four DMs has been adjusted here. According to Eq. (4.58), the precise value of the subjective weight vectors D has been obtained as follows:

$w = \{0.8571 \quad 1.0000 \quad 1.0000 \quad 0.8571 \quad 0.5556\}$

Normalized w is: $w = \{0.2007 \quad 0.2342 \quad 0.2342 \quad 0.2007 \quad 0.1301\}$

Assume that $\alpha = 0.5$, it means that the subjective weights have been assumed to have the same importance as objective weights. Using Eq. (4.59), adjusted weight vector has been obtained as follows: $\mathrm{d} = \{0.2049 \quad 0.2173 \quad 0.2173 \quad 0.2049 \quad 0.1556\}$

Step 7: The whole decision matrix has been generated now. Using Eq. (4.60), the integrated decision matrix of four DMs has been obtained as shown in Table 4.24.

Step 8: In this step, the probability matrix has been computed. Using the Eq. (4.61), the probability matrix of five supplier alternatives has been obtained as follows:

$$\mathrm{p} = \begin{bmatrix} 0.5000 & 0.5101 & 0.6109 & 0.4543 & 0.5244 \\ 0.4899 & 0.5000 & 0.5584 & 0.4536 & 0.4954 \\ 0.3891 & 0.4416 & 0.5000 & 0.3600 & 0.4015 \\ 0.5457 & 0.5464 & 0.6400 & 0.5000 & 0.5587 \\ 0.4756 & 0.5046 & 0.5985 & 0.4413 & 0.5000 \end{bmatrix}$$

Step 9: Finally, the order vector of five alternative suppliers has been determined. Using the Eq. (4.62), the order vector has been obtained as follows:

$e = \{0.2050 \quad 0.1999 \quad 0.1796 \quad 0.2145 \quad 0.2010\}$

The ranking order of alternative suppliers appears as follows: $\mathrm{A4} > \mathrm{A1} > \mathrm{A5} > \mathrm{A2} > \mathrm{A3}$

Therefore, it can be concluded that the supplier A4 is the best supplier amongst five alternative suppliers. Because, the order vector of alternative A4 has highest value, therefore it has been considered as the first preference in selection followed by alternative suppliers A1, A5 and A2. The alternative A3 has the lowest order vector; therefore, it has been treated as the worst alternative.

4.2.6 Comparative Analysis: Fuzzy Set versus Vague Set Based Decision Support System

The final ranking order of alternatives obtained from aforesaid vague set based decision support module has been compared to that of fuzzy embedded decision support system. Table 4.25 represents 7-member linguistic terms sets (similar to Table 4.19) and corresponding fuzzy representation for assignment of criteria weights as well as appropriateness rating against each evaluation criterions for alternative suppliers. Considering same linguistic data set (Table 4.21-4.22) as utilized in vague set based decision support module; linguistic expert data have been transformed into appropriate fuzzy numbers (as depicted in Table 4.25). Then fuzzy operational rules have been explored in order to derive final ranking order of candidate agile suppliers. Aggregated fuzzy weight against individual evaluation indices have been computed and shown in Table 4.26. Similarly, aggregated fuzzy appropriateness ratings (performance extent) of individual evaluation criterions have thus been computed for each of the candidate suppliers; as furnished in Table 4.27. Finally, overall evaluation scores (in terms of fuzzy number) against individual suppliers have been computed and provided in Table 4.28. The following formula has been utilized to compute an overall fuzzy ranking score (Eq. 4.62). The said overall fuzzy ranking score has also been denoted as FOPI (Fuzzy Overall Performance Index).

$$\text{Fuzzy Ranking Score (for } A_1\text{)} = \sum w_{ij} \otimes U_{ij}^{A_1} \qquad (4.62)$$

w_{ij} =Aggregated fuzzy weight of j^{th} criterion; which is under i^{th} broad area of performance (Refer Table 4.18)

$U_{ij}^{A_1}$ = Aggregated fuzzy rating of j^{th} criterion; which is under i^{th} broad area of performance; for alternative A_1

FOPI of individual alternatives have been converted into crisp score (Table 4.29); thus, final ranking order of candidate suppliers has been determined. The performance ranking order appeared as $A_4>A_2>A_1>A_5>A_3$; whereas, in case of vague set based decision support module, it appeared $A_4>A_1>A_5>A_2>A_3$. It has been observed that the best (A4) as well as worst (A3) alternative appeared same in both the approaches; difference was in intermediate alternative options. This may be due to the fact that vague set based decision-making considers decision-maker's weight (importance given to individual expert); whereas, fuzzy set based decision support system thus adapted here does not take that aspect into account.

4.2.7 Concluding Remarks

Supplier selection is a complex decision making processes in supply chain management. Due to increased market uncertainty in recent times, the concept of agile supply chain has paid more attention on selection of agile partner/suppliers. The overall performance of the company/enterprise is highly influenced by their supplier's network integration as well as cooperation. During supplier/partner selection, various quantitative and qualitative, operational and strategic criteria must be considered simultaneously. In this regard a conceptual module has been proposed for potential supplier selection in agile supply chain. Supplier/partner selection in agile supply chain must consider agility related criterions along with traditional evaluation criteria or performance indices. The vague set theory has been fruitfully adapted to solve this multi-criteria decision making problem under uncertain environment. In this work, appropriate ranking order (of candidate suppliers) has been derived by the order vector of probability decision matrix. To this end, the contribution of the present work has been summarized below:

The paper proposes a decision support module by exploring vague set theory to facilitate supplier selection in agile supply chain. Human judgment bears some kind of uncertainty. Incompleteness and inconsistency arising from decision-makers' information (due to subjectivity of the evaluation indices) has been overcome by exploring the concept of vague numbers. The application of vague set theory in Multi-Criteria Group Decision Making (MCGDM) has been reported in literature to a limited extent. Application of vague set as a decision making tool in agile supplier selection appears relative new and unexplored area of research. As compared to fuzzy sets, vague sets can provide more reliable judgment. The said decision-making framework can also effectively be applied in other decision-making situations where evaluation criterions are of subjective in nature and the criteria weights are not precisely known. However, limitation of the aforesaid vague set based decision making module is that it can only consider a set of criterions (performance indicators). It cannot work with the evaluation index system which is of multi-level criteria hierarchy (main criteria, sub-criteria, sub-sub criteria and so on).

Table 4.18: Hierarchy criteria of the supplier selection in agile supply chain (Luo at al. 2009)

Goal	Broad area of performance	Performance indicators/criterions
Supplier's evaluation in agile SC	Management and technology capability, C_1	**Integration ability, C_{11}**
		Strategic programming, C_{12}
		R&D investment, C_{13}
		Manufacture adaption level, C_{14}
		Throughput capacity, C_{15}
		Environment adaption ability, C_{16}
		Production techniques level, C_{17}
		Learning organization, C_{18}
		Product response time, C_{19}
		Compatible cooperation culture, $C_{1,10}$
	Financial quality, C_2	**Liquidity ratio, C_{21}**
		Inventory turnover, C_{22}
		Net assets value per share, C_{23}
		Earnings per share of stock, C_{24}
		Net operating margin, C_{25}
		Asset/liability ratio, C_{26}
		Net profits growth rates, C_{27}
		Assets rates of increment, C_{28}
		Accounts receivable turnover, C_{29}
		Stockholders' equity ratio, $C_{2,10}$
		Cash flow per share, $C_{2,11}$
		Debt/equity ratio, $C_{2,12}$
	Company resources and quality, C_3	**Human resource quality, C_{31}**
		General reputation, C_{32}
		Fixed assets scope, C_{33}
		Information sharing level, C_{34}
		IT level, C_{35}
		Value of trademark, C_{36}
		Product quality, C_{37}
		Quality/Cost, C_{38}
		Service quality, C_{39}

Table 4.19: Linguistic scale (for collecting expert opinion) and corresponding vague representation [Source: Zhang et al., 2009]

Linguistic terms for assigning criteria ratings	Linguistic terms for assigning criteria weights	Equivalent vague value
Very Poor, VP	Very Low, VL	(0.0, 0.1)
Poor, P	Low, L	(0.1, 0.3)
Medium Poor, MP	Medium Low, ML	(0.3, 0.4)
Fair, F	Medium, M	(0.4, 0.5)
Medium Good, MG	Medium High, MH	(0.5, 0.6)
Good, G	High, H	(0.6, 0.9)
Very Good, VG	Very High, VH	(0.9, 1.0)

Table 4.20: Decision maker's importance weight

	Decision-Makers				
	DM_1	DM_2	DM_3	DM_4	DM_5
Linguistic weights	H	VH	VH	H	MH

Table 4.21: Criteria weights (in linguistic terms) as given by the expert group

Performance indicators/ Criterions (C_{ij})	Linguistic weights				
	DM_1	DM_2	DM_3	DM_4	DM_5
Integration ability, C_{11}	H	H	M	M	H
Strategic programming, C_{12}	VH	MH	VH	H	H
R&D investment, C_{13}	H	H	MH	H	MH
Manufacture adaption level, C_{14}	M	VH	VH	H	H
Throughput capacity, C_{15}	VH	H	VH	H	H
Environment adaption ability, C_{16}	VH	MH	MH	H	MH
Production techniques level, C_{17}	VH	H	M	M	M
Learning organization, C_{18}	H	H	H	VH	VH
Product response time, C_{19}	M	MH	MH	VH	VH
Compatible cooperation culture, $C_{1,10}$	VH	MH	MH	H	H
Liquidity ratio, C_{21}	VH	VH	MH	M	VH
Inventory turnover, C_{22}	VH	VH	MH	MH	MH
Net assets value per share, C_{23}	H	H	H	H	H
Earnings per share of stock, C_{24}	MH	MH	H	H	H
Net operating margin, C_{25}	M	VH	M	VH	MH
Asset/liability ratio, C_{26}	VH	VH	MH	VH	MH
Net profits growth rates, C_{27}	H	H	H	VH	VH
Assets rates of increment, C_{28}	MH	M	MH	M	MH
Accounts receivable turnover, C_{29}	MH	MH	MH	MH	MH
Stockholders' equity ratio, $C_{2,10}$	VH	H	VH	H	H
Cash flow per share, $C_{2,11}$	H	H	H	H	H
Debt/equity ratio, $C_{2,12}$	H	H	VH	M	VH
Human resource quality, C_{31}	H	H	MH	M	VH
General reputation, C_{32}	H	H	MH	M	M
Fixed assets scope, C_{33}	MH	MH	VH	MH	VH
Information sharing level, C_{34}	VH	MH	H	H	H
IT level, C_{35}	VH	VH	H	MH	H
Value of trademark, C_{36}	MH	VH	H	MH	H
Product quality, C_{37}	MH	VH	H	M	MH
Quality/Cost, C_{38}	VH	H	VH	VH	VH
Service quality, C_{39}	VH	MH	MH	H	H

Table 4.22: Criteria rating (expressed in linguistic terms) as given by the expert group against individual alternative suppliers

Performance indicators/ Criterions (C_{ij})	Supplier(s)	Linguistic ratings				
		DM_1	DM_2	DM_3	DM_4	DM_5
Integration ability, C_{11}	A1	MG	F	G	MG	VG
	A2	VG	VG	G	G	G
	A3	G	G	MG	MG	G
	A4	G	MP	F	F	MP
	A5	G	G	VG	VG	G
Strategic programming, C_{12}	A1	F	G	G	F	G
	A2	MG	VG	G	F	G
	A3	VG	MG	MG	MG	MG
	A4	G	G	VG	G	VG
	A5	MG	VG	MG	VG	MG
R&D investment, C_{13}	A1	F	G	G	G	F
	A2	G	VG	MG	VG	VG
	A3	G	MP	MG	MP	G
	A4	VG	VG	VG	G	G
	A5	MG	VG	G	G	VG
Manufacture adaption level, C_{14}	A1	F	G	G	G	G
	A2	MG	G	MG	G	VG
	A3	VG	G	MG	VG	VG
	A4	VG	G	VG	VG	VG
	A5	G	G	F	MG	MG
Throughput capacity, C_{15}	A1	G	MG	F	VG	MG
	A2	F	VG	F	MP	VG
	A3	F	G	G	MP	MP
	A4	VG	G	G	G	G
	A5	G	G	MG	VG	MG
Environment adaption ability, C_{16}	A1	MG	VG	MG	MG	G
	A2	G	G	MG	MG	G
	A3	MG	F	MP	F	F
	A4	MP	MP	G	G	F
	A5	VG	G	G	MG	MG
Production techniques level, C_{17}	A1	G	MG	MG	MG	MG
	A2	G	VG	G	G	G
	A3	G	VG	VG	G	G
	A4	G	MG	G	G	G
	A5	G	MG	MG	F	F
Learning organization, C_{18}	A1	VG	VG	G	F	F
	A2	VG	G	MG	VG	VG
	A3	MG	MG	MG	MP	MP
	A4	G	VG	G	VG	G
	A5	VG	G	VG	VG	VG
Product response time, C_{19}	A1	G	MG	G	G	G
	A2	G	MG	G	MG	F
	A3	VG	VG	G	F	F

	A4	G	MG	G	VG	G
	A5	G	VG	VG	G	G
Compatible cooperation culture, $C_{1,10}$	A1	VG	MG	G	G	G
	A2	MP	G	F	G	F
	A3	MG	G	MG	G	MG
	A4	G	G	VG	G	G
	A5	MP	F	F	G	G
Liquidity ratio, C_{21}	A1	G	VG	MG	VG	F
	A2	VG	G	MG	F	VG
	A3	MP	P	MG	F	MP
	A4	G	MG	VG	F	VG
	A5	MG	F	MG	F	G
Inventory turnover, C_{22}	A1	VG	G	G	MG	G
	A2	G	G	G	MG	G
	A3	MG	G	G	VG	MG
	A4	VG	VG	G	G	G
	A5	MP	MP	MG	F	F
Net assets value per share, C_{23}	A1	F	G	MG	MG	MG
	A2	VG	MG	G	G	MG
	A3	VG	VG	G	VG	G
	A4	G	MP	G	F	F
	A5	F	F	MP	MP	P
Earnings per share of stock, C_{24}	A1	VG	VG	G	VG	VG
	A2	G	G	F	F	MP
	A3	F	G	F	G	VG
	A4	G	MG	MG	G	VG
	A5	G	VG	VG	G	G
Net operating margin, C_{25}	A1	G	G	G	G	G
	A2	G	VG	G	VG	G
	A3	MG	MG	MG	MG	G
	A4	G	G	G	G	F
	A5	G	G	VG	VG	G
Asset/liability ratio, C_{26}	A1	VG	G	VG	MG	MG
	A2	F	F	MP	MP	MP
	A3	F	MG	MG	F	MP
	A4	G	G	G	VG	VG
	A5	G	MG	MG	MG	VG
Net profits growth rates, C_{27}	A1	G	VG	G	G	G
	A2	MG	MG	G	G	F
	A3	G	VG	G	G	G
	A4	VG	G	G	G	G
	A5	G	G	F	F	G
Assets rates of increment, C_{28}	A1	VG	G	VG	VG	G
	A2	MG	MG	G	G	VG
	A3	VG	G	G	G	G
	A4	G	VG	VG	VG	G
	A5	G	F	G	F	MG
Accounts receivable turnover, C_{29}	A1	G	F	G	G	MG
	A2	G	VG	G	G	MG
	A3	MP	G	F	MP	MP

	A4	G	MG	MG	G	MG
	A5	G	G	VG	G	VG
Stockholders' equity ratio, $C_{2,10}$	A1	MG	G	MG	MG	G
	A2	G	VG	G	G	G
	A3	G	MG	G	G	G
	A4	G	VG	VG	G	G
	A5	MG	MG	F	F	F
Cash flow per share, $C_{2,11}$	A1	VG	G	G	G	VG
	A2	VG	G	G	G	VG
	A3	G	MP	MP	F	F
	A4	G	VG	VG	VG	F
	A5	G	F	MG	MG	G
Debt/equity ratio, $C_{2,12}$	A1	G	VG	G	G	G
	A2	MG	G	G	G	G
	A3	G	VG	G	VG	G
	A4	G	G	G	G	G
	A5	G	MG	G	MG	G
Human resource quality, C_{31}	A1	G	G	G	G	G
	A2	G	VG	G	G	G
	A3	MG	G	VG	VG	VG
	A4	MG	G	G	G	F
	A5	VG	G	VG	VG	G
General reputation, C_{32}	A1	F	G	MG	MG	MG
	A2	VG	G	VG	VG	G
	A3	G	G	G	G	G
	A4	G	G	G	G	G
	A5	G	G	VG	G	F
Fixed assets scope, C_{33}	A1	MG	MG	MG	MG	G
	A2	VG	G	VG	VG	G
	A3	MG	G	MG	G	G
	A4	MG	G	MG	MG	MG
	A5	MG	F	G	F	G
Information sharing level, C_{34}	A1	G	G	MG	F	G
	A2	G	MG	MP	MP	MP
	A3	G	G	VG	F	G
	A4	MG	MG	G	G	MP
	A5	G	G	VG	G	G
IT level, C_{35}	A1	F	F	G	G	F
	A2	VG	G	G	G	VG
	A3	G	G	G	G	G
	A4	MG	MG	G	G	G
	A5	VG	G	VG	VG	G
Value of trademark, C_{36}	A1	F	VG	MG	MG	G
	A2	G	G	G	G	F
	A3	MP	MP	F	F	F
	A4	VG	G	G	G	G
	A5	F	G	VG	F	MG
Product quality, C_{37}	A1	G	VG	MG	MG	MG
	A2	VG	MG	MG	MG	MG
	A3	MG	VG	G	G	G

	A4	G	MG	G	G	F
	A5	G	VG	G	G	G
Quality/Cost, C_{38}	A1	G	G	G	G	VG
	A2	G	G	MG	G	G
	A3	G	G	MG	VG	VG
	A4	MG	F	F	MG	MG
	A5	VG	G	G	G	MG
Service quality, C_{39}	A1	G	G	G	F	F
	A2	MG	G	G	G	VG
	A3	MG	VG	MG	MG	G
	A4	VG	G	VG	VG	G
	A5	VG	G	VG	G	G

Table 4.23: Weighted decision matrix for the set of candidate suppliers

Performance indicators/ Criterions (C_{ij})	Supplier(s)	Weighted decision information				
		DM_1	DM_2	DM_3	DM_4	DM_5
C_{11}	A1	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
	A4	(0.6,0.9)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)
	A5	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
C_{12}	A1	(0.4,0.5)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A3	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A4	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)
	A5	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
C_{13}	A1	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
	A3	(0.6,0.9)	(0.3,0.4)	(0.5,0.6)	(0.3,0.4)	(0.5,0.6)
	A4	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
	A5	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
C_{14}	A1	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A3	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A4	(0.4,0.5)	(0.6,0.9)	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)
	A5	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)
C_{15}	A1	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
	A2	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.3,0.4)	(0.6,0.9)
	A3	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)	(0.3,0.4)	(0.3,0.4)
	A4	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A5	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
C_{16}	A1	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A3	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)

	A4	(0.3,0.4)	(0.3,0.4)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)
	A5	(0.9,1)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.5)
C_{17}	A1	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A3	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A4	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A5	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
C_{18}	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.9,1.0)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.3,0.4)	(0.3,0.4)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)	(0.6,0.9)
	A5	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)	(0.9,1.0)
C_{19}	A1	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A2	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)
	A3	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A4	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)
	A5	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
$C_{1,10}$	A1	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A2	(0.3,0.4)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
	A4	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A5	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)
C_{21}	A1	(0.6,0.9)	(0.9,1.0)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A2	(0.9,1.0)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.9,1.0)
	A3	(0.3,0.4)	(0.1,0.3)	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)
	A4	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.9,1.0)
	A5	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
C_{22}	A1	(0.9,1.0)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A3	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A4	(0.9,1.0)	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A5	(0.3,0.4)	(0.3,0.4)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
C_{23}	A1	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A4	(0.6,0.9)	(0.3,0.4)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)
	A5	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)	(0.3,0.4)	(0.1,0.3)
C_{24}	A1	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)
	A3	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)
	A4	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A5	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
C_{25}	A1	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
	A2	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
	A3	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)
	A4	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)
	A5	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
C_{26}	A1	(0.9,1.0)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)	(0.3,0.4)	(0.3,0.4)
	A3	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)

	A4	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.5,0.6)
	A5	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
C_{27}	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A5	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
C_{28}	A1	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A2	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A3	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A4	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A5	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
C_{29}	A1	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A3	(0.3,0.4)	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)	(0.3,0.4)
	A4	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A5	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
$C_{2,10}$	A1	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A3	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A4	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)
	A5	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
$C_{2,11}$	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A3	(0.6,0.9)	(0.3,0.4)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)
	A5	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
$C_{2,12}$	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A2	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A5	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
C_{31}	A1	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
	A3	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.9,1.0)
	A4	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A5	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
C_{32}	A1	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A3	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A4	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A5	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
C_{33}	A1	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.9,1.0)	(0.5,0.6)	(0.6,0.9)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A4	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A5	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
C_{34}	A1	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
	A2	(0.6,0.9)	(0.5,0.6)	(0.3,0.4)	(0.3,0.4)	(0.3,0.4)
	A3	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)

	A4	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.3,0.4)
	A5	(0.6,0.9)	0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
C_{35}	A1	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)
	A2	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A4	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A5	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
C_{36}	A1	(0.4,0.5)	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A2	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)
	A3	(0.3,0.4)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A4	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A5	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)
C_{37}	A1	(0.5,0.6)	(0.9,1.0)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A2	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A3	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)
	A4	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)
	A5	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)
C_{38}	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.9,1.0)
	A4	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)
	A5	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)
C_{39}	A1	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A2	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A4	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A5	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)

Table 4.24: The integrated decision matrix

Performance indicators/Criterions (C_{ij})	Alternative suppliers				
	A1	A2	A3	A4	A5
C_{11}	(0.4516, 0.5827)	(0.5156, 0.7311)	(0.5156, 0.7311)	(0.4037, 0.5447)	(0.5156, 0.7311)
C_{12}	(0.4963, 0.6709)	(0.5168, 0.6914	(0.5820, 0.6820)	(0.6435, 0.8565)	(0.5205, 0.6615)
C_{13}	(0.5062, 0.6906)	(0.5627, 0.7881)	(0.4361, 0.5770)	(0.5627, 0.7881)	(0.5422, 0.7267)
C_{14}	(0.5590, 0.8180)	(0.5373, 0.7529)	(0.5373, 0.7529)	(0.6242, 0.8398)	(0.4795, 0.6230)
C_{15}	(0.5193, 0.7012)	(0.4541, 0.6287)	(0.4509, 0.6378)	(0.6615, 0.9205)	(0.5627, 0.7881)
C_{16}	(0.5000, 0.6000)	(0.5205, 0.6615)	(0.3988, 0.4988)	(0.4205, 0.5615)	(0.5820, 0.6664)
C_{17}	(0.4627, 0.6037)	(0.4844, 0.6689)	(0.4844, 0.6689)	(0.4627, 0.6037)	(0.4627, 0.6037)
C_{18}	(0.5279, 0.7558)	(0.6864, 0.8709)	(0.4279, 0.5279)	(0.6615, 0.9205)	(0.7082, 0.9361)
C_{19}	(0.5156, 0.6877)	(0.4640, 0.5640)	(0.4435, 0.5435)	(0.5770, 0.7082)	(0.5156, 0.6877)
$C_{1,10}$	(0.6180, 0.7901)	(0.4422, 0.5832)	(0.5205, 0.6615)	(0.5565, 0.7696)	(0.4516, 0.6237)
C_{21}	(0.5714, 0.7123)	(0.6454, 0.7889)	(0.3205, 0.4422)	(0.5622, 0.7032)	(0.4733, 0.6045)
C_{22}	(0.6037, 0.7472)	(0.5422, 0.7267)	(0.5217, 0.6652)	(0.6689, 0.7689)	(0.3795, 0.4795)
C_{23}	(0.5012, 0.6447)	(0.5627, 0.7881)	(0.6000, 0.9000)	(0.4627, 0.6472)	(0.3111, 0.4267)
C_{24}	(0.5578, 0.7733)	(0.4267, 0.5267)	(0.4938, 0.6659)	(0.5361, 0.7082)	(0.5578, 0.7733)
C_{25}	(0.5000, 0.6844)	(0.5000, 0.6844)	(0.4578, 0.5578)	(0.4844, 0.6689)	(0.5000, 0.6844)
C_{26}	(0.6037, 0.7472)	(0.3422, 0.4422)	(0.4279, 0.5279)	(0.6242, 0.8086)	(0.5205, 0.6615)
C_{27}	(0.6000, 0.9000)	(0.5267, 0.7111)	(0.6000, 0.9000)	(0.6000, 0.9000)	(0.5156, 0.7311)
C_{28}	(0.4578, 0.5578)	(0.4578, 0.5578)	(0.4578, 0.5578)	(0.4578, 0.5578)	(0.4578, 0.5578)
C_{29}	(0.4783, 0.5783)	(0.5000, 0.6000)	(0.3652, 0.4652)	(0.5000, 0.6000)	(0.5000, 0.6000)
$C_{2,10}$	(0.5373, 0.7119)	(0.6000, 0.9000)	(0.5783, 0.8348)	(0.6652, 0.9217)	(0.4422, 0.5422)
$C_{2,11}$	(0.6000, 0.9000)	(0.6000, 0.9000)	(0.3975, 0.5385)	(0.5689, 0.8378)	(0.5143, 0.6864)
$C_{2,12}$	(0.5590, 0.8180)	(0.5385, 0.7566)	(0.5590, 0.8180)	(0.5590, 0.8180)	(0.5373, 0.7529)
C_{31}	(0.5373, 0.7529)	(0.5373, 0.7529)	(0.5635, 0.7069)	(0.4857, 0.6291)	(0.5373, 0.7529)
C_{32}	(0.4652, 0.6087)	(0.5062, 0.6906)	(0.5062, 0.6906)	(0.5062, 0.6906)	(0.5062, 0.6906)
C_{33}	(0.5156, 0.6467)	(0.6025, 0.7336)	(0.5156, 0.6467)	(0.5000, 0.6000)	(0.4951, 0.6697)
C_{34}	(0.5156, 0.6877)	(0.4049, 0.5459)	(0.5373, 0.7529)	(0.5111, 0.6955)	(0.5783, 0.8348)
C_{35}	(0.4640, 0.6074)	(0.6410, 0.8590)	(0.5795, 0.8385)	(0.5373, 0.7119)	(0.6410, 0.8590)
C_{36}	(0.5820, 0.7131)	(0.5279, 0.7148)	(0.3578, 0.4578)	(0.5590, 0.7771)	(0.5025, 0.6894)
C_{37}	(0.5664, 0.6664)	(0.4795, 0.5795)	(0.5882, 0.7316)	(0.4857, 0.6291)	(0.5882, 0.7316)
C_{38}	(0.6467, 0.9156)	(0.5783, 0.8348)	(0.6864, 0.8709)	(0.4565, 0.5565)	(0.6459, 0.8738)
C_{39}	(0.4844, 0.6254)	(0.5361, 0.7082)	(0.5156, 0.6467)	(0.6180, 0.7901)	(0.6180, 0.7901)

Table 4.25: Linguistic scale (for collecting expert opinion) and corresponding fuzzy representation [Source: Shemshadi et al., 2011]

Linguistic terms for criteria ratings	Linguistic terms for assigning criteria weights	Generalized Trapezoidal Fuzzy Numbers
Very Poor, VP	Very Low, VL	(0, 0, 0.1, 0.2)
Poor, P	Low, L	(0.1, 0.2, 0.2, 0.3)
Medium Poor, MP	Medium Low, ML	(0.2, 0.3, 0.4, 0.5)
Fair, F	Medium, M	(0.4, 0.5, 0.5, 0.6)
Medium Good, MG	Medium High, MH	(0.5, 0.6, 0.7, 0.8)
Good, G	High, H	(0.7, 0.8, 0.8, 0.9)
Very Good, VG	Very High, VH	(0.8, 0.9, 1, 1)

Table 4.26: Aggregated fuzzy weight of performance criterions

Performance indicators/ Criterions (C_{ij})	Aggregated fuzzy weight
Integration ability, C_{11}	(0.58, 0.68, 0.68, 0.78)
Strategic programming, C_{12}	(0.70, 0.80, 0.86, 0.92)
R&D investment, C_{13}	(0.62, 0.72, 0.76, 0.86)
Manufacture adaption level, C_{14}	(0.68, 0.78, 0.82, 0.88)
Throughput capacity, C_{15}	(0.74, 0.84, 0.88, 0.94)
Environment adaption ability, C_{16}	(0.60, 0.70, 0.78, 0.86)
Production techniques level, C_{17}	(0.54, 0.64, 0.66, 0.74)
Learning organization, C_{18}	(0.74, 0.84, 0.88, 0.94)
Product response time, C_{19}	(0.60, 0.70, 0.78, 0.84)
Compatible cooperation culture, $C_{1,10}$	(0.64, 0.74, 0.80, 0.88)
Liquidity ratio, C_{21}	(0.66, 0.76, 0.84, 0.88)
Inventory turnover, C_{22}	(0.62, 0.72, 0.82, 0.88)
Net assets value per share, C_{23}	(0.70, 0.80, 0.80, 0.90)
Earnings per share of stock, C_{24}	(0.62, 0.72, 0.76, 0.86)
Net operating margin, C_{25}	(0.58, 0.68, 0.74, 0.80)
Asset/liability ratio, C_{26}	(0.68, 0.78, 0.88, 0.92)
Net profits growth rates, C_{27}	(0.74, 0.84, 0.88, 0.94)
Assets rates of increment, C_{28}	(0.46, 0.56, 0.62, 0.72)
Accounts receivable turnover, C_{29}	(0.50, 0.60, 0.70, 0.80)
Stockholders' equity ratio, $C_{2,10}$	(0.74, 0.84, 0.88, 0.94)
Cash flow per share, $C_{2,11}$	(0.70, 0.80, 0.80, 0.90)
Debt/equity ratio, $C_{2,12}$	(0.68, 0.78, 0.82, 0.88)
Human resource quality, C_{31}	(0.62, 0.72, 0.76, 0.84)
General reputation, C_{32}	(0.54, 0.64, 0.66, 0.76)
Fixed assets scope, C_{33}	(0.62, 0.72, 0.82, 0.88)
Information sharing level, C_{34}	(0.68, 0.78, 0.82, 0.90)
IT level, C_{35}	(0.70, 0.80, 0.86, 0.92)
Value of trademark, C_{36}	(0.64, 0.74, 0.80, 0.88)
Product quality, C_{37}	(0.58, 0.68, 0.74, 0.82)
Quality/Cost, C_{38}	(0.78, 0.88, 0.96, 0.98)
Service quality, C_{39}	(0.64, 0.74, 0.80, 0.88)

Table 4.27: Aggregated fuzzy rating against individual performance criterions for alternative suppliers

Criterions (C_{ij})	Aggregated fuzzy rating against individual performance criterions				
	A_1	A_2	A_3	A_4	A_5
C_{11}	(0.58,0.68,0.74,0.82)	(0.74,0.84,0.88,0.94)	(0.62,0.72,0.76,0.86)	(0.38,0.48,0.52,0.62)	(0.74,0.84,0.88,0.94)
C_{12}	(0.58,0.68,0.68,0.78)	(0.62,0.72,0.76,0.84)	(0.56,0.66,0.76,0.84)	(0.74,0.84,0.88,0.94)	(0.62,0.72,0.82,0.88)
C_{13}	(0.58,0.68,0.68,0.78)	(0.72,0.82,0.90,0.94)	(0.46,0.56,0.62,0.72)	(0.76,0.86,0.92,0.96)	(0.70,0.80,0.86,0.92)
C_{14}	(0.64,0.74,0.74,0.84)	(0.64,0.74,0.80,0.88)	(0.72,0.82,0.90,0.94)	(0.78,0.88,0.96,0.98)	(0.56,0.66,0.70,0.80)
C_{15}	(0.58,0.68,0.74,0.82)	(0.52,0.62,0.68,0.74)	(0.44,0.54,0.58,0.68)	(0.72,0.82,0.84,0.92)	(0.64,0.74,0.80,0.88)
C_{16}	(0.58,0.68,0.74,0.82)	(0.52,0.62,0.68,0.74)	(0.44,0.54,0.58,0.68)	(0.72,0.82,0.84,0.92)	(0.64,0.74,0.80,0.88)
C_{17}	(0.54,0.64,0.72,0.82)	(0.72,0.82,0.84,0.92)	(0.74,0.84,0.88,0.94)	(0.66,0.76,0.78,0.88)	(0.50,0.60,0.64,0.74)
C_{18}	(0.62,0.72,0.76,0.82)	(0.72,0.82,0.90,0.94)	(0.38,0.48,0.58,0.68)	(0.74,0.84,0.88,0.94)	(0.78,0.88,0.96,0.98)
C_{19}	(0.66,0.76,0.78,0.88)	(0.56,0.66,0.70,0.80)	(0.62,0.72,0.76,0.82)	(0.68,0.78,0.82,0.90)	(0.74,0.84,0.88,0.94)
$C_{1,10}$	(0.68,0.78,0.82,0.90)	(0.48,0.58,0.60,0.70)	(0.58,0.68,0.74,0.84)	(0.72,0.82,0.84,0.92)	(0.48,0.58,0.60,0.70)
C_{21}	(0.64,0.74,0.80,0.86)	(0.64,0.74,0.80,0.86)	(0.28,0.38,0.44,0.54)	(0.64,0.74,0.80,0.86)	(0.50,0.60,0.64,0.74)
C_{22}	(0.68,0.78,0.82,0.90)	(0.66,0.76,0.78,0.88)	(0.64,0.74,0.80,0.88)	(0.74,0.84,0.88,0.94)	(0.34,0.44,0.50,0.60)
C_{23}	(0.52,0.62,0.68,0.78)	(0.64,0.74,0.80,0.88)	(0.76,0.86,0.92,0.96)	(0.48,0.58,0.60,0.70)	(0.26,0.36,0.40,0.50)
C_{24}	(0.78,0.88,0.96,0.98)	(0.48,0.58,0.60,0.70)	(0.60,0.70,0.72,0.80)	(0.64,0.74,0.80,0.88)	(0.74,0.84,0.88,0.94)
C_{25}	(0.70,0.80,0.80,0.90)	(0.74,0.84,0.88,0.94)	(0.54,0.64,0.72,0.82)	(0.64,0.74,0.74,0.84)	(0.74,0.84,0.88,0.94)
C_{26}	(0.66,0.76,0.84,0.90)	(0.28,0.38,0.44,0.54)	(0.40,0.50,0.56,0.66)	(0.74,0.84,0.88,0.94)	(0.60,0.70,0.78,0.86)
C_{27}	(0.72,0.82,0.84,0.92)	(0.56,0.66,0.70,0.80)	(0.72,0.82,0.84,0.92)	(0.72,0.82,0.84,0.92)	(0.58,0.68,0.68,0.78)
C_{28}	(0.76,0.86,0.92,0.96)	(0.64,0.74,0.80,0.88)	(0.72,0.82,0.84,0.92)	(0.76,0.86,0.92,0.96)	(0.54,0.64,0.66,0.76)
C_{29}	(0.60,0.70,0.72,0.82)	(0.68,0.78,0.82,0.90)	(0.34,0.44,0.50,0.60)	(0.58,0.68,0.74,0.84)	(0.74,0.84,0.88,0.94)
$C_{2,10}$	(0.58,0.68,0.74,0.84)	(0.72,0.82,0.84,0.92)	(0.66,0.76,0.78,0.88)	(0.74,0.84,0.88,0.94)	(0.44,0.54,0.58,0.68)
$C_{2,11}$	(0.74,0.84,0.88,0.94)	(0.74,0.84,0.88,0.94)	(0.38,0.48,0.52,0.62)	(0.70,0.80,0.86,0.90)	(0.56,0.66,0.70,0.80)
$C_{2,12}$	(0.72,0.82,0.84,0.92)	(0.66,0.76,0.78,0.88)	(0.74,0.84,0.88,0.94)	(0.70,0.80,0.80,0.90)	(0.62,0.72,0.76,0.86)
C_{31}	(0.70,0.80,0.80,0.90)	(0.72,0.82,0.84,0.92)	(0.72,0.82,0.90,0.94)	(0.60,0.70,0.72,0.82)	(0.76,0.86,0.92,0.96)
C_{32}	(0.52,0.62,0.68,0.78)	(0.76,0.86,0.92,0.96)	(0.70,0.80,0.80,0.90)	(0.70,0.80,0.80,0.90)	(0.66,0.76,0.78,0.86)
C_{33}	(0.54,0.64,0.72,0.82)	(0.76,0.86,0.92,0.96)	(0.62,0.72,0.76,0.86)	(0.54,0.64,0.72,0.82)	(0.54,0.64,0.66,0.76)
C_{34}	(0.60,0.70,0.72,0.82)	(0.36,0.46,0.54,0.64)	(0.66,0.76,0.78,0.86)	(0.52,0.62,0.68,0.78)	(0.72,0.82,0.84,0.92)
C_{35}	(0.52,0.62,0.62,0.72)	(0.74,0.84,0.88,0.94)	(0.70,0.80,0.80,0.90)	(0.62,0.72,0.76,0.86)	(0.76,0.86,0.92,0.96)
C_{36}	(0.58,0.68,0.74,0.82)	(0.64,0.74,0.74,0.84)	(0.32,0.42,0.46,0.56)	(0.72,0.82,0.84,0.92)	(0.56,0.66,0.70,0.78)
C_{37}	(0.60,0.70,0.78,0.86)	(0.56,0.66,0.76,0.84)	(0.68,0.78,0.82,0.90)	(0.60,0.70,0.72,0.82)	(0.72,0.82,0.84,0.92)
C_{38}	(0.72,0.82,0.84,0.92)	(0.66,0.76,0.78,0.88)	(0.70,0.80,0.86,0.92)	(0.46,0.56,0.62,0.72)	(0.68,0.78,0.82,0.90)
C_{39}	(0.58,0.68,0.68,0.78)	(0.68,0.78,0.82,0.90)	(0.60,0.70,0.78,0.86)	(0.76,0.86,0.92,0.96)	(0.74,0.84,0.88,0.94)

Table 4.28: Fuzzy Ranking Score (or FOPI) of candidate suppliers

Criterions (C_{ij})	Fuzzy Ranking Score (or FOPI) = $\sum w_{ij} \otimes U_{ij}^{A_1}$				
	A_1	A_2	A_3	A_4	A_5
C_{11}	(0.336,0.462,0.503,0.640)	(0.429,0.571,0.598,0.733)	(0.360,0.490,0.517,0.671)	(0.220,0.326,0.354,0.484)	(0.429,0.571,0.598,0.733)
C_{12}	(0.406,0.544,0.585,0.718)	(0.434,0.576,0.654,0.773)	(0.392,0.528,0.654,0.773)	(0.518,0.672,0.757,0.865)	(0.434,0.576,0.705,0.810)
C_{13}	(0.360,0.490,0.517,0.671)	(0.446,0.590,0.684,0.808)	(0.285,0.403,0.471,0.619)	(0.471,0.619,0.699,0.826)	(0.434,0.576,0.654,0.791)
C_{14}	(0.435,0.577,0.607,0.739)	(0.435,0.577,0.656,0.774)	(0.490,0.640,0.738,0.827)	(0.530,0.686,0.787,0.862)	(0.381,0.515,0.574,0.704)
C_{15}	(0.429,0.571,0.651,0.771)	(0.385,0.521,0.598,0.696)	(0.326,0.454,0.510,0.639)	(0.533,0.689,0.739,0.865)	(0.474,0.622,0.704,0.827)
C_{16}	(0.348,0.476,0.577,0.705)	(0.312,0.434,0.530,0.636)	(0.264,0.378,0.452,0.585)	(0.432,0.574,0.655,0.791)	(0.384,0.518,0.624,0.757)
C_{17}	(0.292,0.410,0.475,0.607)	(0.389,0.525,0.554,0.681)	(0.400,0.538,0.581,0.696)	(0.356,0.486,0.515,0.651)	(0.270,0.384,0.422,0.548)
C_{18}	(0.459,0.605,0.669,0.771)	(0.533,0.689,0.792,0.884)	(0.281,0.403,0.510,0.639)	(0.548,0.706,0.774,0.884)	(0.577,0.739,0.845,0.921)
C_{19}	(0.396,0.532,0.608,0.739)	(0.336,0.462,0.546,0.672)	(0.372,0.504,0.593,0.689)	(0.408,0.546,0.640,0.756)	(0.444,0.588,0.686,0.790)
$C_{1,10}$	(0.435,0.577,0.656,0.792)	(0.307,0.429,0.480,0.616)	(0.371,0.503,0.592,0.739)	(0.461,0.607,0.672,0.810)	(0.307,0.429,0.480,0.616)
C_{21}	(0.422,0.562,0.672,0.757)	(0.422,0.562,0.672,0.757)	(0.185,0.289,0.370,0.475)	(0.422,0.562,0.672,0.757)	(0.330,0.456,0.538,0.651)
C_{22}	(0.422,0.562,0.672,0.792)	(0.409,0.547,0.640,0.774)	(0.397,0.533,0.656,0.774)	(0.459,0.605,0.722,0.827)	(0.211,0.317,0.410,0.528)
C_{23}	(0.364,0.496,0.544,0.702)	(0.448,0.592,0.640,0.792)	(0.532,0.688,0.736,0.864)	(0.336,0.464,0.480,0.630)	(0.182,0.288,0.320,0.450)
C_{24}	(0.484,0.634,0.730,0.843)	(0.298,0.418,0.456,0.602)	(0.372,0.504,0.547,0.688)	(0.397,0.533,0.608,0.757)	(0.459,0.605,0.669,0.808)
C_{25}	(0.406,0.544,0.592,0.720)	(0.429,0.571,0.651,0.752)	(0.313,0.435,0.533,0.656)	(0.371,0.503,0.548,0.672)	(0.429,0.571,0.651,0.752)
C_{26}	(0.449,0.593,0.739,0.828)	(0.190,0.296,0.387,0.497)	(0.272,0.390,0.493,0.607)	(0.503,0.655,0.774,0.865)	(0.408,0.546,0.686,0.791)
C_{27}	(0.533,0.689,0.739,0.865)	(0.414,0.554,0.616,0.752)	(0.533,0.689,0.739,0.865)	(0.533,0.689,0.739,0.865)	(0.429,0.571,0.598,0.733)
C_{28}	(0.350,0.482,0.570,0.691)	(0.294,0.414,0.496,0.634)	(0.331,0.459,0.521,0.662)	(0.350,0.482,0.570,0.691)	(0.248,0.358,0.409,0.547)
C_{29}	(0.300,0.420,0.504,0.656)	(0.340,0.468,0.574,0.720)	(0.170,0.264,0.350,0.480)	(0.290,0.408,0.518,0.672)	(0.370,0.504,0.616,0.752)
$C_{2,10}$	(0.429,0.571,0.651,0.790)	(0.533,0.689,0.739,0.865)	(0.488,0.638,0.686,0.827)	(0.548,0.706,0.774,0.884)	(0.326,0.454,0.510,0.639)
$C_{2,11}$	(0.518,0.672,0.704,0.846)	(0.518,0.672,0.704,0.846)	(0.266,0.384,0.416,0.558)	(0.490,0.640,0.688,0.810)	(0.392,0.528,0.560,0.720)
$C_{2,12}$	(0.490,0.640,0.689,0.810)	(0.449,0.593,0.640,0.774)	(0.503,0.655,0.722,0.827)	(0.476,0.624,0.656,0.792)	(0.422,0.562,0.623,0.757)
C_{31}	(0.434,0.576,0.608,0.756)	(0.446,0.590,0.638,0.773)	(0.446,0.590,0.684,0.790)	(0.372,0.504,0.547,0.689)	(0.471,0.619,0.699,0.806)
C_{32}	(0.281,0.397,0.449,0.593)	(0.410,0.550,0.607,0.730)	(0.378,0.512,0.528,0.684)	(0.378,0.512,0.528,0.684)	(0.356,0.486,0.515,0.654)
C_{33}	(0.335,0.461,0.590,0.722)	(0.471,0.619,0.754,0.845)	(0.384,0.518,0.623,0.757)	(0.335,0.461,0.590,0.722)	(0.335,0.461,0.541,0.669)
C_{34}	(0.408,0.546,0.590,0.738)	(0.245,0.359,0.443,0.576)	(0.449,0.593,0.640,0.774)	(0.354,0.484,0.558,0.702)	(0.490,0.640,0.689,0.828)
C_{35}	(0.364,0.496,0.533,0.662)	(0.518,0.672,0.757,0.865)	(0.490,0.640,0.688,0.828)	(0.434,0.576,0.654,0.791)	(0.532,0.688,0.791,0.883)
C_{36}	(0.371,0.503,0.592,0.722)	(0.410,0.548,0.592,0.739)	(0.205,0.311,0.368,0.493)	(0.461,0.607,0.672,0.810)	(0.358,0.488,0.560,0.686)
C_{37}	(0.348,0.476,0.577,0.705)	(0.325,0.449,0.562,0.689)	(0.394,0.530,0.607,0.738)	(0.348,0.476,0.533,0.672)	(0.418,0.558,0.622,0.754)
C_{38}	(0.562,0.722,0.806,0.902)	(0.515,0.669,0.749,0.862)	(0.546,0.704,0.826,0.902)	(0.359,0.493,0.595,0.706)	(0.530,0.686,0.787,0.882)
C_{39}	(0.371,0.503,0.544,0.686)	(0.435,0.577,0.656,0.792)	(0.384,0.518,0.624,0.757)	(0.486,0.636,0.736,0.845)	(0.474,0.622,0.704,0.827)

Table 4.29: FOPI of alternatives and ranking order

Alternative	FOPI	Crisp Score	Performance ranking order	
			Fuzzy based DSS	Vague set based DSS
A_1	(0.37,0.61,0.91,1.43)	0.8305	**3**	**2**
A_2	(0.37,0.61,0.92,1.44)	0.8373	**2**	**4**
A_3	(0.35,0.57,0.87,1.38)	0.7921	**5**	**5**
A_4	(0.39,0.64,0.95,1.48)	0.8647	**1**	**1**
A_5	(0.37,0.61,0.91,1.43)	0.8304	**4**	**3**

CHAPTER 5

A FUZZY EMBEDDED LEAGILITY EVALUATION MODULE IN SUPPLY CHAIN

5.1 Coverage

In today's ever changing global business environment, successful survival of manufacturing firms/production units depends on the extent of fulfillment of dynamic customers' demands. Appropriate supply chain strategy is of vital concern in this context. Lean principles correspond to zero inventory level; whereas, agile concepts motivate safety inventory to face and withstand in turbulent market conditions. The leagile paradigm is gaining prime importance in the contemporary scenario which includes salient features of both leanness as well as agility. While lean strategy affords markets with predictable demand, low variety and long product life cycle; agility performs best in a volatile environment with high variety, mass-customization and short product life cycle.

