A Fuzzy Multi-Attribute Decision Making Model for Selecting the Best Supply Chain Strategy: Lean, Agile or Leagile

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Abstract

During recent years, determining appropriate strategy in the supply chain has become an important strategic issue. However, the nature of these decisions usually is complex and unstructured. To determine the best supply chain strategy, many quantitative and qualitative attributes such as cost, responsiveness and flexibility can be taken into account. In order to approximate the human subjective evaluation process, it would be desirable to apply a fuzzy MADM model. In this paper a fuzzy multi-attribute decision making (FMADM) model is developed to deal with strategy selection problem in a supply chain. A case study is used to validate the proposed model and the corresponding results show the power of the proposed model in handling subjective data in multi-attribute decision making process.

Keywords: Fuzzy multi-attribute decision making, Supply chain management, Strategy selection

1. Introduction

A key feature of contemporary business is the competition among the supply chains instead of companies. In other words, delivering the right product, at the right time with a reasonable cost to consumers is not only the lynch pin to competitive success but also the key to survival [1]. The latter part of the 20th century saw the lean production paradigm positively impact many market sectors ranging from automotive industries to electronic industries. The focus of the lean approach has essentially been on the elimination of waste or muda. The upsurge of interest in lean manufacturing can be traced to the Toyota Production Systems. Lean is about doing more with less [2]. In particular there is much evidence to suggest that level scheduling combined with the elimination of muda as successfully delivered a wide range of products to those markets where cost is the primary order winning criteria. However, there are many other markets where the order winner is availability. This has led to the emergence of the agile paradigm typified by 'quick response' and similar initiatives [3]. Agility is a business wide capability that embraces organizational structures; information point in the material, systems, logistics processes and in particular, mindsets [4, 5]. Agility is being defined as the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety [3]. The emphasis is on adaptability to changes in the business environment and on addressing market and customer needs proactively [2]. A key characteristic of an agile organization is flexibility [6, 7, 8]. Indeed the origins of agility as a business concept lie in flexible manufacturing systems (FMS). Initially it was thought that the route to manufacturing flexibility was through automation to enable rapid change (e.g. reduced set-up times) and thus a greater responsiveness to changes in product mix or volume. Later this idea of manufacturing flexibility was extended into the wider business context [9] and the concept of agility as an organizational orientation was born [1]. Nevertheless, both paradigms lean and agile have their own advantages and imperfections and are not exclusive

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paradigms. So effectiveness of agility and leanness depends on business environment characteristics and customer needs. Even, they may be combined to advantage in a number of different ways. Hence, customer satisfaction and marketplace understanding are crucial elements for consideration when attempting to establish a new supply chain strategy. Combining agility and leanness in one supply chain via the strategic use of a decoupling point has been termed ‘‘leagility’’ [10]. The decoupling point is in the material flow streams to which the customer orders penetrates [11]. Therefore leagile is the combination of the lean and agile paradigms 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 market place [12].

The goal of this research is to investigate lean and agile concepts in the area of supply chain management and to represent a FMADM model to select the best supply chain strategy according to system characteristics. The rest of this paper is organized as follows. In the next section, some related works are reviewed. Section 3 illustrates the basic definitions and notations of the fuzzy numbers, linguistic variables and the fuzzy TOPSIS method. In Section 4, we present a hierarchical model for selecting the best supply chain strategy and decision making criteria. Section 5, describes numerical examples to demonstrate the applicability of proposed method. Finally, concluding remarks are summarized in Section 6.