Successful implementation of leagile concept requires evaluation of the total performance metric and development of a route map for integrating lean production and agile supply in the total supply chain. To this end, the present work proposes a leagility evaluation framework using fuzzy set theory. A structured framework consisting of leagile capabilities/attributes as well as criterions has been explored to assess an overall organizational leagility index. Future opportunities towards improving leagility degree have been identified as well.

Literature has been found rich enough in delivering in-depth understanding of lean, agile and leagile concepts in supply chain management. Potential benefits of individual supply chain strategies in appropriate situation have been well documented. The need for combining lean as well as agile principles in a total supply chain has also been clearly highlighted. While adopting a particular supply chain strategy; performance assessment is indeed necessary. Relatively less work has been found reported in literature concerning different aspects of performance appraisement of leagility driven supply chain. Motivated by this, present work attempts to develop an efficient leagility assessment module in fuzzy context through an empirical research.

5.2 Fuzzy Preliminaries

Fuzzy logic is basically a multi-value logic which permits intermediate values to be defined between conventional ones like true/false, low/high, good/bad, etc. It is an established fact that, as the complexities surrounding a system increase, making a precise statement about the state of the system becomes very difficult.

To deal with vagueness in human thought, Zadeh (1965) first introduced the fuzzy set theory, which has the capability to represent/manipulate data and information possessing based on non-statistical uncertainties. Moreover fuzzy set theory has been designed to mathematically represent uncertainty and vagueness and to provide formalized tools for dealing with the imprecision inherent to decision making problems. Some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed from Zadeh (1975), Buckley (1985), Negi (1989), Kaufmann and Gupta (1991).The basic definitions and notations below will be used throughout this paper until otherwise stated.

5.2.1 Definition of Fuzzy Sets

Definition 1. A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ which associates with each element x in X a real number in the interval $[0,1]$. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$ (Kaufmann and Gupta, 1991).

Definition 2. A fuzzy set $\tilde{A}$ in a universe of discourse X is convex if and only if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min\left(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\right) \tag{5.1}$$

For all x_1, x_2 in X and all $\lambda \in [0,1]$, where $\min$ denotes the minimum operator (Klir and Yuan, 1995).

Definition 3. The height of a fuzzy set is the largest membership grade attained by any element in that set. A fuzzy set $\tilde{A}$ in the universe of discourse X is called normalized when the height of $\tilde{A}$ is equal to 1 (Klir and Yuan, 1995).

5.2.2 Definitions of fuzzy numbers

Definition 1. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Fig. 5.1 shows a fuzzy number $\tilde{n}$ in the universe of discourse X that conforms to this definition (Kaufmann and Gupta, 1991).

Definition 2. The α -cut of fuzzy number $\tilde{n}$ is defined as:

$$\tilde{n}^{\alpha} = \{x_i : \mu_{\tilde{n}}(x_i) \geq \alpha, x_i \in X\}, \tag{5.2}$$

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

The symbol $\tilde{n}^{\alpha}$ represents a non-empty bounded interval contained in X , which can be denoted by $\tilde{n}^{\alpha} = [n_l^{\alpha}, n_u^{\alpha}]$, n_l^{α} and n_u^{α} are the lower and upper bounds of the closed interval, respectively (Kaufmann and Gupta, 1991; Zimmermann, 1991). For a fuzzy number $\tilde{n}$, if $n_l^{\alpha} > 0$ and $n_u^{\alpha} \leq 1$ for all $\alpha \in [0,1]$, then $\tilde{n}$ is called a standardized (normalized) positive fuzzy number (Negi, 1989).

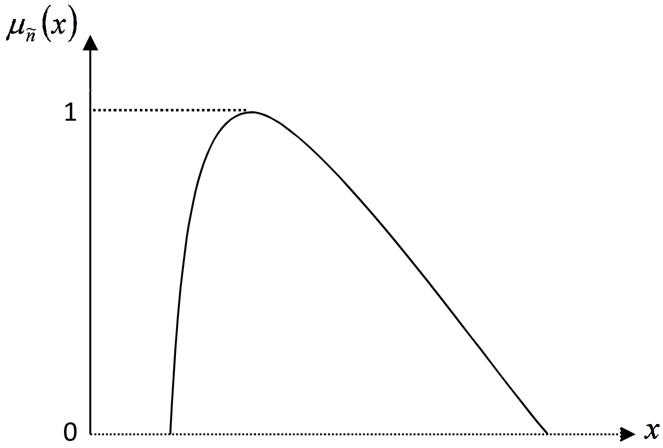

Fig. 5.1: A fuzzy number $\tilde{n}$

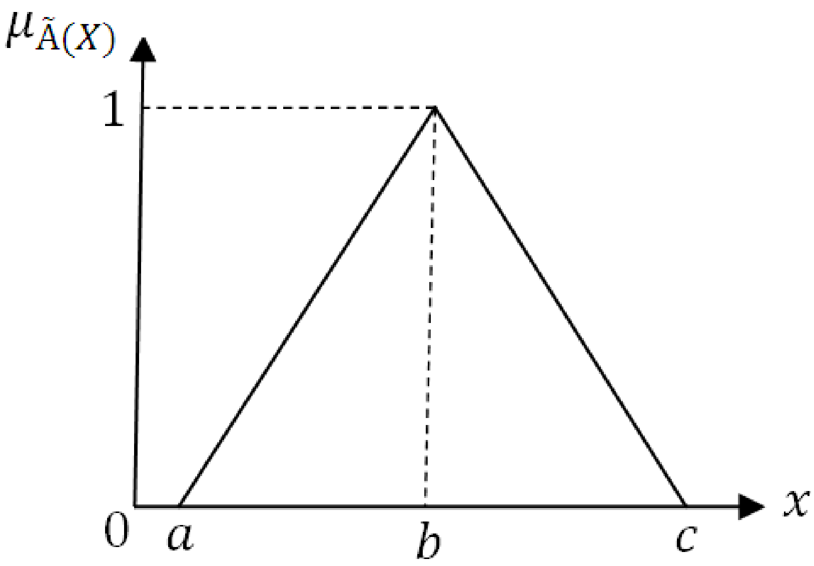

Fig. 5.2: A triangular fuzzy number $\tilde{A}$

Definition 3. Suppose, a positive triangular fuzzy number (PTFN) is $\tilde{A}$ and that can be defined as (a,b,c) shown in Fig. 5.2. The membership function $\mu_{\tilde{n}}(x)$ is defined as:

$$\mu_{\tilde{A}}(x)=\begin{cases}(x-a)/(b-a), & if\ a\leq x\leq b,\\ (c-x)/(c-b), & if\ b\leq x\leq c,\\ 0, & otherwise,\end{cases} \tag{5.3}$$

Based on extension principle, the fuzzy sum $\oplus$ and fuzzy subtraction Θ of any two triangular fuzzy numbers are also triangular fuzzy numbers; but the multiplication $\otimes$ of any two triangular fuzzy numbers is only approximate triangular fuzzy number (Zadeh, 1975). Let's have a two positive triangular fuzzy numbers, such as $\tilde{A}_1=(a_{1,}\ b_1,c_1)$, and $\tilde{A}_2=(a_2,b_2,c_2)$, and a positive real number $r=(r,r,r)$, some algebraic operations can be expressed as follows:

$$\tilde{A}_1\oplus\tilde{A}_2=(a_1+a_2,b_1+b_2,c_1+c_2) \tag{5.4}$$

$$\tilde{A}_1\,\Theta\,\tilde{A}_2=(a_1-a_2,b_1-b_2,c_1-c_2),\ \text{(5)}\ \tilde{A}_1\otimes\tilde{A}_2=(a_1a_2,b_1b_2,c_1c_2), \tag{5.5}$$

$$r\otimes\tilde{A}_1=(ra_1,rb_1,rc_1), \tag{5.6}$$

$$\tilde{A}_1\varnothing\tilde{A}_2=(a_1/c_2,b_1/b_2,c_1/a_2), \tag{5.7}$$

The operations of $\vee(\max)$ and $\wedge(\min)$ are defined as:

$$\tilde{A}_1(\vee)\tilde{A}_2=(a_1\vee a_2,b_1\vee b_2,c_1\vee c_2), \tag{5.8}$$

$$\tilde{A}_1(\wedge)\tilde{A}_2=(a_1\wedge a_2,b_1\wedge b_2,c_1\wedge c_2), \tag{5.9}$$

Here, $r>0$, and $a_1,b_1,c_1>0$,

Also the crisp value of triangular fuzzy number set $\tilde{A}_1$ can be determined by defuzzification which locates the Best Non-fuzzy Performance (BNP) value. Thus, the BNP values of fuzzy number are calculated by using the center of area (COA) method as follows: (Moeinzadeh and Hajfathaliha, 2010)

$$\text{BNP}_i = \frac{[(c-a)+(b-a)]}{3}+a, \qquad \forall_i, \tag{5.10}$$

Definition 4. A matrix $\tilde{\mathbf{D}}$ is called a fuzzy matrix if at least one element is a fuzzy number (Buckley, 1985).

5.2.3 Linguistic Variable

Definition 1. A linguistic variable is the variable whose values are not expressed in numbers but words or sentences in a natural or artificial language (Zadeh, 1975). The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well-defined to be reasonably described in conventional quantitative expressions (Zimmermann, 1991). For example, 'weight' is a linguistic variable whose values are 'very low', 'low', 'medium', 'high', 'very high', etc. Fuzzy numbers can also represent these linguistic values.

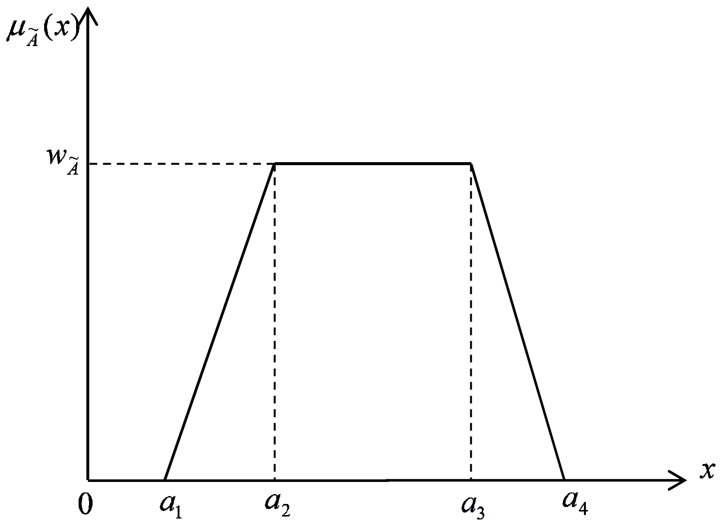

Fig. 5.3: Trapezoidal fuzzy number $\tilde{A}$

5.2.4 The concept of Generalized Trapezoidal Fuzzy Numbers

By the definition given by (Chen, 1985), a generalized trapezoidal fuzzy number can be defined as $\tilde{A} = (a_1, a_2, a_3, a_4; w_{\tilde{A}})$, as shown in Fig. 5.3.

and the membership function $\mu_{\tilde{A}}(x): R \to [0,1]$ is defined as follows:

$$\mu_{\tilde{A}}(x)=\begin{cases}\dfrac{x-a_1}{a_2-a_1}\times w_{\tilde{A}}, & x\in(a_1,a_2)\\ w_{\tilde{A}}, & x\in(a_2,a_3)\\ \dfrac{x-a_4}{a_3-a_4}\times w_{\tilde{A}}, & x\in(a_3,a_4)\\ 0, & x\in(-\infty,a_1)\cup(a_4,\infty)\end{cases} \quad (5.11)$$

Here, $a_1 \le a_2 \le a_3 \le a_4$ and $w_{\tilde{A}} \in [0,1]$

The elements of the generalized trapezoidal fuzzy numbers $x \in R$ are real numbers, and its membership function $\mu_{\tilde{A}}(x)$ is the regularly and continuous convex function, it shows that the membership degree to the fuzzy sets. If $-1 \le a_1 \le a_2 \le a_3 \le a_4 \le 1$, then $\tilde{A}$ is called the normalized trapezoidal fuzzy number. Especially, if $w_{\tilde{A}} = 1$, then $\tilde{A}$ is called trapezoidal fuzzy number (a_1, a_2, a_3, a_4); if $a_1 < a_2 = a_3 < a_4$, then $\tilde{A}$ is reduced to a triangular fuzzy number. If $a_1 = a_2 = a_3 = a_4$, then $\tilde{A}$ is reduced to a real number.

Suppose that $\tilde{a} = (a_1, a_2, a_3, a_4; w_{\tilde{a}})$ and $\tilde{b} = (b_1, b_2, b_3, b_4; w_{\tilde{b}})$ are two generalized trapezoidal fuzzy numbers, then the operational rules of the generalized trapezoidal fuzzy numbers $\tilde{a}$ and $\tilde{b}$ are shown as follows (Chen and Chen, 2009):

$$\tilde{a} \oplus \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \oplus (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (5.12)$$

$$\tilde{a} - \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) - (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a_1 - b_4, a_2 - b_3, a_3 - b_2, a_4 - b_1; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (5.13)$$

$$\tilde{a} \otimes \tilde{b} = (a_1, a_2, a_3, a_4; w_{\tilde{a}}) \otimes (b_1, b_2, b_3, b_4; w_{\tilde{b}}) =$$

$$(a, b, c, d; \min(w_{\tilde{a}}, w_{\tilde{b}})) \quad (5.14)$$

Here,

$$a = \min\left(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4\right)$$

$$b = \min\left(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3\right)$$

$$c = \max\left(a_2 \times b_2, a_2 \times b_3, a_3 \times b_2, a_3 \times b_3\right)$$

$$d = \max\left(a_1 \times b_1, a_1 \times b_4, a_4 \times b_1, a_4 \times b_4\right)$$

If $a_1, a_2, a_3, a_4, b_1, b_2, b_3, b_4$ are real numbers, then

$$\tilde{a} \otimes \tilde{b} = \left(a1 \times b1, a2 \times b2, a3 \times b3, a4 \times b4; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right)$$

$$\tilde{a} / \tilde{b} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right) \Big/ \left(b_1, b_2, b_3, b_4; w_{\tilde{b}}\right)$$

$$= \left(a_1 / b_4, a_2 / b_3, a_3 / b_2, a_4 / b_1; \min\left(w_{\tilde{a}}, w_{\tilde{b}}\right)\right) \tag{5.15}$$

Chen and Chen (2003) proposed the concept of COG point of generalized trapezoidal fuzzy numbers, and suppose that the COG point of the generalized trapezoidal fuzzy number $\tilde{a} = \left(a_1, a_2, a_3, a_4; w_{\tilde{a}}\right)$ is $\left(x_{\tilde{a}}, y_{\tilde{a}}\right)$, then:

$$y_{\tilde{a}} = \begin{cases} \dfrac{w_{\tilde{a}} \times \left(\dfrac{a_3 - a_2}{a_4 - a_1} + 2\right)}{6}, & if\ a_1 \neq a_4 \\ \dfrac{w_{\tilde{a}}}{2}, & if\ a_1 = a_4 \end{cases} \tag{5.16}$$

$$x_{\tilde{a}} = \frac{y_{\tilde{a}} \times \left(a_2 + a_3\right) + \left(a_1 + a_4\right) \times \left(w_{\tilde{a}} - y_{\tilde{a}}\right)}{2 \times w_{\tilde{a}}} \tag{5.17}$$

5.2.5 Ranking of Generalized Trapezoidal Fuzzy Numbers

The centroid of a trapezoid is considered as the balancing point of the trapezoid (Fig. 5.4). Divide the trapezoid into three plane figures. These three plane figures are a triangle (APB), a rectangle (BPQC), and a triangle (CQD), respectively. Let the centroids of the three plane figures be G_1, G_2, and G_3 respectively. The Incentre of these Centroids G_1, G_2 and G_3 is taken as the point of reference to define the ranking of generalized trapezoidal fuzzy numbers. The reason for selecting this point as a point of reference is that each centroid point are balancing points of each individual plane figure, and the Incentre of these Centroid points is a much more balancing point for a generalized trapezoidal fuzzy number (Thorani et al., 2012). Therefore, this point would be a better reference point than the Centroid point of the trapezoid.

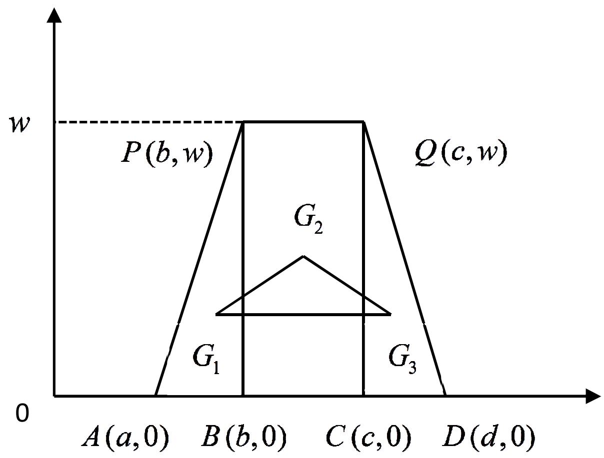

Fig. 5.4: Trapezoidal Fuzzy Number (Thorani et al., 2012)

Consider a generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$, (Fig. 5.4). The Centroids of the three plane figures are $G_1 = \left(\frac{a+2b}{3}, \frac{w}{3}\right)$, $G_2 = \left(\frac{b+c}{2}, \frac{w}{2}\right)$ and $G_3 = \left(\frac{2c+d}{3}, \frac{w}{3}\right)$ respectively.

Equation of the line $\overline{G_1G_3}$ is $y = \frac{w}{3}$ and G_2 does not lie on the line $\overline{G_1G_3}$. Therefore, G_1G_2 and G_3 are non-collinear and they form a triangle.

We define the Incentre $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ of the triangle with vertices G_1, G_2 and G_3 of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ as

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{\alpha\left(\frac{a+2b}{3}\right) + \beta\left(\frac{b+c}{2}\right) + \gamma\left(\frac{2c+d}{3}\right)}{\alpha+\beta+\gamma}, \frac{\alpha\left(\frac{w}{3}\right) + \beta\left(\frac{w}{2}\right) + \gamma\left(\frac{w}{3}\right)}{\alpha+\beta+\gamma} \right) \qquad (5.18)$$

Here

$$\alpha = \frac{\sqrt{(c-3b+2d)^2 + w^2}}{6}$$

$$\beta = \frac{\sqrt{(2c+d-a-2b)^2}}{3}$$

$$\gamma = \frac{\sqrt{(3c-2a-b)^2 + w^2}}{6}$$

As a special case, for triangular fuzzy number $\tilde{A} = (a,b,c,d;w)$, i.e. $c = b$ the Incentre of Centroids is given by

$$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0) = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z}, \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \qquad (5.19)$$

Here,

$$x = \frac{\sqrt{(2d-2b)^2 + w^2}}{6}$$

$$y = \frac{\sqrt{(d-a)^2}}{3}$$

$$z = \frac{\sqrt{(2b-2a)^2 + w^2}}{6}$$

The ranking function of the generalized trapezoidal fuzzy number $\tilde{A} = (a,b,c,d;w)$, which maps the set of all fuzzy numbers to a set of real numbers is defined as,

$$R(\tilde{A}) = x_0 \times y_0 = \left(\frac{x\left(\frac{a+2b}{3}\right) + yb + z\left(\frac{2b+d}{3}\right)}{x+y+z} \times \frac{x\left(\frac{w}{3}\right) + y\left(\frac{w}{2}\right) + z\left(\frac{w}{3}\right)}{x+y+z} \right) \quad (5.20)$$

This is the Area between the incenter of the centroids $I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$ as defined in Eq. (19) and the original point.

The Mode (m) of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$, is defined as:

$$m = \frac{1}{2}\int_0^w (b+c)dx = \frac{w}{2}(b+c) \quad (5.21)$$

The Spread(s) of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$, is defined as:

$$s = \int_0^w (d-a)dx = w(d-a) \quad (5.22)$$

The left spread (ls) of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$, is defined as:

$$ls = \int_0^w (b-a)dx = w(b-a) \quad (5.23)$$

The right spread (rs) of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$, is defined as:

$$rs = \int_0^w (d-c)dx = w(d-c) \quad (5.24)$$

Using the above definitions we now define the ranking procedure of two generalized trapezoidal fuzzy numbers.

Let $\tilde{A} = (a_1, b_1, c_1, d_1; w_1)$ and $\tilde{B} = (a_2, b_2, c_2, d_2; w_2)$ be two generalized trapezoidal fuzzy numbers. The working procedure to compare $\tilde{A}$ and $\tilde{B}$ is as follows:

Step 1: Find $R(\tilde{A})$ and $R(\tilde{B})$

Case (i) If $R(\tilde{A}) > R(\tilde{B})$ then $\tilde{A} > \tilde{B}$

Case (ii)If $R(\tilde{A}) < R(\tilde{B})$then $\tilde{A} < \tilde{B}$

Case (iii) If $R(\tilde{A}) = R(\tilde{B})$comparison is not possible, then go to ***step 2***.

Step 2: Find $m(\tilde{A})$and $m(\tilde{B})$

Case (i) If $m(\tilde{A}) > m(\tilde{B})$then $\tilde{A} > \tilde{B}$

Case (ii)If $m(\tilde{A}) < m(\tilde{B})$then $\tilde{A} < \tilde{B}$

Case (iii) If $m(\tilde{A}) = m(\tilde{B})$comparison is not possible, then go to ***step 3***.

Step 3: Find $s(\tilde{A})$and $s(\tilde{B})$

Case (i) If $s(\tilde{A}) > s(\tilde{B})$then $\tilde{A} < \tilde{B}$

Case (ii)If $s(\tilde{A}) < s(\tilde{B})$then $\tilde{A} > \tilde{B}$

Case (iii) If $s(\tilde{A}) = s(\tilde{B})$comparison is not possible, then go to ***step 4***.

Step 4: Find $ls(\tilde{A})$and $ls(\tilde{B})$

Case (i) If $ls(\tilde{A}) > ls(\tilde{B})$then $\tilde{A} > \tilde{B}$

Case (ii)If $ls(\tilde{A}) < ls(\tilde{B})$then $\tilde{A} < \tilde{B}$

Case (iii) If $ls(\tilde{A}) = ls(\tilde{B})$comparison is not possible, then go to ***step 5***.

Step 5: Examine w_1 and w_2

Case (i) If $w_1 > w_2$ then $\tilde{A} > \tilde{B}$

Case (ii) If $w_1 < w_2$ then $\tilde{A} < \tilde{B}$

Case (iii) If $w_1 = w_2$ then $\tilde{A} \approx \tilde{B}$

5.3 Leagility Evaluation: A Conceptual Framework

Leagile supply chain is a new conception that proposed in the context of diversified and personalized customer demands; it can quickly response fast changing demands, and modularize all kinds of personalized products as much as possible (Zhang et al., 2012). Successful implication of leagility driven supply chain requires its performance to be assessed.

The procedural hierarchical framework (Table 5.1) for leagility evaluation assessment module has been illustrated as follows.

The assessment framework is based on a leagile capabilities-attribute-criterion hierarchy; and it consists of five leagile enablers (at 1st level), forty leagile attributes (at 2nd level) and hundred eighty eight leagile criterions (at 3rd level). This descriptive model is very much comprehensive; it has been partially adapted from the work (Vinodh and Aravindraj, 2012) and extended up to 3rd level with the help of extensive literature survey from internet. The model addresses all major dimensions (leagile capabilities) of leagility such as (1) virtual enterprise, (2) collaborative relationship, (3) strategic management, (4) knowledge and IT management, (5) customer and market sensitiveness; termed as 1st level evaluation indices or leagile capabilities.

In the proposed three-level evaluation hierarchy, the first level indices have been comprised by examining business operation environments, measuring leagile drives and thereby identifying of leagile supply chain capabilities. The second level of the framework assesses the leagile enabled attributes and synthesizes appropriateness ratings as well as priority weights. The third level of the evaluation module assesses the leagile criterions and synthesizes appropriateness ratings (performance extent) and priority weights.

As the module encompasses various leagile capabilities, attributes as well as leagile criterions; subjectivity of the evaluation indices incorporates various decision-making uncertainty, ambiguity and vagueness. Therefore, a fuzzy logic approach has been utilized towards avoiding imprecision, inconsistency and incompleteness in the decision-making information and to deduce the human error and creation of expert knowledge and interpretation of a large amount of vague data. Above mentioned framework finds a performance representative ‘crisp value’ against each of the 3rd level leagile criterion and finally obtains performance ranking order for different leagile criterions. It is assumed that, higher the crisp value; higher be the performance extent for the said leagile criterion. Procedural steps of leagility appraisement have been summarized below:

1. Construction of general-hierarchy model (set of capabilities/attributes/criterions) towards evaluating leagility extent.

2. Formation of an expert team (Decision-Making group) consisting of a finite number of Decision-Makers (DMs). It is solely the task of the top management to select DMs from important managerial hierarchy level of the enterprise as well as from academia.

3. Selection of appropriate linguistic scale to collect expert opinion in relation to priority weight as well as performance rating of different leagility evaluation indices.

4. Selection of a suitable fuzzy scale to transform DMs linguistic evaluation information into appropriate fuzzy numbers for further data analysis and interpretation.

5. Collection of survey data (expert judgment) in relation to performance ratings and importance weights of leagile indices using linguistic terms.

6. Approximation of the linguistic ratings and weights by using fuzzy numbers. Fuzzy weighted average method is used to aggregate decision-making information.

Assume a 3-level evaluation criteria hierarchy consisting of m capabilities (at 1st level). Under each 1st level capability there exist n number of attributes (at 2nd level). Each 2nd level attribute is followed by p number of criterions.

Fuzzy appropriateness rating $\left(U_{ij}\right)$ of j_{th} 2nd level attribute $\left(C_{ij}\right)$ is computed as follows:

$$U_{ij} = \frac{\sum_{k=1}^{p} w_{ijk} \otimes U_{ijk}}{\sum_{k=1}^{p} w_{ijk}} \tag{5.25}$$

Here,

U_{ijk} = Fuzzy appropriateness rating of k_{th} leagile criterion $\left(C_{ijk}\right)$ at 3rd level

w_{ijk} = Fuzzy priority weight of k_{th} leagile criterion $\left(C_{ijk}\right)$ at 3rd level

Fuzzy appropriateness rating $\left(U_{i}\right)$ of i_{th} 1st level capability $\left(C_{i}\right)$ is computed as follows:

$$U_{i} = \frac{\sum_{j=1}^{n} w_{ij} \otimes U_{ij}}{\sum_{j=1}^{n} w_{ij}} \tag{5.26}$$

Here,

U_{ij} = Fuzzy appropriateness rating of j_{th} leagile attribute $\left(C_{ij}\right)$ at 2nd level computed from Eq. 5.25.

w_{ij} = Fuzzy priority weight of j_{th} leagile attribute $\left(C_{ij}\right)$ at 2nd level

7. Determination of Fuzzy Overall Performance Index (FOPI) and finding the existing leagility level.

Finally, Fuzzy Overall Performance Index (FOPI) is computed as follows:

$$FOPI = \frac{\sum_{i=1}^{m} w_i \otimes U_i}{\sum_{i=1}^{m} w_i} \quad (5.27)$$

Here,

U_i =Fuzzy appropriateness rating of i_{th} leagile capability (C_i) at 1st level computed from Eq. 5.26.

w_i = Fuzzy priority weight of i_{th} leagile capability (C_i) at 1st level

8. Determination of Fuzzy Performance Importance Index (FPII) corresponding to individual 3rd level leagile criterions.

Fuzzy Performance Importance Index (FPII) is computed as follows (Lin et al., 2006):

$$FPII_k = \left[1 - w_{ijk}\right] \otimes U_{ijk} \quad (5.28)$$

Representative crisp value corresponding to individual $FPII_k$ [(k_{th}) 3rd level criterion) is used to determine performance ranking order of 3rd level leagile criterions.

9. Perform gap analysis and identify the barriers (ill-performing areas) to achieve leagility.

5.4 Case Empirical Illustration

The study presents the application of the conceptual model of leagility embedded with lean and agile principles. A fuzzy logic approach has been used for the evaluation of leagility in supply chains. It is aimed to compute the performance of supply chain using both lean and agile concepts (as leagility supply chains) using fuzzy set theory. General hierarchy model for leagility evaluation has been furnished in Table 5.1. Definitions of linguistic variables for assignment of priority weight and performance ratings have been shown in Table 5.2, which is basically a nine-member linguistic term set. Linguistic evaluation information needs to be converted into appropriate fuzzy numbers. A fuzzy scale (Table 5.2) consisting of Generalized Trapezoidal Fuzzy Numbers (GTFNs) has been explored to convert DMs linguistic evaluation into fuzzy numbers. An expert group consists of 10 decision-makers has been constructed by the top management. The expert group has been instructed to utilize aforesaid linguistic scale towards assigning appropriateness rating against each of the 3rd level leagile criterions; priority weights against individual leagile capabilities (at 1st level), attributes (at 2nd level) as well as criterions (at 3rd level). Priority weight of leagile criterions (in linguistic term) assigned by the decision-makers (DMs) has been shown in Table 5.3 in APPENDIX-C. Table 5.4 (in APPENDIX-C) represents appropriateness rating (in linguistic terms) of leagile criterions assigned by the decision-makers (DMs). Linguistic priority weight of leagile attributes (at 2nd level) as well as leagile enablers (at 1st level) given by decision maker (DMs) have been shown in Table 5.5 and Table 5.6 (in APPENDIX-C), respectively. Linguistic data have been converted into appropriate fuzzy numbers as depicted in Table 5.2. The '*Aggregated Average Rule*' has been utilized to accumulate decision-makers' opinion. Table 5.7 (in APPENDIX-C) represents aggregated fuzzy priority weight as well as aggregated fuzzy rating of individual leagile criterions. Aggregated fuzzy priority weight and computed fuzzy rating (computed using Eq. 5.25) of leagile attributes have been given in Table 5.8 (in APPENDIX-C). Aggregated fuzzy priority weight and computed fuzzy rating (computed using Eq. 5.26) of leagile enablers have been tabulated in Table 5.9 (in APPENDIX-C). The FOPI thus becomes (Eq. 5.27): (0.399, 0.554, 1.170, 1.580, 1.000).

Table 5.10 represents computed values of FPII against individual 3rd level leagile criterions (using Eq. 5.28) and corresponding performance ranking order.

5.5 Concluding Remarks

Improved supply chain agility and leanness imply that a supply chain is capable of quickly responding to variations in customer demand with cost and waste reduction. Leanness in a supply chain maximizes profits through cost reduction, while agility maximizes profit through providing exactly what the customer requires. Aforesaid work aimed to present an integrated fuzzy based performance appraisement module in an organizational leagile supply chain.

This work proposes a Fuzzy Overall Performance Index (FOPI) to assess the combined agility and leanness measure (leagility) of the organizational supply chain. This evaluation module helps to assess existing organizational leagility degree; it can be considered as a ready reference to compare performance of different leagile organization (running under similar supply chain architecture) and to benchmark candidate leagile enterprises; so that best practices can be transmitted to the less-performing organizations. Moreover, there is scope to identify ill-performing areas (barriers of leagility) which require special managerial attention for future improvement.

Table 5.1: General Hierarchy Criteria (GHC) for leagility evaluation

Goal	Leagile enablers (1st level)	Leagile attributes (2nd level)	Leagile criterions (3rd level)	References/ citations
Leagility (C)	Virtual enterprises (C_1)	Virtual retail stores (C_{11})	Customer care (C_{111}) Merchandise and Security (C_{112}) Effective shopping (C_{113}) Virtual store atmosphere (C_{114}) Virtual store (C_{115})	(Vrechopoulos et al., 2001) http://www.bartertrends.com/creating-a-virtual-retail-store.html
		E- fulfilment logistics (C_{12})	Meeting customer expectations (C_{121}) Inventory availability (C_{122}) On time delivery (C_{123}) Outsourcing the functions to third party (C_{124}) Transparency and complete documentation of all processes (C_{125})	http://www.globalmillenniamarketing.com/article_fulfillment_ecommerce_ebusiness.htm, http://www.logwinlogistics.com/services/specials/efulfillment.html, (Bayles, 2002) (Bayles, 2002) http://www.logwinlogistics.com/services/specials/efulfillment.html
		Outsourcing (C_{13})	Information technology outsourcing (C_{131}) Business process outsourcing (C_{132}) Operational outsourcing (C_{133})	http://www.sourcingmag.com/content/what_is_outsourcing.asp http://en.wikipedia.org/wiki/Information_technology_outsourcing http://www.sourcingmag.com/content/what_is_outsourcing.asp http://operationstech.about.com/od/officestaffingandmanagem/a/OutSrcAdvantg.htm
		Integrated logistics management (C_{14})	Collaborating supply chain players (C_{141}) Process integrity (C_{142})	http://www.four-soft.com/integrated_logistics_management.asp
		Internal SCM (C_{15})	Management support (C_{151}) Structure (C_{152}) Human resource management (C_{153}) Communication (C_{154}) Information systems (C_{155})	(Basnet, 2013)
		Supply chain partner selection (C_{16})	Purchasing and Supply forecast (C_{161}) Response time (C_{162}) Production and logistics management (C_{163}) Partnership management (C_{164}) Financial capability (C_{165}) Technology and knowledge management (C_{166}) Marketing capability (C_{167}) Industrial and organizational competitiveness (C_{168}) Human resource management (C_{169})	http://www.ism.ws/pubs/content.cfm?ItemNumber=9722 (Wu and Barnes, 2010)
		Organisational structure (C_{17})	Environment (C_{171}) Strategy (C_{172}) Technology (C_{173}) Human resources (C_{174})	[*Source:* faculty.mu.edu.sa/download.php?fid=4218]

		Distributed virtual manufacturing (C_{18})	Component objects (C_{181}) Persistent storage objects (C_{182}) Service objects (C_{183}) Interface objects (C_{184})	(Olofsgard, et al., 2002)
		Logistics management (C_{19})	Movement of information (C_{191}) Visibility to their supply chain (C_{192}) Accessibility of shipments (C_{193})	http://www.globalmillenniamarketing.com/article_fulfillment_ecommerce_ebusiness.htm
		E-commerce (C_{110})	Customers satisfaction (C_{1101}) Delivery fulfilment (C_{1102}) Complete visibility across supply chain (C_{1103}) Flexibility in order (C_{1104})	
	Collaborative relationships (C_2)	Enterprise wide relationship management (C_{21})	Database marketing strategies (C_{211}) Marketing campaign management (C_{212}) Extensive interfacing requirement of call centres and web sites (C_{213}) Centralised system in CRS (C_{214}) Empowerment of employee (C_{215}) Automated and systematized communications channels (C_{216})	http://www.information-management.com/issues/19990501/19-1.html
		Supplier relationship management (C_{22})	Organisational structure (C_{221}) Clearly and jointly agreed Governance framework (C_{222}) Supplier engagement model (C_{223}) Joint activities (C_{224}) Value measurement (C_{225}) Systematic collaboration (C_{226}) Technology and systems (C_{227})	http://en.wikipedia.org/wiki/Supplier_relationship_management
		Logistics service providers (C_{23})	Ware housing (C_{231}) Materials handling (C_{232}) Purchasing (C_{233}) Protective packaging (C_{234}) Cooperate with production/ operations (C_{235}) Information maintenance (C_{236})	www.adameurope.eu/prj/7095/.../CourieL_WP2_Chapter2_final.pdf (Pache and Medina, 2007)
		Collaborative planning, forecast and replenishment (C_{24})	Develop front end agreement (C_{241}) Create the Joint Business Plan (C_{242}) Create the Sales Forecast (C_{243}) Identify Exceptions for Sales Forecast (C_{244}) Resolve/Collaborate on Exception Items (C_{245}) Create order forecast (C_{246}) Identify Exceptions for Order Forecast (C_{247}) Resolve/Collaborate on Exception Items (C_{248}) Order generation (C_{249})	http://en.wikipedia.org/wiki/Collaborative_planning,_forecasting,_and_replenishment

		Collaborative order fulfilment visibility (C_{25})	Business process (C_{251}) Process management (C_{252}) Infrastructure (C_{253})	(Alt et al., 2005)
	Strategic management (C_3)	Nature of management (C_{31})	Corporate (C_{311}) Business (C_{312}) Functional (C_{313}) Operational (C_{314})	www.huntingdon.edu/uploadedFiles/.../david_sm13_ppt_01.ppt http://en.wikipedia.org/wiki/Strategic_management
		Inventory management (C_{32})	Proper merchandise assortment while ordering, shipping, handling (C_{321}) Systems and processes that identify inventory requirements (C_{322}) Replenishment techniques (C_{323}) Monitoring of material movements (C_{324}) ABC analysis (C_{325})	http://en.wikipedia.org/wiki/Inventory
		Cycle time reduction (C_{33})	Pull-oriented lean manufacturing (C_{331}) Demand flow manufacturing (C_{332}) Cross-functional Integration (C_{333}) Supply chain management (C_{334})	http://www.rmdonovan.com/cycle_time-reduction/
		Time management (C_{34})	Creating an environment conducive to effectiveness (C_{341}) Setting of priorities (C_{342}) Carrying out activity around those priorities (C_{343}) Process of reduction of time spent on non-priorities (C_{344})	http://en.wikipedia.org/wiki/Time_management
		Development of new technology (C_{35})	Publicly performed research (C_{351}) Direct Subsidies for private research (C_{352}) Tax incentives (C_{353}) Intellectual property rights (C_{354})	(Bannon and Roodman, 2004)
		Process management (C_{36})	Processes need to align to business goals (C_{361}) Customer focus (C_{362}) Importance of benchmarks (C_{363}) Establish process owners (C_{364})	http://en.wikipedia.org/wiki/Business_Process_Improvement
		Production planning (C_{37})	Effective utilisation of resources (C_{371}) Steady flow of production (C_{372}) Estimate the resources (C_{373}) Ensure optimum inventory (C_{374}) Co-ordinate activities of departments (C_{375}) Minimise wastage of raw materials (C_{376}) Improves labour productivity (C_{377}) Helps to capture the market (C_{378}) Facilitate quality improvement (C_{379}) Results in consumer satisfaction (C_{3710}) Reduce the production costs (C_{3711})	http://kalyan-city.blogspot.com/2012/01/what-is-production-planning-meaning.html

		Quality status (C_{38})	Developing the quality strategy (C_{381}) Establishing goals and objectives (C_{382}) Identifying specific quality initiatives (C_{383}) Implementing action plans (C_{384})	(Beecroft, 1999)
		Product design and service (C_{39})	Cheaper, to disassemble (C_{391}) Refurbish or recycle after the initial Use phase (C_{392}) Durability of products (C_{393}) Product modularity and upgradeability (C_{394})	http://www.brass.cf.ac.uk/uploads/wpstratmgtofPSSsAW1005.pdf
		Manufacturing set up (C_{310})	Manufacturing basic setup (C_{3101}) Security (C_{3102}) Manufacturing core functions setup (C_{3103}) Manufacturing production functions setup (C_{3104}) Manufacturing management functions setup (C_{3105}) Manufacturing planning functions setup (C_{3106})	http://mbs.microsoft.com/downloads/public/GP10Docs/MfgSetup.pdf
		Human resources (C_{311})	The hiring process (C_{3111}) Classification (C_{3112}) Compensation (C_{3113}) Benefits (C_{3114}) Employee relation (C_{3115}) Legal compliance (C_{3116}) Performance management (C_{3117})	http://www.co.moore.nc.us/index.php/what-exactly-is-hr?lang=
		Vendor management (C_{312})	Risk analysis (C_{3121}) Due Diligence in Vendor Selection (C_{3122}) Documenting the Vendor Relationship Contract Issues (C_{3123}) Ongoing Supervision and Monitoring of Vendors (C_{3124})	http://www.cunaopsscouncil.org/news/323.html
	Knowledge and IT management (C_4)	E- business (C_{41})	Strategy (C_{411}) Website effectiveness (C_{412}) Integration of business Processes (C_{413}) E-Business management (C_{414})	(Sparrow, 2001)
		Re-engineered working pattern (C_{42})	Process focus (C_{421}) Managing Change and Risk (C_{422}) Document improvement (C_{423})	http://142.51.19.180/drdnotes/3146_cox_ch13.htm
		Decentralisation (C_{43})	Locality of expertise modelling (C_{431}) Lower control complexity of the expertise modelling process (C_{432}) Privacy or individualisation (C_{433}) Graceful degradation of the overall performance (C_{434})	(Yimam and Kobsa, 2000)

		Supply chain visibility (C_{44})	Demand visibility (C_{441}) Fulfilment visibility (C_{442}) Procurement visibility (C_{443}) Manufacturing visibility (C_{444}) Transportation visibility (C_{445})	http://www.krannert.purdue.edu/centers/dcmme_gscmi/downloads/2012%20spring/gordonWipro.pdf (Francis, 2008)
		Equipment engineering system (EES) (C_{45})	Data Collection and Pre-processing (C_{451}) Data Storage and Management (C_{452}) Tool template library (C_{453}) Data Selection, Query, and Retrieval (C_{454}) Data Display and Visualization (C_{455}) Data Analysis and Transformation (C_{456}) Production and Process Monitoring (C_{457}) Tool and Process Characterization (C_{458})	http://www.sematech.org/videos/SemiconWest-06/p039141.pdf
		Information system (C_{46})	Transaction processing systems (C_{461}) Management information systems (C_{462}) Decision support systems (C_{463}) Executive information systems (C_{464})	http://araku.ac.ir/~a_fiantial/ISR_Lec_[4].pdf
		Electronic data Interchange(EDI) (C_{47})	Exchange of structured business information (C_{471}) Faster transactions support (C_{472}) Improved business cycle time (C_{473}) Application service (C_{474}) Translation service (C_{475}) Communication service (C_{476})	http://220.227.161.86/22529ittstm_U10_cp6.pdf, http://en.wikipedia.org/wiki/Electronic_data_interchange
	Customer and Market Sensitiveness (C_5)	Customer focus (C_{51})	Customer driven products and process (C_{511}) Accurate customer voice translation (C_{512}) Avenues for increasing customer values (C_{513})	(Vinodh and Aravindraj, 2013)
		Market sensitivity (C_{52})	Market trend analysis (C_{521}) Gathering of customer responses (C_{522}) Market winning criteria (C_{523})	
		Culture and change management (C_{53})	Institutionalisation of change management Programmes (C_{531}) Development of communication plans (C_{532}) Continuous and lifelong learning (C_{533})	
		Product service level (C_{54})	Design for serviceability (C_{541}) Well-equipped service centres (C_{542}) Extensive service facilities (C_{543})	
		Mass customisation (C_{55})	Focus on product variety (C_{551}) Products tuned to customers' requirements (C_{552}) Market dynamism (C_{553})	
		Quality of product (C_{56})	Implementation of total quality management Principles (C_{561}) Formation of quality circles (C_{562}) Adoption of standard quality measures (C_{563})	

Table 5.2: Definitions of linguistic variables for priority weight and appropriateness ratings (with corresponding fuzzy representation) (A-9 member linguistic term set)

Linguistic terms (Attribute ratings)	Linguistic terms (Priority weights)	Generalized trapezoidal fuzzy numbers
Absolutely Poor (AP)	Absolutely Low (AL)	(0, 0, 0, 0; 1)
Very Poor (VP)	Very Low (VL)	(0, 0, 0.02, 0.07; 1)
Poor (P)	Low (L)	(0.04, 0.10, 0.18, 0.23; 1)
Medium Poor (MP)	Medium Low (ML)	(0.17, 0.22, 0.36, 0.42; 1)
Medium (M)	Medium (M)	(0.32, 0.41, 0.58, 0.65; 1)
Medium Good (MG)	Medium High (MH)	(0.58, 0.63, 0.80, 0.86; 1)
Good (G)	High (H)	(0.72, 0.78, 0.92, 0.97; 1)
Very Good (VG)	Very High (VH)	(0.93, 0.98, 1, 1; 1)
Absolutely Good (AG)	Absolutely High (AH)	(1, 1, 1, 1; 1)