2. Literature review

Naylor et al. [10] compared the lean and agile manufacturing paradigms, highlighting the similarities and differences. They showed how the need for agility and leanness depends upon the total supply chain strategy, by considering market knowledge, information enrichment and the position of the decoupling point. The lean and agile paradigms, though distinctly different, can be combined within successfully designed and operated total supply chains [13, 10]. Cristopher and Towill [1] have sought to bring together the lean and agile philosophies to highlight the differences in their approach, but also to show the various ways in which these paradigms may be combined to enable highly competitive supply chains. They have focused on ‘market qualifiers’ and ‘market winners’. The lean supply paradigm has taught us the importance of reducing variation and enabling flow, so reducing the need for protective inventory and capacity. However, with the growth in product innovation and demand uncertainty, supply chains now need to strategically locate inventory and capacity. Investment in capacity to protect material flow rather than inventory is central to the agile supply paradigm and the use of separation principles provides a practical approach to exploring innovative approaches to mitigating the impact of the conflict. Stratton et al. [14] identify how TRIZ separation principles and TOC tools may be combined in the integrated development of responsive and efficient supply chains. Cagliano et al. [15] empirically explored the supply strategies of European manufacturing firms. Four clusters have been identified on the basis of the supplier selection criteria and the integration mechanisms adopted. Vonderembse et al. [16] discuss supply chain strategy types including lean, agile and hybrid across three types of products: standard, innovative, and hybrid. They have developed a framework for categorizing the supply chain types according to product characteristics and stage of the product life cycle. Agarwal et al. [2] develop an analytic network process (ANP) model to identify the best supply chain strategy. They explore the relationship among lead-time, cost, quality, and service level and the leanness and agility of a supply chain.

Although there are many researches regarding conceptual approaches for selecting the supply chain strategy, most of the related literatures are devoted to some specific perspectives, such as supply chain type, product type and etc. It is clear that, selecting the supply chain strategy without considering all the relevant aspects does not lead to an effective result. This paper exploits the advantages of previous works to develop a comprehensive model for selecting the best supply chain strategy, which considerers all the relevant dimensions and using both quantitative and qualitative criteria. To overcome the issue of complexity and uncertainty in the considered problem, the fuzzy technique for order performance by similarity to ideal solution (Fuzzy-TOPSIS) is used to identify the most appropriate supply chain strategy.

3. Methodology

MADM deals with the problem of choosing an option from a set of alternatives which are characterized in terms of their attributes. It requires information on the preferences among the instances of an attribute, and the preferences across the existing attributes. An important advantage of most MADM techniques is that they are capable to analyze both quantitative and qualitative evaluation criteria together. The decision maker may express or define a ranking for the attributes as importance/weight. The aim of the MADM is to obtain the optimum alternative that has the highest degree of satisfaction for all of the relevant attributes. TOPSIS, outranking, and AHP are three of the most frequently used MADM techniques. TOPSIS and Fuzzy TOPSIS have been applied to solve a variety of problems [17, 18]. TOPSIS views a MADM problem with *m* alternatives as a geometric system with *m* points in the *n* dimensional space. The method is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. TOPSIS defines an index called similarity (or relative closeness) to the positive-ideal solution and the remoteness from the negative-ideal solution. Then the method chooses an alternative with the maximum similarity to the positive-ideal solution [19]. Despite the convenience of TOPSIS in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision maker's judgments, fuzziness and vagueness existing in many decision making problems may contribute to the imprecise judgments of decision makers in conventional TOPSIS approach. In other words, under many conditions, crisp data are inadequate to model real-life situations. Since human judgments including preferences are often vague and cannot be estimated with an exact numerical value, a more realistic approach may be to use linguistic assessments instead of numerical values.

Fuzzy TOPSIS refers to a method for multi-attribute decision making (MADM) under uncertainty, where a finite number of decision alternatives are evaluated under a finite number of performance criteria. The purpose of the analysis is to rank the alternatives in a subjective order of preference. The overall performance of these alternatives is herein assessed via proper assignment of numerical grades or scores measured through fuzzy theories to address the issue of vagueness of human preferential judgment [20]. A present study represents a FMADM model and explores the use of Fuzzy TOPSIS to select the best supply chain strategy according to system characteristics. Details of the proposed methodology are discussed sequentially in the following sections [21]. In summation, the algorithm of fuzzy TOPSIS method used in this paper is given as follows [20]:

Step 1: Form a committee of decision-makers, and then identify the evaluation criteria.

Step 2: Choose the appropriate linguistic variables for the importance weight of the criteria and the linguistic ratings for alternatives.

Step3: convert the linguistic evaluations into triangular fuzzy numbers to construct the fuzzy-decision matrix and determine the fuzzy weight of each criterion.

Step 4: normalized fuzzy weight of each criterion and fuzzy-decision matrix.

Step 5: Construct weighted normalized fuzzy decision matrix.

Step 6: Determine FPIS and FNIS.

Step 7: Calculate the distance of each alternatives from FPIS and FNIS, respectively.