Table 5.10: Computation of FPII and ranking order of leagile criterions

Leagile criterions, C_{ijk}	FPII = U_{ij}*[(1,1,1,1,1)-W_{ij}]	$I_{\tilde{A}}(\bar{x}_0, \bar{y}_0)$	$R(\bar{A}) = x_0 \times y_0$	Ranking Order
C_{111}	(0.038,0.069,0.174,0.221;1.000)	(0.1232,0.3779)	0.0466	23
C_{112}	(0.052,0.086,0.201,0.261;1.000)	(0.1461,0.3811)	0.0557	9
C_{113}	(0.020,0.045,0.131,0.174;1.000)	(0.0901,0.3727)	0.0336	40
C_{114}	(0.008,0.022,0.074,0.107;1.000)	(0.0507,0.3610)	0.0183	56
C_{115}	(0.045,0.080,0.194,0.252;1.000)	(0.1394,0.3810)	0.0531	13
C_{121}	(0.029,0.056,0.143,0.184;1.000)	(0.1011,0.3730)	0.0377	35
C_{122}	(0.034,0.069,0.186,0.246;1.000)	(0.1303,0.3816)	0.0497	17
C_{123}	(0.054,0.093,0.214,0.270;1.000)	(0.1554,0.3823)	0.0594	4
C_{124}	(0.016,0.033,0.097,0.141;1.000)	(0.0686,0.3660)	0.0251	52
C_{125}	(0.047,0.084,0.206,0.259;1.000)	(0.1466,0.3821)	0.0560	7
C_{131}	(0.015,0.032,0.093,0.132;1.000)	(0.0654,0.3648)	0.0239	53
C_{132}	(0.053,0.085,0.187,0.236;1.000)	(0.1380,0.3775)	0.0521	14
C_{133}	(0.040,0.073,0.180,0.229;1.000)	(0.1284,0.3788)	0.0486	20
C_{141}	(0.038,0.073,0.193,0.252;1.000)	(0.1353,0.3820)	0.0517	15
C_{142}	(0.023,0.053,0.160,0.218;1.000)	(0.1097,0.3791)	0.0416	32
C_{151}	(0.057,0.091,0.206,0.265;1.000)	(0.1509,0.3811)	0.0575	6

C_{152}	(0.036,0.067,0.170,0.214;1.000)	(0.1198,0.3773)	0.0452	26
C_{153}	(0.018,0.040,0.113,0.154;1.000)	(0.0788,0.3689)	0.0291	47
C_{154}	(0.029,0.056,0.147,0.194;1.000)	(0.1036,0.3746)	0.0388	34
C_{155}	(0.035,0.065,0.173,0.224;1.000)	(0.1211,0.3788)	0.0459	25
C_{161}	(0.013,0.038,0.124,0.172;1.000)	(0.0836,0.3731)	0.0312	43
C_{162}	(0.067,0.100,0.207,0.263;1.000)	(0.1559,0.3791)	0.0591	5
C_{163}	(0.033,0.065,0.169,0.219;1.000)	(0.1188,0.3781)	0.0449	27
C_{164}	(0.006,0.018,0.061,0.093;1.000)	(0.0419,0.3576)	0.0150	58
C_{165}	(0.038,0.072,0.193,0.254;1.000)	(0.1352,0.3823)	0.0517	15
C_{166}	(0.018,0.038,0.110,0.154;1.000)	(0.0768,0.3689)	0.0283	48
C_{167}	(0.053,0.095,0.231,0.286;1.000)	(0.1642,0.3850)	0.0632	1
C_{168}	(0.037,0.077,0.201,0.255;1.000)	(0.1401,0.3828)	0.0536	12
C_{169}	(0.006,0.017,0.064,0.107;1.000)	(0.0450,0.3602)	0.0162	57
C_{171}	(0.031,0.059,0.160,0.215;1.000)	(0.1124,0.3775)	0.0424	30
C_{172}	(0.028,0.053,0.141,0.189;1.000)	(0.0996,0.3737)	0.0372	36
C_{173}	(0.029,0.051,0.128,0.174;1.000)	(0.0922,0.3705)	0.0341	39
C_{174}	(0.033,0.067,0.179,0.232;1.000)	(0.1248,0.3801)	0.0474	22
C_{181}	(0.040,0.066,0.153,0.204;1.000)	(0.1122,0.3738)	0.0419	31
C_{182}	(0.027,0.052,0.138,0.183;1.000)	(0.0970,0.3729)	0.0362	37
C_{183}	(0.058,0.091,0.196,0.249;1.000)	(0.1453,0.3786)	0.0550	10
C_{184}	(0.028,0.052,0.130,0.174;1.000)	(0.0934,0.3708)	0.0346	38
C_{191}	(0.012,0.033,0.102,0.134;1.000)	(0.0690,0.3669)	0.0253	51
C_{192}	(0.043,0.072,0.170,0.213;1.000)	(0.1228,0.3760)	0.0462	24
C_{193}	(0.040,0.067,0.164,0.207;1.000)	(0.1175,0.3755)	0.0441	29
C_{1101}	(0.030,0.060,0.161,0.209;1.000)	(0.1124,0.3770)	0.0424	30
C_{1102}	(0.052,0.086,0.201,0.261;1.000)	(0.1461,0.3811)	0.0557	9
C_{1103}	(0.012,0.036,0.118,0.161;1.000)	(0.0792,0.3716)	0.0294	45
C_{1104}	(0.008,0.022,0.074,0.107;1.000)	(0.0507,0.3610)	0.0183	56
C_{211}	(0.045,0.080,0.194,0.252;1.000)	(0.1394,0.3810)	0.0531	13
C_{212}	(0.029,0.056,0.143,0.184;1.000)	(0.1011,0.3730)	0.0377	35
C_{213}	(0.034,0.069,0.186,0.246;1.000)	(0.1303,0.3816)	0.0497	17
C_{214}	(0.054,0.093,0.214,0.270;1.000)	(0.1554,0.3823)	0.0594	4
C_{215}	(0.024,0.043,0.110,0.154;1.000)	(0.0794,0.3673)	0.0292	46
C_{216}	(0.047,0.084,0.206,0.259;1.000)	(0.1466,0.3821)	0.0560	7
C_{221}	(0.025,0.046,0.123,0.164;1.000)	(0.0870,0.3698)	0.0322	42
C_{222}	(0.053,0.085,0.187,0.236;1.000)	(0.1380,0.3775)	0.0521	14
C_{223}	(0.032,0.063,0.167,0.216;1.000)	(0.1171,0.3779)	0.0442	28
C_{224}	(0.038,0.073,0.193,0.252;1.000)	(0.1353,0.3820)	0.0517	15
C_{225}	(0.023,0.053,0.160,0.218;1.000)	(0.1097,0.3791)	0.0416	32

C_{226}	(0.057,0.091,0.206,0.265;1.000)	(0.1509,0.3811)	0.0575	6
C_{227}	(0.028,0.052,0.130,0.174;1.000)	(0.0934,0.3708)	0.0346	38
C_{231}	(0.012,0.033,0.102,0.134;1.000)	(0.0690,0.3669)	0.0253	51
C_{232}	(0.043,0.072,0.170,0.213;1.000)	(0.1228,0.3760)	0.0462	24
C_{233}	(0.040,0.067,0.164,0.207;1.000)	(0.1175,0.3755)	0.0441	29
C_{234}	(0.030,0.060,0.161,0.209;1.000)	(0.1124,0.3770)	0.0424	30
C_{235}	(0.052,0.086,0.201,0.261;1.000)	(0.1461,0.3811)	0.0557	9
C_{236}	(0.012,0.036,0.118,0.161;1.000)	(0.0792,0.3716)	0.0294	45
C_{241}	(0.008,0.022,0.074,0.107;1.000)	(0.0507,0.3610)	0.0183	56
C_{242}	(0.045,0.080,0.194,0.252;1.000)	(0.1394,0.3810)	0.0531	13
C_{243}	(0.029,0.056,0.143,0.184;1.000)	(0.1011,0.3730)	0.0377	35
C_{244}	(0.034,0.069,0.186,0.246;1.000)	(0.1303,0.3816)	0.0497	17
C_{245}	(0.045,0.083,0.200,0.256;1.000)	(0.1435,0.3815)	0.0547	11
C_{246}	(0.024,0.043,0.110,0.154;1.000)	(0.0794,0.3673)	0.0292	46
C_{247}	(0.047,0.084,0.206,0.259;1.000)	(0.1466,0.3821)	0.0560	7
C_{248}	(0.015,0.032,0.093,0.132;1.000)	(0.0654,0.3648)	0.0239	53
C_{249}	(0.053,0.085,0.187,0.236;1.000)	(0.1380,0.3775)	0.0521	14
C_{251}	(0.040,0.073,0.180,0.229;1.000)	(0.1284,0.3788)	0.0486	20
C_{252}	(0.045,0.082,0.205,0.265;1.000)	(0.1459,0.3829)	0.0558	8
C_{253}	(0.023,0.053,0.160,0.218;1.000)	(0.1097,0.3791)	0.0416	32
C_{311}	(0.048,0.076,0.174,0.227;1.000)	(0.1279,0.3766)	0.0482	21
C_{312}	(0.036,0.067,0.170,0.214;1.000)	(0.1198,0.3773)	0.0452	26
C_{313}	(0.018,0.040,0.113,0.154;1.000)	(0.0788,0.3689)	0.0291	47
C_{314}	(0.029,0.056,0.147,0.194;1.000)	(0.1036,0.3746)	0.0388	34
C_{321}	(0.035,0.065,0.173,0.224;1.000)	(0.1211,0.3788)	0.0459	25
C_{322}	(0.013,0.038,0.124,0.172;1.000)	(0.0836,0.3731)	0.0312	43
C_{323}	(0.055,0.083,0.174,0.229;1.000)	(0.1316,0.3751)	0.0494	18
C_{324}	(0.033,0.065,0.169,0.219;1.000)	(0.1188,0.3781)	0.0449	27
C_{325}	(0.016,0.032,0.090,0.123;1.000)	(0.0633,0.3632)	0.0230	54
C_{331}	(0.038,0.072,0.193,0.254;1.000)	(0.1352,0.3823)	0.0517	15
C_{332}	(0.025,0.046,0.123,0.167;1.000)	(0.0872,0.3700)	0.0323	41
C_{333}	(0.053,0.095,0.231,0.286;1.000)	(0.1642,0.3850)	0.0632	1
C_{334}	(0.020,0.058,0.174,0.229;1.000)	(0.1177,0.3813)	0.0449	27
C_{341}	(0.006,0.017,0.064,0.107;1.000)	(0.0450,0.3602)	0.0162	57
C_{342}	(0.031,0.059,0.160,0.215;1.000)	(0.1124,0.3775)	0.0424	30
C_{343}	(0.028,0.053,0.141,0.189;1.000)	(0.0996,0.3737)	0.0372	36
C_{344}	(0.021,0.037,0.099,0.139;1.000)	(0.0711,0.3650)	0.0259	50
C_{351}	(0.033,0.067,0.179,0.232;1.000)	(0.1248,0.3801)	0.0474	22
C_{352}	(0.040,0.066,0.153,0.204;1.000)	(0.1122,0.3738)	0.0419	31

C_{353}	(0.017,0.037,0.109,0.152;1.000)	(0.0759,0.3685)	0.0280	49
C_{354}	(0.058,0.091,0.196,0.249;1.000)	(0.1453,0.3786)	0.0550	10
C_{361}	(0.030,0.060,0.161,0.209;1.000)	(0.1124,0.3770)	0.0424	30
C_{362}	(0.060,0.095,0.214,0.274;1.000)	(0.1571,0.3820)	0.0600	3
C_{363}	(0.020,0.045,0.131,0.174;1.000)	(0.0901,0.3727)	0.0336	40
C_{364}	(0.008,0.022,0.074,0.107;1.000)	(0.0507,0.3610)	0.0183	56
C_{371}	(0.045,0.080,0.194,0.252;1.000)	(0.1394,0.3810)	0.0531	13
C_{372}	(0.029,0.056,0.143,0.184;1.000)	(0.1011,0.3730)	0.0377	35
C_{373}	(0.034,0.069,0.186,0.246;1.000)	(0.1303,0.3816)	0.0497	17
C_{374}	(0.054,0.093,0.214,0.270;1.000)	(0.1554,0.3823)	0.0594	4
C_{375}	(0.016,0.033,0.097,0.141;1.000)	(0.0686,0.3660)	0.0251	52
C_{376}	(0.055,0.093,0.219,0.272;1.000)	(0.1574,0.3829)	0.0603	2
C_{377}	(0.015,0.032,0.093,0.132;1.000)	(0.0654,0.3648)	0.0239	53
C_{378}	(0.053,0.085,0.187,0.236;1.000)	(0.1380,0.3775)	0.0521	14
C_{379}	(0.032,0.063,0.167,0.216;1.000)	(0.1171,0.3779)	0.0442	28
C_{3710}	(0.045,0.082,0.205,0.265;1.000)	(0.1459,0.3829)	0.0558	8
C_{3711}	(0.023,0.053,0.160,0.218;1.000)	(0.1097,0.3791)	0.0416	32
C_{381}	(0.048,0.076,0.174,0.227;1.000)	(0.1279,0.3766)	0.0482	21
C_{382}	(0.036,0.067,0.170,0.214;1.000)	(0.1198,0.3773)	0.0452	26
C_{383}	(0.018,0.040,0.113,0.154;1.000)	(0.0788,0.3689)	0.0291	47
C_{384}	(0.029,0.056,0.147,0.194;1.000)	(0.1036,0.3746)	0.0388	34
C_{391}	(0.035,0.065,0.173,0.224;1.000)	(0.1211,0.3788)	0.0459	25
C_{392}	(0.013,0.038,0.124,0.172;1.000)	(0.0836,0.3731)	0.0312	43
C_{393}	(0.055,0.083,0.174,0.229;1.000)	(0.1316,0.3751)	0.0494	18
C_{394}	(0.033,0.065,0.169,0.219;1.000)	(0.1188,0.3781)	0.0449	27
C_{3101}	(0.006,0.018,0.061,0.093;1.000)	(0.0419,0.3576)	0.0150	58
C_{3102}	(0.038,0.072,0.193,0.254;1.000)	(0.1352,0.3823)	0.0517	15
C_{3103}	(0.018,0.038,0.110,0.154;1.000)	(0.0768,0.3689)	0.0283	48
C_{3104}	(0.053,0.095,0.231,0.286;1.000)	(0.1642,0.3850)	0.0632	1
C_{3105}	(0.037,0.077,0.201,0.255;1.000)	(0.1401,0.3828)	0.0536	12
C_{3106}	(0.006,0.017,0.064,0.107;1.000)	(0.0450,0.3602)	0.0162	57
C_{3111}	(0.031,0.059,0.160,0.215;1.000)	(0.1124,.3775)	0.0424	30
C_{3112}	(0.028,0.053,0.141,0.189;1.000)	(0.0996,0.3737)	0.0372	36
C_{3113}	(0.021,0.037,0.099,0.139;1.000)	(0.0711,0.3650)	0.0259	50
C_{3114}	(0.033,0.067,0.179,0.232;1.000)	(0.1248,0.3801)	0.0474	22
C_{3115}	(0.040,0.066,0.153,0.204;1.000)	(0.1122,0.3738)	0.0419	31
C_{3116}	(0.017,0.037,0.109,0.152;1.000)	(0.0759,0.3685)	0.0280	49
C_{3117}	(0.058,0.091,0.196,0.249;1.000)	(0.1453,0.3786)	0.0550	10
C_{3121}	(0.028,0.052,0.130,0.174;1.000)	(0.0934,0.3708)	0.0346	38

C_{3122}	(0.012,0.033,0.102,0.134;1.000)	(0.0690,0.3669)	0.0253	51
C_{3123}	(0.043,0.072,0.170,0.213;1.000)	(0.1228,0.3760)	0.0462	24
C_{3124}	(0.040,0.067,0.164,0.207;1.000)	(0.1175,0.3755)	0.0441	29
C_{411}	(0.030,0.060,0.161,0.209;1.000)	(0.1124,0.3770)	0.0424	30
C_{412}	(0.052,0.086,0.201,0.261;1.000)	(0.1461,0.3811)	0.0557	9
C_{413}	(0.012,0.036,0.118,0.161;1.000)	(0.0792,0.3716)	0.0294	45
C_{414}	(0.008,0.022,0.074,0.107;1.000)	(0.0507,0.3610)	0.0183	56
C_{421}	(0.045,0.080,0.194,0.252;1.000)	(0.1394,0.3810)	0.0531	13
C_{422}	(0.029,0.056,0.143,0.184;1.000)	(0.1011,0.3730)	0.0377	35
C_{423}	(0.034,0.069,0.186,0.246;1.000)	(0.1303,0.3816)	0.0497	17
C_{431}	(0.043,0.076,0.180,0.229;1.000)	(0.1296,0.3780)	0.0490	19
C_{432}	(0.016,0.033,0.097,0.141;1.000)	(0.0686,0.3660)	0.0251	52
C_{433}	(0.045,0.078,0.187,0.234;1.000)	(0.1340,0.3789)	0.0508	16
C_{434}	(0.015,0.032,0.093,0.132;1.000)	(0.0654,0.3648)	0.0239	53
C_{441}	(0.053,0.085,0.187,0.236;1.000)	(0.1380,0.3775)	0.0521	14
C_{442}	(0.030,0.057,0.149,0.197;1.000)	(0.1053,0.3748)	0.0395	33
C_{443}	(0.038,0.073,0.193,0.252;1.000)	(0.1353,0.3820)	0.0517	15
C_{444}	(0.023,0.053,0.160,0.218;1.000)	(0.1097,0.3791)	0.0416	32
C_{445}	(0.048,0.076,0.174,0.227;1.000)	(0.1279,0.3766)	0.0482	21
C_{451}	(0.028,0.052,0.130,0.174;1.000)	(0.0934,0.3708)	0.0346	38
C_{452}	(0.012,0.033,0.102,0.134;1.000)	(0.0690,0.3669)	0.0253	51
C_{453}	(0.043,0.072,0.170,0.213;1.000)	(0.1228,0.3760)	0.0462	24
C_{454}	(0.040,0.067,0.164,0.207;1.000)	(0.1175,0.3755)	0.0441	29
C_{455}	(0.030,0.060,0.161,0.209;1.000)	(0.1124,0.3770)	0.0424	30
C_{456}	(0.052,0.086,0.201,0.261;1.000)	(0.1461,0.3811)	0.0557	9
C_{457}	(0.012,0.036,0.118,0.161;1.000)	(0.0792,0.3716)	0.0294	45
C_{458}	(0.008,0.022,0.074,0.107;1.000)	(0.0507,0.3610)	0.0183	56
C_{461}	(0.045,0.080,0.194,0.252;1.000)	(0.1394,0.3810)	0.0531	13
C_{462}	(0.029,0.056,0.143,0.184;1.000)	(0.1011,0.3730)	0.0377	35
C_{463}	(0.032,0.063,0.169,0.226;1.000)	(0.1186,0.3789)	0.0449	27
C_{464}	(0.054,0.093,0.214,0.270;1.000)	(0.1554,0.3823)	0.0594	4
C_{471}	(0.014,0.027,0.080,0.122;1.000)	(0.0573,0.3619)	0.0207	55
C_{472}	(0.047,0.084,0.206,0.259;1.000)	(0.1466,0.3821)	0.0560	7
C_{473}	(0.015,0.032,0.093,0.132;1.000)	(0.0654,0.3648)	0.0239	53
C_{474}	(0.053,0.085,0.187,0.236;1.000)	(0.1380,0.3775)	0.0521	14
C_{475}	(0.032,0.063,0.167,0.216;1.000)	(0.1171,0.3779)	0.0442	28
C_{476}	(0.038,0.073,0.193,0.252;1.000)	(0.1353,0.3820)	0.0517	15
C_{511}	(0.023,0.053,0.160,0.218;1.000)	(0.1097,0.3791)	0.0416	32
C_{512}	(0.048,0.076,0.174,0.227;1.000)	(0.1279,0.3766)	0.0482	21

C_{513}	(0.036,0.067,0.170,0.214;1.000)	(0.1198,0.3773)	0.0452	26
C_{521}	(0.018,0.040,0.113,0.154;1.000)	(0.0788,0.3689)	0.0291	47
C_{522}	(0.029,0.056,0.147,0.194;1.000)	(0.1036,0.3746)	0.0388	34
C_{523}	(0.035,0.065,0.173,0.224;1.000)	(0.1211,0.3788)	0.0459	25
C_{531}	(0.013,0.038,0.124,0.172;1.000)	(0.0836,0.3731)	0.0312	43
C_{532}	(0.055,0.083,0.174,0.229;1.000)	(0.1316,0.3751)	0.0494	18
C_{533}	(0.033,0.065,0.169,0.219;1.000)	(0.1188,0.3781)	0.0449	27
C_{541}	(0.006,0.018,0.061,0.093;1.000)	(0.0419,0.3576)	0.0150	58
C_{542}	(0.038,0.072,0.193,0.254;1.000)	(0.1352,0.3823)	0.0517	15
C_{543}	(0.018,0.038,0.110,0.154;1.000)	(0.0768,0.3689)	0.0283	48
C_{551}	(0.053,0.095,0.231,0.286;1.000)	(0.1642,0.3850)	0.0632	1
C_{552}	(0.020,0.058,0.174,0.229;1.000)	(0.1177,0.3813)	0.0449	27
C_{553}	(0.006,0.017,0.064,0.107;1.000)	(0.0450,0.3602)	0.0162	57
C_{561}	(0.031,0.059,0.160,0.215;1.000)	(0.1124,0.3775)	0.0424	30
C_{562}	(0.028,0.053,0.141,0.189;1.000)	(0.0996,0.3737)	0.0372	36
C_{563}	(0.021,0.037,0.099,0.139;1.000)	(0.0711,0.3650)	0.0259	50

CHAPTER 6

PERFORMANCE APPRAISEMENT AND BENCHMARKING OF LEAGILITY INSPIRED INDUSTRIES: A FUZZY BASED DECISION MAKING APPROACH

6.1 Coverage

In the 21st century, the present competitive era has forced the leaders of organizational management to be more proactive and concerned on enhancing business value by modifying existing/traditional supply chain strategies in order to sustain in the global marketplace. In this context, the adaptation of leagility concept in supply chain management has gained vital importance. Leagility is the combination of two different concepts (or realm): lean and agile; one imposes the ability to streamline the processes depending on cost reduction through minimizing wastes *(muda)* and enriching customer perspectives; whereas, the other facilitates to act efficiently as well as tactfully against volatile unpredictable market demand and also to ensure quick response to the customers. Leagility itself combining the silent features of lean and agile concept into existing supply chain strategy; their appropriate implementation has become the key success factor for modern business today. Therefore, leagility inspired supply chain performance appraisement (as well as benchmarking) has become the major issue in today's supply chain management research. The main problem that arises in assessing leagility extent is due to subjectivity of evaluation indices (attributes/criterions). In order to avoid vagueness, incompleteness as well as inconsistency in subjective evaluation information; the leagile supply chain performance attributes have been evaluated in terms of fuzzy terminology. The 'Degree of Similarity' concept between two Interval-Valued Fuzzy Numbers (IVFNs) adapted from fuzzy set theory has been explored here for performance appraisement as well as benchmarking of leagile industries (alternatives). A case empirical study has been executed for selection of the best performed leagile organization by using the proposed degree of similarity approach in conjugation with the concept of 'closeness coefficient' adapted from TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), a well-known decision-making tool.

6.2 The Concept of IVFNs and Their Arithmetic Operations

Some basic concepts of IVFNs and their arithmetic operations have been discussed here. Wang and Li (1998) defined IVFNs and presented their extended operational rules. From Chen and Lai (2011), the trapezoidal IVFN $\tilde{\tilde{A}}$, as shown in Fig. 6.1, can be represented by

$$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right],$$

Here, $a_1^L \le a_2^L \le a_3^L \le a_4^L$, $a_1^U \le a_2^U \le a_3^U \le a_4^U$, $\tilde{\tilde{A}}^L$ denotes the lower IVFN, $\tilde{\tilde{A}}^U$ denotes the upper IVFN, and $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$.

Assume that there are two IVFNs $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$, where;

$\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right]$, and

$\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$,

$0 \le w_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1$, $\tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U$, $0 \le w_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1$, and $\tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U$.

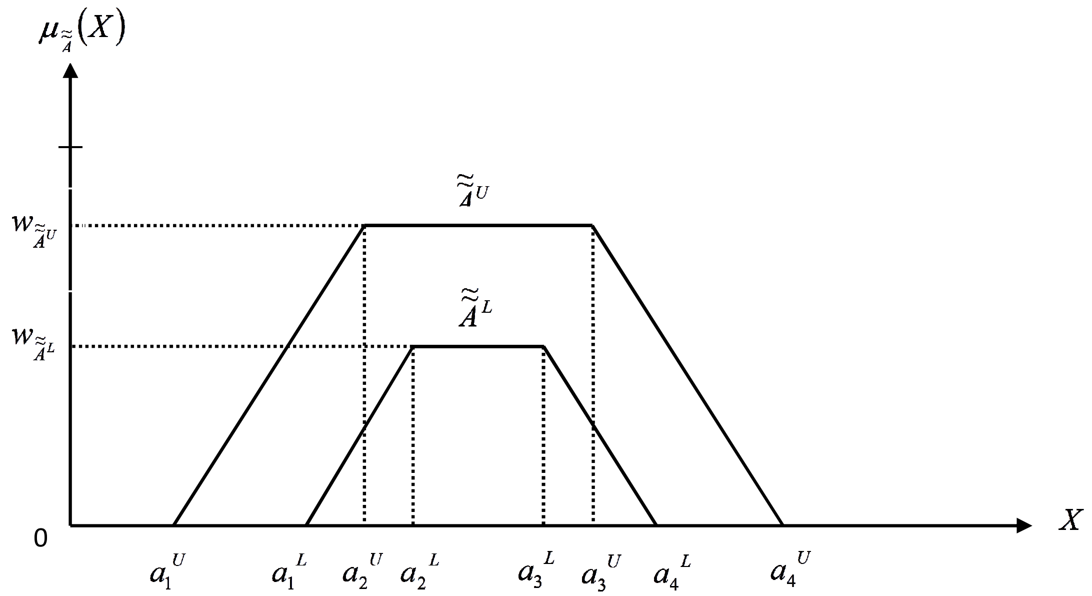

Fig.6.1: An interval valued trapezoidal fuzzy number

The arithmetic operations between IVFNs $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ as given by Wei and Chen (2009) have been reproduced as follows:

1. IVFNs addition $\oplus$

$$\tilde{\tilde{A}} \oplus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \oplus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \left(a_1^L + b_1^L, a_2^L + b_2^L, a_3^L + b_3^L, a_4^L + b_4^L; \mathbf{min}\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \left(a_1^U + b_1^U, a_2^U + b_2^U, a_3^U + b_3^U, a_4^U + b_4^U; \mathbf{min}\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right) \quad (6.1)$$

2. IVFNs subtraction $\ominus$

$$\tilde{\tilde{A}} \ominus \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \ominus \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \left(a_1^L - b_1^L, a_2^L - b_2^L, a_3^L - b_3^L, a_4^L - b_4^L; \mathbf{min}\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \left(a_1^U - b_1^U, a_2^U - b_2^U, a_3^U - b_3^U, a_4^U - b_4^U; \mathbf{min}\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right) \quad (6.2)$$

3. IVFNs multiplication $\otimes$

$$\tilde{\tilde{A}} \otimes \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] \otimes \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \left(a_1^L \times b_1^L, a_2^L \times b_2^L, a_3^L \times b_3^L, a_4^L \times b_4^L; \mathbf{min}\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \left(a_1^U \times b_1^U, a_2^U \times b_2^U, a_3^U \times b_3^U, a_4^U \times b_4^U; \mathbf{min}\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right) \quad (6.3)$$

4. IVFNs division

$$\tilde{\tilde{A}} / \tilde{\tilde{B}} = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right] / \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$$

$$= \begin{bmatrix} \left(\min\left(U^L\right), \min\left(U^L - x^L\right), \max\left(U^L - y^L\right), \max\left(U^L\right); \min\left(w_{\tilde{\tilde{A}}}^L, w_{\tilde{\tilde{B}}}^L\right)\right), \\ \left(\min\left(U^U\right), \min\left(U^U - x^U\right), \max\left(U^U - y^U\right), \max\left(U^U\right); \min\left(w_{\tilde{\tilde{A}}}^U, w_{\tilde{\tilde{B}}}^U\right)\right) \end{bmatrix} \quad (6.4)$$

Where $U^L = \left\{\frac{a_1^L}{b_1^L}, \frac{a_2^L}{b_2^L}, \frac{a_3^L}{b_3^L}, \frac{a_4^L}{b_{41}^L}\right\}$, $U^U = \left\{\frac{a_1^U}{b_1^U}, \frac{a_2^U}{b_2^U}, \frac{a_3^U}{b_3^U}, \frac{a_4^U}{b_4^U}\right\}$,

$x^L = \min\left(U^L\right)$, $x^U = \min\left(U^U\right)$, $y^L = \max\left(U^L\right)$, $y^U = \max\left(U^U\right)$, $U^L - x^L$ denotes excluding the element x^L from the set U^L, $U^U - x^U$ denotes excluding the element x^U from the set U^U, $U^L - y^L$ denotes excluding the element y^L from the set U^L and $U^U - y^U$ denotes excluding the element y^U from set U^U.

6.3 Degree of Similarity between Two IVFNs

There is numerous similarity measure methods between fuzzy numbers have been reported in fuzzy-theory literature. This paper explores the theory of similarity measure between IVFNs as presented by Chen and Lai (2011) that combines the concepts of the geometric distance, the perimeter, the height and the COG (center of gravity) points of IVFNs in order to calculate the degree of similarity between IVFNs. The brief description of this similarity measure has been presented here.

Let $\tilde{\tilde{A}}$ and $\tilde{\tilde{B}}$ be two IVFNs, where $\tilde{\tilde{A}} = \left[\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U\right] = \left[\left(a_1^L, a_2^L, a_3^L, a_4^L; w_{\tilde{\tilde{A}}}^L\right), \left(a_1^U, a_2^U, a_3^U, a_4^U; w_{\tilde{\tilde{A}}}^U\right)\right]$

and $\tilde{\tilde{B}} = \left[\tilde{\tilde{B}}^L, \tilde{\tilde{B}}^U\right] = \left[\left(b_1^L, b_2^L, b_3^L, b_4^L; w_{\tilde{\tilde{B}}}^L\right), \left(b_1^U, b_2^U, b_3^U, b_4^U; w_{\tilde{\tilde{B}}}^U\right)\right]$,

$0 \le a_1^L \le a_2^L \le a_3^L \le a_4^L \le 1, 0 \le a_1^U \le a_2^U \le a_3^U \le a_4^U \le 1, 0 \le w_{\tilde{\tilde{A}}}^L \le w_{\tilde{\tilde{A}}}^U \le 1, \tilde{\tilde{A}}^L \subset \tilde{\tilde{A}}^U;$

$0 \le b_1^L \le b_2^L \le b_3^L \le b_4^L \le 1, 0 \le b_1^U \le b_2^U \le b_3^U \le b_4^U \le 1, 0 \le w_{\tilde{\tilde{B}}}^L \le w_{\tilde{\tilde{B}}}^U \le 1, \tilde{\tilde{B}}^L \subset \tilde{\tilde{B}}^U.$

First, the areas $A\left(\tilde{\tilde{A}}^L\right)$, $A\left(\tilde{\tilde{A}}^U\right)$, $A\left(\tilde{\tilde{B}}^L\right)$, and $A\left(\tilde{\tilde{B}}^U\right)$ of the lower trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{B}}^L$ and the upper trapezoidal fuzzy numbers $\tilde{\tilde{A}}^U$ and $\tilde{\tilde{B}}^U$ are calculated, followed by the COG points

$\left(x_{\tilde{\tilde{A}}^L}^*, y_{\tilde{\tilde{A}}^L}^*\right)$, $\left(x_{\tilde{\tilde{A}}^U}^*, y_{\tilde{\tilde{A}}^U}^*\right)$, $\left(x_{\tilde{\tilde{B}}^L}^*, y_{\tilde{\tilde{B}}^L}^*\right)$, and $\left(x_{\tilde{\tilde{B}}^U}^*, y_{\tilde{\tilde{B}}^U}^*\right)$ of $A\left(\tilde{\tilde{A}}^L\right)$, $A\left(\tilde{\tilde{A}}^U\right)$, $A\left(\tilde{\tilde{B}}^L\right)$, and $A\left(\tilde{\tilde{B}}^U\right)$ respectively.

Next, the COG points $\left(x_{\tilde{\tilde{A}}}^*, y_{\tilde{\tilde{A}}}^*; x_{\tilde{\tilde{B}}}^*, y_{\tilde{\tilde{B}}}^*\right)$ of the IVFNs $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{B}}^L$ are calculated, followed by the degree of similarity, $S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right)$ and $S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)$, between the lower trapezoidal fuzzy numbers $\tilde{\tilde{A}}^L$, $\tilde{\tilde{B}}^L$ and the upper trapezoidal fuzzy numbers $\tilde{\tilde{A}}^U$, $\tilde{\tilde{B}}^U$ respectively. Finally, the degree of similarity between IVFNs is calculated as follows:

$$S\left(\tilde{\tilde{A}}, \tilde{\tilde{B}}\right) = \left[\frac{S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) + S\left(\tilde{\tilde{A}}^U, \tilde{\tilde{B}}^U\right)}{2} \times (1 - \Delta x) \times (1 - \Delta y)\right]^{\left(\frac{1}{1+2t}\right)} * \left(1 - \left|w_{\tilde{\tilde{A}}}^U - w_{\tilde{\tilde{B}}}^U - w_{\tilde{\tilde{A}}}^L + w_{\tilde{\tilde{B}}}^L\right|\right)^{\frac{u}{2}} \tag{6.5}$$

$$\text{Here, } t = \begin{cases} 1, if\ A\left(\tilde{\tilde{A}}^U\right) - A\left(\tilde{\tilde{A}}^L\right) \ne 0\ and\ A\left(\tilde{\tilde{B}}^U\right) - A\left(\tilde{\tilde{B}}^L\right) \ne 0, \\ 0, Otherwise, \end{cases} \tag{6.6}$$

$$u = \begin{cases} 1, if\ a_1^U = a_4^U\ and\ b_1^U = b_4^U, \\ 0, Otherwise. \end{cases} \tag{6.7}$$

$$S\left(\tilde{\tilde{A}}^L, \tilde{\tilde{B}}^L\right) = \begin{cases} \left[1 - \frac{\sum_{i=1}^{4}\left|a_i^L - b_i^L\right|}{4}\right] \times \frac{\mathbf{min}\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \mathbf{min}\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)}{\mathbf{max}\left(L\left(\tilde{\tilde{A}}^L\right), L\left(\tilde{\tilde{B}}^L\right)\right) + \mathbf{max}\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right)}, if\ \mathbf{min}\left(w_{\tilde{\tilde{A}}^L}, w_{\tilde{\tilde{B}}^L}\right) \ne 0, \\ 0, Otherwise \end{cases} \tag{6.8}$$

$$S\left(\tilde{\tilde{A}}^U,\tilde{\tilde{B}}^U\right)=\begin{cases}\left[1-\frac{\sum_{i=1}^{4}\left|a_i^U-b_i^U\right|}{4}\right]\times\frac{\min\left(L\left(\tilde{\tilde{A}}^U\right),L\left(\tilde{\tilde{B}}^U\right)\right)+\min\left(w_{\tilde{\tilde{A}}^U},w_{\tilde{\tilde{B}}^U}\right)}{\max\left(L\left(\tilde{\tilde{A}}^U\right),L\left(\tilde{\tilde{B}}^U\right)\right)+\max\left(w_{\tilde{\tilde{A}}^U},w_{\tilde{\tilde{B}}^U}\right)}, if\ \min\left(w_{\tilde{\tilde{A}}^U},w_{\tilde{\tilde{B}}^U}\right)\neq 0,\\ 0, Otherwise\end{cases} \tag{6.9}$$

$$\Delta x=\begin{cases}\left|x^*_{\tilde{\tilde{A}}}-x^*_{\tilde{\tilde{B}}}\right|, if\ A\left(\tilde{\tilde{A}}^U\right)-A\left(\tilde{\tilde{A}}^L\right)\neq 0\ and\ A\left(\tilde{\tilde{B}}^U\right)-A\left(\tilde{\tilde{B}}^L\right)\neq 0,\\ 0, Otherwise,\end{cases} \tag{6.10}$$

$$\Delta y=\begin{cases}\left|y^*_{\tilde{\tilde{A}}}-y^*_{\tilde{\tilde{B}}}\right|, if\ A\left(\tilde{\tilde{A}}^U\right)-A\left(\tilde{\tilde{A}}^L\right)\neq 0\ and\ A\left(\tilde{\tilde{B}}^U\right)-A\left(\tilde{\tilde{B}}^L\right)\neq 0,\\ 0, Otherwise.\end{cases} \tag{6.11}$$

$$L\left(\tilde{\tilde{A}}^L\right)=\sqrt{\left(a_1^L-a_2^L\right)^2+w^2_{\tilde{\tilde{A}}^L}}+\sqrt{\left(a_3^L-a_4^L\right)^2+w^2_{\tilde{\tilde{A}}^L}}+\left(a_3^L-a_2^L\right)+\left(a_4^L-a_1^L\right), \tag{6.12}$$

$$L\left(\tilde{\tilde{B}}^L\right)=\sqrt{\left(b_1^L-b_2^L\right)^2+w^2_{\tilde{\tilde{B}}^L}}+\sqrt{\left(b_3^L-b_4^L\right)^2+w^2_{\tilde{\tilde{B}}^L}}+\left(b_3^L-b_2^L\right)+\left(b_4^L-b_1^L\right), \tag{6.13}$$

$$L\left(\tilde{\tilde{A}}^U\right)=\sqrt{\left(a_1^U-a_2^U\right)^2+w^2_{\tilde{\tilde{A}}^U}}+\sqrt{\left(a_3^U-a_4^U\right)^2+w^2_{\tilde{\tilde{A}}^U}}+\left(a_3^U-a_2^U\right)+\left(a_4^U-a_1^U\right), \tag{6.14}$$

$$L\left(\tilde{\tilde{B}}^U\right)=\sqrt{\left(b_1^U-b_2^U\right)^2+w^2_{\tilde{\tilde{B}}^U}}+\sqrt{\left(b_3^U-b_4^U\right)^2+w^2_{\tilde{\tilde{B}}^U}}+\left(b_3^U-b_2^U\right)+\left(b_4^U-b_1^U\right). \tag{6.15}$$

6.4 Proposed Methodology

In this section, the procedural framework towards leagility performance evaluation has been described. This evaluation procedure is based on the 'similarity measures method' proposed by (Chen and Lai, 2011) to identify the most appropriate solution from a set of leagile alternatives (organizational SCs) in accordance with the overall performance extent.

Assume that there are a number of alternative organizations/industries (A_1, A_2, A_3, A_4, A_5) to be evaluated in terms of leagility performance. The 2-level leagility assessment index system consists of various attributes as well as criterions in the 1st level and 2nd level, respectively. A group of decision- makers (DMs) has been formed to provide expert judgment based on the said leagile model as shown in Tables 6.1-6.2. Then, based on decision-makers' judgment (opinion), linguistic evaluation information are transformed into appropriate fuzzy numbers. Finally, fuzzy mathematic rules and degree of similarity based closeness coefficient concept is explored towards appraisement as well as benchmarking of leagile alternatives. The fuzzy similarity measure approach is applied for alternative industries with respect to positive ideal solution called 'excellent' performing solution (ideal leagile industry) and negative ideal solution called 'worst' performing solution (anti-ideal leagile industry). The detailed description of the procedure is provided in subsequent section.

6.4.1. Determination Fuzzy Overall Performance Index (FOPI)

The fuzzy overall performance index is an information fusion which consolidates the fuzzy ratings and fuzzy weights of different evaluation indices that influence leagile supply chain performance extent. It is also called overall enterprise leagility. For determining FOPI following procedures need to be followed.

Step 1: Determine of the appropriate linguistic scale

Initially the linguistic terms are used to assess the performance ratings and priority weights of leagile indices (attributes/criterions). Since vagueness is associated with individuals' subjective opinion, linguistic information is transformed into appropriate fuzzy numbers. In order to assess the performance rating of leagile criterions considered in Table 6.1 (2nd level indices), the following nine linguistic variables {***Absolutely Poor (AP), Very Poor (VP), Poor (P), Medium Poor (MP), Medium (M), Medium Good (MG), Good (G), Very Good (VG) and Absolutely Good (AG)***} can be used (Table 6.3). Similarly, to assign importance weights (priority degree) of the leagile attributes (at 1st level) as well as criterions (at 2nd level), the linguistic variables {***Absolutely Low (AL), Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH), High (H), Very High (VH), Absolutely High (AH)***} can be utilized (Table 6.3). The linguistic variables must be accepted among the decision-makers (DMs) of the enterprise taking into consideration the company policy, company characteristics, business changes and competitive situation.

Step 2: Measurement of performance ratings and importance weights

Once the linguistic variables are accepted by the decision makers (DMs) for assessing the performance ratings and importance weights of leagile attributes/criterions; the decision-makers are then asked to use aforesaid linguistic scales to assess performance rating against each criterions and to assign importance weights towards each of the leagile criterions as well as attributes for all the leagile alternatives separately.

Step 3: Approximation of the linguistic terms by interval valued trapezoidal fuzzy numbers

After collection of expert opinion, data expressed in linguistic terms as provided by the decision-makers, are to be analyzed using the concept of Interval-Valued (IV) trapezoidal fuzzy numbers in fuzzy set theory (Chen, 2006; Wang and Li, 1998). The linguistic variables are approximated by Interval-Valued (IV) trapezoidal fuzzy numbers (shown in Table 6.3). Next, the aggregated fuzzy priority weight against each leagile criterion (2^{nd} level indices), as well as leagile attributes (1^{st} level indices), and appropriateness rating against each leagile criterion (2^{nd} level indices) for the alternative industries is calculated separately. The aggregated fuzzy rating as well as priority weight is computed based on the method of averaging opinions of the decision-makers (fuzzy average rule).

Step 4. Calculation of Fuzzy Overall Performance Index (FOPI)

After aggregating fuzzy rating as well as priority weight of attribute as well as criteria the fuzzy performance index has been calculated at the criteria level and then extended to attribute level. Fuzzy index system (at 2^{nd} level) encompasses several leagile criteria (Table 6.1). The fuzzy index (appropriateness rating) of each leagile attribute (at 1^{st} level) has been calculated as follows:

$$U_i = \frac{\sum_{j=1}^{m} \left(w_{i,j} \otimes U_{i,j} \right)}{\sum_{j=1}^{m} w_{i,j}} \qquad (6.16)$$

Here $U_{i,j}$ represents aggregated fuzzy performance measure (rating) and $w_{i,j}$ represents aggregated fuzzy weight for priority importance corresponding to j_{th} leagile criteria $C_{i,j}$ which is under i_{th} leagile attribute C_i (at 1^{st} level). $j = 1, 2, 3, ...m.$

Thus, fuzzy overall performance index $U(FOPI)$ has been calculated as follows:

$$U(FOPI)=\frac{\sum_{i=1}^{n}(w_i \otimes U_i)}{\sum_{i=1}^{n} w_i} \qquad (6.17)$$

Here U_i = Computed fuzzy performance rating of i^{th} leagile attribute C_i (computed by Eq. 6.16); w_i = Aggregated fuzzy weight of i^{th} leagile attribute C_i, and $i = 1, 2, 3, ...n$. Let's represent this FOPI as $\tilde{\tilde{R}}_i$; where i represents i^{th} alternative.

At this stage, this simplified decision-making matrix is formed (as shown below).

$$\begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \\ A_5 \end{matrix}\begin{bmatrix} FOPI_{A_1} \\ FOPI_{A_2} \\ FOPI_{A_3} \\ FOPI_{A_4} \\ FOPI_{A_5} \end{bmatrix}$$

Since each $\left(FOPI_{A_i}\right)\Big|_{i=1,2,...,5} = \tilde{\tilde{R}}_i\Big|_{i=1,2,...,5}$ is represented by corresponding IVFN score, it seems difficult to get a ranking order of leagile alternatives. Therefore, it is proposed that the concept of degree of similarity (DOS) between two IVFNs can be explored along with the formulation of closeness coefficient adapted from TOPSIS technique. An ideal solution $\left(FOPI_{Ideal}\right) = \tilde{\tilde{R}}^*$ and an anti-ideal solution $\left(FOPI_{Anti-Ideal}\right) = \tilde{\tilde{R}}^-$ are defined; and the DOS between individual $\left(FOPI_{A_i}\right)\Big|_{i=1,2,...,5}$ with respect to $\left(FOPI_{Ideal}\right)$ and $\left(FOPI_{Anti-Ideal}\right)$ are computed separately. The DOS value being a numeric score in between [0, 1]; the final closeness coefficient also provides a numeric value. This facilitates in determining appropriate ranking order of leagile alternatives.