Step 8: Calculate the closeness coefficient of each alternatives.

Step 9: According to the closeness coefficient, we can understand the assessment status of each alternative and determine the ranking order of all alternatives.

Although we can determine the ranking order of all feasible strategies, a more realistic approach may be to use a linguistic variable to describe the current assessment status of each strategy in accordance with its closeness coefficient. In order to describe the assessment status of each strategy, we divide the interval [0, 1] into five sub-intervals. Five linguistic variables with respect to the sub-intervals are defined to divide the assessment status of strategies into five classes [20]. The decision rules of the five classes are shown in Table 1.

Table 1: Approval status

Closeness Coefficient (CC_i)	Assessment status
$CC_i \in [0,0.2]$	Do not recommend
$CC_i \in [0.2,0.35]$	Recommend with high risk
$CC_i \in [0.35,0.5]$	Recommend with low risk
$CC_i \in [0.5,0.85]$	Approved
$CC_i \in [0.85,1]$	Approved and preferred

According to the table 1, it means that:

If $CC_i \in [0, 0.2]$, then strategy A_i belongs to Class I and the assessment status of strategy A_i is "*not recommend*";

If $CC_i \in [0.2, 0.35]$, then strategy A_i belongs to Class II and the assessment status of strategy A_i is "*recommend with high risk*";

If $CC_i \in [0.35, 0.5]$, then strategy A_i belongs to Class III and the assessment status of strategy A_i is "*recommend with low risk*";

If $CC_i \in [0.5, 0.85]$, then strategy A_i belongs to class IV and the assessment status of strategy A_i is "*approved*";

If $CC_i \in [0.85, 1]$, then strategy A_i belongs to Class V and the assessment status of strategy A_i is "*approved and preferred to recommend*".

3.1. Fuzzy numbers

In this section, some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed from Buckley [22], Kaufmann and Gupta [23], Negi [24] and Zadeh [25]. The basic definitions and notations below will be used throughout this paper until otherwise stated.

Definition 3.1. 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 $\tilde{A}$ [23].

Definition 3.2. A fuzzy set $\tilde{A}$ in the universe of discourse X is convex if and only if:

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

For all x_1, x_2 in X and $\lambda \in [0,1]$, where min denotes the minimum operator [26].

Definition 3.3. 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 [26].

Definition 3.4. A fuzzy number is a fuzzy subset in the universe of discourse *X* that is both convex and normal. Fig. 1 shows a fuzzy number $\tilde{n}$ in the universe of discourse *X* that conforms to this definition [23].

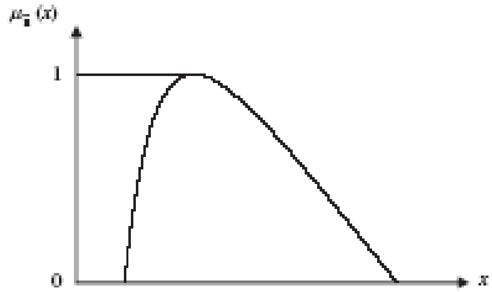

Figure 1: Fuzzy number $\tilde{n}$

Definition 3.5. A positive trapezoidal fuzzy number (PTFN) $\widetilde{A}$ can be defined as $\widetilde{A}=(a_1,a_2,a_3,a_4)$ the membership function, $\mu_{\widetilde{A}}(x)$ is defined as: [23]

$$\mu_{\tilde{A}}(x)=\begin{cases}1 & a_2\le x\le a_3\\ \dfrac{x-a_1}{a_2-a_1} & a_1\le x\le a_2\\ \dfrac{a_4-x}{a_4-a_3} & a_3\le x\le a_4\\ 0 & x\le a_1, x\ge a_4\end{cases}$$

For a trapezoidal fuzzy number, $\widetilde{A}=(a_1,a_2,a_3,a_4)$ if $a_2=a_3$, then $\widetilde{A}$ is called a triangular fuzzy number and is showed as $\widetilde{A}=(a_1,a_2,a_3)$ (figure.2).

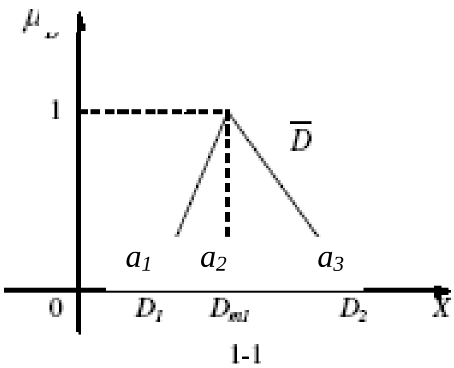

Figure 2: Triangular fuzzy number

In other word a_1,a_2,a_3 are the lowest possible value, the most possible value, and the largest possible value respectively.

Definition 3.6. A linguistic variable is a variable whose values are expressed in linguistic terms [27]. 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.

It is not possible to make mathematical operations directly on linguistic values. This is why; the linguistic scale must be converted into a fuzzy scale. In the literature about fuzzy methods, one can find a variety of different fuzzy scales. (See, for example [28, 29, 30]. The triangular fuzzy conversion scale given in figure 3 is used in the evaluation model of this paper (adapted from [31]).

4. A hierarchical model for selecting the best supply chain strategy

The first step is devoted to construct a model to identify the system alternatives and criteria to evaluate the supply chain strategies. Due to the complexity of the decision making process in selecting the supply chain strategy, a hierarchical model is used in this paper. Figure 4 shows the hierarchical model for selecting the best supply chain strategy. The key parameters for this model can be categorized into four levels. The first level of the model deals with the essence of the difference between leanness and agility in terms of the total value provided to the customer, which included responsiveness, (service level) that is the critical factor calling for agility, and cost, that is clearly linked to leanness [1]. In order to specify the effects of cost and responsiveness on decision making alternatives, these two criteria are broken into relevant sub criteria which lie in level 2. Sub criterions of cost are inventory cost, process cost, supply cost, transportation cost and shortage cost. Sub criteria of responsiveness are flexibility, lead time and innovation. The third level of model consists of flexibility's sub criteria which are product type flexibility (machine flexibility), volume flexibility (production capacity flexibility), supply flexibility, manpower flexibility and transportation flexibility. The fourth level of model deals with the decision making alternatives which are lean, agile and leagile strategies. The overall objective is to select the best strategy for improving performance of the case supply chain. In order to select the most appropriate supply chain strategy, decision makers should determine the important weight of each criterion and performance rating of alternatives with respect to each criterion and by using linguistic variables. Then the linguistic variables should be converted to fuzzy triangular numbers and finally, the ranking order of alternatives can be determined using fuzzy TOPSIS approach. In the next section, the decision making criteria will be explained in detail.

4.1. Responsiveness

Responsiveness is related to the ability of a manufacturing system to utilize its existing resources to make a rapid and balanced response to predictable and unpredictable changes [32]. It is the ability to identify changes and respond fast to them, reactively or proactively, and recover from them [33]. Three sub criteria under the umbrella of responsiveness are considered in the hierarchy to evaluate the importance of responsiveness over the alternatives.

Flexibility

Flexibility is the ability to process different products and achieve different objectives with the same facilities. A key characteristic of an agile organization is flexibility [6, 8]. Initially it is thought that the route to manufacturing flexibility is through automation to enable rapid changeovers (i.e. reduced set-up times) and thus enable a greater responsiveness to changes in product mix or volume. Later this idea of manufacturing flexibility is extended into the wider business context that embraces organizational structures, information systems, logistics processes and in particular, mindsets. The supply chain may be broken down into three basic segments: sourcing, manufacturing and delivery. Any firm's supply chain flexibility is determined by how it's physical components [2]. Thus in this paper, five sub criteria have been considered for supply chain flexibility.

Product type flexibility: represents the ability of the plant to manufacture a range of products with different processing requirements, and rapid response to changes of product families using existing facilities.

Volume flexibility: represents the ability of the plant to change its capacity and functionality with maximum reusability against demand fluctuation.

Supply flexibility: represents the ability of the plant to provide raw material from different supplier with different cost, quality, speed and etc.

Manpower flexibility: represents the ability of the plant to employ the multi skill operators with different level of expertise, which can change their tasks when market changes take place.

Transportation flexibility: represents the ability of the supply chain to use different transportation approach witch have different cost and speed, according to customer requirements.