6.4.2. Similarity Measure with respect to the Ideal Solution

At this stage, the similarity measure between an ideal solution (ideal alternative) and the calculated Fuzzy Overall Performance Index (FOPI) of the alternatives is computed. It is assumed that the ideal solution possesses the excellent performance characteristics which are represented by $\tilde{\tilde{R}}^*$.

$$\begin{aligned}\tilde{\tilde{R}}^* &= \left[\left(r_1^{*L}, r_2^{*L}, r_3^{*L}, r_4^{*L}; w^L_{\tilde{\tilde{R}}^*}\right), \left(r_1^{*U}, r_2^{*U}, r_3^{*U}, r_4^{*U}; w^U_{\tilde{\tilde{R}}^*}\right)\right] \\ &= \left[(1.0, 1.0, 1.0, 1.0; 1.0), (1.0, 1.0, 1.0, 1.0; 1.0)\right]\end{aligned} \tag{6.18}$$

The proposed similarity measure to evaluate the degree of similarity $S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^*\right)$ between the IVFNs of $\tilde{\tilde{R}}_i$ and the ideal solution $\tilde{\tilde{R}}^*$ is computed as follows·

$$\begin{aligned}S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^*\right) &= \left[\frac{S\left(\tilde{\tilde{R}}_i^L, \tilde{\tilde{R}}^{*L}\right) + S\left(\tilde{\tilde{R}}_i^U, \tilde{\tilde{R}}^{*U}\right)}{2} \times (1-\Delta x) \times (1-\Delta y)\right]^{\left(\frac{1}{1+2t}\right)} \times \left(1-\left|w^U_{\tilde{\tilde{R}}_i} - w^U_{\tilde{\tilde{R}}^*} - w^L_{\tilde{\tilde{R}}_i} + w^L_{\tilde{\tilde{R}}^*}\right|\right)^{\frac{U}{2}}, \\ &= \left[\frac{S\left(\tilde{\tilde{R}}_i^L, \tilde{\tilde{R}}^{*L}\right) + S\left(\tilde{\tilde{R}}_i^U, \tilde{\tilde{R}}^{*U}\right)}{2}\right] \times \left(1-\left|w^U_{\tilde{\tilde{R}}_i} - w^L_{\tilde{\tilde{R}}_i}\right|\right)^{\frac{U}{2}}\end{aligned} \tag{6.19}$$

$$t = \begin{cases} 1, \; if \; A\left(\tilde{\tilde{R}}_i^U\right) - A\left(\tilde{\tilde{R}}_i^L\right) \neq 0 \; and \; A\left(\tilde{\tilde{R}}^{*U}\right) - A\left(\tilde{\tilde{R}}^{*L}\right) \neq 0, \\ 0, \; otherwise, \end{cases} = 0 \tag{6.20}$$

$$u = \begin{cases} 1, \; if \; r_{i1}^U = r_{i4}^U \; and \; r_1^{*U} = r_4^{*U}, \\ 0, \; otherwise \end{cases} \tag{6.21}$$

6.4.3. Similarity Measure with respect to the Negative Ideal Solution

The same procedure is applied to obtain similarity measure between the negative ideal solution and the calculated Fuzzy Overall Performance Index (FOPI) of individual alternatives. In this part, it is assumed that negative ideal solution has the worst performance characteristics and which are represented by $\tilde{\tilde{R}}^-$.

$$\begin{aligned}\tilde{\tilde{R}}^- &= \left[\left(r_1^{-L}, r_2^{-L}, r_3^{-L}, r_4^{-L}; w_{\tilde{\tilde{R}}^-}^L\right), \left(r_1^{-U}, r_2^{-U}, r_3^{-U}, r_4^{-U}; w_{\tilde{\tilde{R}}^-}^U\right)\right] \\ &= \left[(0.0, 0.0, 0.0, 0.0, 1.0), (0.0, 0.0, 0.0, 0.0, 1.0)\right]\end{aligned} \qquad (6.22)$$

Then the proposed similarity measure to evaluate the degree of similarity $S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^-\right)$ between the IVFNs of $\tilde{\tilde{R}}_i$ and the negative ideal solution ($\tilde{\tilde{R}}^-$) is as follows.

$$\begin{aligned}S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^-\right) &= \left[\frac{S\left(\tilde{\tilde{R}}_i^L, \tilde{\tilde{R}}^{-L}\right) + S\left(\tilde{\tilde{R}}_i^U, \tilde{\tilde{R}}^{-U}\right)}{2} \times (1-\Delta x) \times (1-\Delta y)\right]^{\left(\frac{1}{1+2t}\right)} \times \left(1 - \left|w_{\tilde{\tilde{R}}_i}^U - w_{\tilde{\tilde{R}}^-}^U - w_{\tilde{\tilde{R}}_i}^L + w_{\tilde{\tilde{R}}^-}^L\right|\right)^{\frac{U}{2}}, \\ &= \left[\frac{S\left(\tilde{\tilde{R}}_i^L, \tilde{\tilde{R}}^{-L}\right) + S\left(\tilde{\tilde{R}}_i^U, \tilde{\tilde{R}}^{-U}\right)}{2}\right] \times \left(1 - \left|w_{\tilde{\tilde{R}}_i}^U - w_{\tilde{\tilde{R}}_i}^L\right|\right)^{\frac{U}{2}}\end{aligned}$$

(6.23)

$$t = \begin{cases} 1, \ if \ A\left(\tilde{\tilde{R}}_i^U\right) - A\left(\tilde{\tilde{R}}_i^L\right) \neq 0 \ and \ A\left(\tilde{\tilde{R}}^{-U}\right) - A\left(\tilde{\tilde{R}}^{-L}\right) \neq 0, \\ 0, \ otherwise, \end{cases} = 0 \qquad (6.24)$$

$$u = \begin{cases} 1, \ if \ r_{i1}^U = r_{i4}^U \ and \ r_1^{-U} = r_4^{-U}, \\ 0, \ otherwise \end{cases} \qquad (6.25)$$

6.4.4. Determination of Closeness Coefficient (CC): Ranking of Alternatives

Finally, the closeness coefficient C_{i*} (of $\tilde{\tilde{R}}_i$) i.e. the relative closeness to the ideal solution $\tilde{\tilde{R}}^*$ is computed as follows:

$$C_{i*} = \frac{S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^*\right)}{S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^*\right) + S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^-\right)}, \quad 0 < C_{i*} < 1, \quad i = 1, 2, ..., n \qquad (6.26)$$

(Here, n represents the total number of alternatives, here it is 5). A set of alternatives can now be preference ranked in descending order of C_{i*} as C_{i*} corresponds to Higher-is-Better (HB) criterion. High C_{i*} represents high performance extent of the corresponding alternative.

6.5 Empirical Research

In order to analyze decision-making problems in relation to leagile alternative selection; the concept of fuzzy degree of similarity in conjugation with the concept of 'closeness coefficient' adapted from TOPSIS has been proposed.

In this empirical part of research, five candidate enterprises/organizations (A_1, A_2, A_3, A_4, A_5) running under similar leagility inspired SC architecture (as depicted in Table 6.1) has been selected. The unified aim of this work has been to derive appropriate ranking order of candidate alternatives (enterprises/organizations) and select the best one (benchmarking) in view of leagile SC performance. In this research, the leagility evaluation index system (hierarchy-criteria), thus adapted from the reporting by (Ramana et al., 2013), comprises a 2-level hierarchy (Tables 6.1-6.2). The 1st level considers four main features (indices) of leagility. These are: (i) Operational Performance, C_1 (ii) Customer Service Performance, C_2 (iii) Flexibility, C_3 and (iv) Organizational Performance, C_4. Each of the aforementioned 1st level attribute has been further classified into four 2nd level indices called criterions.

Assuming a committee of five decision-makers (DMs) has been formed to take part in the decision-making towards selecting the best performing leagile SC (corresponding organization). Individual members (experts) of the said decision-making group thus selected must be aware of the said decision-making scenario and they must possess vast experience in this field.

Personnel like management consultant/practitioner as well as academician must be properly selected to participate as experts (decision-makers).

This decision-making group has been instructed to visit individual enterprises (candidate alternative firms) in order to inspect ongoing performance extent of the leagility driven SC. After careful survey as well as periodic (or prolonged, if necessary) inspection, the decision-making group has been asked to provide expert judgment (decision information) in regards of leagile performance extent of the alternative enterprises.

Since most of the evaluation measures (attributes/criterions) being subjective in nature; the decision-making group had to rely on providing linguistic judgment against individual evaluation indices. A linguistic preference scale for assignment of the priority weights (for leagile attributes as well as criterions) has been chosen as per Table 6.3. Similarly, performance extent (appropriateness rating) of various leagile criterions has been evaluated in terms of linguistic variables as per the scale shown in Table 6.3. Linguistic decision-making information in regards of priority weight of individual leagile criterions as well as attributes has been furnished in Tables 6.4-6.5 (shown herewith in APPENDIX-D) as provided by the experts. Similarly, linguistic score on appropriateness rating against individual 2^{nd} level criterions as given by the experts have been presented in Tables 6.6-6.10 in APPENDIX-D, for alternatives A_1, A_2, A_3, A_4, A_5 respectively.

Aforesaid linguistic data has been transformed into appropriate fuzzy numbers in accordance with the scales as shown in Table 6.3. Fuzzy Average Rule (FAR) has been explored in order to aggregate multiple DMs opinions into a unique fuzzy representative value. Thus aggregated fuzzy priority weight of individual attributes (as well as criterions) (Table 6.11-6.12) and aggregated fuzzy appropriateness rating (performance extent) of individual 2^{nd} level criterions has been computed (Table 6.13-6.15), for individual alternatives A_1, A_2, A_3, A_4, A_5, respectively. Fuzzy appropriateness rating of individual 1^{st} level attributes has been computed based on the following relationship (Eq. 6.16); and shown in Table 6.16.

In the final step, the overall leagility index (or $FOPI_{A_i}$) for alternative A_i has been computed as per (Eq. 6.17).

$$[FOPI]_{A_1} = [(0.658, 0.713, 0.825, 0.865; 0.800), (0.658, 0.713, 0.825, 0.865; 1.000)]$$

Similar procedure has been utilized to calculate the FOPI for other alternatives. The Fuzzy Overall Performance Index (FOPI) for alternatives A_2, A_3, A_4, A_5 are as follows.

$$[FOPI]_{A_2} = [(0.686, 0.744, 0.865, 0.908; 0.800), (0.686, 0.744, 0.865, 0.908; 1.000)]$$

$$[FOPI]_{A_3} = [(0.612, 0.671, 0.789, 0.833; 0.800), (0.612, 0.671, 0.789, 0.833; 1.000)]$$

$$[FOPI]_{A_4} = [(0.735, 0.789, 0.896, 0.933; 0.800), (0.735, 0.789, 0.896, 0.933; 1.000)]$$

$$[FOPI]_{A_5} = [(0.633, 0.691, 0.806, 0.848; 0.800), (0.633, 0.691, 0.806, 0.848; 1.000)]$$

This FOPI has been represented by $\tilde{\tilde{R}}_i$ (i represents i^{th} alternative).

By using Eq. (6.18-6.21), the similarity measure to evaluate the degree of similarity (DOS) between the IVFNs of FOPI $\tilde{\tilde{R}}_i\Big|_{i=1,2,...,5}$ and the ideal solution $\tilde{\tilde{R}}^*$ has been computed. The results have been as follows:

$S(\tilde{\tilde{R}}_1, \tilde{\tilde{R}}^*) = 0.6926$, $S(\tilde{\tilde{R}}_2, \tilde{\tilde{R}}^*) = 0.7254$, $S(\tilde{\tilde{R}}_3, \tilde{\tilde{R}}^*) = 0.6579$

$S(\tilde{\tilde{R}}_4, \tilde{\tilde{R}}^*) = 0.7586$, $S(\tilde{\tilde{R}}_5, \tilde{\tilde{R}}^*) = 0.6742$

Based on Eq. (6.22-6.25), the similarity measure to evaluate the degrees of similarity between the IVFNs of FOPI $\tilde{\tilde{R}}_i\Big|_{i=1,2,...,5}$ and the negative ideal solution of attribute $\tilde{\tilde{R}}^-$ has been computed. The results have been given below.

$S(\tilde{\tilde{R}}_1, \tilde{\tilde{R}}^-) = 1.5979$, $S(\tilde{\tilde{R}}_2, \tilde{\tilde{R}}^-) = 1.6314$, $S(\tilde{\tilde{R}}_3, \tilde{\tilde{R}}^-) = 1.5638$

$S(\tilde{\tilde{R}}_4, \tilde{\tilde{R}}^-) = 1.6634$, $S(\tilde{\tilde{R}}_5, \tilde{\tilde{R}}^-) = 1.5799$

The closeness coefficient to the ideal solution has been computed using Eq. (6.26).

$$C_{i*} = \frac{S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^*\right)}{S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^*\right) + S\left(\tilde{\tilde{R}}_i, \tilde{\tilde{R}}^-\right)}, \quad 0 < C_{i*} < 1, \quad i = 1, 2, ..., n$$

$$C_{1*} = \frac{0.6926}{0.6926 + 1.5979} = 0.3024$$

$C_{2*} = 0.3078$, $C_{3*} = 0.2961$, $C_{4*} = 0.3132$, $C_{5*} = 0.2991$

Finally, the preference order of candidate alternatives has been derived. Based on the closeness coefficient value, alternative leagile enterprises have been ranked accordingly and the best one has been selected. According to the descending order of the values C_{i*}, alternative preference order appears as $A_4 > A_2 > A_1 > A_5 > A_3$.

6.6 Concluding Remarks

The SC performance evaluation has become indeed essential in recent business management. Lean, agile and leagile supply chain philosophies have come into picture in order to modify traditional SC focus in pursuit of achieving competitive advantage in the global market. For the organizations who want to adapt/implement leagile principle; it becomes necessary to analyze the performance extent in regards of leagile attributes as well as criterions. As expert judgments are subjective in nature associated with imprecise and vague evaluation information; aforesaid work explored linguistic terms to represent DMs opinion which was converted into corresponding IVFNs; because IVFNs are more appropriate for analyzing qualitative information in some complex situations of Multi-Criteria Decision Making (MCDM). The introduction of 'fuzzy degree of similarity measure method' embedded with the concept of closeness coefficient (adapted from TOPSIS) is the unique contribution of this work. This approach has been fruitfully explored here towards benchmarking of leagile alternatives. The same can also be applied in other MCDM problems appearing in decision sciences.

Table 6.1: Leagile supply chain performance framework (Ramana et al., 2013)

Goal	1st level indices (attributes)	2nd level indices (criterions)
Leagile supply chain performance, C	Operational performance, C_1	Product Cycle time, C_{11}
		Due-date performance, C_{12}
		Cost, C_{13}
		Quality, C_{14}
	Customer service performance, C_2	Customer satisfaction, C_{21}
		Delivery dependability, C_{22}
		Responsiveness, C_{23}
		Orders fill capacity, C_{24}
	Flexibility, C_3	Product development flexibility, C_{31}
		Sourcing flexibility, C_{32}
		Manufacturing flexibility, C_{33}
		IT flexibility, C_{34}
	Organizational performance, C_4	Market share, C_{41}
		Return on investment, C_{42}
		Sales growth, C_{43}
		Green Image, C_{44}

Table 6.2: Definitions of leagile attributes/criterions as considered in Table 6.1

Attributes/criterions	Definition	References
Operational performance	Operational performance is the alignment of all business units within an organization to ensure that they are working together to achieve core business goals.	(Ramana et al., 2013; Devaraj et al., 2007)
Customer service performance	Customer service performance is the ability to respond to customers' ever-changing wants and needs in a timely way.	(Ramana et al., 2013; Inman et al., 2011)
Flexibility	Flexibility is the organization's ability to meet an increasing variety of customer expectations without excessive costs, time, organizational disruptions, or performance losses. In other words the ability of the system to quickly adjust to any change in relevant factors like product, process, loads and machine failure.	(Slack, 1983; Beach et al., 2000; Zhang et al., 2003)
Organizational performance	Organizational performance refers to how well an organization achieves its market-oriented goals as well as its financial goals. Thus, they must set up the measurement performance items as return on assets, market share and growth rate.	(Devaraj et al. 2007; Ramana et al., 2013)
Product cycle time	The total time taken from the start of production of the product or service to its completion. Cycle time includes processing time, move time, waiting time and inspection time, only the first of which creates value.	(Griffin, 2002)
Due-date performance	It is the performance to finishing the products without delay with their predefined specific due-date and a dispatching rule based on the total processing time, the production capacity, pre-defined order release criteria and historical data, to ensure deliveries are made on time.	(Kuo et al., 2009)
Cost	An amount that has to be paid or given up in order to get something. In business, the cost may be one of acquisition, in which case the amount of money expended to acquire it is counted as cost.	http://en.wikipedia.org/wiki/Cost
Quality	The totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs.	(Lin et al., 2006) http://en.wikipedia.org/wiki/Quality_(business)
Customer satisfaction	Customer satisfaction is a measure of the degree to which a product or service meets the customer's expectations.	(Yu et al., 2013)
Delivery dependability	Delivery dependability means keeping delivery promises.	http://www.blackwellreference.com/public/tocnode?id=g9780631233176_chunk_g97814051109698_ss1-1
Responsiveness	Ability to react purposefully and within an appropriate time scale to customer demand or changes in the marketplace, to bring about or maintain competitive advantage.	(Lin et al., 2006; Holweg, 2005)

Orders fill capacity	The capacity of orders processed within a period without stock outs or need to back order, expressed as a percentage of total number of order processed within that period.	http://www.businessdictionary.com/definition/order-fill.html
Product development flexibility	Product development flexibility is the ability to make changes in the product being developed or in how it is developed, even relatively late in development, without being too disruptive. Consequently, the later one can make changes, the more flexible the process is, the less disruptive the change is, the greater the flexibility.	(Beach et al., 2000; Zhang et al., 2003)
Sourcing flexibility	The availability of a range of options and the ability of the purchasing process to effectively exploit them so as to respond to changing requirements related to the supply of purchased components.	(Swafford et al., 2006; Beach et al., 2000)
Manufacturing flexibility	The ability to produce a variety of products in the quantities that customers demand while maintaining high performance. It is strategically important for enhancing competitive position and winning customer orders.	(Swafford et al., 2006; Zhang et al., 2003)
IT flexibility	It is flexibility which deals with external environmental changes, changing internal customer needs, and rapid technology changes.	(Patten et al., 2005)
Market share	The percentage of a market accounted for by a specific entity.	http://en.wikipedia.org/wiki/Market_share
Return on investment	Return on investment (ROI) is the concept of an investment of some resource yielding a benefit to the investor. In other words, ROI is a performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments.	http://en.wikipedia.org/wiki/Return_on_investment
Sales growth	The amount by which the average sales volume of a company's product or services has grown, typically from year to year. The rate of increase in a company's sales.	http://www.businessdictionary.com/definition/sales-growth.html
Green image	Green image is the generation of social and economic activity that preserves and enhances environmental quality while using natural resources more efficiently.	(Yusuf et al., 2012)

Table 6.3: Nine-member linguistic terms and their corresponding interval-valued fuzzy numbers representation
(For assignment of priority weights and appropriateness ratings)

Linguistic terms (for priority weights)	Linguistic terms (appropriateness ratings)	Interval-valued trapezoidal fuzzy numbers
Absolutely Low (AL)	Absolutely Poor (AP)	[(0, 0, 0, 0; 0.8), (0, 0, 0, 0; 1.0)]
Very Low (VL)	Very Poor (VP)	[(0, 0, 0.02, 0.07; 0.8), (0, 0, 0.02, 0.07; 1.0)]
Low (L)	Poor (P)	[(0.04, 0.10, 0.18, 0.23; 0.8), (0.04, 0.10, 0.18, 0.23; 1.0)]
Medium Low (ML)	Medium Poor (MP)	[(0.17, 0.22, 0.36, 0.42; 0.8), (0.17, 0.22, 0.36, 0.42; 1.0)]
Medium (M)	Medium (M)	[(0.32, 0.41, 0.58, 0.65; 0.8), (0.32, 0.41, 0.58, 0.65; 1.0)]
Medium High (MH)	Medium Good (MG)	[(0.58, 0.63, 0.80, 0.86; 0.8), (0.58, 0.63, 0.80, 0.86; 1.0)]
High (H)	Good (G)	[(0.72, 0.78, 0.92, 0.97; 0.8), (0.72, 0.78, 0.92, 0.97; 1.0)]
Very High (VH)	Very Good (VG)	[(0.93, 0.98, 1, 1; 0.8), (0.93, 0.98, 1, 1; 1.0)]
Absolutely High (AH)	Absolutely Good (AG)	[(1, 1, 1, 1; 0.8), (1, 1, 1, 1; 1.0)]
Source: (Wei and Chen, 2009)		

Table 6.11: Aggregated fuzzy criteria weight

Criterions	Aggregated criteria weight expressed in fuzzy numbers
C_{11}	[(0.73,0.79,0.91,0.95;0.80),(0.73,0.79,0.91,0.95; 1.00)]
C_{12}	[(0.77,0.83,0.90,0.92;0.80),(0.77,0.83,0.90,0.92; 1.00)]
C_{13}	[(0.78,0.83,0.93,0.96;0.80),(0.78,0.83,0.93,0.96; 1.00)]
C_{14}	[(0.83,0.87,0.94,0.97;0.80),(0.83,0.87,0.94,0.97; 1.00)]
C_{21}	[(0.71,0.76,0.89,0.93;0.80),(0.71,0.76,0.89,0.93; 1.00)]
C_{22}	[(0.52,0.60,0.73,0.78;0.80),(0.52,0.60,0.73,0.78; 1.00)]
C_{23}	[(0.63,0.69,0.82,0.87;0.80),(0.63,0.69,0.82,0.87; 1.00)]
C_{24}	[(0.78,0.83,0.90,0.92;0.80),(0.78,0.83,0.90,0.92; 1.00)]
C_{31}	[(0.37,0.45,0.60,0.67;0.80),(0.37,0.45,0.60,0.67; 1.00)]
C_{32}	[(0.55,0.61,0.75,0.80;0.80),(0.55,0.61,0.75,0.80; 1.00)]
C_{33}	[(0.38,0.44,0.55,0.59;0.80),(0.38,0.44,0.55,0.59; 1.00)]
C_{34}	[(0.73,0.79,0.91,0.95;0.80),(0.73,0.79,0.91,0.95; 1.00)]
C_{41}	[(0.39,0.45,0.60,0.66;0.80),(0.39,0.45,0.60,0.66; 1.00)]
C_{42}	[(0.56,0.63,0.78,0.84;0.80),(0.56,0.63,0.78,0.84; 1.00)]
C_{43}	[(0.75,0.80,0.90,0.94;0.80),(0.75,0.80,0.90,0.94; 1.00)]
C_{11}	[(0.58,0.64,0.78,0.84;0.80),(0.58,0.64,0.78,0.84; 1.00)]

Table 6.12: Aggregated fuzzy attribute weight

Attributes	Aggregated fuzzy attribute weight
C_1	[(0.78,0.83,0.93,0.96;0.80),(0.78,0.83,0.93,0.96;1.00)]
C_2	[(0.85,0.88,0.94,0.97;0.80),(0.85,0.88,0.94,0.97;1.00)]
C_3	[(0.80,0.86,0.95,0.98;0.80),(0.80,0.86,0.95,0.98;1.00)]
C_4	[(0.78,0.83,0.93,0.96;0.80),(0.78,0.83,0.93,0.96;1.00)]

Table 6.13: Aggregated fuzzy rating (against individual criterion) of leagile alternatives

Criterions	Aggregated criteria rating for alternative [A_1]	Aggregated criteria rating for alternative [A_2]
C_{11}	[(0.82,0.86,0.95,0.98;0.80), (0.82,0.86,0.95,0.98; 1.00)]	[(0.68,0.73,0.86,0.91;0.80),(0.68,0.73,0.86,0.91; 1.00)]
C_{12}	[(0.52,0.57,0.71,0.76;0.80), (0.52,0.57,0.71,0.76; 1.00)]	[(0.73,0.79,0.91,0.95;0.80),(0.73,0.79,0.91,0.95; 1.00)]
C_{13}	[(0.78,0.83,0.93,0.96;0.80), (0.78,0.83,0.93,0.96; 1.00)]	[(0.86,0.90,0.97,0.99;0.80),(0.86,0.90,0.97,0.99; 1.00)]
C_{14}	[(0.79,0.83,0.93,0.96;0.80), (0.79,0.83,0.93,0.96; 1.00)]	[(0.48,0.56,0.72,0.78;0.80),(0.48,0.56,0.72,0.78; 1.00)]
C_{21}	[(0.57,0.62,0.74,0.78;0.80), (0.57,0.62,0.74,0.78; 1.00)]	[(0.60,0.67,0.80,0.85;0.80),(0.60,0.67,0.80,0.85; 1.00)]
C_{22}	[(0.58,0.65,0.80,0.86;0.80), (0.58,0.65,0.80,0.86; 1.00)]	[(0.72,0.78,0.92,0.97;0.80),(0.72,0.78,0.92,0.97; 1.00)]
C_{23}	[(0.72,0.79,0.88,0.92;0.80), (0.72,0.79,0.88,0.92; 1.00)]	[(0.53,0.60,0.76,0.82;0.80),(0.53,0.60,0.76,0.82; 1.00)]
C_{24}	[(0.56,0.63,0.78,0.84;0.80), (0.56,0.63,0.78,0.84; 1.00)]	[(0.45,0.52,0.67,0.73;0.80),(0.45,0.52,0.67,0.73; 1.00)]
C_{31}	[(0.53,0.59,0.66,0.69;0.80), (0.53,0.59,0.66,0.69; 1.00)]	[(0.64,0.71,0.82,0.85;0.80),(0.64,0.71,0.82,0.85; 1.00)]
C_{32}	[(0.75,0.79,0.91,0.95;0.80), (0.75,0.79,0.91,0.95; 1.00)]	[(0.86,0.90,0.97,0.99;0.80),(0.86,0.90,0.97,0.99; 1.00)]
C_{33}	[(0.55,0.61,0.76,0.82;0.80), (0.55,0.61,0.76,0.82; 1.00)]	[(0.61,0.66,0.82,0.88;0.80),(0.61,0.66,0.82,0.88; 1.00)]
C_{34}	[(0.70,0.76,0.86,0.90;0.80), (0.70,0.76,0.86,0.90; 1.00)]	[(0.78,0.82,0.94,0.98;0.80),(0.78,0.82,0.94,0.98; 1.00)]
C_{41}	[(0.85,0.90,0.97,0.99;0.80), (0.85,0.90,0.97,0.99; 1.00)]	[(0.72,0.76,0.89,0.93;0.80),(0.72,0.76,0.89,0.93; 1.00)]
C_{42}	[(0.53,0.58,0.72,0.78;0.80), (0.53,0.58,0.72,0.78; 1.00)]	[(0.90,0.94,0.98,0.99;0.80),(0.90,0.94,0.98,0.99; 1.00)]
C_{43}	[(0.53,0.58,0.67,0.70;0.80), (0.53,0.58,0.67,0.70; 1.00)]	[(0.64,0.69,0.85,0.90;0.80),(0.64,0.69,0.85,0.90; 1.00)]
C_{11}	[(0.79,0.83,0.93,0.96;0.80), (0.79,0.83,0.93,0.96; 1.00)]	[(0.82,0.86,0.95,0.98;0.80),(0.82,0.86,0.95,0.98; 1.00)]

Table 6.14: Aggregated criteria rating of leagile alternatives

Criterions	Aggregated criteria rating for alternative [A_3]	Aggregated criteria rating for alternative [A_4]
C_{11}	(0.65,0.72,0.84,0.89;0.80),(0.65,0.72,0.84,0.89; 1.00)	(0.83,0.87,0.94,0.97;0.80),(0.83,0.87,0.94,0.97; 1.00)
C_{12}	(0.60,0.67,0.80,0.85;0.80),(0.60,0.67,0.80,0.85; 1.00)	(0.86,0.90,0.97,0.99;0.80),(0.86,0.90,0.97,0.99; 1.00)
C_{13}	(0.72,0.79,0.88,0.92;0.80),(0.72,0.79,0.88,0.92; 1.00)	(0.73,0.79,0.91,0.95;0.80),(0.73,0.79,0.91,0.95; 1.00)
C_{14}	(0.57,0.62,0.74,0.78;0.80),(0.57,0.62,0.74,0.78; 1.00)	(0.65,0.72,0.84,0.89;0.80),(0.65,0.72,0.84,0.89; 1.00)
C_{21}	(0.46,0.52,0.64,0.69;0.80),(0.46,0.52,0.64,0.69; 1.00)	(0.68,0.73,0.86,0.91;0.80),(0.68,0.73,0.86,0.91; 1.00)
C_{22}	(0.53,0.60,0.76,0.82;0.80),(0.53,0.60,0.76,0.82; 1.00)	(0.72,0.79,0.88,0.92;0.80),(0.72,0.79,0.88,0.92; 1.00)
C_{23}	(0.50,0.56,0.70,0.75;0.80),(0.50,0.56,0.70,0.75; 1.00)	(0.48,0.54,0.71,0.78;0.80),(0.48,0.54,0.71,0.78; 1.00)
C_{24}	(0.72,0.79,0.88,0.92;0.80),(0.72,0.79,0.88,0.92; 1.00)	(0.66,0.72,0.87,0.93;0.80),(0.66,0.72,0.87,0.93; 1.00)
C_{31}	(0.32,0.39,0.54,0.61;0.80),(0.32,0.39,0.54,0.61; 1.00)	(0.90,0.94,0.98,0.99;0.80),(0.90,0.94,0.98,0.99; 1.00)
C_{32}	(0.67,0.72,0.80,0.83;0.80),(0.67,0.72,0.80,0.83; 1.00)	(0.66,0.72,0.87,0.93;0.80),(0.66,0.72,0.87,0.93; 1.00)
C_{33}	(0.80,0.84,0.93,0.96;0.80),(0.80,0.84,0.93,0.96; 1.00)	(0.72,0.79,0.88,0.92;0.80),(0.72,0.79,0.88,0.92; 1.00)
C_{34}	(0.82,0.86,0.95,0.98;0.80),(0.82,0.86,0.95,0.98; 1.00)	(0.90,0.94,0.98,0.99;0.80),(0.90,0.94,0.98,0.99; 1.00)
C_{41}	(0.37,0.45,0.62,0.69;0.80),(0.37,0.45,0.62,0.69; 1.00)	(0.72,0.77,0.88,0.92;0.80),(0.72,0.77,0.88,0.92; 1.00)
C_{42}	(0.60,0.67,0.80,0.85;0.80),(0.60,0.67,0.80,0.85; 1.00)	(0.86,0.90,0.97,0.99;0.80),(0.86,0.90,0.97,0.99; 1.00)
C_{43}	(0.58,0.65,0.80,0.86;0.80),(0.58,0.65,0.80,0.86; 1.00)	(0.69,0.75,0.90,0.95;0.80),(0.69,0.75,0.90,0.95; 1.00)
C_{44}	(0.64,0.71,0.82,0.85;0.80),(0.64,0.71,0.82,0.85; 1.00)	(0.70,0.76,0.86,0.90;0.80),(0.70,0.76,0.86,0.90; 1.00)

Table 6.15: Aggregated criteria rating for leagile alternative

Criterions	Aggregated criteria rating for alternative [A_5]
C_{11}	[(0.67,0.72,0.82,0.85;0.80),(0.67,0.72,0.82,0.85;1.00)]
C_{12}	[(0.67,0.73,0.84,0.87;0.80),(0.67,0.73,0.84,0.87;1.00)]
C_{13}	[(0.79,0.83,0.90,0.92;0.80),(0.79,0.83,0.90,0.92;1.00)]
C_{14}	[(0.67,0.72,0.82,0.85;0.80),(0.67,0.72,0.82,0.85;1.00)]
C_{21}	[(0.70,0.76,0.86,0.90;0.80),(0.70,0.76,0.86,0.90;1.00)]
C_{22}	[(0.77,0.80,0.88,0.90;0.80),(0.77,0.80,0.88,0.90;1.00)]
C_{23}	[(0.50,0.57,0.74,0.80;0.80),(0.50,0.57,0.74,0.80;1.00)]
C_{24}	[(0.53,0.59,0.74,0.80;0.80),(0.53,0.59,0.74,0.80;1.00)]
C_{31}	[(0.45,0.52,0.67,0.73;0.80),(0.45,0.52,0.67,0.73;1.00)]
C_{32}	[(0.63,0.69,0.82,0.87;0.80),(0.63,0.69,0.82,0.87;1.00)]
C_{33}	[(0.68,0.73,0.86,0.91;0.80),(0.68,0.73,0.86,0.91;1.00)]

C_{34}	[(0.52,0.60,0.73,0.78;0.80),(0.52,0.60,0.73,0.78;1.00)]
C_{41}	[(0.78,0.83,0.90,0.92;0.80),(0.78,0.83,0.90,0.92;1.00)]
C_{42}	[(0.34,0.42,0.57,0.63;0.80),(0.34,0.42,0.57,0.63;1.00)]
C_{43}	[(0.78,0.83,0.90,0.92;0.80),(0.78,0.83,0.90,0.92;1.00)]
C_{44}	[(0.71,0.76,0.89,0.93;0.80),(0.71,0.76,0.89,0.93;1.00)]

Table 6.16: Computed fuzzy rating (against individual attribute) of leagile alternatives

Alternatives	C_1	C_2	C_3	C_4
A_1	[(0.73,0.78,0.88,0.92; 0.80), (0.73,0.78,0.88,0.92; 1.00)]	[(0.61,0.67,0.80,0.85; 0.80), (0.61,0.67,0.80,0.85; 1.00)]	[(0.65,0.70,0.81,0.85; 0.80), (0.65,0.70,0.81,0.85; 1.00)]	[(0.65,0.70,0.81,0.85; 0.80), (0.65,0.70,0.81,0.85; 1.00)]
A_2	[(0.68,0.74,0.86,0.91; 0.80), (0.68,0.74,0.86,0.91; 1.00)]	[(0.56,0.63,0.78,0.84; 0.80), (0.56,0.63,0.78,0.84; 1.00)]	[(0.74,0.79,0.90,0.93; 0.80), (0.74,0.79,0.90,0.93; 1.00)]	[(0.76,0.81,0.92,0.95; 0.80), (0.76,0.81,0.92,0.95; 1.00)]
A_3	[(0.64,0.70,0.82,0.86; 0.80), (0.64,0.70,0.82,0.86; 1.00)]	[(0.56,0.62,0.75,0.79; 0.80), (0.56,0.62,0.75,0.79; 1.00)]	[(0.68,0.73,0.82,0.86; 0.80), (0.68,0.73,0.82,0.86; 1.00)]	[(0.57,0.63,0.77,0.82; 0.80), (0.57,0.63,0.77,0.82; 1.00)]
A_4	[(0.77,0.82,0.92,0.95; 0.80), (0.77,0.82,0.92,0.95; 1.00)]	[(0.63,0.69,0.83,0.88; 0.80), (0.63,0.69,0.83,0.88; 1.00)]	[(0.80,0.85,0.93,0.96; 0.80), (0.80,0.85,0.93,0.96; 1.00)]	[(0.74,0.79,0.90,0.94; 0.80), (0.74,0.79,0.90,0.94; 1.00)]
A_5	[(0.70,0.75,0.84,0.88; 0.80), (0.70,0.75,0.84,0.88; 1.00)]	[(0.62,0.68,0.80,0.85; 0.80), (0.62,0.68,0.80,0.85; 1.00)]	[(0.57,0.63,0.77,0.82; 0.80), (0.57,0.63,0.77,0.82; 1.00)]	[(0.65,0.71,0.81,0.85; 0.80), (0.65,0.71,0.81,0.85; 1.00)]

CHAPTER 7

CASE STUDY: ESTIMATION OF ORGANIZATIONAL LEANNESS, AGILITY AND LEAGILITY DEGREE

7.1 Coverage

In modern business scenario, supply chain system is the backbone of any industry or an organization. Therefore, effective management and efficient performance of supply chain system are of vital importance for the companies to be competitive in the global market. Different supply chain management approaches (resulted from paradigm shift in manufacturing strategies) has been adapted by the companies in order to improve existing supply chain system to ensure quick response to fluctuating customer demand, to supply mass customized products and to go for efficient utilization of resources. In this regard, the management has always been attracted towards lean, agile and leagile supply chain system. Therefore, an evaluation of the extent of leanness, agility as well as leagility in industrial supply chain is indeed essential in course of assessing overall business performance.

In the present work, a case research has been carried out in an Indian automobile sector; the supply chain performance index has been measured, from the viewpoint of leanness, agility as well as leagility, separately. In order to evaluate performance extent of individual aspects (lean/ agile/ leagile) of the organizational supply chain; different criteria hierarchy (evaluation index system for lean, agile and leagile performance estimation) have been considered; a conceptual performance assessment module has been established in conjugation with fuzzy set theory. The fuzzy set theory has been explored to deal with uncertain evaluation information due to variation in human perception in relation to subjective evaluation criteria, thus facilitating the said decision-making process. Moreover, lean, agile and leagile criterions have been ranked in accordance with their existing performance level. This could help in identifying ill-performing supply chain segments (areas) which require subsequent future improvement to boost up organizational leanness, agility as well as leagility degree.

7.2 Problem Definition

In the present work, an attempt has been made to evaluate organizational performance in terms of existing leanness, agility as well as leagility extent of existing supply chain through a case research. Based on an evaluation index system for each of the supply chain philosophy (lean, agile as well as leagile) an overall performance metric indicating organizational leanness, agility and leagility extent has been determined. Subjective evaluation information expressed in linguistic terminology, collected from a group of decision makers (DMs)/experts, inherently contains some ambiguity, vagueness as well as incompleteness. As expert panels' judgments are conflicting in nature; therefore fuzzy numbers set theory has been utilized to measure suitability extent (appropriateness rating) in regards of ongoing performance of different indices as depicted in the evaluation index system (criteria hierarch), for individual lean, agile and leagile supply chain construct. The performances of different evaluation indices have been determined separately for lean, agile and leagile supply chain and ranked accordingly. For this purpose, the concept of 'crisp' transformation of fuzzy numbers has been explored.

There are several methods of fuzzy numbers ranking as reported in the literature; some of which have been reviewed and compared by (Bortolan and Degani, 1985; Wang and Kerre, 2001). In this work, we have used 'radius of gyrations of centroids method' for ranking a fuzzy numbers in facilitating criteria ranking and subsequent decision making process under uncertain environment.

7.3 Fuzzy Preliminaries

7.3.1 Fuzzy Concepts

Some fuzzy basic definitions of fuzzy logic are described here as presented by (Thorani et al., 2012) and (Shankar et al., 2012).

Definition 1: Let U is a Universe set. A fuzzy set $\tilde{A}$ of U is defined by a membership function $f_{\tilde{A}}: U \rightarrow [0,1]$, where $f_{\tilde{A}}(x)$ is the degree of x in $\tilde{A}$, $\forall x \in U$.

Definition 2: A fuzzy set $\tilde{A}$ of Universe set U is normal if and only if $\sup_{x \in U} f_{\tilde{A}}(x) = 1$.

Definition 3: A fuzzy set $\tilde{A}$ of Universe set U is convex it and only if

$$f_{\tilde{A}}(\lambda x + (1-\lambda)y) \geq \min\left(f_{\tilde{A}}(x), f_{\tilde{A}}(y)\right), \forall x, y \in U \; and \; \lambda \in [0,1].$$

Definition 4: A fuzzy set $\tilde{A}$ of Universe set U is a fuzzy number if $\tilde{A}$ is normal and convex on U.

Definition 5: A real fuzzy number $\tilde{A}$ is described as any fuzzy subset of the real line $\tilde{A}$ with membership function $f_{\tilde{A}}(x)$ possessing the following properties:

(a) $f_{\tilde{A}}(x)$ is a continuous mapping from $\Re$ to the closed interval $[0, w]$. $0 < w \leq 1$

(b) $f_{\tilde{A}}(x) = 0$, for all $x \in (-\infty, a)$

(c) $f_{\tilde{A}}(x)$ is strictly increasing on $[a, b]$

(d) $f_{\tilde{A}}(x) = 1$, for all $x \in [b, c]$

(e) $f_{\tilde{A}}(x)$ is strictly decreasing on $[c, d]$

(f) $f_{\tilde{A}}(x) = 0$, for all $x \in (d, \infty)$, where a, b, c, d are real numbers.

Definition 6: Let R be the set of all real numbers. We assume that the membership function of the real fuzzy number $\tilde{A}$ can be expressed for all $x \in R$:

$$f_{\tilde{A}}(x) = \begin{cases} f_{\tilde{A}}^{L}, & a \le x \le b, \\ w, & b \le x \le c, \\ f_{\tilde{A}}^{R}, & c \le x \le d, \\ 0, & otherwise. \end{cases} \quad (7.1)$$

where $0 < w \le 1$ is a constant, a, b, c, d are real numbers and $f_{\tilde{A}}^{L} : [a, b] \to [0, w]$, $f_{\tilde{A}}^{R} : [c, d] \to [0, w]$ are two strictly monotonic and continuous function from $\Re$ to the closed interval $[0, w]$. It is customary to write a fuzzy number as $\tilde{A} = (a, b, c, d; w)$. If $w = 1$ then $\tilde{A} = (a, b, c, d; 1)$ is a normalized fuzzy number, otherwise $\tilde{A}$ is said to be generalized or non-normal fuzzy number. If the membership function $f_{\tilde{A}}(x)$ is piecewise linear, then $\tilde{A}$ is said to be a trapezoidal fuzzy number

The membership function of a trapezoidal fuzzy number is given by:

$$f_{\tilde{A}}(x) = \begin{cases} \dfrac{w(x-a)}{b-a}, & a \le x \le b, \\ w, & b \le x \le c, \\ \dfrac{w(x-d)}{c-d}, & c \le x \le d, \\ 0, & otherwise. \end{cases} \quad (7.2)$$

If, $w = 1$, then $\tilde{A} = (a, b, c, d; 1)$ is a normalized trapezoidal fuzzy number and $\tilde{A}$ is a generalized or non-normal trapezoidal fuzzy number if $0 < w < 1$.

7.3.2 The Radius of Gyration of Fuzzy Numbers

The radius of gyration (ROG) is a concept in mechanics. The ROG point (r_x, r_y) for a fuzzy number $\tilde{A}$ is provided as (Deng et al., 2006).

$$r_x = \sqrt{\frac{I_x(\tilde{A})}{A(\tilde{A})}}$$

$$r_y = \sqrt{\frac{I_y(\tilde{A})}{A(\tilde{A})}}$$

Here $I_x(\tilde{A})$ and $I_y(\tilde{A})$ are moment of inertia of $\tilde{A}$ with respect to x and y axis respectively and $A(\tilde{A})$ is the area of $\tilde{A}$.

7.3.3 Ranking of Fuzzy Numbers

The fuzzy ranking approach proposed by (Ganesh and Jayakumar, 2014), based on radius of gyration point of centroids. They have considered the centroid of a trapezoid is as the balancing point of the trapezoid (Fig. 7.1) Dividing the trapezoid into three plane figures. These three plane figures are a triangle (APB), a rectangle (BPQC), and a triangle (CQD), respectively. Let the centroids of the three plane figures be $G_1, G_2 \& G_3$ respectively. The orthocenter of these centroids $G_1, G_2 \& G_3$ is taken as the point of reference to define the ranking of generalized trapezoidal fuzzy numbers. The reason for selecting this point as a point of reference is that each centroid point are balancing points of each individual plane figure, and the orthocentre of these centroid points is a much more balancing point for a generalized trapezoidal fuzzy number. Orthocentre is the point where the three altitudes of a triangle intersect. The altitude of a triangle is a line which passes through a vertex of a triangle and is perpendicular to the opposite side. Therefore, this point would be a better reference point than the centroid point of the trapezoid.

Consider a generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$. The centroids of the three plane figures are

$G_1 = \left(\frac{a+2b}{3}, \frac{w}{3}\right)$, $G_2 = \left(\frac{b+c}{2}, \frac{w}{2}\right)$ and $G_3 = \left(\frac{2c+d}{3}, \frac{w}{3}\right)$ respectively. Equation of the line $\overleftrightarrow{G_1G_3}$ is $y = \frac{w}{3}$ and G_2 does not lie on the line $\overleftrightarrow{G_1G_3}$. Therefore, G_1, G_2 and G_3 are nonlinear and they form a triangle.

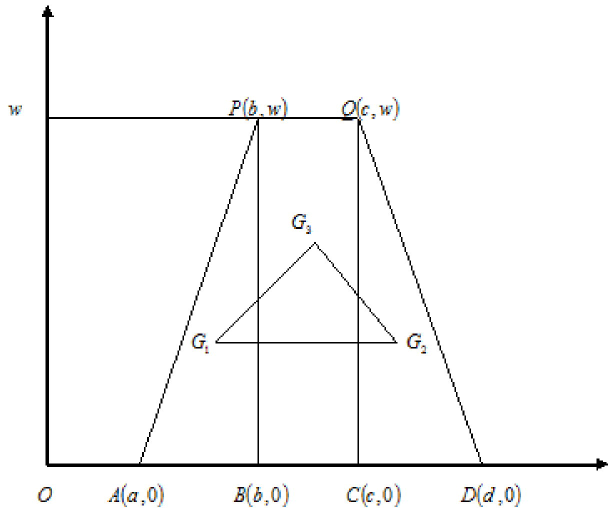

Fig. 7.1: Radius of gyration of centroids in trapezoidal fuzzy numbers

They have defined the radius of gyration point of a triangle with vertices G_1, G_2 and G_3 of the generalized trapezoidal fuzzy number $\tilde{A} = (a, b, c, d; w)$ as:

$$\left(r_x^{\tilde{A}}, r_y^{\tilde{A}}\right) = \left(\sqrt{\frac{(2(c-b)+(d-a))^2}{162} + \frac{(2(a+d)+7(b+c))^2}{324}}, \sqrt{\frac{11}{72}w}\right) \quad (7.3)$$

As a special case, for triangular fuzzy number $\tilde{A} = (a, b, d; w)$

That is, $c = b$ the radius of gyration point of centroids is given by

$$\left(r_x^{\tilde{A}}, r_y^{\tilde{A}}\right) = \left(\sqrt{\frac{(d-a)^2}{162} + \frac{(2(a+d)+14b)^2}{324}}, \sqrt{\frac{11}{72}w}\right) \quad (7.4)$$

Now, $A = (a_1, b_1, c_1, d_1; w_1)$ and $B = (a_2, b_2, c_2, d_2; w_2)$ be to two generalized trapezoidal fuzzy numbers. The working procedure to compare A and B is as follows:

Find $r_y(A)$ and $r_x(B)$

Case (i): if $r_x(A) \rangle r_x(B) \Rightarrow A \rangle B$

Case (ii): if $r_x(A) \langle r_x(B) \Rightarrow A \langle B$

Case (iii): if $r_x(A) = r_x(B) \Rightarrow A = B$

Similarly,

$$r_y(A) \rangle r_y(B) \Rightarrow A \rangle B$$

$$r_y(A) \langle r_y(B) \Rightarrow A \langle B$$

$$r_y(A) = r_y(B) \Rightarrow A = B$$

In aforesaid method, the centoids of the part of trapezoidal fuzzy number are calculated followed by the calculation of the radius of gyration of these centroids. In most centroid method the centroids of fuzzy number has consider as reference point, as the centroid is a balancing point of trapezoids. But the radius of gyration of centroids can be considered a much more balancing point than the centroid. The main advantage of this method is that the method provides the correct ordering of generalized trapezoidal normal and non-normal fuzzy numbers and also the method is very simple and easy to apply in practice.

7.4 Proposed Lean, Agile and Leagile Index Appraisement Modeling: A Case Study

A case study has been conducted in a famous automobile manufacturing company located at Tamil Nadu, India. The company's footprint in India has been growing steadily since its inception in 2005. Marked by an impressive rise in sales, award-winning quality from locally-built products, an expanding range of innovative cars and a rapidly evolving dealer network, the growth underlines the strategic importance of India to the said company. Guided by its global Brand commitment 'Innovation and Excitement for Everyone' the company delivers cutting-edge technology, Innovative design and a rewarding experience to all its customers. In India, the company has been constantly expanding innovative and exciting product offerings across hatchback, sports car, SUV and sedan segments.

The case study is mainly based on the questionnaire survey to various levels of management authorities such as managers, executive engineers and supervisors from different departments of the said company; the group has been considered as the panel of decision makers (experts). They all are well educated (possessing minimum bachelor degree) and all are having at least 5 year of experience in the concerned firm. The questionnaire has been prepared considering three aspects for lean/agile/leagile dimensions (or indices), separately. The questionnaire proforma has been shown in the Appendix E (placed at the end of this chapter). During data gathering it has been assured that the data would be strictly used for academic purpose only. Therefore, experts were requested to provide personal opinion (without any biasness) based on their experience. As human decision making often encounters some kind of imprecision, ambiguity as well as vague information. In order to avoid these, the linguistic variable has been used for expert data collection.

To precede the evaluation of lean, agile and leagile performance indices, initially the assessment team has been formed and then the prepared questionnaire has been circulated to the decision makers (respondents) asking for their opinion. The decision makers have provided expert judgment in linguistic terms. For the analysis purpose, we have adopted fuzzy set theory and converted this linguistic variable into appropriate fuzzy numbers. Finally, based on fuzzy operational rules, expert data have been analyzed. The procedural steps of the entire appraisement framework along with results of the aforesaid case research have been summarized below.

Step 1: Evaluation index platform and preparation of questionnaire

The two-level conceptual hierarchy-criteria have been developed for leanness, agility and leagility assessment, separately.

Leanness appraisement module consists of five capabilities in the first level (Level I) and a total thirty three attributes in second level (Level II) as shown in Table 7.1. The agility appraisement module consists of four capabilities in first level and a total of eleven attributes in second level as shown in Table 7.2. Similarly, the leagility assessment module consists of four capabilities in first level and a total of fifteen attributes in second level as shown in Table 7.3.

For the survey purpose, we have considered only second level of attributes and the questionnaire has been prepared in relation to appropriateness ratings against individual second level attributes for leanness, agility as well as leagility assessment framework, separately (Appendix E).

Step 2: Formation of the expert team

A committee has been formed consisting of a group of 20 decision makers (DMs).

Step 3: Selection of appropriate scale of linguistic variables and corresponding fuzzy numbers scale

The five member linguistic variable such as **Unsatisfactory (U)**, **Poor (P)**, **Medium (M)**, **Satisfactory (S)**, and **Excellent (E**) has been selected for assessing performance ratings of individual evaluation indices. The linguistic variables and their corresponding triangular fuzzy numbers have been shown in Table 7.4.

Step 4: Collection of DMs opinion

The decision makers are being asked to express his/her opinion in relation to the attribute rating in linguistic term. The collected data has been shown in Table 7.5, 7.6 & 7.7 separately, for leanness, agility and leagility index assessment, respectively.

Step 4: Approximation of the linguistic ratings with equivalent fuzzy numbers

The data collected from the group of decision makers have been converted into triangular fuzzy numbers using the Table 7.4. Then, we have aggregated fuzzy appropriateness ratings given by the DMs as per the fuzzy set rules. The aggregated fuzzy appropriateness ratings for individual 2nd level attributes have been shown in Table 7.8, 7.9 & 7.10, for leanness, agility and leagility assessment, respectively.

Step 5: Calculation of Overall Performance Index (OPI)

By considering the equal importance weight of all the attributes for each of the individual supply chain philosophies; we have calculated overall performance index (OPI) for the organizational supply chain for lean, agile and leagile aspects, separately using the following formula:

The computed fuzzy appropriateness rating U_i of i^{th} 1st level capability is obtained as per the formula given below.

$$U_i = \frac{1}{n}\sum_{j=1}^{n} U_{ij} \qquad (7.5)$$

Here, U_{ij} is the aggregated fuzzy appropriateness rating of j^{th} 2nd level attribute C_{ij} which is under i^{th} 1st level capability C_i.

Computed fuzzy appropriateness rating for various 1st level capabilities have been obtained as follows:

Computed fuzzy appropriateness rating for Lean capabilities (Level-I)

$U_1 = (0.392, 0.642, 0.858)$, $U_2 = (0.425, 0.675, 0.875)$, $U_3 = (0.393, 0.643, 0.850)$,

$U_4 = (0.393, 0.642, 0.856)$, $U_5 = (0.330, 0.580, 0.807)$

Computed fuzzy appropriateness rating of agile capabilities (Level-I)

$U_1 = (0.358, 0.608, 0.833)$, $U_2 = (0.450, 0.700, 0.888)$, $U_3 = (0.444, 0.694, 0.888)$,

$U_4 = (0.446, 0.696, 0.896)$

<u>Computed fuzzy appropriateness rating of leagile capabilities (Level-I)</u>

$U_1 = (0.381, 0.631, 0.844)$, $U_2 = (0.416, 0.666, 0.872)$, $U_3 = (0.378, 0.628, 0.844)$,

$U_4 = (0.346, 0.596, 0.825)$

Overall performance index (lean, agile and leagile index, separately) is obtained by the following equation:

$$OPI = \frac{1}{m}\sum_{i=1}^{m} U_i \qquad (7.6)$$

Here, U_i is the computed fuzzy appropriateness rating of i^{th} 1st capability C_i which is obtained from Eq. (7.5).

Overall performance index (OPI) for the organizational supply chain from leanness, agility and leagility view point has been computed separately as:

$$OPI_{(Lean)} = (0.3863, 0.6363, 0.8493)$$

$$OPI_{(Agile)} = (0.4245, 0.6745, 0.8760)$$

$$OPI_{(Leagile)} = (0.3802, 0.6302, 0.8461)$$

The overall performance index (in terms of crisp score) after defuzzification appears as:

$OPI_{(Lean)} = 0.6240$; $OPI_{(Agile)} = 0.6583$; $OPI_{(Leagile)} = 0.6188$

It can therefore, be concluded that the organizational performance is maximum (highest extent) from agility point of view (Fig. 7.2).

Step 6: Determination of Performance ranking order of 2nd level attributes

The attributes have been ranked in accordance with existing performance level. Aggregated fuzzy performance rating of individual 2nd level attributes has been transformed into 'crisp' score to facilitate ranking. The representative 'crisp' score has been obtained using the concept of radius of gyration of centroid method (towards ranking of fuzzy numbers); as discussed in methodology section using Eq. 7.4. The results have been shown in Table 7.11, 7.12 & 7.13, for leanness, agility and leagility related attributes, respectively. Attribute ranking helps in identifying ill-performing areas. Management should think of future improvement for those areas in order to boost up overall organizational performance in regards of leanness, agility as well as leagility. The graphical representations have been shown in Fig. 7.3 for lean attribute ranking; Fig. 7.4 for agile attribute ranking; and Fig. 7.5 for leagile attribute ranking.

The aforesaid leanness, agility and leagility extent evaluation has been performed based on expert opinion acquired from a group of decision makers. From the calculated results, it has been analyzed that in lean supply chain attributes, maintenance of installed machines (C_{43}), employee's attitude tuned to accept the changes (C_{23}) and optimization of processing sequence and flow in shop floor (C_{27}) has the 1, 2 and 3 ranking order respectively. It means the considered organization is more concerned about the maintenance of machines, fulfilling employee expectation and optimized operations. But the attribute like C_{53}, C_{57} performing very low, that might be the reason for being low leanness index of the organization because the attributes C_{53}, C_{57} are the most essential attribute to be competitive and for profit maximization. Hence, the organization need to take care of lower ranking order attributes in lean supply chain system.

The result of agility evaluation has shown good result as compared to other two systems (lean and leagile). It means that this organization's agile supply chain is performing well and agility index appeared the highest. The attributes C_{12}, C_{23} and C_{41} have secured the 1, 2 and 3 ranking position on the performance order; and attributes C_{22}, C_{13}, and C_{11} performing very low, that enabled the organization to pay attention on those attributes. However, the overall performance of organizational supply chain from agile point of view is satisfactory; therefore, the agility index obtained is more as compared to leanness and leagility index.

The leagility evaluation indicates that the attributes viz. C_{13}, C_{24} and C_{21} has high ranking order means they are performing well, but attribute $C_{14,}$ C_{41} and C_{11} performing very poor. The management needs to focus on this attributes for future consideration of improved performance.

7.5 Concluding Remarks

An evaluation index system has been proposed in order to assess overall organizational performance extent from view point of leanness, agility as well as leagility. Based on specific hierarchy criteria models for assessment of lean, agile and leagile performance of industrial supply chain; an efficient decision support platform has been conceptualized in the foregoing research. Subjectivity of human judgment containing vagueness and ambiguity has been tackled by exploring the concept of fuzzy numbers set theory. Apart from estimating overall performance index; the study has been extended to identify ill (poor)-performing supply chain areas (in view of lean, agile and leagile strategies) which require future improvement. The case research and the outcome of the data analysis bear significant managerial implication from strategic viewpoint. It would be helpful for various decision-making too.

Table 7.1: Leanness evaluation procedural hierarchy: Conceptual model for assessment of leanness (Vimal and Vinodh, 2012)

Goal	Leanness capabilities (Level I indices)	Leanness attributes (Level II indices)
Leanness assessment	Management responsibility, C_1	Smooth information flow, C_{11}
		Team management for decision-making, C_{12}
		Interchangeability of personnel, C_{13}
		Clearly known management goals, C_{14}
		Management involvement, C_{15}
		Transparency in information sharing, C_{16}
	Manufacturing management, C_2	Prevalence of continuous improvement culture, C_{21}
		Empowerment of personnel to resolve customer problem, C_{22}
		Employee's attitude tuned to accept the changes, C_{23}
		Conduct of pilot study on new, C_{24}
		Produce small lot size, C_{25}
		JIT delivery to customers, C_{26}
		Optimization of processing sequence and flow in shop floor, C_{27}
	Work force leanness, C_3	Flexible workforce to adapt the adaptation of new technologies, C_{31}
		Multi-skilled personnel, C_{32}
		Implementation of job rotation system, C_{33}
		Strong employee spirit and cooperation, C_{34}
		Employee empowerment, C_{35}
	Technology leanness, C_4	Identification and prioritization of critical machines, C_{41}
		Implementation of TPM techniques, C_{42}
		Maintenance of installed machines, C_{43}
		Implementation of Poka-Yoke, C_{44}
		Usage of ANDON device, C_{45}
		Introduction of card system, C_{46}
		Products designed for easy serviceability, C_{47}
		Service centers well equipped with spares, C_{48}
	Manufacturing strategy, C_5	Standardization of components, C_{51}
		Systematic process control, C_{52}
		Products exceeding customer's expectations, C_{53}
		Conduct of survey/studies to ensure quality status, C_{54}
		Use of TQM tools, C_{55}

		Productivity linked to the personnel prosperity, C_{56}
		Reduction of non-value adding cost, C_{57}

Table 7.2: Agility evaluation procedural hierarchy: Conceptual model for assessment of agility (Zanjirchi et al., 2010)

Goal	Agile capabilities (Level I indices)	Agile attributes (Level II indices)
Agility assessment	Flexibility, C_1	Sourcing flexibility, C_{11}
		Manufacturing flexibility, C_{12}
		Delivery flexibility, C_{13}
	Responsiveness, C_2	Sourcing responsiveness, C_{21}
		Manufacturing responsiveness, C_{22}
		Delivery responsiveness, C_{23}
	Competency, C_3	Cooperation and internal-external balance, C_{31}
		Capabilities of human resources, C_{32}
	Cost, C_4	Sourcing cost, C_{41}
		Manufacturing cost, C_{42}
		Delivery cost, C_{43}

Table 7.3: Leagility evaluation procedural hierarchy: Conceptual model for assessment of leagility (Ramana et al., 2013)

Goal	Leagile capabilities (Level I indices)	Leagile attributes (Level II indices)
Leagility assessment	Operational performance, C_1	Product cycle time, C_{11}
		Due-date performance, C_{12}
		Cost, C_{13}
		Quality, C_{14}
	Customer service performance, C_2	Customer satisfaction, C_{21}
		Delivery dependability, C_{22}
		Responsiveness, C_{23}
		Order fill capacity, C_{24}
	Flexibility, C_3	Product design flexibility, C_{31}
		Sourcing flexibility, C_{32}
		Manufacturing flexibility, C_{33}

		IT flexibility, C_{34}
	Organizational performance, C_4	Market share, C_{41}
		Return on investment, C_{42}
		Green image, C_{43}

Table 7.4: Linguistic scale for assignment of appropriateness rating (of various 2nd level indices) and corresponding fuzzy representation

Linguistic variables	Generalized triangular fuzzy numbers
Unsatisfactory (U)	(0, 0, 0.25)
Poor (P)	(0, 0.25, 0.5)
Medium (M)	(0.25, 0.5, 0.75)
Satisfactory (S)	(0.5, 0.75, 1.0)
Excellent (E)	(0.75, 1.0, 1.0)

Table 7.5: Survey data in relation to appropriateness rating of lean indices (at II level)

C_{ij}	Appropriateness rating of lean indices (expressed in linguistic terms) as given by the decision-makers																			
	DM1	**DM2**	**DM3**	**DM4**	**DM5**	**DM6**	**DM7**	**DM8**	**DM9**	**DM10**	**DM11**	**DM12**	**DM13**	**DM14**	**DM15**	**DM16**	**DM17**	**DM18**	**DM19**	**DM20**
C_{11}	S	M	S	P	M	M	E	S	M	M	M	M	M	M	P	M	S	S	S	M
C_{12}	M	P	S	M	S	S	M	M	S	S	S	S	E	E	E	S	M	M	M	S
C_{13}	S	M	M	S	M	E	S	P	M	M	S	M	S	M	M	M	S	M	E	S
C_{14}	P	S	E	S	S	P	M	S	S	M	M	P	M	M	S	S	S	S	S	M
C_{15}	E	M	M	M	E	S	S	M	S	P	E	S	S	P	M	E	M	S	M	E
C_{16}	S	S	E	S	M	M	P	E	E	S	M	M	M	S	E	M	S	M	S	S
C_{21}	S	S	S	M	P	E	S	S	P	M	P	P	E	E	S	S	S	S	S	E
C_{22}	M	M	S	E	M	S	M	M	S	P	M	M	S	S	M	M	S	S	M	M
C_{23}	E	S	S	S	S	E	S	M	M	S	S	S	S	M	M	S	M	M	E	S
C_{24}	S	P	M	M	M	M	M	S	S	M	M	S	M	E	P	E	S	E	S	S
C_{25}	M	S	S	S	P	S	E	M	E	S	P	P	E	S	S	M	S	E	M	S
C_{26}	E	M	E	E	E	E	M	P	S	M	S	M	S	S	P	M	E	E	S	M
C_{27}	S	E	M	M	M	M	S	E	M	E	S	P	S	M	E	E	S	E	S	M
C_{31}	M	S	S	E	S	S	E	M	S	M	M	S	M	P	S	S	S	S	S	E
C_{32}	S	E	P	S	E	P	P	E	M	P	S	M	S	M	M	M	M	M	M	S

C_{33}	S	M	M	E	M	M	M	S	M	S	P	E	P	S	E	S	S	S	E	P
C_{34}	M	E	S	M	P	S	S	E	S	E	E	S	M	M	M	M	M	M	M	E
C_{35}	P	S	M	M	E	P	S	P	S	M	M	M	S	P	S	E	S	S	S	M
C_{41}	S	M	P	E	S	P	M	M	M	M	E	S	S	S	E	S	S	E	S	P
C_{42}	M	S	S	M	M	M	M	S	E	S	S	M	M	M	P	M	S	S	M	M
C_{43}	M	E	M	S	S	E	S	M	E	P	M	M	E	E	M	E	S	S	S	S
C_{44}	S	M	S	S	P	S	S	S	P	M	S	S	M	S	E	S	M	M	S	E
C_{45}	E	M	M	E	M	S	S	P	S	S	M	M	S	M	M	M	S	S	S	M
C_{46}	M	S	M	S	S	M	E	S	M	M	M	P	M	M	M	S	S	M	M	M
C_{47}	M	S	S	M	P	P	M	E	S	S	P	S	S	S	P	M	E	S	M	P
C_{48}	S	E	M	E	M	S	S	M	P	E	S	M	M	E	M	E	M	M	S	M
C_{51}	P	S	P	S	S	M	S	M	M	M	M	M	S	M	S	S	E	E	E	S
C_{52}	M	P	S	M	M	M	M	S	M	S	M	S	M	S	P	M	E	S	S	S
C_{53}	P	P	S	P	M	M	P	P	P	M	E	P	P	P	M	M	S	S	M	M
C_{54}	M	M	M	S	P	P	M	E	M	M	S	P	S	E	P	E	S	S	S	S
C_{55}	S	S	P	E	S	S	S	M	S	S	M	S	M	S	S	S	S	M	S	P
C_{56}	P	E	S	P	M	M	P	S	M	M	S	M	S	M	M	M	M	S	M	S
C_{57}	E	M	M	M	P	P	M	M	P	P	P	M	M	M	P	S	E	S	E	M

Table 7.6: Survey data in relation to appropriateness rating of agility indices (at II level)

C_{ij}	Appropriateness rating of agile indices (expressed in linguistic terms) as given by the decision-makers																			
	DM1	**DM2**	**DM3**	**DM4**	**DM5**	**DM6**	**DM7**	**DM8**	**DM9**	**DM10**	**DM11**	**DM12**	**DM13**	**DM14**	**DM15**	**DM16**	**DM17**	**DM18**	**DM19**	**DM20**
C_{11}	P	P	M	P	M	M	M	S	M	M	M	S	M	P	S	M	S	M	M	M
C_{12}	E	E	E	M	S	S	P	M	S	S	E	M	S	M	E	S	S	E	S	S
C_{13}	M	S	M	S	P	P	S	S	P	M	S	S	S	S	M	M	M	M	M	S
C_{21}	S	M	S	M	S	M	E	E	M	S	M	M	M	E	S	S	S	S	S	M
C_{22}	M	S	P	S	E	E	M	M	E	M	P	P	E	M	M	M	E	S	E	E
C_{23}	E	M	S	E	P	S	S	S	M	E	S	M	M	S	S	E	E	S	S	S
C_{31}	S	S	M	M	M	S	M	M	S	E	M	S	S	E	P	M	E	E	S	M
C_{32}	M	S	E	S	S	E	S	M	E	M	S	M	P	M	E	S	S	S	M	E
C_{41}	E	E	S	M	P	M	S	S	S	S	M	E	S	S	S	E	S	M	S	S
C_{42}	M	M	M	S	M	S	P	E	E	S	S	S	M	M	P	M	E	S	E	E
C_{43}	S	S	S	M	S	M	E	M	S	M	P	P	S	E	S	S	S	S	E	S

Table 7.7: Survey data in relation to appropriateness rating of leagility indices (at II level)

C_{ij}	Appropriateness rating of leagile indices (expressed in linguistic terms) as given by the decision-makers																			
	DM1	**DM2**	**DM3**	**DM4**	**DM5**	**DM6**	**DM7**	**DM8**	**DM9**	**DM10**	**DM11**	**DM12**	**DM13**	**DM14**	**DM15**	**DM16**	**DM17**	**DM18**	**DM19**	**DM20**
C_{11}	P	P	E	P	M	M	M	S	M	M	E	P	P	E	M	M	S	M	S	M
C_{12}	E	M	M	M	S	S	M	M	S	E	S	M	M	M	E	S	M	S	M	S
C_{13}	M	S	S	S	S	M	S	M	E	S	M	S	E	S	S	E	E	S	S	M
C_{14}	P	M	M	S	P	M	E	S	M	P	S	M	S	M	P	M	S	M	S	E
C_{21}	E	S	S	M	E	P	M	E	S	M	M	E	M	S	S	S	S	S	M	S
C_{22}	S	M	M	E	P	S	P	M	M	S	E	S	M	S	M	M	M	E	S	M
C_{23}	M	S	M	S	M	M	M	E	S	S	S	P	S	P	S	S	M	S	M	S
C_{24}	E	S	S	M	S	E	S	S	M	M	M	M	P	E	E	E	S	M	E	M
C_{31}	S	E	E	S	S	S	M	P	S	P	S	S	E	M	M	M	M	S	E	S
C_{32}	M	M	M	M	E	P	M	E	P	E	S	M	P	S	S	E	M	M	S	E
C_{33}	M	S	S	M	P	S	M	M	M	S	M	S	M	P	P	S	S	S	S	M
C_{34}	M	E	M	M	S	M	S	P	S	M	S	P	S	M	M	E	S	S	M	M
C_{41}	S	M	P	S	M	P	E	M	M	P	E	P	M	S	E	M	M	M	M	S
C_{42}	M	S	M	S	M	S	S	S	P	M	M	M	S	M	S	S	S	P	S	M
C_{43}	E	S	S	M	M	M	M	E	M	S	P	M	M	M	M	M	S	M	S	S

Table 7.8: Aggregated fuzzy appropriateness ratings for lean indices (at Level II)

C_{ij}	Aggregated fuzzy ratings
C_{11}	(0.325, 0.575, 0.813)
C_{12}	(0.425, 0.675, 0.888)
C_{13}	(0.375, 0.625, 0.850)
C_{14}	(0.363, 0.613, 0.850)
C_{15}	(0.425, 0.675, 0.863)
C_{16}	(0.438, 0.688, 0.888)
C_{21}	(0.425, 0.675, 0.875)
C_{22}	(0.350, 0.600, 0.838)
C_{23}	(0.463, 0.713, 0.925)
C_{24}	(0.388, 0.638, 0.850)
C_{25}	(0.425, 0.675, 0.875)
C_{26}	(0.463, 0.713, 0.875)
C_{27}	(0.463, 0.713, 0.888)
C_{31}	(0.450, 0.700, 0.913)
C_{32}	(0.338, 0.588, 0.800)
C_{33}	(0.400, 0.650, 0.850)
C_{34}	(0.425, 0.675, 0.863)
C_{35}	(0.350, 0.600, 0.825)
C_{41}	(0.413, 0.663, 0.863)
C_{42}	(0.350, 0.600, 0.838)
C_{43}	(0.475, 0.725, 0.900)
C_{44}	(0.413, 0.663, 0.888)
C_{45}	(0.388, 0.638, 0.863)
C_{46}	(0.338, 0.588, 0.825)
C_{47}	(0.338, 0.588, 0.813)
C_{48}	(0.425, 0.675, 0.863)
C_{51}	(0.400, 0.650, 0.863)
C_{52}	(0.350, 0.600, 0.838)
C_{53}	(0.200, 0.450, 0.688)
C_{54}	(0.363, 0.613, 0.825)
C_{55}	(0.413, 0.663, 0.900)
C_{56}	(0.313, 0.563, 0.800)
C_{57}	(0.275, 0.525, 0.738)

Table 7.9: Aggregated fuzzy appropriateness ratings for agile indices (at level II)

C_{ij}	Aggregated fuzzy ratings
C_{11}	(0.250, 0.500, 0.750)
C_{12}	(0.500, 0.750, 0.925)
C_{13}	(0.325, 0.575, 0.825)
C_{21}	(0.438, 0.688, 0.900)
C_{22}	(0.425, 0.675, 0.838)
C_{23}	(0.488, 0.738, 0.925)
C_{31}	(0.425, 0.675, 0.875)
C_{32}	(0.463, 0.713, 0.900)

C_{41}	(0.475, 0.725, 0.925)
C_{42}	(0.425, 0.675, 0.863)
C_{43}	(0.438, 0.688, 0.900)

Table 7.10: Aggregated fuzzy appropriateness ratings for leagile indices (at level II)

C_{ij}	Aggregated fuzzy ratings
C_{11}	(0.300, 0.550, 0.763)
C_{12}	(0.413, 0.663, 0.875)
C_{13}	(0.488, 0.738, 0.938)
C_{14}	(0.325, 0.575, 0.800)
C_{21}	(0.450, 0.700, 0.900)
C_{22}	(0.375, 0.625, 0.838)
C_{23}	(0.375, 0.625, 0.863)
C_{24}	(0.463, 0.713, 0.888)
C_{31}	(0.438, 0.688, 0.888)
C_{32}	(0.388, 0.638, 0.825)
C_{33}	(0.325, 0.575, 0.825)
C_{34}	(0.363, 0.613, 0.838)
C_{41}	(0.325, 0.575, 0.788)
C_{42}	(0.350, 0.600, 0.850)
C_{43}	(0.363, 0.613, 0.838)

Table 7.11: Evaluation of ranking order for lean attributes

C_{ij}	Radius of gyration point (r_x ,r_y)	Ranking order
C_{11}	(0.5749, 0.3909)	25
C_{12}	(0.6718, 0.3909)	7
C_{13}	(0.6233, 0.3909)	17
C_{14}	(0.6123, 0.3909)	18
C_{15}	(0.6689, 0.3909)	9
C_{16}	(0.6829, 0.3909)	6
C_{21}	(0.6704, 0.3909)	8
C_{22}	(0.5998, 0.3909)	20
C_{23}	(0.7093, 0.3909)	2
C_{24}	(0.6344, 0.3909)	16
C_{25}	(0.6704, 0.3909)	8
C_{26}	(0.7035, 0.3909)	4
C_{27}	(0.7050, 0.3909)	3
C_{31}	(0.6968, 0.3909)	5
C_{32}	(0.5845, 0.3909)	24
C_{33}	(0.6454, 0.3909)	14
C_{34}	(0.6689, 0.3909)	9
C_{35}	(0.5984, 0.3909)	21
C_{41}	(0.6579, 0.3909)	12
C_{42}	(0.5998, 0.3909)	20
C_{43}	(0.7174, 0.3909)	1

C_{44}	(0.6608, 0.3909)	11
C_{45}	(0.6358, 0.3909)	15
C_{46}	(0.5874, 0.3909)	22
C_{47}	(0.5859, 0.3909)	23
C_{48}	(0.6689, 0.3909)	9
C_{51}	(0.6469, 0.3909)	13
C_{52}	(0.5998, 0.3909)	20
C_{53}	(0.4502, 0.3909)	28
C_{54}	(0.6094, 0.3909)	19
C_{55}	(0.6622, 0.3909)	10
C_{56}	(0.5624, 0.3909)	26
C_{57}	(0.5221, 0.3909)	27

Table 7.12: Evaluation of ranking order for agile attributes

C_{ij}	Radius of gyration point (r_x ,r_y)	Ranking order
C_{11}	(0.5015, 0.3909)	10
C_{12}	(0.7424, 0.3909)	1
C_{13}	(0.5763, 0.3909)	9
C_{21}	(0.6843, 0.3909)	5
C_{22}	(0.6661, 0.3909)	8
C_{23}	(0.7314, 0.3909)	2
C_{31}	(0.6704, 0.3909)	6
C_{32}	(0.7064, 0.3909)	4
C_{41}	(0.7203, 0.3909)	3
C_{42}	(0.6689, 0.3909)	7
C_{43}	(0.6843, 0.3909)	5

Table 7.13: Evaluation of ranking order for leagile attributes

C_{ij}	Radius of gyration point (r_x ,r_y)	Ranking order
C_{11}	(0.5470, 0.3909)	14
C_{12}	(0.6593, 0.3909)	5
C_{13}	(0.7328, 0.3909)	1
C_{14}	(0.5734, 0.3909)	12
C_{21}	(0.6953, 0.3909)	3
C_{22}	(0.6219, 0.3909)	8
C_{23}	(0.6248, 0.3909)	7
C_{24}	(0.7050, 0.3909)	2
C_{31}	(0.6829, 0.3909)	4
C_{32}	(0.6315, 0.3909)	6
C_{33}	(0.5763, 0.3909)	11
C_{34}	(0.6109, 0.3909)	9
C_{41}	(0.5720, 0.3909)	13
C_{42}	(0.6013, 0.3909)	10
C_{43}	(0.6109, 0.3909)	9

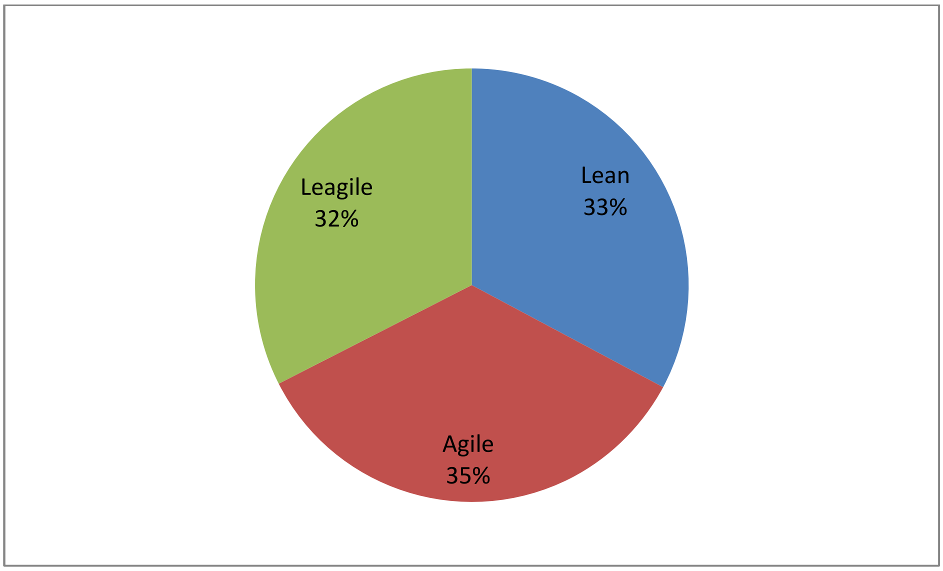

Fig. 7.2: Comparison on organizational leanness, agility as well as leagility extent

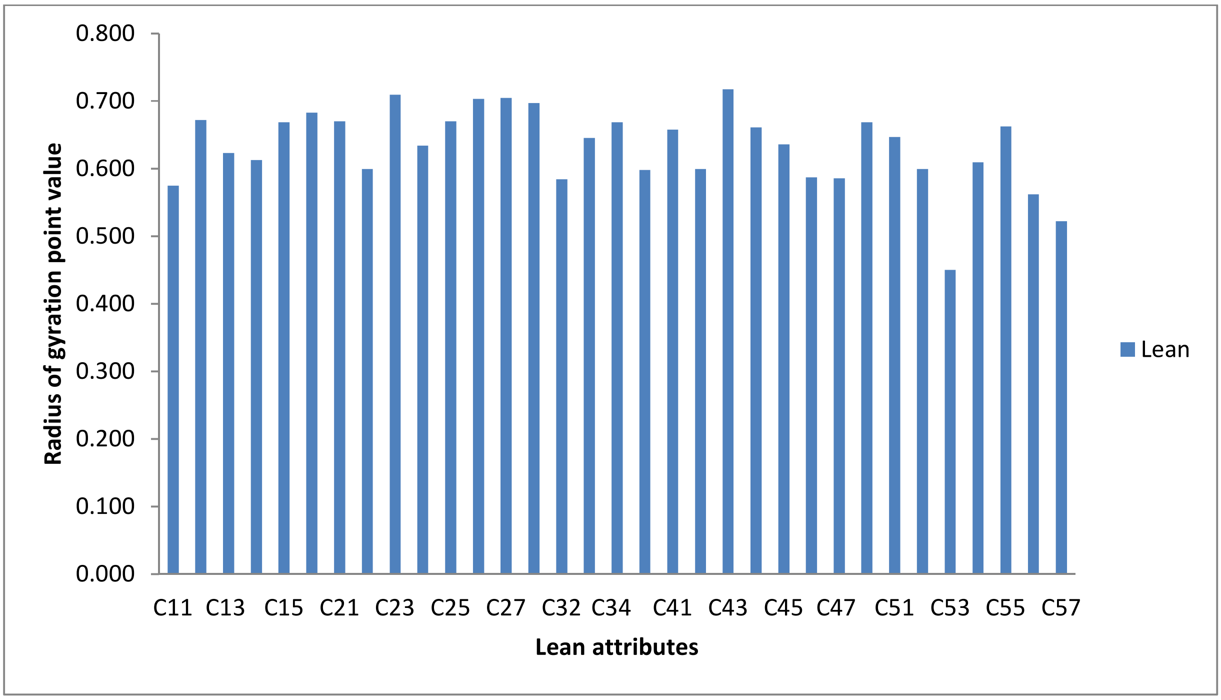

Fig. 7.3: Lean attribute ranking

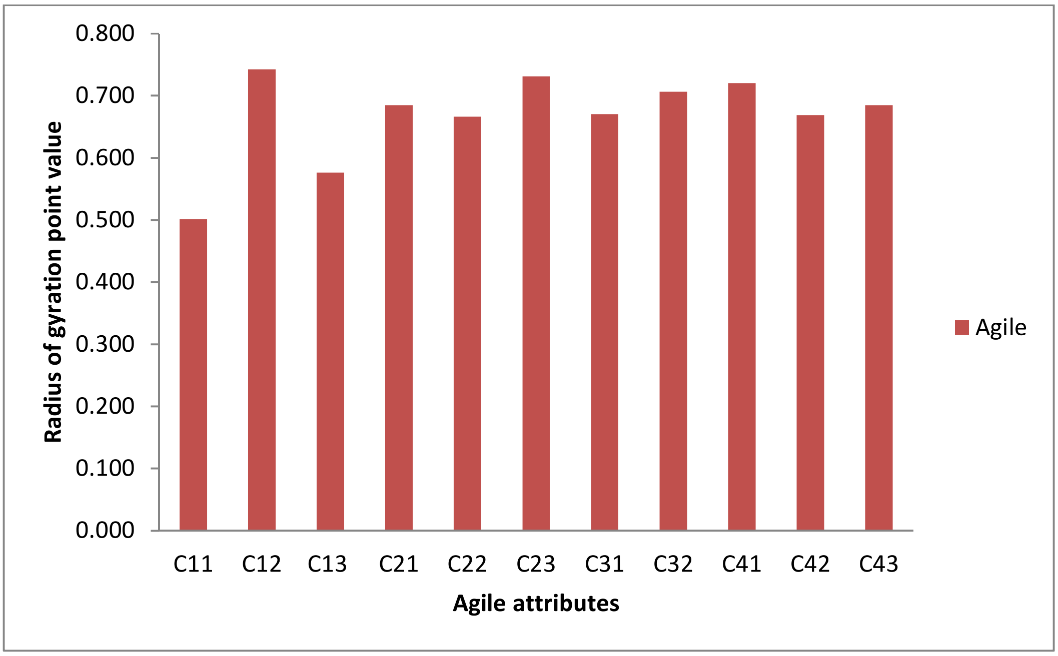

Fig. 7.4: Agile attribute ranking

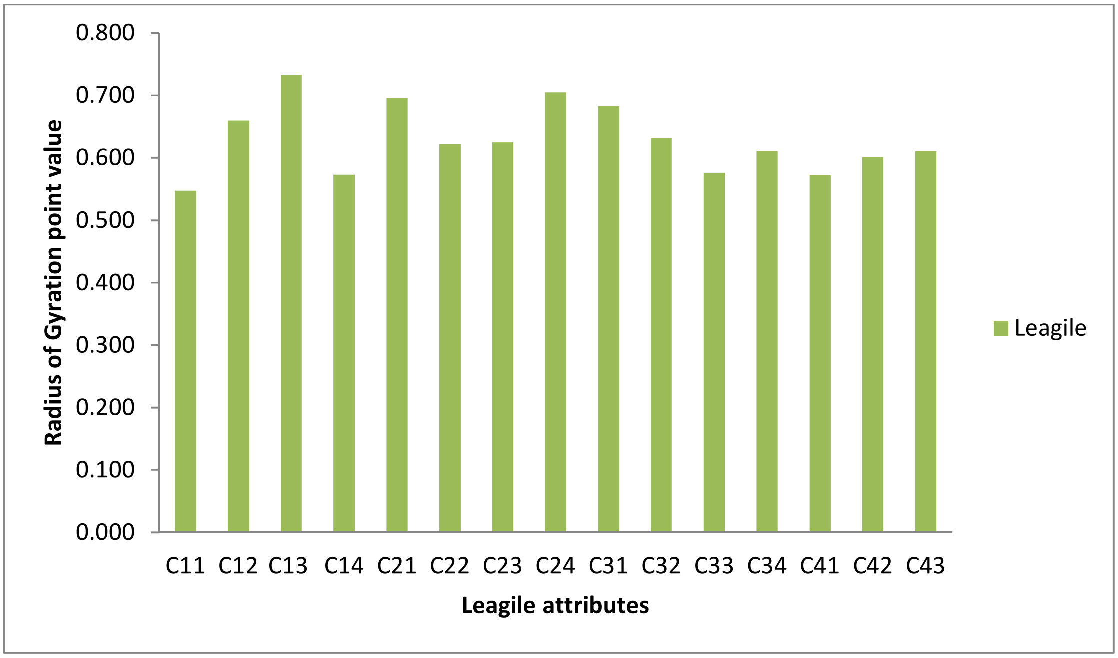

Fig. 7.5: Leagile attribute ranking

Appendix E

Survey Questionnaire

Organizational supply chain leanness: Lean manufacturing, lean enterprise, or lean production, often simply, "lean", is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Working from the perspective of the customer who consumes a product or service, "value" is defined as any action or process that a customer would be willing to pay for.

Organizational supply chain Agility: Introduction of velocity, flexibility and responsiveness into manufacturing

Leagility in Organizational Supply Chain: Lean+Agile principles

Organizational leanness, agility and leagility appraisement

Thank you for participating in this survey. It is assured that all information will be treated as confidential and only be used for academic purposes.

When assessing individual evaluation indices; it is preferable that you SHOULD NOT focus on a particular product/service or project in relation to your organization. Please think in general terms (from your experience) on projects/products/services (as a whole) related to your organizational supply chain.

Respondent's Name: ……………………………………………………………………………………………………….
Job Title: ………
Company Name: ………...
Division: ………...
City: …………………………… State: ……………………… Zip: ……………………… Country: ……………………….
E-mail: …………………………………………………………………… Telephone: ………………………………………...

General information [Please put √ mark]

1. My years of Experience in this organization is:

   (a) 0- 5 years, (b) 5- 10 years, (c) 10- 15 years, (d) 15- 20 years, (e) 20+ years

2. I would rate my knowledge pertaining these assessment aspects (leanness, agility, leagility) as:

   (a) Excellent (b) Good (c) Fair (d) Poor

Lean Performance Evaluation (Questionnaire 1)

[Please put √ mark against your choice]

Leanness attributes (Evaluation indices)	Unsatisfactory	Poor	Medium	Satisfactory	Excellent
Smooth information flow					
Team management for decision-making					
Interchangeability of personnel					
Clearly known management goals					
Management involvement					
Transparency in information sharing					
Prevalence of continuous improvement culture					
Empowerment of personnel to resolve customer problem					
Employee's attitude tuned to accept the changes					
Conduct of pilot study on new					
Produce small lot size					
JIT delivery to customers					
Optimization of processing sequence and flow in shop floor					
Flexible workforce to adapt the adaptation of new technologies					
Multi-skilled personnel					
Implementation of job rotation system					
Strong employee spirit and cooperation					
Employee empowerment					
Identification and prioritization of critical machines					
Implementation of TPM techniques					
Maintenance of installed machines					
Implementation of Poka-Yoke					
Usage of ANDON device					
Introduction of card system					
Products designed for easy serviceability					
Service centers well equipped with spares					
Standardization of components					
Systematic process control					

Leanness attributes (Evaluation indices) (Continued)	**Unsatisfactory**	**Poor**	**Medium**	**Satisfactory**	**Excellent**
Products exceeding customer's expectations					
Conduct of survey/studies to ensure quality status					
Use of TQM tools					
Productivity linked to the personnel prosperity					
Reduction of non-value adding cost					

Agile Performance Evaluation (Questionnaire 2)

[Please put √ mark against your choice]

Agile attributes (Evaluation indices)	**Unsatisfactory**	**Poor**	**Medium**	**Satisfactory**	**Excellent**
Sourcing flexibility					
Manufacturing flexibility					
Delivery flexibility					
Sourcing responsiveness					
Manufacturing responsiveness					
Delivery responsiveness					
Cooperation and internal-external balance					
Capabilities of human resources					
Sourcing cost					
Manufacturing cost					
Delivery cost					

Leagile (Lean+Agile) Performance Evaluation (Questionnaire 3)

[Please put √ mark against your choice]

Leagile attributes (Evaluation indices)	Unsatisfactory	Poor	Medium	Satisfactory	Excellent
Product cycle time					
Due-date performance					
Cost					
Quality					
Customer satisfaction					
Delivery dependability					
Responsiveness					
Order fill capacity					
Product design flexibility					
Sourcing flexibility					
Manufacturing flexibility					
IT flexibility					
Market share					
Return on investment					
Green image					

CHAPTER 8

CONTRIBUTIONS AND FUTURE SCOPE

The contributions of the present dissertation have been pointed out below.

- Exploration of ISM (Interpretive Structural Modeling) approach in understanding interrelationships amongst major enablers/capabilities of lean, agile and leagile manufacturing, separately. The major capabilities of lean manufacturing that have been investigated viz. (i) management responsibility, (ii) manufacturing management leanness, (iii) work force leanness, (iv) technology leanness, and (v) manufacturing strategy leanness. Flexibility, responsiveness, competency and cost have been considered as major agile enablers; whereas, (i) virtual enterprises, (ii) collaborative relationships, (iii) strategic management, (iv) knowledge and IT management, and (v) customer and market sensitiveness have been treated as major capabilities/drivers of leagile manufacturing.

- Development of decision support systems (DSS) towards estimating unique evaluation metric for organizational leanness. Theories of (i) generalized fuzzy numbers set, (ii) generalized interval-valued fuzzy numbers set, as well as (iii) grey numbers set have been utilized to facilitate leanness appraisement modeling for organizational supply chain.

- Aforesaid leanness appraisement decision support modules have been extended towards identifying ill-performing supply chain entities through performance ranking of lean criterions. The theory of fuzzy numbers ranking by '*Maximizing Set and Minimizing Set*' has been adapted at this stage for lean criteria ranking. In this DSS, three types of decision-makers (DMs having different risk bearing attitude) i.e. pessimistic $(\alpha = 0)$, neutral or moderate $(\alpha = 0.5)$, and optimistic $(\alpha = 1)$ have been considered, and thereby, the effect of different decision-making attitude on lean criteria ranking has been investigated as well. In the proposed lean extent appraisement module using generalized interval-valued fuzzy numbers set theory, the concept of '*Degree of Similarity*' (DOS) (between two interval-valued fuzzy numbers) has been utilized towards identifying ill-performing lean criterions (lean barriers).

- In the proposed DSS towards lean metric appraisement in 'grey context', the concept of *Overall Grey Performance Index (OGPI)* to represent organizational overall leanness extent; the concepts of *Grey Performance Importance Index (GPII)* and the '*grey possibility degree*' (between two grey numbers) have been fruitfully explored for identifying lean barriers. This seems to be the unique contribution of the present dissertation deserves mention.

- Agility appraisement module has been attempted in fuzzy environment. The work utilized generalized trapezoidal fuzzy numbers set theory. Apart from estimating overall agility index, the study has also been extended to identify various agile barriers. The theory of fuzzy numbers ranking by '*Maximizing Set and Minimizing Set*' approach and the concept of fuzzy DOS as proposed by pioneers have been simultaneously utilized for evaluating performance ranking order of agile criterions. The study has proved the application potential of the concept of DOS as an alternative mean (as compared to '*Maximizing Set and Minimizing Set*' theory) in order to identify obstacles of agility (agile barriers).

- Supplier/partner selection module (in agile supply chain) has been articulated in this work by exploring the concept of vague numbers set theory. Application of vague set based DSS has been compared with fuzzy embedded DSS. The work exhibits application potential of vague set in agile suppliers' selection decision-making; which seems quite new and hardly found in existing literature.

- Combining salient features of lean and agile manufacturing, an integrated criteria hierarchy (general hierarchy criteria) has been developed to support a leagility driven supply chain. Aforesaid evaluation index system has been constructed consisting of leagile enablers, attributes as well as criterions. A fuzzy embedded leagility evaluation module has been proposed. Apart from estimating overall leagility index at an organizational level (its supply chain), the work has been extended towards identifying ill-performing SC entities (barriers of leagile manufacturing). The concept of '*Incentre of Centroids*' (for ranking of generalized trapezoidal fuzzy numbers) has been utilized at this stage for evaluating performance ranking order of leagile criterions thus facilitating in identifying obstacles towards effective implementation of leagile strategy in the organizational supply chain.

- A fuzzy based decision support system has been proposed for performance appraisal as well as performance benchmarking of candidate industries operating under similar 'leagility inspired' supply chain construct. The theory of generalized interval-valued fuzzy numbers set theory, the concept of fuzzy 'Degree of Similarity' adapted from fuzzy set theory and the concept of 'closeness coefficient' (also called relative closeness or closeness ratio) adapted from TOPSIS have been integrated logically to develop a sound decision-making module for performance benchmarking of leagile alternatives. Through performance benchmarking, best practices of leagility driven supply chain can easily be identified and transmitted to the others. Organizations can follow their peers in order to achieve desired level of leagility.

- Finally, the case study performed in a famous automotive sector (located at Tamil Nadu, INDIA) reflects procedural steps and implementation pathways of the proposed fuzzy based decision support system towards estimating a quantitative (fuzzy) performance metric (overall assessment index) of organizational leanness, agility as well as leagility, respectively. It has been observed that the agile performance has appeared the highest for the case organization.

The limitations of the present work have been indicated below.

- According to (Sharifi, et al., 2001) four elements are required to shape the agile manufacturing:

1. **Agility Drivers** (drivers of agility): Factors that drive and guide the company in the pursuit of agility: (Example: market trends, competitor's actions, customer's desires etc.)
2. **Strategic Abilities:** widely regarded as an attribute in agile organizations;
3. **Agility Capabilities** (skills that enable agility): Features that the company should seek to become agile. (Example: Flexibility, competence, response speed etc.)
4. **Agility Providers:** The factors available at the company that can provide agility. (Example: Trained and qualified personnel, advanced technologies and organization, working in an integrated manner.

[Source: Sharifi H, Colquhoun G, Barclay I, Dann Z, Agile manufacturing: a management and operational framework, *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, 215(6) (2001): 857-869]

Though there is a slight demarcation between capabilities and providers; however, in Chapter 2, the terminologies viz. capabilities/enablers/providers have been assumed synonymous. Also, in Chapters 3-7, the general hierarchy criteria (evaluation index system) thus adapted here for assessing organizational leanness/agility/leagility, respectively, has been made comprised of various capabilities-attributes as well as criterions in a 3-level integrated evaluation platform. In the 1st level, the evaluation indices have been referred as capabilities/providers; whereas, in the 2nd and 3rd level, various evaluation indices have been denoted as attributes and criterions, respectively.

- The General Hierarchy Criteria (GHC), also called evaluation index system, towards estimating an equivalent quantitative metric (for lean/agile/leagile supply chain, respectively), has been adapted from past literature. The evaluation index system mostly consists of 3-levels comprising various lean/agile/leagile capabilities/enablers (at 1^{st} level), attributes (at 2^{nd} level) and criterions (at 3^{rd} level). In some cases, only 2-level criteria hierarchy has been explored. However, aforementioned criteria hierarchies have not been standardized. It has not been tested whether these criteria hierarchies are industry-specific (example: manufacturing or service sector) or may tend to vary from one industry/organization to another depending on the particular supply chain construct.

- The linguistic scale and corresponding representative fuzzy/grey numbers scale thus chosen for collecting expert opinion (human judgment) have been taken from existing literature. However, sensitivity of these scales has not been tested. In the proposed fuzzy based decision support systems, fuzzy numbers with a variety of membership functions have been explored (viz. triangular/trapezoidal/interval-valued fuzzy numbers). It is felt necessary to investigate which fuzzy number (corresponding membership function) is capable of providing the most reliable prediction result.

- Decision-makers (experts) play an important role in decision-making. Due to involvement of ill-defined evaluation indices (of lean/agile/leagile manufacturing), decision-making has to rely on subjective judgment of the decision-makers. Since human judgment often carries some extent of ambiguity and vagueness; it is necessary to transform the linguistic expert opinion into appropriate fuzzy/grey/vague numbers. This can further be analyzed through mathematics of fuzzy/grey/vague set theories. In such a decision-making process, the optimal number of decision-makers needed to participate to reach a concrete and feasible decision outcome, is completely unknown. Literature also seems to be silent on this aspect. That's why, in the present work, it has been assumed that the decision-making group (expert panel) has been constituted by the industry top management itself.

- The proposed decision support systems (towards appraising leanness, agility as well as leagility) have been extended to identify ill-performing supply chain entities (barriers of lean/agile/leagile manufacturing) through performance ranking of various evaluation indices (criterions). However, the necessary action plan (future work plan) has not been recommended to overcome those obstacles in order to boost up extent of organizational leanness/agility/leagility degree.

- Various decision support systems have been proposed here towards appraising organizational leanness/agility/leagility followed by suppliers' selection (in agile supply chain). Theories of fuzzy set, grey set as well as vague set have been explored. However, decision support systems thus developed herein have not been validated through reliability testing as well as sensitivity analysis.

- In the proposed fuzzy based decision support system in which the concept of generalized fuzzy numbers set theory has been utilized for lean/agile metric evaluation for the case empirical organization, the approach of fuzzy numbers ranking by 'Maximizing Set and Minimizing Set' has been adapted towards deriving performance ranking order of lean/agile criterions. Such performance ranking can help in identifying lean/agile barriers. Here, three types of decision-makers (pessimistic, neutral and optimistic) i.e. three different decision-making attitudes of the decision-makers have been considered. However, the effect of decision-making environment in the final decision outcome has not been investigated.

- In Chapter 6, a fuzzy embedded decision support system has been developed towards performance appraisement and benchmarking of alternative industries which have adapted/implemented leagile strategies. It has been assumed that the candidate industries have already achieved leagility to a varied degree and they have been operating under similar supply chain construct (leagility inspired SC). It is worth of investigating how leagile performance could be compared and benchmarked amongst different industries having different supply chain construct.

Aforementioned aspects may be investigated in future work.

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LIST OF PUBLICATIONS

Journal Publications

1. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, 2013, *Agility Appraisement and Identification of Agile Barriers in a Supply Chain*, **International Journal of Services and Operations Management**, 16(4): 478-505, Inderscience Publishers, Switzerland.
2. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, 2013, *Interrelationship of Capabilities/Enablers for Lean, Agile and Leagile Manufacturing: An ISM Approach*, **International Journal of Process Management and Benchmarking**, 3(3): 290-313, Inderscience Publishers, Switzerland.
3. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, 2014, *Leanness Estimation Procedural Hierarchy using Interval-Valued Fuzzy Sets (IVFS)*, **Benchmarking: an International Journal**, 21(2): 150-183, Emerald Group Publishing Limited, UK.
4. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Leanness Metric Evaluation Platform in Fuzzy Context*, **Journal of Modelling in Management**, Emerald Group Publishing Limited, UK. **(Accepted)**
5. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, 2014, *Lean Metric Appraisement using grey numbers*, **Grey Systems: Theory and Applications**, 4(3): 400-425, Emerald Group Publishing Limited, UK.
6. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Supplier /Partner Selection in Agile Supply Chain: Application of Vague Set as a Decision Making Tool*, **Benchmarking: an International Journal**, Emerald Group Publishing Limited, UK. **(Accepted)**
7. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Evaluation Indices for Organizational Leanness, Agility and Leagility: A Case Research in an Indian Automotive Sector*, **International Journal of Agile Systems and Management**, Inderscience Publishers, Switzerland. **(Accepted)**

Publications in Proceedings of International/ National Conferences

1. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Analyzing Leanness Extent in Manufacturing using Grey Numbers*, Proceedings of National Conference on Emerging Challenges for Sustainable Business, June 1-2, 2012, Department of Management Studies, Indian Institute of Technology, Roorkee-247 667.
2. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Leanness Estimation in Fuzzy Context*, Proceeedings of the 3rd National Conference on Recent Advances in Manufacturing (RAM-2012), June 27-29, 2012, organized by Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat-395007.
3. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Supply Chain Agility Appraisement Module in Fuzzy Paradigm*, National Conference on Recent Trends in Operations and Supply Chain Management, August 4, 2012, organized by School of Management, Gautam Buddha University, Yamuna Expressway, Greater Noida-201310, Gautam Budh Nagar, UP.
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5. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Analyzing Lean Manufacturing in Fuzzy Context*, International Conference on Marketing Paradigms in Emerging Economies organized by Faculty of Management Studies, during 4-5 December, 2012 at Banaras Hindu University, Varanasi.
6. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Leagility Assessment using Fuzzy Logic*, World Congress on Frontiers of Mechanical, Aeronautical and Automobile Engineering (WCFMAAE-2013), organized by Krishi Sanskriti, on February 2-3, 2013 at Vishwakarma Bhawan, Shaheed Jeet Singh Marg, Indian Institute of Technology, Delhi, Hauzkhas, New Delhi-110016.
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9. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *Development of a Decision Support System for Leagility Assessment in Fuzzy Environment*, The 2013 Asia-Pacific International Congress on Engineering and Natural Sciences (APICENS 2013) held in Bangkok, Thailand, during 16-18 April, 2013.
10. Arup Gourab Sahoo, Santosh Kumar Sahu, **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *A Fuzzy Based Decision Support Framework towards Benchmarking of Enterprise (Supply Chain) Agility: An Empirical Research,* International Conference on Management of Marketing, Banking, Business and Finance for Sustainable Economy (MBFSE- 2014), organized by Social Welfare Foundation, during on 5-6 July, 2014, at Jawaharlal Nehru University, New Delhi.

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1. **Chhabi Ram Matawale**, Saurav Datta, Siba Sankar Mahapatra, *A Fuzzy Embedded Leagility Assessment Module in Supply Chain*, **Benchmarking: an International Journal**, Emerald Group Publishing Limited, UK.
2. **Chhabi Ram Matawale**, Saurav Datta, Kannan Govindan, Siba Sankar Mahapatra, *Supplier Selection in Agile Supply Chain: Application Potential of Fuzzy Multi-Level Multi-Criteria Decision Making Approach in Comparison with Fuzzy based Technique for Order Preference by Similarity to Ideal Solution and Fuzzy based Multi-Objective Optimization by Ratio Analysis*, **Computers and Industrial Engineering**, Elsevier Science.

Resume

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Matriculation	GHSS, Rajim	MP Board, Bhopal	General Subjects	1998	First
Intermediate	GHHSS, Raipur	MP Board, Bhopal	Mathematics	2000	Second
B. E.	Govt. Engineering College Bilaspur	GGDU, Bilaspur	Mechanical Engineering	2006	First
M. Tech.	IIT, Bombay	IIT, Bombay	Materials Science	2009	First
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CHHABI RAM MATAWALE

APPENDICES

APPENDIX-A (Additional Data Tables of Chapter 3)

Table 3.3: Appropriateness rating of lean criterions given by decision-makers

Leanness criterions $C_{i,j,k}$	Rating $U_{i,j,k}$	Appropriateness rating expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1,1}$	$U_{1,1,1}$	VG	VG	AG	AG	VG
$C_{1,1,2}$	$U_{1,1,2}$	G	G	G	G	G
$C_{1,1,3}$	$U_{1,1,3}$	G	VG	G	VG	VG
$C_{1,2,1}$	$U_{1,2,1}$	MG	MG	G	MG	MG
$C_{1,2,2}$	$U_{1,2,2}$	M	M	MG	M	M
$C_{1,2,3}$	$U_{1,2,3}$	VG	VG	G	VG	VG
$C_{2,1,1}$	$U_{2,1,1}$	MG	G	G	G	MG
$C_{2,1,2}$	$U_{2,1,2}$	G	G	G	G	G
$C_{2,2,1}$	$U_{2,2,1}$	G	G	G	G	G
$C_{2,2,2}$	$U_{2,2,2}$	VG	VG	G	G	G
$C_{2,3,1}$	$U_{2,3,1}$	M	MG	G	MG	M
$C_{2,3,2}$	$U_{2,3,2}$	MG	MG	MG	MG	MG
$C_{2,3,3}$	$U_{2,3,3}$	G	G	G	G	G
$C_{2,4,1}$	$U_{2,4,1}$	VG	AG	AG	AG	VG
$C_{2,4,2}$	$U_{2,4,2}$	G	G	G	G	G
$C_{2,4,3}$	$U_{2,4,3}$	G	VG	VG	VG	VG
$C_{2,5,1}$	$U_{2,5,1}$	MG	M	M	M	M
$C_{2,5,2}$	$U_{2,5,2}$	MP	M	M	M	MP
$C_{2,5,3}$	$U_{2,5,3}$	G	G	G	G	G
$C_{2,6,1}$	$U_{2,6,1}$	G	G	G	G	G
$C_{2,6,2}$	$U_{2,6,2}$	VG	AG	AG	AG	AG
$C_{2,6,3}$	$U_{2,6,3}$	VG	VG	G	G	G
$C_{2,7,1}$	$U_{2,7,1}$	G	G	G	G	VG
$C_{2,7,2}$	$U_{2,7,2}$	AG	G	VG	VG	G
$C_{2,8,1}$	$U_{2,8,1}$	M	M	MG	MG	MG
$C_{2,8,2}$	$U_{2,8,2}$	G	G	G	G	G
$C_{2,8,3}$	$U_{2,8,3}$	G	MG	G	G	MG
$C_{2,9,1}$	$U_{2,9,1}$	VG	G	G	G	G

$C_{2,9,2}$	$U_{2,9,2}$	G	G	G	G	G
$C_{2,10,1}$	$U_{2,10,1}$	M	M	MP	M	M
$C_{2,10,2}$	$U_{2,10,2}$	P	P	MP	M	M
$C_{3,1,1}$	$U_{3,1,1}$	MP	MP	MP	MP	M
$C_{3,1,2}$	$U_{3,1,2}$	MG	MG	MG	MG	MG
$C_{3,1,3}$	$U_{3,1,3}$	G	G	G	G	G
$C_{3,2,1}$	$U_{3,2,1}$	VG	AG	AG	AG	AG
$C_{3,2,2}$	$U_{3,2,2}$	VG	VG	G	G	G
$C_{4,1,1}$	$U_{4,1,1}$	G	G	G	G	VG
$C_{4,1,2}$	$U_{4,1,2}$	AG	G	VG	VG	G
$C_{4,1,3}$	$U_{4,1,3}$	M	M	MG	MG	MG
$C_{4,1,4}$	$U_{4,1,4}$	G	G	G	G	G
$C_{4,2,1}$	$U_{4,2,1}$	VG	AG	AG	AG	VG
$C_{4,2,2}$	$U_{4,2,2}$	G	G	G	G	G
$C_{4,2,3}$	$U_{4,2,3}$	G	VG	VG	VG	VG
$C_{4,3,1}$	$U_{4,3,1}$	AG	G	VG	VG	G
$C_{4,3,2}$	$U_{4,3,2}$	M	M	MG	MG	MG
$C_{4,3,3}$	$U_{4,3,3}$	G	G	G	G	G
$C_{4,4,1}$	$U_{4,4,1}$	G	MG	G	G	MG
$C_{4,4,2}$	$U_{4,4,2}$	G	G	G	G	G
$C_{4,4,3}$	$U_{4,4,3}$	M	M	MP	M	M
$C_{4,4,4}$	$U_{4,4,4}$	P	P	MP	M	M
$C_{4,5,1}$	$U_{4,5,1}$	MP	MP	MP	MP	M
$C_{4,5,2}$	$U_{4,5,2}$	VG	VG	VG	VG	VG
$C_{4,6,1}$	$U_{4,6,1}$	G	G	G	G	G
$C_{4,6,2}$	$U_{4,6,2}$	VG	VG	AG	AG	VG
$C_{4,6,3}$	$U_{4,6,3}$	G	G	G	G	G
$C_{4,7,1}$	$U_{4,7,1}$	G	VG	G	VG	VG
$C_{4,7,2}$	$U_{4,7,2}$	MG	MG	G	MG	MG
$C_{4,7,3}$	$U_{4,7,3}$	MG	G	MG	G	MG
$C_{4,8,1}$	$U_{4,8,1}$	M	M	M	MG	M
$C_{4,8,2}$	$U_{4,8,2}$	MG	MG	MG	MG	G
$C_{4,8,3}$	$U_{4,8,3}$	AG	G	VG	VG	G
$C_{4,9,1}$	$U_{4,9,1}$	M	M	MG	MG	MG

$C_{4,9,2}$	$U_{4,9,2}$	G	G	G	G	G
$C_{4,9,3}$	$U_{4,9,3}$	G	MG	G	G	MG
$C_{4,9,4}$	$U_{4,9,4}$	AG	G	G	G	VG
$C_{4,9,5}$	$U_{4,9,5}$	G	G	MG	G	G
$C_{5,1,1}$	$U_{5,1,1}$	VG	VG	AG	AG	VG
$C_{5,1,2}$	$U_{5,1,2}$	G	G	G	G	G
$C_{5,1,3}$	$U_{5,1,3}$	G	VG	G	VG	VG
$C_{5,2,1}$	$U_{5,2,1}$	MG	MG	G	MG	MG
$C_{5,2,2}$	$U_{5,2,2}$	P	P	MP	M	M
$C_{5,2,3}$	$U_{5,2,3}$	MP	MP	MP	MP	M
$C_{5,3,1}$	$U_{5,3,1}$	VG	VG	VG	VG	VG
$C_{5,3,2}$	$U_{5,3,2}$	G	G	VG	G	G
$C_{5,3,3}$	$U_{5,3,3}$	AG	G	VG	VG	G
$C_{5,3,4}$	$U_{5,3,4}$	M	M	MG	MG	MG
$C_{5,4,1}$	$U_{5,4,1}$	G	G	G	G	G
$C_{5,4,2}$	$U_{5,4,2}$	G	MG	G	G	MG
$C_{5,5,1}$	$U_{5,5,1}$	G	G	G	G	G
$C_{5,5,2}$	$U_{5,5,2}$	M	M	MP	M	M
$C_{5,6,1}$	$U_{5,6,1}$	P	P	MP	M	M
$C_{5,6,2}$	$U_{5,6,2}$	MP	MP	MP	MP	M
$C_{5,6,3}$	$U_{5,6,3}$	G	VG	VG	VG	VG
$C_{5,7,1}$	$U_{5,7,1}$	AG	G	VG	VG	G
$C_{5,7,2}$	$U_{5,7,2}$	M	M	MG	MG	MG

Table 3.4: Priority weight of lean criterions given by decision-makers

Leanness criterions $C_{i,j,k}$	Weight $w_{i,j,k}$	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1,1}$	$W_{1,1,1}$	AH	AH	AH	VH	VH
$C_{1,1,2}$	$W_{1,1,2}$	H	H	H	H	H
$C_{1,1,3}$	$W_{1,1,3}$	MH	H	H	H	H
$C_{1,2,1}$	$W_{1,2,1}$	MH	H	MH	H	H
$C_{1,2,2}$	$W_{1,2,2}$	VH	VH	VH	VH	VH
$C_{1,2,3}$	$W_{1,2,3}$	H	H	H	H	H
$C_{2,1,1}$	$W_{2,1,1}$	MH	MH	H	H	MH
$C_{2,1,2}$	$W_{2,1,2}$	AH	AH	AH	AH	AH
$C_{2,2,1}$	$W_{2,2,1}$	H	H	H	H	H
$C_{2,2,2}$	$W_{2,2,2}$	M	ML	MH	MH	MH
$C_{2,3,1}$	$W_{2,3,1}$	H	VH	H	VH	H
$C_{2,3,2}$	$W_{2,3,2}$	H	H	H	H	H
$C_{2,3,3}$	$W_{2,3,3}$	VH	AH	VH	H	H
$C_{2,4,1}$	$W_{2,4,1}$	MH	H	H	H	H
$C_{2,4,2}$	$W_{2,4,2}$	VH	H	VH	H	VH
$C_{2,4,3}$	$W_{2,4,3}$	H	H	H	H	H
$C_{2,5,1}$	$W_{2,5,1}$	H	H	H	H	H
$C_{2,5,2}$	$W_{2,5,2}$	H	H	H	VH	VH
$C_{2,5,3}$	$W_{2,5,3}$	MH	MH	H	H	MH
$C_{2,6,1}$	$W_{2,6,1}$	H	H	H	H	H
$C_{2,6,2}$	$W_{2,6,2}$	H	H	H	H	H
$C_{2,6,3}$	$W_{2,6,3}$	VH	AH	VH	H	H
$C_{2,7,1}$	$W_{2,7,1}$	MH	H	H	H	H
$C_{2,7,2}$	$W_{2,7,2}$	VH	H	VH	H	VH
$C_{2,8,1}$	$W_{2,8,1}$	MH	H	H	H	H
$C_{2,8,2}$	$W_{2,8,2}$	MH	H	MH	H	H
$C_{2,8,3}$	$W_{2,8,3}$	VH	VH	VH	VH	VH
$C_{2,9,1}$	$W_{2,9,1}$	H	H	H	H	H
$C_{2,9,2}$	$W_{2,9,2}$	MH	MH	H	H	MH

$C_{2,10,1}$	$W_{2,10,1}$	AH	AH	AH	AH	AH
$C_{2,10,2}$	$W_{2,10,2}$	H	H	H	H	H
$C_{3,1,1}$	$W_{3,1,1}$	M	ML	MH	MH	MH
$C_{3,1,2}$	$W_{3,1,2}$	H	H	H	H	VH
$C_{3,1,3}$	$W_{3,1,3}$	VH	VH	VH	VH	VH
$C_{3,2,1}$	$W_{3,2,1}$	H	H	H	H	H
$C_{3,2,2}$	$W_{3,2,2}$	H	VH	H	H	H
$C_{4,1,1}$	$W_{4,1,1}$	MH	MH	H	H	MH
$C_{4,1,2}$	$W_{4,1,2}$	AH	AH	AH	AH	AH
$C_{4,1,3}$	$W_{4,1,3}$	H	H	H	H	H
$C_{4,1,4}$	$W_{4,1,4}$	M	ML	MH	MH	MH
$C_{4,2,1}$	$W_{4,2,1}$	MH	MH	H	H	H
$C_{4,2,2}$	$W_{4,2,2}$	H	VH	H	H	H
$C_{4,2,3}$	$W_{4,2,3}$	AH	AH	VH	H	H
$C_{4,3,1}$	$W_{4,3,1}$	MH	H	H	H	H
$C_{4,3,2}$	$W_{4,3,2}$	MH	H	MH	H	H
$C_{4,3,3}$	$W_{4,3,3}$	VH	VH	VH	VH	VH
$C_{4,4,1}$	$W_{4,4,1}$	H	H	H	H	H
$C_{4,4,2}$	$W_{4,4,2}$	MH	H	H	H	H
$C_{4,4,3}$	$W_{4,4,3}$	MH	H	MH	H	H
$C_{4,4,4}$	$W_{4,4,4}$	VH	VH	VH	VH	VH
$C_{4,5,1}$	$W_{4,5,1}$	H	H	H	H	H
$C_{4,5,2}$	$W_{4,5,2}$	VH	H	VH	VH	VH
$C_{4,6,1}$	$W_{4,6,1}$	MH	H	M	M	MH
$C_{4,6,2}$	$W_{4,6,2}$	MH	MH	H	H	H
$C_{4,6,3}$	$W_{4,6,3}$	VH	VH	VH	H	VH
$C_{4,7,1}$	$W_{4,7,1}$	H	H	H	H	H
$C_{4,7,2}$	$W_{4,7,2}$	ML	M	M	M	M
$C_{4,7,3}$	$W_{4,7,3}$	H	MH	H	MH	H
$C_{4,8,1}$	$W_{4,8,1}$	MH	H	H	H	H
$C_{4,8,2}$	$W_{4,8,2}$	MH	H	MH	H	H
$C_{4,8,3}$	$W_{4,8,3}$	VH	VH	VH	VH	VH
$C_{4,9,1}$	$W_{4,9,1}$	H	H	H	H	H
$C_{4,9,2}$	$W_{4,9,2}$	MH	H	H	H	H

$C_{4,9,3}$	$W_{4,9,3}$	MH	H	MH	H	H
$C_{4,9,4}$	$W_{4,9,4}$	VH	VH	VH	VH	VH
$C_{4,9,5}$	$W_{4,9,5}$	H	H	H	H	H
$C_{5,1,1}$	$W_{5,1,1}$	MH	H	H	H	H
$C_{5,1,2}$	$W_{5,1,2}$	MH	H	MH	H	H
$C_{5,1,3}$	$W_{5,1,3}$	VH	VH	VH	VH	VH
$C_{5,2,1}$	$W_{5,2,1}$	H	H	H	H	H
$C_{5,2,2}$	$W_{5,2,2}$	VH	H	H	H	H
$C_{5,2,3}$	$W_{5,2,3}$	H	VH	H	H	VH
$C_{5,3,1}$	$W_{5,3,1}$	H	H	H	H	H
$C_{5,3,2}$	$W_{5,3,2}$	MH	H	H	H	H
$C_{5,3,3}$	$W_{5,3,3}$	MH	H	MH	H	H
$C_{5,3,4}$	$W_{5,3,4}$	VH	VH	VH	VH	VH
$C_{5,4,1}$	$W_{5,4,1}$	H	H	H	H	H
$C_{5,4,2}$	$W_{5,4,2}$	VH	VH	VH	VH	VH
$C_{5,5,1}$	$W_{5,5,1}$	H	H	VH	H	H
$C_{5,5,2}$	$W_{5,5,2}$	MH	H	H	H	H
$C_{5,6,1}$	$W_{5,6,1}$	MH	H	MH	H	H
$C_{5,6,2}$	$W_{5,6,2}$	VH	VH	VH	VH	VH
$C_{5,6,3}$	$W_{5,6,3}$	H	H	H	H	H
$C_{5,7,1}$	$W_{5,7,1}$	VH	H	H	VH	H
$C_{5,7,2}$	$W_{5,7,2}$	H	VH	H	H	VH

Table 3.5: Priority weight of lean attributes given by decision-makers

Leanness attributes $C_{i,j}$	Weight $w_{i,j}$	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	$W_{1,1}$	H	H	H	H	H
$C_{1,2}$	$W_{1,2}$	AH	H	H	AH	H
$C_{2,1}$	$W_{2,1}$	MH	MH	MH	MH	H
$C_{2,2}$	$W_{2,2}$	MH	H	VH	VH	VH
$C_{2,3}$	$W_{2,3}$	H	AH	AH	H	H
$C_{2,4}$	$W_{2,4}$	M	MH	MH	MH	H
$C_{2,5}$	$W_{2,5}$	AH	AH	AH	H	H
$C_{2,6}$	$W_{2,6}$	H	H	H	H	H
$C_{2,7}$	$W_{2,7}$	VH	AH	AH	VH	H
$C_{2,8}$	$W_{2,8}$	MH	VH	MH	H	VH
$C_{2,9}$	$W_{2,9}$	H	H	AH	H	VH
$C_{2,10}$	$W_{2,10}$	H	H	H	VH	VH
$C_{3,1}$	$W_{3,1}$	VH	VH	H	H	VH
$C_{3,2}$	$W_{3,2}$	MH	H	H	H	H
$C_{4,1}$	$W_{4,1}$	VH	VH	H	H	AH
$C_{4,2}$	$W_{4,2}$	VH	VH	VH	VH	VH
$C_{4,3}$	$W_{4,3}$	H	H	H	H	H
$C_{4,4}$	$W_{4,4}$	VH	VH	H	H	H
$C_{4,5}$	$W_{4,5}$	H	VH	H	VH	VH
$C_{4,6}$	$W_{4,6}$	VH	VH	VH	H	VH
$C_{4,7}$	$W_{4,7}$	H	H	AH	H	H
$C_{4,8}$	$W_{4,8}$	H	H	H	H	H
$C_{4,9}$	$W_{4,9}$	VH	H	VH	MH	H
$C_{5,1}$	$W_{5,1}$	H	H	H	H	VH
$C_{5,2}$	$W_{5,2}$	VH	VH	VH	H	VH
$C_{5,3}$	$W_{5,3}$	VH	H	VH	H	VH
$C_{5,4}$	$W_{5,4}$	AH	H	H	AH	AH
$C_{5,5}$	$W_{5,5}$	VH	H	VH	VH	VH
$C_{5,6}$	$W_{5,6}$	H	H	H	H	H
$C_{5,7}$	$W_{5,7}$	H	VH	VH	H	H

Table 3.6: Priority weight of lean enablers given by decision-makers

Lean enablers C_i	Weight w_i	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
C_1	W_1	VH	VH	H	H	H
C_2	W_2	AH	AH	VH	AH	VH
C_3	W_3	H	H	H	H	H
C_4	W_4	MH	H	H	VH	H
C_5	W_5	AH	VH	H	H	AH

Table 3.13: Appropriateness rating of lean criterions given by decision-makers

Leanness criterions $C_{i,j,k}$	Rating $U_{i,j,k}$	Appropriateness rating expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1,1}$	$U_{1,1,1}$	VG	VG	G	AG	VG
$C_{1,1,2}$	$U_{1,1,2}$	G	G	G	G	G
$C_{1,1,3}$	$U_{1,1,3}$	G	VG	G	VG	VG
$C_{1,2,1}$	$U_{1,2,1}$	MG	MG	G	MG	MG
$C_{1,2,2}$	$U_{1,2,2}$	M	M	G	M	M
$C_{1,2,3}$	$U_{1,2,3}$	VG	VG	G	VG	VG
$C_{2,1,1}$	$U_{2,1,1}$	MG	G	G	G	MG
$C_{2,1,2}$	$U_{2,1,2}$	G	G	G	G	G
$C_{2,2,1}$	$U_{2,2,1}$	G	G	G	G	G
$C_{2,2,2}$	$U_{2,2,2}$	VG	VG	G	G	G
$C_{2,3,1}$	$U_{2,3,1}$	M	MG	G	G	M
$C_{2,3,2}$	$U_{2,3,2}$	MG	MG	MG	MG	MG
$C_{2,3,3}$	$U_{2,3,3}$	G	G	G	G	G
$C_{2,4,1}$	$U_{2,4,1}$	VG	AG	AG	AG	VG
$C_{2,4,2}$	$U_{2,4,2}$	G	G	G	G	G
$C_{2,4,3}$	$U_{2,4,3}$	G	VG	VG	G	VG
$C_{2,5,1}$	$U_{2,5,1}$	MG	M	M	M	M
$C_{2,5,2}$	$U_{2,5,2}$	MP	M	M	M	MP
$C_{2,5,3}$	$U_{2,5,3}$	G	G	G	G	G
$C_{2,6,1}$	$U_{2,6,1}$	G	G	G	G	G
$C_{2,6,2}$	$U_{2,6,2}$	VG	AG	AG	AG	AG
$C_{2,6,3}$	$U_{2,6,3}$	VG	VG	G	G	G
$C_{2,7,1}$	$U_{2,7,1}$	G	G	G	G	VG
$C_{2,7,2}$	$U_{2,7,2}$	AG	G	VG	VG	G
$C_{2,8,1}$	$U_{2,8,1}$	M	M	MG	MG	MG
$C_{2,8,2}$	$U_{2,8,2}$	G	G	G	G	G
$C_{2,8,3}$	$U_{2,8,3}$	G	G	G	G	MG
$C_{2,9,1}$	$U_{2,9,1}$	VG	G	G	G	G
$C_{2,9,2}$	$U_{2,9,2}$	G	G	G	G	G
$C_{2,10,1}$	$U_{2,10,1}$	M	M	MP	M	M

$C_{2,10,2}$	$U_{2,10,2}$	P	P	MP	M	M
$C_{3,1,1}$	$U_{3,1,1}$	MP	MP	MP	MP	M
$C_{3,1,2}$	$U_{3,1,2}$	MG	MG	MG	MG	MG
$C_{3,1,3}$	$U_{3,1,3}$	G	G	G	G	G
$C_{3,2,1}$	$U_{3,2,1}$	VG	AG	VG	AG	AG
$C_{3,2,2}$	$U_{3,2,2}$	VG	VG	G	G	G
$C_{4,1,1}$	$U_{4,1,1}$	G	G	G	G	VG
$C_{4,1,2}$	$U_{4,1,2}$	AG	G	VG	VG	G
$C_{4,1,3}$	$U_{4,1,3}$	M	M	MG	MG	MG
$C_{4,1,4}$	$U_{4,1,4}$	G	G	G	G	G
$C_{4,2,1}$	$U_{4,2,1}$	VG	AG	AG	AG	VG
$C_{4,2,2}$	$U_{4,2,2}$	G	G	G	G	G
$C_{4,2,3}$	$U_{4,2,3}$	G	VG	VG	VG	VG
$C_{4,3,1}$	$U_{4,3,1}$	AG	G	VG	VG	G
$C_{4,3,2}$	$U_{4,3,2}$	M	M	MG	MG	MG
$C_{4,3,3}$	$U_{4,3,3}$	G	G	G	G	G
$C_{4,4,1}$	$U_{4,4,1}$	G	MG	G	G	MG
$C_{4,4,2}$	$U_{4,4,2}$	G	G	G	G	G
$C_{4,4,3}$	$U_{4,4,3}$	M	M	MP	M	M
$C_{4,4,4}$	$U_{4,4,4}$	P	P	MP	M	M
$C_{4,5,1}$	$U_{4,5,1}$	MP	MP	MP	MP	M
$C_{4,5,2}$	$U_{4,5,2}$	VG	G	VG	VG	VG
$C_{4,6,1}$	$U_{4,6,1}$	G	G	G	G	G
$C_{4,6,2}$	$U_{4,6,2}$	VG	VG	AG	AG	VG
$C_{4,6,3}$	$U_{4,6,3}$	G	G	G	G	G
$C_{4,7,1}$	$U_{4,7,1}$	G	VG	G	VG	VG
$C_{4,7,2}$	$U_{4,7,2}$	MG	MG	G	MG	MG
$C_{4,7,3}$	$U_{4,7,3}$	MG	G	MG	G	MG
$C_{4,8,1}$	$U_{4,8,1}$	M	M	M	MG	M
$C_{4,8,2}$	$U_{4,8,2}$	MG	MG	MG	G	G
$C_{4,8,3}$	$U_{4,8,3}$	AG	G	VG	VG	G
$C_{4,9,1}$	$U_{4,9,1}$	M	M	MG	MG	MG
$C_{4,9,2}$	$U_{4,9,2}$	G	G	G	G	G
$C_{4,9,3}$	$U_{4,9,3}$	G	MG	G	G	MG

$C_{4,9,4}$	$U_{4,9,4}$	AG	G	G	G	VG
$C_{4,9,5}$	$U_{4,9,5}$	G	G	MG	G	G
$C_{5,1,1}$	$U_{5,1,1}$	VG	VG	AG	AG	VG
$C_{5,1,2}$	$U_{5,1,2}$	G	G	G	G	G
$C_{5,1,3}$	$U_{5,1,3}$	G	VG	G	VG	VG
$C_{5,2,1}$	$U_{5,2,1}$	MG	MG	G	MG	MG
$C_{5,2,2}$	$U_{5,2,2}$	P	P	MP	M	M
$C_{5,2,3}$	$U_{5,2,3}$	MP	MP	MP	MP	M
$C_{5,3,1}$	$U_{5,3,1}$	VG	VG	VG	VG	VG
$C_{5,3,2}$	$U_{5,3,2}$	G	G	VG	G	G
$C_{5,3,3}$	$U_{5,3,3}$	AG	G	VG	VG	G
$C_{5,3,4}$	$U_{5,3,4}$	M	M	MG	MG	MG
$C_{5,4,1}$	$U_{5,4,1}$	G	G	G	G	G
$C_{5,4,2}$	$U_{5,4,2}$	G	MG	G	G	MG
$C_{5,5,1}$	$U_{5,5,1}$	G	G	G	G	G
$C_{5,5,2}$	$U_{5,5,2}$	M	M	MP	M	M
$C_{5,6,1}$	$U_{5,6,1}$	P	P	P	M	M
$C_{5,6,2}$	$U_{5,6,2}$	MP	MP	MP	MP	M
$C_{5,6,3}$	$U_{5,6,3}$	G	VG	VG	VG	VG
$C_{5,7,1}$	$U_{5,7,1}$	AG	G	VG	VG	G
$C_{5,7,2}$	$U_{5,7,2}$	M	M	MG	MG	MG

Table 3.14: Priority weight of lean criterions given by decision-makers

Leanness criterions $C_{i,j,k}$	Weight $W_{i,j,k}$	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1,1}$	$W_{1,1,1}$	AH	AH	AH	VH	VH
$C_{1,1,2}$	$W_{1,1,2}$	H	H	H	H	H
$C_{1,1,3}$	$W_{1,1,3}$	MH	H	H	H	H
$C_{1,2,1}$	$W_{1,2,1}$	MH	H	MH	H	H
$C_{1,2,2}$	$W_{1,2,2}$	VH	VH	VH	VH	VH
$C_{1,2,3}$	$W_{1,2,3}$	H	H	H	H	H
$C_{2,1,1}$	$W_{2,1,1}$	MH	MH	H	H	MH
$C_{2,1,2}$	$W_{2,1,2}$	AH	AH	AH	AH	AH
$C_{2,2,1}$	$W_{2,2,1}$	H	H	H	H	H
$C_{2,2,2}$	$W_{2,2,2}$	M	ML	M	MH	MH
$C_{2,3,1}$	$W_{2,3,1}$	H	VH	H	VH	H
$C_{2,3,2}$	$W_{2,3,2}$	H	H	H	H	H
$C_{2,3,3}$	$W_{2,3,3}$	VH	AH	VH	H	H
$C_{2,4,1}$	$W_{2,4,1}$	MH	H	H	H	H
$C_{2,4,2}$	$W_{2,4,2}$	VH	H	VH	H	VH
$C_{2,4,3}$	$W_{2,4,3}$	H	H	H	H	H
$C_{2,5,1}$	$W_{2,5,1}$	H	H	H	H	H
$C_{2,5,2}$	$W_{2,5,2}$	H	H	H	VH	VH
$C_{2,5,3}$	$W_{2,5,3}$	MH	MH	H	H	MH
$C_{2,6,1}$	$W_{2,6,1}$	H	H	H	H	H
$C_{2,6,2}$	$W_{2,6,2}$	H	H	H	H	H
$C_{2,6,3}$	$W_{2,6,3}$	VH	AH	VH	H	H
$C_{2,7,1}$	$W_{2,7,1}$	MH	H	H	H	H
$C_{2,7,2}$	$W_{2,7,2}$	VH	H	VH	H	VH
$C_{2,8,1}$	$W_{2,8,1}$	MH	H	H	H	H
$C_{2,8,2}$	$W_{2,8,2}$	MH	H	MH	H	H
$C_{2,8,3}$	$W_{2,8,3}$	VH	VH	VH	VH	VH
$C_{2,9,1}$	$W_{2,9,1}$	H	H	H	H	H
$C_{2,9,2}$	$W_{2,9,2}$	MH	MH	H	H	MH
$C_{2,10,1}$	$W_{2,10,1}$	AH	AH	AH	AH	AH

$C_{2,10,2}$	$W_{2,10,2}$	H	H	H	H	H
$C_{3,1,1}$	$W_{3,1,1}$	M	ML	M	MH	MH
$C_{3,1,2}$	$W_{3,1,2}$	H	H	H	H	VH
$C_{3,1,3}$	$W_{3,1,3}$	VH	VH	VH	VH	VH
$C_{3,2,1}$	$W_{3,2,1}$	H	H	H	H	H
$C_{3,2,2}$	$W_{3,2,2}$	H	VH	H	H	H
$C_{4,1,1}$	$W_{4,1,1}$	MH	MH	H	H	MH
$C_{4,1,2}$	$W_{4,1,2}$	AH	AH	AH	AH	AH
$C_{4,1,3}$	$W_{4,1,3}$	H	H	H	H	H
$C_{4,1,4}$	$W_{4,1,4}$	M	ML	MH	MH	MH
$C_{4,2,1}$	$W_{4,2,1}$	MH	MH	H	H	H
$C_{4,2,2}$	$W_{4,2,2}$	H	VH	H	H	H
$C_{4,2,3}$	$W_{4,2,3}$	AH	AH	VH	VH	H
$C_{4,3,1}$	$W_{4,3,1}$	MH	H	H	H	H
$C_{4,3,2}$	$W_{4,3,2}$	MH	H	MH	H	H
$C_{4,3,3}$	$W_{4,3,3}$	VH	VH	VH	VH	VH
$C_{4,4,1}$	$W_{4,4,1}$	H	H	H	H	H
$C_{4,4,2}$	$W_{4,4,2}$	MH	H	H	H	H
$C_{4,4,3}$	$W_{4,4,3}$	MH	H	MH	H	H
$C_{4,4,4}$	$W_{4,4,4}$	VH	VH	VH	VH	VH
$C_{4,5,1}$	$W_{4,5,1}$	H	H	H	H	H
$C_{4,5,2}$	$W_{4,5,2}$	VH	H	VH	VH	VH
$C_{4,6,1}$	$W_{4,6,1}$	MH	H	M	M	MH
$C_{4,6,2}$	$W_{4,6,2}$	MH	MH	H	H	H
$C_{4,6,3}$	$W_{4,6,3}$	VH	VH	VH	H	VH
$C_{4,7,1}$	$W_{4,7,1}$	H	H	H	H	H
$C_{4,7,2}$	$W_{4,7,2}$	ML	M	M	M	M
$C_{4,7,3}$	$W_{4,7,3}$	H	MH	H	MH	H
$C_{4,8,1}$	$W_{4,8,1}$	MH	H	H	H	H
$C_{4,8,2}$	$W_{4,8,2}$	MH	H	MH	H	H
$C_{4,8,3}$	$W_{4,8,3}$	VH	VH	VH	VH	VH
$C_{4,9,1}$	$W_{4,9,1}$	H	H	H	H	H
$C_{4,9,2}$	$W_{4,9,2}$	MH	H	MH	H	H
$C_{4,9,3}$	$W_{4,9,3}$	MH	H	MH	H	H

$C_{4,9,4}$	$W_{4,9,4}$	VH	VH	VH	VH	VH
$C_{4,9,5}$	$W_{4,9,5}$	H	H	H	H	H
$C_{5,1,1}$	$W_{5,1,1}$	MH	H	H	H	H
$C_{5,1,2}$	$W_{5,1,2}$	MH	H	MH	H	H
$C_{5,1,3}$	$W_{5,1,3}$	VH	VH	VH	VH	VH
$C_{5,2,1}$	$W_{5,2,1}$	H	H	H	H	H
$C_{5,2,2}$	$W_{5,2,2}$	VH	H	H	H	H
$C_{5,2,3}$	$W_{5,2,3}$	H	VH	H	H	VH
$C_{5,3,1}$	$W_{5,3,1}$	H	H	H	H	H
$C_{5,3,2}$	$W_{5,3,2}$	MH	H	H	H	H
$C_{5,3,3}$	$W_{5,3,3}$	MH	H	MH	H	H
$C_{5,3,4}$	$W_{5,3,4}$	VH	VH	VH	VH	VH
$C_{5,4,1}$	$W_{5,4,1}$	H	H	H	H	H
$C_{5,4,2}$	$W_{5,4,2}$	VH	VH	VH	VH	VH
$C_{5,5,1}$	$W_{5,5,1}$	H	H	VH	H	H
$C_{5,5,2}$	$W_{5,5,2}$	MH	H	H	H	H
$C_{5,6,1}$	$W_{5,6,1}$	MH	H	MH	H	H
$C_{5,6,2}$	$W_{5,6,2}$	VH	VH	H	VH	VH
$C_{5,6,3}$	$W_{5,6,3}$	H	H	H	H	H
$C_{5,7,1}$	$W_{5,7,1}$	VH	H	H	VH	H
$C_{5,7,2}$	$W_{5,7,2}$	H	VH	H	H	VH

Table 3.15: Priority weight of lean attributes given by decision-makers

Leanness attributes $C_{i,j}$	Weight $W_{i,j}$	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	$W_{1,1}$	H	H	H	H	H
$C_{1,2}$	$W_{1,2}$	AH	H	H	AH	H
$C_{2,1}$	$W_{2,1}$	MH	MH	MH	MH	H
$C_{2,2}$	$W_{2,2}$	MH	H	VH	VH	VH
$C_{2,3}$	$W_{2,3}$	H	AH	H	H	H
$C_{2,4}$	$W_{2,4}$	M	MH	MH	MH	H
$C_{2,5}$	$W_{2,5}$	AH	AH	AH	H	H
$C_{2,6}$	$W_{2,6}$	H	H	H	H	H
$C_{2,7}$	$W_{2,7}$	VH	AH	AH	VH	H
$C_{2,8}$	$W_{2,8}$	MH	VH	MH	H	VH
$C_{2,9}$	$W_{2,9}$	H	H	H	H	VH
$C_{2,10}$	$W_{2,10}$	H	H	H	VH	VH
$C_{3,1}$	$W_{3,1}$	VH	VH	H	H	VH
$C_{3,2}$	$W_{3,2}$	MH	H	H	H	H
$C_{4,1}$	$W_{4,1}$	VH	VH	H	H	AH
$C_{4,2}$	$W_{4,2}$	VH	VH	VH	VH	VH
$C_{4,3}$	$W_{4,3}$	H	H	H	VH	H
$C_{4,4}$	$W_{4,4}$	VH	VH	H	H	H
$C_{4,5}$	$W_{4,5}$	H	VH	H	VH	VH
$C_{4,6}$	$W_{4,6}$	VH	VH	VH	H	VH
$C_{4,7}$	$W_{4,7}$	H	H	AH	H	H
$C_{4,8}$	$W_{4,8}$	H	H	H	H	H
$C_{4,9}$	$W_{4,9}$	VH	H	VH	MH	H
$C_{5,1}$	$W_{5,1}$	H	H	H	H	VH
$C_{5,2}$	$W_{5,2}$	VH	VH	VH	H	VH
$C_{5,3}$	$W_{5,3}$	VH	H	VH	H	VH
$C_{5,4}$	$W_{5,4}$	AH	H	H	H	AH
$C_{5,5}$	$W_{5,5}$	VH	H	VH	VH	VH
$C_{5,6}$	$W_{5,6}$	H	H	H	H	H
$C_{5,7}$	$W_{5,7}$	H	VH	VH	H	H

Table 3.16: Priority weight of lean enablers given by decision-makers

Lean enablers C_i	Weight W_i	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
C_1	W_1	VH	VH	H	VH	H
C_2	W_2	AH	AH	AH	AH	VH
C_3	W_3	H	H	H	H	H
C_4	W_4	MH	H	MH	VH	H
C_5	W_5	AH	VH	H	H	AH

Table 3.23: Appropriateness rating of lean criterions given by decision-makers

Leanness criterions $C_{i,j,k}$	Rating $U_{i,j,k}$	Appropriateness rating expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1,1}$	$U_{1,1,1}$	VG	VG	VG	VG	VG
$C_{1,1,2}$	$U_{1,1,2}$	G	G	G	G	G
$C_{1,1,3}$	$U_{1,1,3}$	G	VG	G	VG	VG
$C_{1,2,1}$	$U_{1,2,1}$	MG	MG	G	MG	MG
$C_{1,2,2}$	$U_{1,2,2}$	M	M	MG	M	M
$C_{1,2,3}$	$U_{1,2,3}$	VG	VG	G	VG	VG
$C_{2,1,1}$	$U_{2,1,1}$	MG	G	G	G	MG
$C_{2,1,2}$	$U_{2,1,2}$	G	G	G	G	G
$C_{2,2,1}$	$U_{2,2,1}$	G	G	G	G	G
$C_{2,2,2}$	$U_{2,2,2}$	VG	VG	G	G	G
$C_{2,3,1}$	$U_{2,3,1}$	M	MG	G	MG	M
$C_{2,3,2}$	$U_{2,3,2}$	MG	MG	MG	MG	MG
$C_{2,3,3}$	$U_{2,3,3}$	G	G	G	G	G
$C_{2,4,1}$	$U_{2,4,1}$	VG	VG	VG	VG	VG
$C_{2,4,2}$	$U_{2,4,2}$	G	G	G	G	G
$C_{2,4,3}$	$U_{2,4,3}$	G	VG	VG	VG	VG
$C_{2,5,1}$	$U_{2,5,1}$	MG	M	M	M	M
$C_{2,5,2}$	$U_{2,5,2}$	MP	M	M	M	MP
$C_{2,5,3}$	$U_{2,5,3}$	G	G	G	G	G
$C_{2,6,1}$	$U_{2,6,1}$	G	G	G	G	G
$C_{2,6,2}$	$U_{2,6,2}$	VG	VG	VG	VG	VG
$C_{2,6,3}$	$U_{2,6,3}$	VG	VG	G	G	G
$C_{2,7,1}$	$U_{2,7,1}$	G	G	G	G	VG
$C_{2,7,2}$	$U_{2,7,2}$	VG	G	VG	VG	G
$C_{2,8,1}$	$U_{2,8,1}$	M	M	MG	MG	MG
$C_{2,8,2}$	$U_{2,8,2}$	G	G	G	G	G
$C_{2,8,3}$	$U_{2,8,3}$	G	MG	G	G	MG
$C_{2,9,1}$	$U_{2,9,1}$	VG	G	G	G	G
$C_{2,9,2}$	$U_{2,9,2}$	G	G	G	G	G
$C_{2,10,1}$	$U_{2,10,1}$	M	M	MP	M	M
$C_{2,10,2}$	$U_{2,10,2}$	P	P	MP	M	M
$C_{3,1,1}$	$U_{3,1,1}$	MP	MP	MP	MP	M
$C_{3,1,2}$	$U_{3,1,2}$	MG	MG	MG	MG	MG

$C_{3,1,3}$	$U_{3,1,3}$	G	G	G	G	G
$C_{3,2,1}$	$U_{3,2,1}$	VG	VG	G	VG	G
$C_{3,2,2}$	$U_{3,2,2}$	VG	VG	G	G	G
$C_{4,1,1}$	$U_{4,1,1}$	G	G	G	G	VG
$C_{4,1,2}$	$U_{4,1,2}$	VG	G	VG	VG	G
$C_{4,1,3}$	$U_{4,1,3}$	M	M	MG	MG	MG
$C_{4,1,4}$	$U_{4,1,4}$	G	G	G	G	G
$C_{4,2,1}$	$U_{4,2,1}$	VG	G	G	G	VG
$C_{4,2,2}$	$U_{4,2,2}$	G	G	G	G	G
$C_{4,2,3}$	$U_{4,2,3}$	G	VG	VG	VG	VG
$C_{4,3,1}$	$U_{4,3,1}$	G	G	VG	VG	G
$C_{4,3,2}$	$U_{4,3,2}$	M	M	MG	MG	MG
$C_{4,3,3}$	$U_{4,3,3}$	G	G	G	G	G
$C_{4,4,1}$	$U_{4,4,1}$	G	MG	G	G	MG
$C_{4,4,2}$	$U_{4,4,2}$	G	G	G	G	G
$C_{4,4,3}$	$U_{4,4,3}$	M	M	MP	M	M
$C_{4,4,4}$	$U_{4,4,4}$	P	P	MP	M	M
$C_{4,5,1}$	$U_{4,5,1}$	MP	MP	MP	MP	M
$C_{4,5,2}$	$U_{4,5,2}$	VG	VG	VG	VG	VG
$C_{4,6,1}$	$U_{4,6,1}$	G	G	G	G	G
$C_{4,6,2}$	$U_{4,6,2}$	VG	VG	G	G	VG
$C_{4,6,3}$	$U_{4,6,3}$	G	G	G	G	G
$C_{4,7,1}$	$U_{4,7,1}$	G	VG	G	VG	VG
$C_{4,7,2}$	$U_{4,7,2}$	MG	MG	G	MG	MG
$C_{4,7,3}$	$U_{4,7,3}$	MG	G	MG	G	MG
$C_{4,8,1}$	$U_{4,8,1}$	M	M	M	MG	M
$C_{4,8,2}$	$U_{4,8,2}$	MG	MG	MG	MG	G
$C_{4,8,3}$	$U_{4,8,3}$	G	G	VG	VG	G
$C_{4,9,1}$	$U_{4,9,1}$	M	M	MG	MG	MG
$C_{4,9,2}$	$U_{4,9,2}$	G	G	G	G	G
$C_{4,9,3}$	$U_{4,9,3}$	G	MG	G	G	MG
$C_{4,9,4}$	$U_{4,9,4}$	G	G	G	G	VG
$C_{4,9,5}$	$U_{4,9,5}$	G	G	MG	G	G
$C_{5,1,1}$	$U_{5,1,1}$	VG	VG	G	G	VG
$C_{5,1,2}$	$U_{5,1,2}$	G	G	G	G	G
$C_{5,1,3}$	$U_{5,1,3}$	G	VG	G	VG	VG
$C_{5,2,1}$	$U_{5,2,1}$	MG	MG	G	MG	MG

$C_{5,2,2}$	$U_{5,2,2}$	P	P	MP	M	M
$C_{5,2,3}$	$U_{5,2,3}$	MP	MP	MP	MP	M
$C_{5,3,1}$	$U_{5,3,1}$	VG	VG	VG	VG	VG
$C_{5,3,2}$	$U_{5,3,2}$	G	G	VG	G	G
$C_{5,3,3}$	$U_{5,3,3}$	G	G	VG	VG	G
$C_{5,3,4}$	$U_{5,3,4}$	M	M	MG	MG	MG
$C_{5,4,1}$	$U_{5,4,1}$	G	G	G	G	G
$C_{5,4,2}$	$U_{5,4,2}$	G	MG	G	G	MG
$C_{5,5,1}$	$U_{5,5,1}$	G	G	G	G	G
$C_{5,5,2}$	$U_{5,5,2}$	M	M	MP	M	M
$C_{5,6,1}$	$U_{5,6,1}$	P	P	MP	M	M
$C_{5,6,2}$	$U_{5,6,2}$	MP	MP	MP	MP	M
$C_{5,6,3}$	$U_{5,6,3}$	G	VG	VG	VG	VG
$C_{5,7,1}$	$U_{5,7,1}$	G	G	VG	VG	G
$C_{5,7,2}$	$U_{5,7,2}$	M	M	MG	MG	MG

Table 3.24: Priority weight of lean criterions given by decision-makers

Leanness criterions $C_{i,j,k}$	Weight $w_{i,j,k}$	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1,1}$	$w_{1,1,1}$	H	H	H	VH	VH
$C_{1,1,2}$	$w_{1,1,2}$	H	H	H	H	H
$C_{1,1,3}$	$w_{1,1,3}$	MH	H	H	H	H
$C_{1,2,1}$	$w_{1,2,1}$	MH	H	MH	H	H
$C_{1,2,2}$	$w_{1,2,2}$	VH	VH	VH	VH	VH
$C_{1,2,3}$	$w_{1,2,3}$	H	H	H	H	H
$C_{2,1,1}$	$w_{2,1,1}$	MH	MH	H	H	MH
$C_{2,1,2}$	$w_{2,1,2}$	H	H	H	H	H
$C_{2,2,1}$	$w_{2,2,1}$	H	H	H	H	H
$C_{2,2,2}$	$w_{2,2,2}$	M	ML	MH	MH	MH
$C_{2,3,1}$	$w_{2,3,1}$	H	VH	H	VH	H
$C_{2,3,2}$	$w_{2,3,2}$	H	H	H	H	H
$C_{2,3,3}$	$w_{2,3,3}$	VH	H	VH	H	H
$C_{2,4,1}$	$w_{2,4,1}$	MH	H	H	H	H

$C_{2,4,2}$	$w_{2,4,2}$	VH	H	VH	H	VH
$C_{2,4,3}$	$w_{2,4,3}$	H	H	H	H	H
$C_{2,5,1}$	$w_{2,5,1}$	H	H	H	H	H
$C_{2,5,2}$	$w_{2,5,2}$	H	H	H	VH	VH
$C_{2,5,3}$	$w_{2,5,3}$	MH	MH	H	H	MH
$C_{2,6,1}$	$w_{2,6,1}$	H	H	H	H	H
$C_{2,6,2}$	$w_{2,6,2}$	H	H	H	H	H
$C_{2,6,3}$	$w_{2,6,3}$	VH	H	VH	H	H
$C_{2,7,1}$	$w_{2,7,1}$	MH	H	H	H	H
$C_{2,7,2}$	$w_{2,7,2}$	VH	H	VH	H	VH
$C_{2,8,1}$	$w_{2,8,1}$	MH	H	H	H	H
$C_{2,8,2}$	$w_{2,8,2}$	MH	H	MH	H	H
$C_{2,8,3}$	$w_{2,8,3}$	VH	VH	VH	VH	VH
$C_{2,9,1}$	$w_{2,9,1}$	H	H	H	H	H
$C_{2,9,2}$	$w_{2,9,2}$	MH	MH	H	H	MH
$C_{2,10,1}$	$w_{2,10,1}$	H	H	H	H	H
$C_{2,10,2}$	$w_{2,10,2}$	H	H	H	H	H
$C_{3,1,1}$	$w_{3,1,1}$	M	ML	MH	MH	MH
$C_{3,1,2}$	$w_{3,1,2}$	H	H	H	H	VH
$C_{3,1,3}$	$w_{3,1,3}$	VH	VH	VH	VH	VH
$C_{3,2,1}$	$w_{3,2,1}$	H	H	H	H	H
$C_{3,2,2}$	$w_{3,2,2}$	H	VH	H	H	H
$C_{4,1,1}$	$w_{4,1,1}$	MH	MH	H	H	MH
$C_{4,1,2}$	$w_{4,1,2}$	VH	H	H	H	H
$C_{4,1,3}$	$w_{4,1,3}$	H	H	H	H	H
$C_{4,1,4}$	$w_{4,1,4}$	M	ML	MH	MH	MH
$C_{4,2,1}$	$w_{4,2,1}$	MH	MH	H	H	H
$C_{4,2,2}$	$w_{4,2,2}$	H	VH	H	H	H
$C_{4,2,3}$	$w_{4,2,3}$	H	H	H	H	VH
$C_{4,3,1}$	$w_{4,3,1}$	MH	H	H	H	H
$C_{4,3,2}$	$w_{4,3,2}$	MH	H	MH	H	H
$C_{4,3,3}$	$w_{4,3,3}$	VH	VH	VH	VH	VH
$C_{4,4,1}$	$w_{4,4,1}$	H	H	H	H	H
$C_{4,4,2}$	$w_{4,4,2}$	MH	H	H	H	H
$C_{4,4,3}$	$w_{4,4,3}$	MH	H	MH	H	H
$C_{4,4,4}$	$w_{4,4,4}$	VH	VH	VH	VH	VH
$C_{4,5,1}$	$w_{4,5,1}$	H	H	H	H	H

$C_{4,5,2}$	$w_{4,5,2}$	VH	H	VH	VH	VH
$C_{4,6,1}$	$w_{4,6,1}$	MH	H	M	M	MH
$C_{4,6,2}$	$w_{4,6,2}$	MH	MH	H	H	H
$C_{4,6,3}$	$w_{4,6,3}$	VH	VH	VH	H	VH
$C_{4,7,1}$	$w_{4,7,1}$	H	H	H	H	H
$C_{4,7,2}$	$w_{4,7,2}$	ML	M	M	M	M
$C_{4,7,3}$	$w_{4,7,3}$	H	MH	H	MH	H
$C_{4,8,1}$	$w_{4,8,1}$	MH	H	H	H	H
$C_{4,8,2}$	$w_{4,8,2}$	MH	H	MH	H	H
$C_{4,8,3}$	$w_{4,8,3}$	VH	VH	VH	VH	VH
$C_{4,9,1}$	$w_{4,9,1}$	H	H	H	H	H
$C_{4,9,2}$	$w_{4,9,2}$	MH	H	H	H	H
$C_{4,9,3}$	$w_{4,9,3}$	MH	H	MH	H	H
$C_{4,9,4}$	$w_{4,9,4}$	VH	VH	VH	VH	VH
$C_{4,9,5}$	$w_{4,9,5}$	H	H	H	H	H
$C_{5,1,1}$	$w_{5,1,1}$	MH	H	H	H	H
$C_{5,1,2}$	$w_{5,1,2}$	MH	H	MH	H	H
$C_{5,1,3}$	$w_{5,1,3}$	VH	VH	VH	VH	VH
$C_{5,2,1}$	$w_{5,2,1}$	H	H	H	H	H
$C_{5,2,2}$	$w_{5,2,2}$	VH	H	H	H	H
$C_{5,2,3}$	$w_{5,2,3}$	H	VH	H	H	VH
$C_{5,3,1}$	$w_{5,3,1}$	H	H	H	H	H
$C_{5,3,2}$	$w_{5,3,2}$	MH	H	H	H	H
$C_{5,3,3}$	$w_{5,3,3}$	MH	H	MH	H	H
$C_{5,3,4}$	$w_{5,3,4}$	VH	VH	VH	VH	VH
$C_{5,4,1}$	$w_{5,4,1}$	H	H	H	H	H
$C_{5,4,2}$	$w_{5,4,2}$	VH	VH	VH	VH	VH
$C_{5,5,1}$	$w_{5,5,1}$	H	H	VH	H	H
$C_{5,5,2}$	$w_{5,5,2}$	MH	H	H	H	H
$C_{5,6,1}$	$w_{5,6,1}$	MH	H	MH	H	H
$C_{5,6,2}$	$w_{5,6,2}$	VH	VH	VH	VH	VH
$C_{5,6,3}$	$w_{5,6,3}$	H	H	H	H	H
$C_{5,7,1}$	$w_{5,7,1}$	VH	H	H	VH	H
$C_{5,7,2}$	$w_{5,7,2}$	H	VH	H	H	VH

Table 3.25: Priority weight of lean attributes given by decision-makers

Leanness attributes $C_{i,j}$	Weight $w_{i,j}$	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
$C_{1,1}$	$w_{1,1}$	H	H	H	H	H
$C_{1,2}$	$w_{1,2}$	H	H	H	VH	H
$C_{2,1}$	$w_{2,1}$	MH	MH	MH	MH	H
$C_{2,2}$	$w_{2,2}$	MH	H	VH	VH	VH
$C_{2,3}$	$w_{2,3}$	H	H	VH	H	H
$C_{2,4}$	$w_{2,4}$	M	MH	MH	MH	H
$C_{2,5}$	$w_{2,5}$	H	H	VH	H	H
$C_{2,6}$	$w_{2,6}$	H	H	H	H	H
$C_{2,7}$	$w_{2,7}$	VH	H	H	VH	H
$C_{2,8}$	$w_{2,8}$	MH	VH	MH	H	VH
$C_{2,9}$	$w_{2,9}$	H	H	H	H	VH
$C_{2,10}$	$w_{2,10}$	H	H	H	VH	VH
$C_{3,1}$	$w_{3,1}$	VH	VH	H	H	VH
$C_{3,2}$	$w_{3,2}$	MH	H	H	H	H
$C_{4,1}$	$w_{4,1}$	VH	VH	H	H	H
$C_{4,2}$	$w_{4,2}$	VH	VH	VH	VH	VH
$C_{4,3}$	$w_{4,3}$	H	H	H	H	H
$C_{4,4}$	$w_{4,4}$	VH	VH	H	H	H
$C_{4,5}$	$w_{4,5}$	H	VH	H	VH	VH
$C_{4,6}$	$w_{4,6}$	VH	VH	VH	H	VH
$C_{4,7}$	$w_{4,7}$	H	H	VH	H	H
$C_{4,8}$	$w_{4,8}$	H	H	H	H	H
$C_{4,9}$	$w_{4,9}$	VH	H	VH	MH	H
$C_{5,1}$	$w_{5,1}$	H	H	H	H	VH
$C_{5,2}$	$w_{5,2}$	VH	VH	VH	H	VH
$C_{5,3}$	$w_{5,3}$	VH	H	VH	H	VH
$C_{5,4}$	$w_{5,4}$	H	H	H	VH	H
$C_{5,5}$	$w_{5,5}$	VH	H	VH	VH	VH
$C_{5,6}$	$w_{5,6}$	H	H	H	H	H
$C_{5,7}$	$w_{5,7}$	H	VH	VH	H	H

Table 3.26: Priority weight of lean enablers given by decision-makers

Lean enablers C_i	Weight w_i	Priority weight expressed in linguistic variables				
		DM1	DM2	DM3	DM4	DM5
C_1	w_1	VH	VH	H	H	H
C_2	w_2	VH	VH	VH	VH	VH
C_3	w_3	H	H	H	H	H
C_4	w_4	MH	H	H	VH	H
C_5	w_5	VH	VH	H	H	H

APPENDIX-B (Additional Data Tables of Chapter 4)

Table 4.3: Appropriateness rating of agile criterions given by decision-makers

Agile criterions C_{ijk}	Appropriateness rating (expressed in linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_{111}	VG	VG	G	AG	VG
C_{112}	G	G	G	G	G
C_{113}	G	VG	G	VG	VG
C_{121}	MG	MG	G	MG	MG
C_{122}	M	M	G	M	M
C_{123}	VG	VG	G	VG	VG
C_{131}	MG	G	G	G	MG
C_{132}	G	G	G	G	G
C_{133}	G	G	G	G	G
C_{211}	VG	VG	G	G	G
C_{212}	M	MG	G	G	M
C_{213}	MG	MG	MG	MG	MG
C_{221}	G	G	G	G	G
C_{222}	VG	AG	AG	AG	VG
C_{231}	G	G	G	G	G
C_{232}	G	VG	VG	G	VG
C_{233}	MG	M	M	M	M
C_{311}	MP	M	M	M	MP
C_{321}	G	G	G	G	G
C_{322}	G	G	G	G	G
C_{323}	VG	AG	AG	AG	AG
C_{324}	VG	VG	G	G	G
C_{331}	G	G	G	G	VG
C_{411}	AG	G	VG	VG	G
C_{421}	M	M	MG	MG	MG
C_{4222}	G	G	G	G	G
C_{423}	G	G	G	G	MG
C_{431}	VG	G	G	G	G

Table 4.4: Priority weight of agile criterions given by decision-makers

Agile criterions C_{ijk}	Priority weight (expressed in linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_{111}	AH	AH	AH	VH	VH
C_{112}	H	H	H	H	H
C_{113}	MH	H	H	H	H
C_{121}	MH	H	MH	H	H
C_{122}	VH	VH	VH	VH	VH
C_{123}	H	H	H	H	H
C_{131}	MH	MH	H	H	MH
C_{132}	AH	AH	AH	AH	AH
C_{133}	H	H	H	H	H
C_{211}	M	ML	M	MH	MH
C_{212}	H	VH	H	VH	H
C_{213}	H	H	H	H	H
C_{221}	VH	AH	VH	H	H
C_{222}	MH	H	H	H	H
C_{231}	VH	H	VH	H	VH
C_{232}	H	H	H	H	H
C_{233}	H	H	H	H	H
C_{311}	H	H	H	VH	VH
C_{321}	MH	MH	H	H	MH
C_{322}	H	H	H	H	H
C_{323}	H	H	H	H	H
C_{324}	VH	AH	VH	H	H
C_{331}	MH	H	H	H	H
C_{411}	VH	H	VH	H	VH
C_{421}	MH	H	H	H	H
C_{4222}	MH	H	MH	H	H
C_{423}	VH	VH	VH	VH	VH
C_{431}	H	H	H	H	H

Table 4.5: Priority weight of agile attributes given by decision-makers

Agile attributes C_{ij}	Priority weight (expressed in linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_{11}	H	H	H	H	H
C_{12}	AH	H	H	AH	H
C_{13}	MH	MH	MH	MH	H
C_{21}	MH	H	VH	VH	VH
C_{22}	H	AH	H	H	H
C_{23}	M	MH	MH	MH	H
C_{31}	H	H	H	VH	VH
C_{32}	H	H	H	H	H
C_{33}	MH	H	H	H	H
C_{41}	VH	H	VH	H	VH
C_{42}	H	H	H	H	VH
C_{43}	H	H	H	H	H

Table 4.6: Priority weight of agile capabilities/enablers given by decision-makers

Agile enablers C_i	Priority weight (expressed in linguistic terms) as given by decision-makers				
	DM1	DM2	DM3	DM4	DM5
C_1	VH	VH	H	VH	H
C_2	AH	AH	AH	AH	VH
C_3	H	H	H	H	H
C_4	MH	H	MH	VH	H

APPENDIX-C (Additional Data Tables of Chapter 5)

Table 5.3: Priority weight of leagile criterions (in linguistic term) assigned by the decision-makers (DMs)

Leagile criterions, C_{ijk}	Priority weight of leagile criterions (in linguistic term)									
	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
C_{111}	MH	H	AH	MH	VH	H	H	AH	H	MH
C_{112}	H	M	H	VH	MH	H	MH	H	VH	AH
C_{113}	MH	AH	AH	VH	H	H	H	AH	H	H
C_{114}	AH	H	VH	AH	AH	H	AH	VH	H	H
C_{115}	MH	VH	H	H	MH	VH	MH	H	VH	H
C_{121}	AH	MH	H	VH	MH	H	AH	AH	H	H
C_{122}	H	H	VH	MH	H	H	H	MH	H	VH
C_{123}	MH	H	H	H	M	H	AH	AH	H	H
C_{124}	H	VH	VH	AH	AH	H	VH	MH	VH	H
C_{125}	H	MH	MH	MH	H	AH	H	MH	H	VH
C_{131}	VH	VH	AH	AH	VH	MH	H	H	AH	H
C_{132}	H	AH	H	H	MH	AH	VH	M	MH	MH
C_{133}	MH	MH	VH	H	H	MH	H	AH	AH	H
C_{141}	H	MH	MH	H	VH	H	VH	H	H	MH
C_{142}	VH	H	H	H	H	H	MH	VH	H	H
C_{151}	MH	M	H	VH	MH	VH	H	MH	H	AH
C_{152}	H	AH	MH	H	H	MH	AH	AH	H	MH
C_{153}	VH	AH	H	H	H	AH	MH	H	VH	AH
C_{154}	MH	H	AH	H	VH	MH	AH	VH	H	H
C_{155}	H	VH	MH	AH	H	MH	H	MH	H	AH
C_{161}	H	H	AH	H	H	H	VH	H	H	VH
C_{162}	MH	AH	H	VH	VH	M	MH	MH	VH	H
C_{163}	MH	MH	AH	VH	H	AH	H	H	H	H
C_{164}	VH	AH	VH	H	H	H	AH	AH	AH	VH
C_{165}	VH	H	H	MH	H	VH	H	MH	MH	H
C_{166}	H	H	H	H	VH	MH	VH	AH	AH	VH
C_{167}	MH	H	AH	MH	H	H	MH	H	H	MH
C_{168}	MH	H	H	MH	H	H	H	AH	H	H
C_{169}	H	VH	VH	AH	VH	VH	H	VH	H	AH
C_{171}	VH	H	MH	MH	H	VH	VH	H	H	MH
C_{172}	H	VH	MH	MH	AH	H	H	H	VH	VH

C_{173}	MH	H	MH	VH	VH	VH	H	VH	MH	AH
C_{174}	H	H	H	H	VH	MH	AH	H	MH	H
C_{181}	VH	VH	M	AH	H	MH	H	H	H	VH
C_{182}	MH	VH	AH	H	H	H	AH	H	VH	MH
C_{183}	H	H	MH	VH	VH	M	MH	AH	H	MH
C_{184}	VH	VH	MH	AH	H	H	H	MH	VH	AH
C_{191}	AH	AH	H	H	AH	AH	AH	H	H	H
C_{192}	H	MH	AH	VH	AH	MH	MH	AH	MH	H
C_{193}	VH	MH	MH	MH	H	AH	AH	MH	H	AH
C_{1101}	MH	H	AH	H	VH	H	H	AH	H	MH
C_{1102}	H	M	H	VH	MH	H	MH	H	VH	AH
C_{1103}	H	AH	AH	VH	H	H	H	AH	H	H
C_{1104}	AH	H	VH	AH	AH	H	AH	VH	H	H
C_{211}	MH	VH	H	H	MH	VH	MH	H	VH	H
C_{212}	AH	MH	H	VH	MH	H	AH	AH	H	H
C_{213}	H	H	VH	MH	H	H	H	MH	H	VH
C_{214}	MH	H	H	H	M	H	AH	AH	H	H
C_{215}	MH	VH	VH	AH	AH	H	VH	MH	VH	H
C_{216}	H	MH	MH	MH	H	AH	H	MH	H	VH
C_{221}	MH	VH	AH	AH	VH	MH	H	H	AH	H
C_{222}	H	AH	H	H	MH	AH	VH	M	MH	MH
C_{223}	H	MH	VH	H	H	MH	H	AH	AH	H
C_{224}	H	MH	MH	H	VH	H	VH	H	H	MH
C_{225}	VH	H	H	H	H	H	MH	VH	H	H
C_{226}	MH	M	H	VH	MH	VH	H	MH	H	AH
C_{227}	VH	VH	MH	AH	H	H	H	MH	VH	AH
C_{231}	AH	AH	H	H	AH	AH	AH	H	H	H
C_{232}	H	MH	AH	VH	AH	MH	MH	AH	MH	H
C_{233}	VH	MH	MH	MH	H	AH	AH	MH	H	AH
C_{234}	MH	H	AH	H	VH	H	H	AH	H	MH
C_{235}	H	M	H	VH	MH	H	MH	H	VH	AH
C_{236}	H	AH	AH	VH	H	H	H	AH	H	H
C_{241}	AH	H	VH	AH	AH	H	AH	VH	H	H
C_{242}	MH	VH	H	H	MH	VH	MH	H	VH	H
C_{243}	AH	MH	H	VH	MH	H	AH	AH	H	H
C_{244}	H	H	VH	MH	H	H	H	MH	H	VH
C_{245}	H	H	H	H	M	H	AH	AH	H	H

C_{246}	MH	VH	VH	AH	AH	H	VH	MH	VH	H
C_{247}	H	MH	MH	MH	H	AH	H	MH	H	VH
C_{248}	VH	VH	AH	AH	VH	MH	H	H	AH	H
C_{249}	H	AH	H	H	MH	AH	VH	M	MH	MH
C_{251}	MH	MH	VH	H	H	MH	H	AH	AH	H
C_{252}	MH	MH	MH	H	VH	H	VH	H	H	MH
C_{253}	VH	H	H	H	H	H	MH	VH	H	H
C_{311}	AH	M	H	VH	MH	VH	H	MH	H	AH
C_{312}	H	AH	MH	H	H	MH	AH	AH	H	MH
C_{313}	VH	AH	H	H	H	AH	MH	H	VH	AH
C_{314}	MH	H	AH	H	VH	MH	AH	VH	H	H
C_{321}	H	VH	MH	AH	H	MH	H	MH	H	AH
C_{322}	H	H	AH	H	H	H	VH	H	H	VH
C_{323}	VH	AH	H	VH	VH	M	MH	MH	VH	H
C_{324}	MH	MH	AH	VH	H	AH	H	H	H	H
C_{325}	MH	AH	VH	H	H	H	AH	AH	AH	VH
C_{331}	VH	H	H	MH	H	VH	H	MH	MH	H
C_{332}	MH	H	H	H	VH	MH	VH	AH	AH	VH
C_{333}	MH	H	AH	MH	H	H	MH	H	H	MH
C_{334}	H	H	H	H	H	H	H	AH	H	H
C_{341}	H	VH	VH	AH	VH	VH	H	VH	H	AH
C_{342}	VH	H	MH	MH	H	VH	VH	H	H	MH
C_{343}	H	VH	MH	MH	AH	H	H	H	VH	VH
C_{344}	AH	H	MH	VH	VH	VH	H	VH	MH	AH
C_{351}	H	H	H	H	VH	MH	AH	H	MH	H
C_{352}	VH	VH	M	AH	H	MH	H	H	H	VH
C_{353}	VH	VH	AH	H	H	H	AH	H	VH	MH
C_{354}	H	H	MH	VH	VH	M	MH	AH	H	MH
C_{361}	MH	H	AH	H	VH	H	H	AH	H	MH
C_{362}	MH	M	H	VH	MH	H	MH	H	VH	AH
C_{363}	MH	AH	AH	VH	H	H	H	AH	H	H
C_{364}	AH	H	VH	AH	AH	H	AH	VH	H	H
C_{371}	MH	VH	H	H	MH	VH	MH	H	VH	H
C_{372}	AH	MH	H	VH	MH	H	AH	AH	H	H
C_{373}	H	H	VH	MH	H	H	H	MH	H	VH
C_{374}	MH	H	H	H	M	H	AH	AH	H	H
C_{375}	H	VH	VH	AH	AH	H	VH	MH	VH	H

C_{376}	MH	MH	MH	MH	H	AH	H	MH	H	VH
C_{377}	VH	VH	AH	AH	VH	MH	H	H	AH	H
C_{378}	H	AH	H	H	MH	AH	VH	M	MH	MH
C_{379}	H	MH	VH	H	H	MH	H	AH	AH	H
C_{3710}	MH	MH	MH	H	VH	H	VH	H	H	MH
C_{3711}	VH	H	H	H	H	H	MH	VH	H	H
C_{381}	AH	M	H	VH	MH	VH	H	MH	H	AH
C_{382}	H	AH	MH	H	H	MH	AH	AH	H	MH
C_{383}	VH	AH	H	H	H	AH	MH	H	VH	AH
C_{384}	MH	H	AH	H	VH	MH	AH	VH	H	H
C_{391}	H	VH	MH	AH	H	MH	H	MH	H	AH
C_{392}	H	H	AH	H	H	H	VH	H	H	VH
C_{393}	VH	AH	H	VH	VH	M	MH	MH	VH	H
C_{394}	MH	MH	AH	VH	H	AH	H	H	H	H
C_{3101}	VH	AH	VH	H	H	H	AH	AH	AH	VH
C_{3102}	VH	H	H	MH	H	VH	H	MH	MH	H
C_{3103}	H	H	H	H	VH	MH	VH	AH	AH	VH
C_{3104}	MH	H	AH	MH	H	H	MH	H	H	MH
C_{3105}	H	H	MH	MH	H	H	H	AH	H	H
C_{3106}	H	VH	VH	AH	VH	VH	H	VH	H	AH
C_{3111}	VH	H	MH	MH	H	VH	VH	H	H	MH
C_{3112}	H	VH	MH	MH	AH	H	H	H	VH	VH
C_{3113}	AH	H	MH	VH	VH	VH	H	VH	MH	AH
C_{3114}	H	H	H	H	VH	MH	AH	H	MH	H
C_{3115}	VH	VH	M	AH	H	MH	H	H	H	VH
C_{3116}	VH	VH	AH	H	H	H	AH	H	VH	MH
C_{3117}	H	H	MH	VH	VH	M	MH	AH	H	MH
C_{3121}	VH	VH	MH	AH	H	H	H	MH	VH	AH
C_{3122}	AH	AH	H	H	AH	AH	AH	H	H	H
C_{3123}	H	MH	AH	VH	AH	MH	MH	AH	MH	H
C_{3124}	VH	MH	MH	MH	H	AH	AH	MH	H	AH
C_{411}	MH	H	AH	H	VH	H	H	AH	H	MH
C_{412}	H	M	H	VH	MH	H	MH	H	VH	AH
C_{413}	H	AH	AH	VH	H	H	H	AH	H	H
C_{414}	AH	H	VH	AH	AH	H	AH	VH	H	H
C_{421}	MH	VH	H	H	MH	VH	MH	H	VH	H
C_{422}	AH	MH	H	VH	MH	H	AH	AH	H	H

C_{423}	H	H	VH	MH	H	H	H	MH	H	VH
C_{431}	AH	H	H	H	M	H	AH	AH	H	H
C_{432}	H	VH	VH	AH	AH	H	VH	MH	VH	H
C_{433}	AH	MH	MH	MH	H	AH	H	MH	H	VH
C_{434}	VH	VH	AH	AH	VH	MH	H	H	AH	H
C_{441}	H	AH	H	H	MH	AH	VH	M	MH	MH
C_{442}	VH	MH	VH	H	H	MH	H	AH	AH	H
C_{443}	H	MH	MH	H	VH	H	VH	H	H	MH
C_{444}	VH	H	H	H	H	H	MH	VH	H	H
C_{445}	AH	M	H	VH	MH	VH	H	MH	H	AH
C_{451}	VH	VH	MH	AH	H	H	H	MH	VH	AH
C_{452}	AH	AH	H	H	AH	AH	AH	H	H	H
C_{453}	H	MH	AH	VH	AH	MH	MH	AH	MH	H
C_{454}	VH	MH	MH	MH	H	AH	AH	MH	H	AH
C_{455}	MH	H	AH	H	VH	H	H	AH	H	MH
C_{456}	H	M	H	VH	MH	H	MH	H	VH	AH
C_{457}	H	AH	AH	VH	H	H	H	AH	H	H
C_{458}	AH	H	VH	AH	AH	H	AH	VH	H	H
C_{461}	MH	VH	H	H	MH	VH	MH	H	VH	H
C_{462}	AH	MH	H	VH	MH	H	AH	AH	H	H
C_{463}	VH	H	VH	MH	H	H	H	MH	H	VH
C_{464}	H	H	MH	H	M	H	AH	AH	H	H
C_{471}	VH	VH	VH	AH	AH	H	VH	MH	VH	H
C_{472}	H	MH	MH	MH	H	AH	H	MH	H	VH
C_{473}	VH	VH	AH	AH	VH	MH	H	H	AH	H
C_{474}	H	AH	H	H	MH	AH	VH	M	MH	MH
C_{475}	H	MH	VH	H	H	MH	H	AH	AH	H
C_{476}	H	MH	MH	H	VH	H	VH	H	H	MH
C_{511}	VH	H	H	H	H	H	MH	VH	H	H
C_{512}	AH	M	H	VH	MH	VH	H	MH	H	AH
C_{513}	H	AH	MH	H	H	MH	AH	AH	H	MH
C_{521}	VH	AH	H	H	H	AH	MH	H	VH	AH
C_{522}	MH	H	AH	H	VH	MH	AH	VH	H	H
C_{523}	H	VH	MH	AH	H	MH	H	MH	H	AH
C_{531}	H	H	AH	H	H	H	VH	H	H	VH
C_{532}	VH	AH	H	VH	VH	M	MH	MH	VH	H
C_{533}	MH	MH	AH	VH	H	AH	H	H	H	H

C_{541}	VH	AH	VH	H	H	H	AH	AH	AH	VH
C_{542}	VH	H	H	MH	H	VH	H	MH	MH	H
C_{543}	H	H	H	H	VH	MH	VH	AH	AH	VH
C_{551}	MH	H	AH	MH	H	H	MH	H	H	MH
C_{552}	H	H	H	H	H	H	H	AH	H	H
C_{553}	H	VH	VH	AH	VH	VH	H	VH	H	AH
C_{561}	VH	H	MH	MH	H	VH	VH	H	H	MH
C_{562}	H	VH	MH	MH	AH	H	H	H	VH	VH
C_{563}	AH	H	MH	VH	VH	VH	H	VH	MH	AH

Table 5.4: Appropriateness rating of leagile criterions (in linguistic term) assigned by the decision-makers (DMs)

Leagile criterions, C_{ijk}	Appropriateness rating of leagile criterions (in linguistic term)									
	DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
C_{111}	G	VG	MG	G	M	G	AG	M	G	VG
C_{112}	MG	VG	G	G	G	MG	G	G	G	MG
C_{113}	G	G	VG	M	G	VG	MG	G	MG	G
C_{114}	G	MP	MG	G	M	VG	G	M	VG	AG
C_{115}	VG	G	G	AG	G	G	MG	VG	VG	AG
C_{121}	MG	VG	AG	VG	AG	MP	MG	G	G	G
C_{122}	G	G	AG	AG	VG	G	G	G	MP	G
C_{123}	AG	G	G	G	G	VG	VG	MG	G	AG
C_{124}	M	MG	G	MG	AG	G	MG	VG	VG	G
C_{125}	M	VG	AG	M	G	G	G	VG	G	MG
C_{131}	MG	VG	MG	G	MG	MG	AG	G	G	M
C_{132}	G	AG	M	G	M	VG	AG	MP	M	G
C_{133}	MG	G	AG	M	G	AG	G	G	VG	G
C_{141}	M	MG	G	VG	G	G	G	VG	G	M
C_{142}	MP	M	AG	G	MG	MG	AG	G	G	G
C_{151}	G	G	G	G	MG	M	MG	G	MG	AG
C_{152}	AG	G	MG	MG	G	G	M	MG	MG	VG
C_{153}	G	M	M	AG	VG	G	G	VG	G	G
C_{154}	MG	G	G	G	MG	M	VG	VG	VG	G
C_{155}	MG	G	G	MG	G	G	MG	G	MG	MG

C_{161}	VG	MG	M	M	AG	AG	M	MP	G	VG
C_{162}	G	MG	G	G	AG	VG	G	G	AG	VG
C_{163}	G	G	AG	G	G	G	AG	M	AG	G
C_{164}	M	VG	VG	G	G	MG	G	VG	G	MP
C_{165}	MG	MG	G	G	AG	M	MG	G	G	G
C_{166}	G	G	MG	MG	MG	VG	M	AG	AG	M
C_{167}	MG	AG	VG	VG	M	G	G	G	MG	VG
C_{168}	M	AG	AG	VG	AG	G	G	MG	M	AG
C_{169}	G	G	G	G	VG	MG	M	M	G	G
C_{171}	G	M	MG	MP	G	M	G	G	VG	MG
C_{172}	MG	G	G	MG	MP	VG	VG	M	AG	VG
C_{173}	M	AG	AG	M	MG	VG	MG	G	M	M
C_{174}	G	AG	VG	G	M	VG	M	AG	MG	MG
C_{181}	MG	G	M	MG	AG	VG	VG	VG	MP	M
C_{182}	M	MP	VG	AG	VG	MG	G	G	MG	G
C_{183}	VG	MG	G	G	VG	M	AG	AG	M	MP
C_{184}	G	VG	M	AG	G	AG	M	VG	VG	G
C_{191}	MG	G	VG	G	VG	G	VG	AG	G	MG
C_{192}	M	G	G	MG	G	VG	G	G	VG	MG
C_{193}	G	MG	MG	M	MG	G	G	MG	VG	G
C_{1101}	G	VG	MG	G	M	G	AG	M	G	VG
C_{1102}	MG	VG	G	G	G	MG	G	G	G	MG
C_{1103}	G	G	VG	M	G	VG	MG	G	MG	G
C_{1104}	G	MP	MG	G	M	VG	G	M	VG	AG
C_{211}	VG	G	G	AG	G	G	MG	VG	VG	AG
C_{212}	MG	VG	AG	VG	AG	MP	MG	G	G	G
C_{213}	G	G	AG	AG	VG	G	G	G	MP	G
C_{214}	AG	G	G	G	G	VG	VG	MG	G	AG
C_{215}	M	MG	G	MG	AG	G	MG	VG	VG	G
C_{216}	M	VG	AG	M	G	G	G	VG	G	MG
C_{221}	MG	VG	MG	G	MG	MG	AG	G	G	M
C_{222}	G	AG	M	G	M	VG	AG	MP	M	G
C_{223}	MG	G	AG	M	G	AG	G	G	VG	G
C_{224}	M	MG	G	VG	G	G	G	VG	G	M
C_{225}	MP	M	AG	G	MG	MG	AG	G	G	G
C_{226}	G	G	G	G	MG	M	MG	G	MG	AG
C_{227}	G	VG	M	AG	G	AG	M	VG	VG	G

C_{231}	MG	G	VG	G	VG	G	VG	AG	G	MG
C_{232}	M	G	G	MG	G	VG	G	G	VG	MG
C_{233}	G	MG	MG	M	MG	G	G	MG	VG	G
C_{234}	G	VG	MG	G	M	G	AG	M	G	VG
C_{235}	MG	VG	G	G	G	MG	G	G	G	MG
C_{236}	G	G	VG	M	G	VG	MG	G	MG	G
C_{241}	G	MP	MG	G	M	VG	G	M	VG	AG
C_{242}	VG	G	G	AG	G	G	MG	VG	VG	AG
C_{243}	MG	VG	AG	VG	AG	MP	MG	G	G	G
C_{244}	G	G	AG	AG	VG	G	G	G	MP	G
C_{245}	AG	G	G	G	G	VG	VG	MG	G	AG
C_{246}	M	MG	G	MG	AG	G	MG	VG	VG	G
C_{247}	M	VG	AG	M	G	G	G	VG	G	MG
C_{248}	MG	VG	MG	G	MG	MG	AG	G	G	M
C_{249}	G	AG	M	G	M	VG	AG	MP	M	G
C_{251}	MG	G	AG	M	G	AG	G	G	VG	G
C_{252}	M	MG	G	VG	G	G	G	VG	G	M
C_{253}	MP	M	AG	G	MG	MG	AG	G	G	G
C_{311}	G	G	G	G	MG	M	MG	G	MG	AG
C_{312}	AG	G	MG	MG	G	G	M	MG	MG	VG
C_{313}	G	M	M	AG	VG	G	G	VG	G	G
C_{314}	MG	G	G	G	MG	M	VG	VG	VG	G
C_{321}	MG	G	G	MG	G	G	MG	G	MG	MG
C_{322}	VG	MG	M	M	AG	AG	M	MP	G	VG
C_{323}	G	MG	G	G	AG	VG	G	G	AG	VG
C_{324}	G	G	AG	G	G	G	AG	M	AG	G
C_{325}	M	VG	VG	G	G	MG	G	VG	G	MP
C_{331}	MG	MG	G	G	AG	M	MG	G	G	G
C_{332}	G	G	MG	MG	MG	VG	M	AG	AG	M
C_{333}	MG	AG	VG	VG	M	G	G	G	MG	VG
C_{334}	M	AG	AG	VG	AG	G	G	MG	M	AG
C_{341}	G	G	G	G	VG	MG	M	M	G	G
C_{342}	G	M	MG	MP	G	M	G	G	VG	MG
C_{343}	MG	G	G	MG	MP	VG	VG	M	AG	VG
C_{344}	M	AG	AG	M	MG	VG	MG	G	M	M
C_{351}	G	AG	VG	G	M	VG	M	AG	MG	MG
C_{352}	MG	G	M	MG	AG	VG	VG	VG	MP	M

C_{353}	M	MP	VG	AG	VG	MG	G	G	MG	G
C_{354}	VG	MG	G	G	VG	M	AG	AG	M	MP
C_{361}	G	VG	MG	G	M	G	AG	M	G	VG
C_{362}	MG	VG	G	G	G	MG	G	G	G	MG
C_{363}	G	G	VG	M	G	VG	MG	G	MG	G
C_{364}	G	MP	MG	G	M	VG	G	M	VG	AG
C_{371}	VG	G	G	AG	G	G	MG	VG	VG	AG
C_{372}	MG	VG	AG	VG	AG	MP	MG	G	G	G
C_{373}	G	G	AG	AG	VG	G	G	G	MP	G
C_{374}	AG	G	G	G	G	VG	VG	MG	G	AG
C_{375}	M	MG	G	MG	AG	G	MG	VG	VG	G
C_{376}	M	VG	AG	M	G	G	G	VG	G	MG
C_{377}	MG	VG	MG	G	MG	MG	AG	G	G	M
C_{378}	G	AG	M	G	M	VG	AG	MP	M	G
C_{379}	MG	G	AG	M	G	AG	G	G	VG	G
C_{3710}	M	MG	G	VG	G	G	G	VG	G	M
C_{3711}	MP	M	AG	G	MG	MG	AG	G	G	G
C_{381}	G	G	G	G	MG	M	MG	G	MG	AG
C_{382}	AG	G	MG	MG	G	G	M	MG	MG	VG
C_{383}	G	M	M	AG	VG	G	G	VG	G	G
C_{384}	MG	G	G	G	MG	M	VG	VG	VG	G
C_{391}	MG	G	G	MG	G	G	MG	G	MG	MG
C_{392}	VG	MG	M	M	AG	AG	M	MP	G	VG
C_{393}	G	MG	G	G	AG	VG	G	G	AG	VG
C_{394}	G	G	AG	G	G	G	AG	M	AG	G
C_{3101}	M	VG	VG	G	G	MG	G	VG	G	MP
C_{3102}	MG	MG	G	G	AG	M	MG	G	G	G
C_{3103}	G	G	MG	MG	MG	VG	M	AG	AG	M
C_{3104}	MG	AG	VG	VG	M	G	G	G	MG	VG
C_{3105}	M	AG	AG	VG	AG	G	G	MG	M	AG
C_{3106}	G	G	G	G	VG	MG	M	M	G	G
C_{3111}	G	M	MG	MP	G	M	G	G	VG	MG
C_{3112}	MG	G	G	MG	MP	VG	VG	M	AG	VG
C_{3113}	M	AG	AG	M	MG	VG	MG	G	M	M
C_{3114}	G	AG	VG	G	M	VG	M	AG	MG	MG
C_{3115}	MG	G	M	MG	AG	VG	VG	VG	MP	M
C_{3116}	M	MP	VG	AG	VG	MG	G	G	MG	G

C_{3117}	VG	MG	G	G	VG	M	AG	AG	M	MP
C_{3121}	G	VG	M	AG	G	AG	M	VG	VG	G
C_{3122}	MG	G	VG	G	VG	G	VG	AG	G	MG
C_{3123}	M	G	G	MG	G	VG	G	G	VG	MG
C_{3124}	G	MG	MG	M	MG	G	G	MG	VG	G
C_{411}	G	VG	MG	G	M	G	AG	M	G	VG
C_{412}	MG	VG	G	G	G	MG	G	G	G	MG
C_{413}	G	G	VG	M	G	VG	MG	G	MG	G
C_{414}	G	MP	MG	G	M	VG	G	M	VG	AG
C_{421}	VG	G	G	AG	G	G	MG	VG	VG	AG
C_{422}	MG	VG	AG	VG	AG	MP	MG	G	G	G
C_{423}	G	G	AG	AG	VG	G	G	G	MP	G
C_{431}	AG	G	G	G	G	VG	VG	MG	G	AG
C_{432}	M	MG	G	MG	AG	G	MG	VG	VG	G
C_{433}	M	VG	AG	M	G	G	G	VG	G	MG
C_{434}	MG	VG	MG	G	MG	MG	AG	G	G	M
C_{441}	G	AG	M	G	M	VG	AG	MP	M	G
C_{442}	MG	G	AG	M	G	AG	G	G	VG	G
C_{443}	M	MG	G	VG	G	G	G	VG	G	M
C_{444}	MP	M	AG	G	MG	MG	AG	G	G	G
C_{445}	G	G	G	G	MG	M	MG	G	MG	AG
C_{451}	G	VG	M	AG	G	AG	M	VG	VG	G
C_{452}	MG	G	VG	G	VG	G	VG	AG	G	MG
C_{453}	M	G	G	MG	G	VG	G	G	VG	MG
C_{454}	G	MG	MG	M	MG	G	G	MG	VG	G
C_{455}	G	VG	MG	G	M	G	AG	M	G	VG
C_{456}	MG	VG	G	G	G	MG	G	G	G	MG
C_{457}	G	G	VG	M	G	VG	MG	G	MG	G
C_{458}	G	MP	MG	G	M	VG	G	M	VG	AG
C_{461}	VG	G	G	AG	G	G	MG	VG	VG	AG
C_{462}	MG	VG	AG	VG	AG	MP	MG	G	G	G
C_{463}	G	G	AG	AG	VG	G	G	G	MP	G
C_{464}	AG	G	G	G	G	VG	VG	MG	G	AG
C_{471}	M	MG	G	MG	AG	G	MG	VG	VG	G
C_{472}	M	VG	AG	M	G	G	G	VG	G	MG
C_{473}	MG	VG	MG	G	MG	MG	AG	G	G	M
C_{474}	G	AG	M	G	M	VG	AG	MP	M	G

C_{475}	MG	G	AG	M	G	AG	G	G	VG	G
C_{476}	M	MG	G	VG	G	G	G	VG	G	M
C_{511}	MP	M	AG	G	MG	MG	AG	G	G	G
C_{512}	G	G	G	G	MG	M	MG	G	MG	AG
C_{513}	AG	G	MG	MG	G	G	M	MG	MG	VG
C_{521}	G	M	M	AG	VG	G	G	VG	G	G
C_{522}	MG	G	G	G	MG	M	VG	VG	VG	G
C_{523}	MG	G	G	MG	G	G	MG	G	MG	MG
C_{531}	VG	MG	M	M	AG	AG	M	MP	G	VG
C_{532}	G	MG	G	G	AG	VG	G	G	AG	VG
C_{533}	G	G	AG	G	G	G	AG	M	AG	G
C_{541}	M	VG	VG	G	G	MG	G	VG	G	MP
C_{542}	MG	MG	G	G	AG	M	MG	G	G	G
C_{543}	G	G	MG	MG	MG	VG	M	AG	AG	M
C_{551}	MG	AG	VG	VG	M	G	G	G	MG	VG
C_{552}	M	AG	AG	VG	AG	G	G	MG	M	AG
C_{553}	G	G	G	G	VG	MG	M	M	G	G
C_{561}	G	M	MG	MP	G	M	G	G	VG	MG
C_{562}	MG	G	G	MG	MP	VG	VG	M	AG	VG
C_{563}	M	AG	AG	M	MG	VG	MG	G	M	M

Table 5.5: Priority weight of leagile attributes (in linguistic term) given by decision maker (DMs)

Leagile attributes, C_{ij}	Weight	Priority weight of leagile attributes (in linguistic term)									
		DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
C_{11}	W_{11}	MH	VH	MH	AH	AH	H	H	MH	VH	AH
C_{12}	W_{12}	AH	AH	H	H	AH	AH	AH	H	MH	H
C_{13}	W_{13}	MH	MH	AH	VH	AH	MH	MH	AH	MH	H
C_{14}	W_{14}	MH	MH	H	H	H	AH	AH	MH	H	AH
C_{15}	W_{15}	MH	H	AH	H	VH	H	H	AH	H	MH
C_{16}	W_{16}	AH	M	H	VH	MH	MH	MH	H	VH	AH
C_{17}	W_{17}	H	AH	MH	VH	H	MH	H	AH	H	H
C_{18}	W_{18}	AH	H	MH	AH	AH	H	AH	VH	H	H
C_{19}	W_{19}	MH	VH	H	H	MH	VH	MH	H	VH	H
C_{110}	W_{110}	AH	MH	H	VH	MH	H	AH	AH	H	MH
C_{21}	W_{21}	H	H	VH	MH	H	H	H	MH	H	VH

C_{22}	W_{22}	H	H	MH	MH	M	H	AH	AH	H	H
C_{23}	W_{23}	AH	VH	VH	AH	AH	H	MH	MH	VH	H
C_{24}	W_{24}	AH	MH	MH	MH	H	AH	H	MH	H	VH
C_{25}	W_{25}	VH	VH	AH	AH	VH	H	H	H	AH	H
C_{31}	W_{31}	H	AH	H	H	MH	AH	VH	M	MH	MH
C_{32}	W_{32}	H	MH	VH	AH	H	MH	H	AH	AH	H
C_{33}	W_{33}	H	MH	MH	H	VH	H	VH	H	AH	MH
C_{34}	W_{34}	VH	H	H	H	H	H	MH	VH	H	H
C_{35}	W_{35}	AH	M	H	VH	MH	VH	H	MH	H	AH
C_{36}	W_{36}	H	AH	MH	MH	H	MH	AH	AH	H	MH
C_{37}	W_{37}	MH	AH	H	H	H	AH	MH	H	AH	AH
C_{38}	W_{38}	MH	H	AH	H	VH	MH	AH	VH	H	H
C_{39}	W_{39}	H	VH	H	AH	H	MH	H	MH	H	AH
C_{310}	W_{310}	H	H	AH	H	H	H	VH	MH	MH	VH
C_{311}	W_{311}	VH	AH	H	VH	VH	M	MH	MH	VH	H
C_{312}	W_{312}	MH	AH	AH	VH	H	AH	H	AH	H	H
C_{41}	W_{41}	VH	AH	VH	H	H	H	AH	AH	AH	VH
C_{42}	W_{42}	VH	H	H	MH	H	VH	H	MH	MH	H
C_{43}	W_{43}	H	MH	H	H	VH	MH	VH	AH	AH	VH
C_{44}	W_{44}	MH	MH	AH	MH	H	H	MH	H	H	MH
C_{45}	W_{45}	H	H	H	MH	MH	MH	MH	AH	H	H
C_{46}	W_{46}	H	VH	VH	AH	VH	VH	H	VH	AH	AH
C_{47}	W_{47}	VH	H	MH	MH	H	VH	VH	H	H	MH
C_{51}	W_{51}	H	VH	MH	MH	AH	H	MH	H	VH	VH
C_{52}	W_{52}	AH	H	MH	VH	VH	VH	MH	VH	MH	AH
C_{53}	W_{53}	MH	H	H	H	VH	MH	AH	AH	MH	H
C_{54}	W_{54}	MH	VH	M	AH	H	MH	H	H	H	VH
C_{55}	W_{55}	VH	VH	AH	H	H	H	AH	H	VH	MH
C_{56}	W_{56}	H	H	MH	VH	VH	M	MH	AH	H	MH

Table 5.6: Priority weight of leagile enablers (in linguistic term) given by decision maker (DMs)

Leagile enablers, C_i	Weight	Priority weight of leagile enablers (in linguistic term)									
		DM1	DM2	DM3	DM4	DM5	DM6	DM7	DM8	DM9	DM10
C_1	W_1	VH	AH	H	AH	VH	H	AH	AH	VH	MH
C_2	W_2	VH	AH	VH	AH	H	VH	VH	MH	MH	AH
C_3	W_3	AH	AH	AH	H	VH	H	MH	VH	VH	H
C_4	W_4	H	H	MH	VH	MH	AH	H	VH	H	AH
C_5	W_5	VH	MH	H	MH	H	MH	VH	AH	AH	MH

Table 5.7: Aggregated priority weight as well as aggregated appropriateness rating of leagile criterions

Leagile criterions, C_{ijk}	Aggregated fuzzy priority weight (w_{ijk})	Aggregated fuzzy rating (U_{ijk})
C_{111}	(0.755,0.799,0.908,0.946;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{112}	(0.722,0.775,0.886,0.925;1.000)	(0.699,0.755,0.892,0.940;1.000)
C_{113}	(0.811,0.851,0.940,0.971;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{114}	(0.874,0.908,0.968,0.988;1.000)	(0.641,0.697,0.808,0.849;1.000)
C_{115}	(0.741,0.795,0.908,0.946;1.000)	(0.825,0.869,0.948,0.974;1.000)
C_{121}	(0.797,0.836,0.928,0.960;1.000)	(0.735,0.778,0.872,0.905;1.000)
C_{122}	(0.734,0.790,0.912,0.954;1.000)	(0.742,0.788,0.888,0.924;1.000)
C_{123}	(0.722,0.772,0.890,0.933;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{124}	(0.846,0.889,0.956,0.977;1.000)	(0.708,0.760,0.874,0.914;1.000)
C_{125}	(0.713,0.762,0.888,0.932;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{131}	(0.853,0.891,0.956,0.977;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{132}	(0.715,0.762,0.874,0.914;1.000)	(0.622,0.677,0.786,0.828;1.000)
C_{133}	(0.755,0.799,0.908,0.946;1.000)	(0.743,0.792,0.898,0.936;1.000)
C_{141}	(0.720,0.775,0.900,0.943;1.000)	(0.668,0.731,0.856,0.901;1.000)
C_{142}	(0.748,0.805,0.924,0.965;1.000)	(0.653,0.701,0.822,0.867;1.000)
C_{151}	(0.708,0.760,0.874,0.914;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{152}	(0.762,0.801,0.908,0.946;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{153}	(0.832,0.871,0.948,0.974;1.000)	(0.710,0.768,0.876,0.915;1.000)
C_{154}	(0.790,0.834,0.928,0.960;1.000)	(0.715,0.773,0.886,0.925;1.000)
C_{155}	(0.755,0.799,0.908,0.946;1.000)	(0.650,0.705,0.860,0.915;1.000)

C_{161}	(0.790,0.842,0.944,0.979;1.000)	(0.629,0.682,0.782,0.820;1.000)
C_{162}	(0.729,0.780,0.882,0.917;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{163}	(0.769,0.814,0.920,0.957;1.000)	(0.764,0.809,0.910,0.947;1.000)
C_{164}	(0.895,0.928,0.976,0.991;1.000)	(0.674,0.732,0.842,0.881;1.000)
C_{165}	(0.720,0.775,0.900,0.943;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{166}	(0.825,0.869,0.948,0.974;1.000)	(0.675,0.725,0.840,0.882;1.000)
C_{167}	(0.692,0.742,0.880,0.929;1.000)	(0.743,0.795,0.894,0.928;1.000)
C_{168}	(0.720,0.772,0.904,0.951;1.000)	(0.759,0.799,0.880,0.910;1.000)
C_{169}	(0.881,0.924,0.976,0.991;1.000)	(0.647,0.711,0.848,0.898;1.000)
C_{171}	(0.741,0.795,0.908,0.946;1.000)	(0.578,0.640,0.780,0.832;1.000)
C_{172}	(0.783,0.832,0.928,0.960;1.000)	(0.688,0.739,0.838,0.873;1.000)
C_{173}	(0.790,0.837,0.924,0.952;1.000)	(0.609,0.666,0.784,0.829;1.000)
C_{174}	(0.741,0.792,0.912,0.954;1.000)	(0.710,0.760,0.860,0.896;1.000)
C_{181}	(0.757,0.810,0.906,0.939;1.000)	(0.648,0.702,0.804,0.841;1.000)
C_{182}	(0.790,0.834,0.928,0.960;1.000)	(0.667,0.719,0.830,0.870;1.000)
C_{183}	(0.708,0.760,0.874,0.914;1.000)	(0.669,0.719,0.816,0.852;1.000)
C_{184}	(0.811,0.854,0.936,0.963;1.000)	(0.759,0.810,0.892,0.921;1.000)
C_{191}	(0.860,0.890,0.960,0.985;1.000)	(0.783,0.832,0.928,0.960;1.000)
C_{192}	(0.769,0.806,0.904,0.938;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{193}	(0.769,0.806,0.904,0.938;1.000)	(0.645,0.703,0.846,0.897;1.000)
C_{1101}	(0.769,0.814,0.920,0.957;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{1102}	(0.722,0.775,0.886,0.925;1.000)	(0.699,0.755,0.892,0.940;1.000)
C_{1103}	(0.825,0.866,0.952,0.982;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{1104}	(0.874,0.908,0.968,0.988;1.000)	(0.641,0.697,0.808,0.849;1.000)
C_{211}	(0.741,0.795,0.908,0.946;1.000)	(0.825,0.869,0.948,0.974;1.000)
C_{212}	(0.797,0.836,0.928,0.960;1.000)	(0.735,0.778,0.872,0.905;1.000)
C_{213}	(0.734,0.790,0.912,0.954;1.000)	(0.742,0.788,0.888,0.924;1.000)
C_{214}	(0.722,0.772,0.890,0.933;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{215}	(0.832,0.874,0.944,0.966;1.000)	(0.708,0.760,0.874,0.914;1.000)
C_{216}	(0.713,0.762,0.888,0.932;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{221}	(0.818,0.856,0.936,0.963;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{222}	(0.715,0.762,0.874,0.914;1.000)	(0.622,0.677,0.786,0.828;1.000)
C_{223}	(0.769,0.814,0.920,0.957;1.000)	(0.743,0.792,0.898,0.936;1.000)
C_{224}	(0.720,0.775,0.900,0.943;1.000)	(0.668,0.731,0.856,0.901;1.000)

C_{225}	(0.748,0.805,0.924,0.965;1.000)	(0.653,0.701,0.822,0.867;1.000)
C_{226}	(0.708,0.760,0.874,0.914;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{227}	(0.811,0.854,0.936,0.963;1.000)	(0.759,0.810,0.892,0.921;1.000)
C_{231}	(0.860,0.890,0.960,0.985;1.000)	(0.783,0.832,0.928,0.960;1.000)
C_{232}	(0.769,0.806,0.904,0.938;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{233}	(0.769,0.806,0.904,0.938;1.000)	(0.645,0.703,0.846,0.897;1.000)
C_{234}	(0.769,0.814,0.920,0.957;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{235}	(0.722,0.775,0.886,0.925;1.000)	(0.699,0.755,0.892,0.940;1.000)
C_{236}	(0.825,0.866,0.952,0.982;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{241}	(0.874,0.908,0.968,0.988;1.000)	(0.641,0.697,0.808,0.849;1.000)
C_{242}	(0.741,0.795,0.908,0.946;1.000)	(0.825,0.869,0.948,0.974;1.000)
C_{243}	(0.797,0.836,0.928,0.960;1.000)	(0.735,0.778,0.872,0.905;1.000)
C_{244}	(0.734,0.790,0.912,0.954;1.000)	(0.742,0.788,0.888,0.924;1.000)
C_{245}	(0.736,0.787,0.902,0.944;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{246}	(0.832,0.874,0.944,0.966;1.000)	(0.708,0.760,0.874,0.914;1.000)
C_{247}	(0.713,0.762,0.888,0.932;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{248}	(0.853,0.891,0.956,0.977;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{249}	(0.715,0.762,0.874,0.914;1.000)	(0.622,0.677,0.786,0.828;1.000)
C_{251}	(0.755,0.799,0.908,0.946;1.000)	(0.743,0.792,0.898,0.936;1.000)
C_{252}	(0.706,0.760,0.888,0.932;1.000)	(0.668,0.731,0.856,0.901;1.000)
C_{253}	(0.748,0.805,0.924,0.965;1.000)	(0.653,0.701,0.822,0.867;1.000)
C_{311}	(0.750,0.797,0.894,0.928;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{312}	(0.762,0.801,0.908,0.946;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{313}	(0.832,0.871,0.948,0.974;1.000)	(0.710,0.768,0.876,0.915;1.000)
C_{314}	(0.790,0.834,0.928,0.960;1.000)	(0.715,0.773,0.886,0.925;1.000)
C_{321}	(0.755,0.799,0.908,0.946;1.000)	(0.650,0.705,0.860,0.915;1.000)
C_{322}	(0.790,0.842,0.944,0.979;1.000)	(0.629,0.682,0.782,0.820;1.000)
C_{323}	(0.764,0.815,0.902,0.931;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{324}	(0.769,0.814,0.920,0.957;1.000)	(0.764,0.809,0.910,0.947;1.000)
C_{325}	(0.860,0.893,0.956,0.977;1.000)	(0.674,0.732,0.842,0.881;1.000)
C_{331}	(0.720,0.775,0.900,0.943;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{332}	(0.811,0.854,0.936,0.963;1.000)	(0.675,0.725,0.840,0.882;1.000)
C_{333}	(0.692,0.742,0.880,0.929;1.000)	(0.743,0.795,0.894,0.928;1.000)
C_{334}	(0.748,0.802,0.928,0.973;1.000)	(0.759,0.799,0.880,0.910;1.000)

C_{341}	(0.881,0.924,0.976,0.991;1.000)	(0.647,0.711,0.848,0.898;1.000)
C_{342}	(0.741,0.795,0.908,0.946;1.000)	(0.578,0.640,0.780,0.832;1.000)
C_{343}	(0.783,0.832,0.928,0.960;1.000)	(0.688,0.739,0.838,0.873;1.000)
C_{344}	(0.832,0.874,0.944,0.966;1.000)	(0.609,0.666,0.784,0.829;1.000)
C_{351}	(0.741,0.792,0.912,0.954;1.000)	(0.710,0.760,0.860,0.896;1.000)
C_{352}	(0.757,0.810,0.906,0.939;1.000)	(0.648,0.702,0.804,0.841;1.000)
C_{353}	(0.825,0.869,0.948,0.974;1.000)	(0.667,0.719,0.830,0.870;1.000)
C_{354}	(0.708,0.760,0.874,0.914;1.000)	(0.669,0.719,0.816,0.852;1.000)
C_{361}	(0.769,0.814,0.920,0.957;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{362}	(0.708,0.760,0.874,0.914;1.000)	(0.699,0.755,0.892,0.940;1.000)
C_{363}	(0.811,0.851,0.940,0.971;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{364}	(0.874,0.908,0.968,0.988;1.000)	(0.641,0.697,0.808,0.849;1.000)
C_{371}	(0.741,0.795,0.908,0.946;1.000)	(0.825,0.869,0.948,0.974;1.000)
C_{372}	(0.797,0.836,0.928,0.960;1.000)	(0.735,0.778,0.872,0.905;1.000)
C_{373}	(0.734,0.790,0.912,0.954;1.000)	(0.742,0.788,0.888,0.924;1.000)
C_{374}	(0.722,0.772,0.890,0.933;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{375}	(0.846,0.889,0.956,0.977;1.000)	(0.708,0.760,0.874,0.914;1.000)
C_{376}	(0.699,0.747,0.876,0.921;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{377}	(0.853,0.891,0.956,0.977;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{378}	(0.715,0.762,0.874,0.914;1.000)	(0.622,0.677,0.786,0.828;1.000)
C_{379}	(0.769,0.814,0.920,0.957;1.000)	(0.743,0.792,0.898,0.936;1.000)
C_{3710}	(0.706,0.760,0.888,0.932;1.000)	(0.668,0.731,0.856,0.901;1.000)
C_{3711}	(0.748,0.805,0.924,0.965;1.000)	(0.653,0.701,0.822,0.867;1.000)
C_{381}	(0.750,0.797,0.894,0.928;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{382}	(0.762,0.801,0.908,0.946;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{383}	(0.832,0.871,0.948,0.974;1.000)	(0.710,0.768,0.876,0.915;1.000)
C_{384}	(0.790,0.834,0.928,0.960;1.000)	(0.715,0.773,0.886,0.925;1.000)
C_{391}	(0.755,0.799,0.908,0.946;1.000)	(0.650,0.705,0.860,0.915;1.000)
C_{392}	(0.790,0.842,0.944,0.979;1.000)	(0.629,0.682,0.782,0.820;1.000)
C_{393}	(0.764,0.815,0.902,0.931;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{394}	(0.769,0.814,0.920,0.957;1.000)	(0.764,0.809,0.910,0.947;1.000)
C_{3101}	(0.895,0.928,0.976,0.991;1.000)	(0.674,0.732,0.842,0.881;1.000)
C_{3102}	(0.720,0.775,0.900,0.943;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{3103}	(0.825,0.869,0.948,0.974;1.000)	(0.675,0.725,0.840,0.882;1.000)

C_{3104}	(0.692,0.742,0.880,0.929;1.000)	(0.743,0.795,0.894,0.928;1.000)
C_{3105}	(0.720,0.772,0.904,0.951;1.000)	(0.759,0.799,0.880,0.910;1.000)
C_{3106}	(0.881,0.924,0.976,0.991;1.000)	(0.647,0.711,0.848,0.898;1.000)
C_{3111}	(0.741,0.795,0.908,0.946;1.000)	(0.578,0.640,0.780,0.832;1.000)
C_{3112}	(0.783,0.832,0.928,0.960;1.000)	(0.688,0.739,0.838,0.873;1.000)
C_{3113}	(0.832,0.874,0.944,0.966;1.000)	(0.609,0.666,0.784,0.829;1.000)
C_{3114}	(0.741,0.792,0.912,0.954;1.000)	(0.710,0.760,0.860,0.896;1.000)
C_{3115}	(0.757,0.810,0.906,0.939;1.000)	(0.648,0.702,0.804,0.841;1.000)
C_{3116}	(0.825,0.869,0.948,0.974;1.000)	(0.667,0.719,0.830,0.870;1.000)
C_{3117}	(0.708,0.760,0.874,0.914;1.000)	(0.669,0.719,0.816,0.852;1.000)
C_{3121}	(0.811,0.854,0.936,0.963;1.000)	(0.759,0.810,0.892,0.921;1.000)
C_{3122}	(0.860,0.890,0.960,0.985;1.000)	(0.783,0.832,0.928,0.960;1.000)
C_{3123}	(0.769,0.806,0.904,0.938;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{3124}	(0.769,0.806,0.904,0.938;1.000)	(0.645,0.703,0.846,0.897;1.000)
C_{411}	(0.769,0.814,0.920,0.957;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{412}	(0.722,0.775,0.886,0.925;1.000)	(0.699,0.755,0.892,0.940;1.000)
C_{413}	(0.825,0.866,0.952,0.982;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{414}	(0.874,0.908,0.968,0.988;1.000)	(0.641,0.697,0.808,0.849;1.000)
C_{421}	(0.741,0.795,0.908,0.946;1.000)	(0.825,0.869,0.948,0.974;1.000)
C_{422}	(0.797,0.836,0.928,0.960;1.000)	(0.735,0.778,0.872,0.905;1.000)
C_{423}	(0.734,0.790,0.912,0.954;1.000)	(0.742,0.788,0.888,0.924;1.000)
C_{431}	(0.764,0.809,0.910,0.947;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{432}	(0.846,0.889,0.956,0.977;1.000)	(0.708,0.760,0.874,0.914;1.000)
C_{433}	(0.741,0.784,0.896,0.935;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{434}	(0.853,0.891,0.956,0.977;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{441}	(0.715,0.762,0.874,0.914;1.000)	(0.622,0.677,0.786,0.828;1.000)
C_{442}	(0.790,0.834,0.928,0.960;1.000)	(0.743,0.792,0.898,0.936;1.000)
C_{443}	(0.720,0.775,0.900,0.943;1.000)	(0.668,0.731,0.856,0.901;1.000)
C_{444}	(0.748,0.805,0.924,0.965;1.000)	(0.653,0.701,0.822,0.867;1.000)
C_{445}	(0.750,0.797,0.894,0.928;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{451}	(0.811,0.854,0.936,0.963;1.000)	(0.759,0.810,0.892,0.921;1.000)
C_{452}	(0.860,0.890,0.960,0.985;1.000)	(0.783,0.832,0.928,0.960;1.000)
C_{453}	(0.769,0.806,0.904,0.938;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{454}	(0.769,0.806,0.904,0.938;1.000)	(0.645,0.703,0.846,0.897;1.000)

C_{455}	(0.769,0.814,0.920,0.957;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{456}	(0.722,0.775,0.886,0.925;1.000)	(0.699,0.755,0.892,0.940;1.000)
C_{457}	(0.825,0.866,0.952,0.982;1.000)	(0.694,0.753,0.878,0.922;1.000)
C_{458}	(0.874,0.908,0.968,0.988;1.000)	(0.641,0.697,0.808,0.849;1.000)
C_{461}	(0.741,0.795,0.908,0.946;1.000)	(0.825,0.869,0.948,0.974;1.000)
C_{462}	(0.797,0.836,0.928,0.960;1.000)	(0.735,0.778,0.872,0.905;1.000)
C_{463}	(0.755,0.810,0.920,0.957;1.000)	(0.742,0.788,0.888,0.924;1.000)
C_{464}	(0.722,0.772,0.890,0.933;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{471}	(0.867,0.909,0.964,0.980;1.000)	(0.708,0.760,0.874,0.914;1.000)
C_{472}	(0.713,0.762,0.888,0.932;1.000)	(0.696,0.753,0.864,0.904;1.000)
C_{473}	(0.853,0.891,0.956,0.977;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{474}	(0.715,0.762,0.874,0.914;1.000)	(0.622,0.677,0.786,0.828;1.000)
C_{475}	(0.769,0.814,0.920,0.957;1.000)	(0.743,0.792,0.898,0.936;1.000)
C_{476}	(0.720,0.775,0.900,0.943;1.000)	(0.668,0.731,0.856,0.901;1.000)
C_{511}	(0.748,0.805,0.924,0.965;1.000)	(0.653,0.701,0.822,0.867;1.000)
C_{512}	(0.750,0.797,0.894,0.928;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{513}	(0.762,0.801,0.908,0.946;1.000)	(0.673,0.725,0.854,0.900;1.000)
C_{521}	(0.832,0.871,0.948,0.974;1.000)	(0.710,0.768,0.876,0.915;1.000)
C_{522}	(0.790,0.834,0.928,0.960;1.000)	(0.715,0.773,0.886,0.925;1.000)
C_{523}	(0.755,0.799,0.908,0.946;1.000)	(0.650,0.705,0.860,0.915;1.000)
C_{531}	(0.790,0.842,0.944,0.979;1.000)	(0.629,0.682,0.782,0.820;1.000)
C_{532}	(0.764,0.815,0.902,0.931;1.000)	(0.804,0.849,0.940,0.971;1.000)
C_{533}	(0.769,0.814,0.920,0.957;1.000)	(0.764,0.809,0.910,0.947;1.000)
C_{541}	(0.895,0.928,0.976,0.991;1.000)	(0.674,0.732,0.842,0.881;1.000)
C_{542}	(0.720,0.775,0.900,0.943;1.000)	(0.666,0.720,0.858,0.908;1.000)
C_{543}	(0.825,0.869,0.948,0.974;1.000)	(0.675,0.725,0.840,0.882;1.000)
C_{551}	(0.692,0.742,0.880,0.929;1.000)	(0.743,0.795,0.894,0.928;1.000)
C_{552}	(0.748,0.802,0.928,0.973;1.000)	(0.759,0.799,0.880,0.910;1.000)
C_{553}	(0.881,0.924,0.976,0.991;1.000)	(0.647,0.711,0.848,0.898;1.000)
C_{561}	(0.741,0.795,0.908,0.946;1.000)	(0.578,0.640,0.780,0.832;1.000)
C_{562}	(0.783,0.832,0.928,0.960;1.000)	(0.688,0.739,0.838,0.873;1.000)
C_{563}	(0.832,0.874,0.944,0.966;1.000)	(0.609,0.666,0.784,0.829;1.000)

Table 5.8: Aggregated fuzzy priority weight and computed fuzzy rating of leagile attributes

Leagile attributes, C_{ij}	Aggregated fuzzy priority weight (w_{ij})	Computed fuzzy rating (U_{ij})
C_{11}	(0.804,0.841,0.924,0.952;1.000)	(0.579,0.684,0.979,1.122;1.000)
C_{12}	(0.846,0.875,0.948,0.974;1.000)	(0.590,0.695,1.002,1.152;1.000)
C_{13}	(0.755,0.791,0.892,0.927;1.000)	(0.557,0.655,0.946,1.085;1.000)
C_{14}	(0.762,0.801,0.908,0.946;1.000)	(0.508,0.620,0.968,1.149;1.000)
C_{15}	(0.769,0.814,0.920,0.957;1.000)	(0.555,0.658,0.974,1.125;1.000)
C_{16}	(0.736,0.782,0.882,0.917;1.000)	(0.572,0.675,0.968,1.112;1.000)
C_{17}	(0.769,0.814,0.920,0.957;1.000)	(0.518,0.622,0.920,1.070;1.000)
C_{18}	(0.839,0.873,0.948,0.974;1.000)	(0.558,0.660,0.935,1.073;1.000)
C_{19}	(0.741,0.795,0.908,0.946;1.000)	(0.595,0.691,0.979,1.106;1.000)
C_{110}	(0.783,0.821,0.916,0.949;1.000)	(0.564,0.666,0.952,1.091;1.000)
C_{21}	(0.734,0.790,0.912,0.954;1.000)	(0.599,0.705,1.017,1.168;1.000)
C_{22}	(0.708,0.757,0.878,0.922;1.000)	(0.547,0.652,0.965,1.120;1.000)
C_{23}	(0.839,0.876,0.944,0.966;1.000)	(0.579,0.681,0.983,1.123;1.000)
C_{24}	(0.741,0.784,0.896,0.935;1.000)	(0.582,0.684,0.973,1.113;1.000)
C_{25}	(0.867,0.906,0.968,0.988;1.000)	(0.535,0.644,0.988,1.160;1.000)
C_{31}	(0.715,0.762,0.874,0.914;1.000)	(0.569,0.671,0.967,1.108;1.000)
C_{32}	(0.797,0.836,0.928,0.960;1.000)	(0.578,0.679,0.963,1.102;1.000)
C_{33}	(0.748,0.797,0.908,0.946;1.000)	(0.554,0.661,0.996,1.162;1.000)
C_{34}	(0.748,0.805,0.924,0.965;1.000)	(0.529,0.629,0.892,1.024;1.000)
C_{35}	(0.750,0.797,0.894,0.928;1.000)	(0.540,0.643,0.932,1.079;1.000)
C_{36}	(0.748,0.786,0.896,0.935;1.000)	(0.562,0.665,0.955,1.094;1.000)
C_{37}	(0.804,0.838,0.928,0.960;1.000)	(0.571,0.676,0.988,1.142;1.000)
C_{38}	(0.790,0.834,0.928,0.960;1.000)	(0.569,0.671,0.967,1.108;1.000)
C_{39}	(0.769,0.814,0.920,0.957;1.000)	(0.574,0.677,0.980,1.130;1.000)
C_{310}	(0.762,0.812,0.920,0.957;1.000)	(0.566,0.668,0.958,1.100;1.000)
C_{311}	(0.764,0.815,0.902,0.931;1.000)	(0.528,0.630,0.914,1.057;1.000)
C_{312}	(0.839,0.873,0.948,0.974;1.000)	(0.606,0.703,0.979,1.103;1.000)
C_{41}	(0.895,0.928,0.976,0.991;1.000)	(0.564,0.666,0.952,1.091;1.000)
C_{42}	(0.720,0.775,0.900,0.943;1.000)	(0.609,0.715,1.024,1.176;1.000)
C_{43}	(0.811,0.854,0.936,0.963;1.000)	(0.600,0.699,0.973,1.104;1.000)

C_{44}	(0.678,0.727,0.868,0.918;1.000)	(0.531,0.637,0.961,1.124;1.000)
C_{45}	(0.692,0.742,0.880,0.929;1.000)	(0.585,0.685,0.966,1.097;1.000)
C_{46}	(0.909,0.946,0.984,0.994;1.000)	(0.616,0.723,1.034,1.188;1.000)
C_{47}	(0.741,0.795,0.908,0.946;1.000)	(0.558,0.661,0.959,1.104;1.000)
C_{51}	(0.769,0.817,0.916,0.949;1.000)	(0.529,0.631,0.958,1.120;1.000)
C_{52}	(0.818,0.859,0.932,0.955;1.000)	(0.572,0.674,0.972,1.113;1.000)
C_{53}	(0.755,0.799,0.908,0.946;1.000)	(0.592,0.696,0.981,1.125;1.000)
C_{54}	(0.722,0.775,0.886,0.925;1.000)	(0.564,0.661,0.929,1.061;1.000)
C_{55}	(0.825,0.869,0.948,0.974;1.000)	(0.571,0.678,0.985,1.136;1.000)
C_{56}	(0.708,0.760,0.874,0.914;1.000)	(0.513,0.614,0.890,1.030;1.000)

Table 5.9: Aggregated fuzzy priority weight and computed fuzzy rating of leagile enablers

Leagile enablers (C_i)	Aggregated fuzzy weight (w_i)	Computed fuzzy rating (U_i)
C_1	(0.881,0.913,0.964,0.980;1.000)	(0.460,0.594,1.075,1.349;1.000)
C_2	(0.895,0.931,0.972,0.983;1.000)	(0.463,0.602,1.101,1.393;1.000)
C_3	(0.853,0.891,0.956,0.977;1.000)	(0.456,0.592,1.076,1.358;1.000)
C_4	(0.790,0.834,0.928,0.960;1.000)	(0.474,0.612,1.098,1.382;1.000)
C_5	(0.776,0.819,0.916,0.949;1.000)	(0.453,0.589,1.068,1.353;1.000)

APPENDIX-D (Additional Data Tables of Chapter 6)

Table 6.4: Linguistic priority weights of 2nd level criterions as given by the decision-makers

2nd level indices (criterions)	Linguistic priority weights				
	DM1	DM2	DM3	DM4	DM5
C_{11}	H	VH	H	H	MH
C_{12}	VH	VH	H	VH	M
C_{13}	H	H	VH	MH	VH
C_{14}	VH	AH	H	VH	MH
C_{21}	VH	MH	MH	H	H
C_{22}	M	M	VH	M	H
C_{23}	VH	H	MH	MH	M
C_{24}	H	M	AH	VH	VH
C_{31}	H	M	ML	M	M
C_{32}	MH	M	M	MH	VH
C_{33}	MH	VH	M	L	L
C_{34}	VH	H	MH	H	H
C_{41}	M	ML	H	MH	ML
C_{42}	H	H	M	M	VH
C_{43}	MH	MH	VH	VH	H
C_{44}	MH	H	H	ML	H

Table 6.5: Linguistic priority weights of 1st level attributes as given by the decision-makers

1st level indices (attributes)	Linguistic priority weights				
	DM1	DM2	DM3	DM4	DM5
C_1	VH	MH	VH	H	H
C_2	AH	AH	H	VH	MH
C_3	H	VH	H	H	VH
C_4	VH	MH	H	H	VH

Table 6.6: Appropriateness rating of 2nd level criterions as given by the decision-makers **(for Alternative A_1)**

2nd level indices (criterions)	Linguistic appropriateness rating				
	DM1	DM2	DM3	DM4	DM5
C_{11}	VG	AG	G	G	G
C_{12}	MP	MG	MG	VG	M
C_{13}	VG	VG	G	G	MG
C_{14}	VG	AG	G	MG	G
C_{21}	MG	G	VG	MG	P
C_{22}	M	G	G	MG	MG
C_{23}	VG	G	G	VG	M
C_{24}	G	M	M	G	G
C_{31}	G	VG	P	VG	P
C_{32}	AG	G	G	MG	G
C_{33}	MG	G	MG	MP	G
C_{34}	VG	G	VG	M	MG
C_{41}	G	G	VG	VG	VG
C_{42}	G	G	P	MG	MG
C_{43}	MG	MP	VG	VG	P
C_{44}	G	MG	G	AG	VG

Table 6.7: Appropriateness rating of 2nd level criterions as given by the decision-makers **(for Alternative A_2)**

2nd level indices (criterions)	Linguistic appropriateness rating				
	DM1	DM2	DM3	DM4	DM5
C_{11}	MG	G	VG	MG	MG
C_{12}	G	G	VG	MG	G
C_{13}	VG	AG	G	VG	G
C_{14}	G	M	M	G	M
C_{21}	M	VG	G	G	M
C_{22}	G	G	G	G	G
C_{23}	M	G	M	MG	G
C_{24}	M	M	MP	G	G
C_{31}	G	VG	VG	M	M
C_{32}	AG	G	VG	G	VG
C_{33}	MG	MG	MG	G	MG
C_{34}	G	G	G	AG	G
C_{41}	MG	G	AG	MG	G
C_{42}	VG	VG	VG	G	AG
C_{43}	G	MG	G	MG	MG
C_{44}	G	G	VG	G	AG

Table 6.8: Appropriateness rating of 2nd level criterions as given by the decision-makers **(for Alternative A_3)**

2nd level indices (criterions)	Linguistic appropriateness rating				
	DM1	DM2	DM3	DM4	DM5
C_{11}	VG	MG	G	G	M
C_{12}	G	M	VG	G	M
C_{13}	M	G	G	VG	VG
C_{14}	VG	P	MG	G	MG
C_{21}	G	MP	VG	MP	M
C_{22}	G	MG	G	M	M
C_{23}	G	G	MP	G	MP
C_{24}	G	VG	VG	G	M
C_{31}	MG	M	M	M	P
C_{32}	VG	VG	P	G	G
C_{33}	G	AG	AG	MG	G
C_{34}	VG	G	G	AG	G
C_{41}	M	M	M	M	MG
C_{42}	VG	G	M	M	G
C_{43}	G	M	MG	MG	G
C_{44}	M	M	VG	VG	G

Table 6.9: Appropriateness rating of 2nd level criterions as given by the decision-makers **(for Alternative A_4)**

2nd level indices (criterions)	Linguistic appropriateness rating				
	DM1	DM2	DM3	DM4	DM5
C_{11}	AG	VG	MG	G	VG
C_{12}	VG	VG	G	G	AG
C_{13}	G	G	G	MG	VG
C_{14}	M	G	MG	G	VG
C_{21}	MG	MG	VG	MG	G
C_{22}	G	VG	G	VG	M
C_{23}	MG	M	M	MG	MG
C_{24}	MG	G	MG	G	G
C_{31}	VG	G	VG	VG	AG
C_{32}	G	MG	G	MG	G
C_{33}	G	VG	M	G	VG
C_{34}	VG	AG	G	VG	VG
C_{41}	VG	MG	MG	MG	VG
C_{42}	AG	G	VG	VG	G
C_{43}	G	G	G	G	MG
C_{44}	MG	VG	M	G	VG

Table 6.10: Appropriateness rating of 2nd level criterions as given by the decision-makers **(for Alternative A_5)**

2nd level indices (criterions)	Linguistic appropriateness rating				
	DM1	DM2	DM3	DM4	DM5
C_{11}	AG	AG	M	G	M
C_{12}	MG	MG	VG	M	VG
C_{13}	M	G	VG	AG	AG
C_{14}	AG	AG	M	M	G
C_{21}	MG	G	VG	VG	M
C_{22}	VG	M	AG	AG	MG
C_{23}	M	G	MG	MG	M
C_{24}	G	M	MP	G	G
C_{31}	M	G	M	G	MP
C_{32}	VG	M	MG	G	MG
C_{33}	MG	G	MG	MG	VG
C_{34}	VG	M	M	G	M
C_{41}	AG	VG	VG	M	G
C_{42}	M	P	M	M	G
C_{43}	M	G	VG	VG	AG
C_{44}	VG	MG	G	MG	G