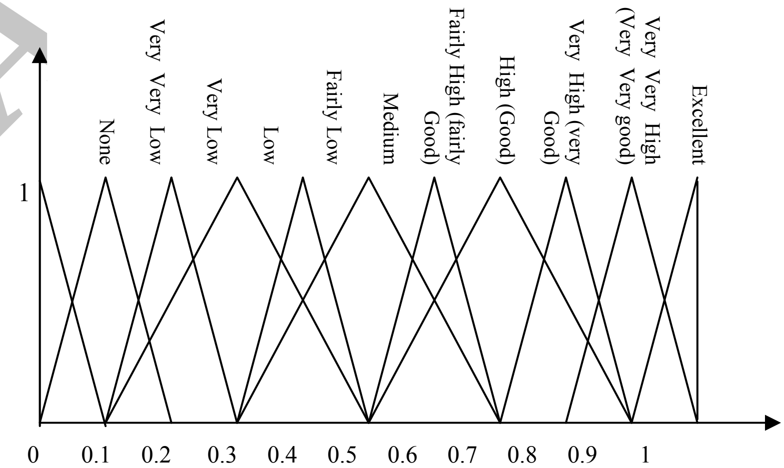

Figure 3: Linguistic variables for importance weight of criteria and rating of alternatives

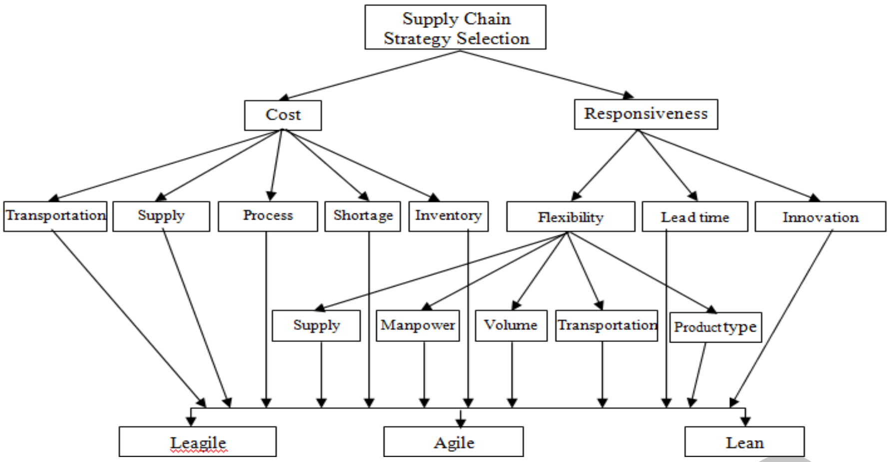

Figure 4: The hierarchical model for selecting the best supply chain strategy

Innovation

Innovation represents the ability of the supply chain to capture proactively the market and customers desire and in taking the competitive advantage of unpredicted opportunities in the market [33]. A proactive manufacturer will integrate with customers and help identify their problems and requirements and also acquire capabilities just ahead of need [34, 35].

Total Lead-time

Total lead-time is the time taken from a customer raising a request for a product or service until it is delivered. Lead-time needs to be reduced in lean manufacturing as by definition excess time is waste and leanness calls for the elimination of all waste. Also, total lead-time has to be minimized to enable agility, as demand is highly volatile and thus difficult to forecast. Therefore, lead time is an important factor in both lean and agile paradigms, but it's more critical factor in agility.

4.2. Cost

This attribute measures the importance of costs over other factors related to supply chain. Economical evaluation of alternatives is one of the most important criteria for selecting them. These kinds of attributes are the most tangible and understandable criteria for management [36]. Fisher makes a similar point which is that where the risk of obsolescence and/or the cost of a stock-out are high relative to the cost of production and distribution.

Where, Physical Costs includes all production, distribution, and storage costs. And Marketability Costs includes all obsolescence and stock out costs. The Physical Product Delivery Process cost source (PDP) dominates lean supply whereas the second cost source (marketability costs) dominates agile supply. Also, cost is divided in to five sub criteria as follows.

Inventory cost

According to Waters at least 25 percent of a typical manufacturing company's value is held in stock. If one adds the cost of buffers in production lines and WIP, the significant role of inventories can be better gauged [36, 37]. Inventory cost, include in this paper comprise storage cost and capital tied up cost.

Shortage cost

Shortage cost consists of the lost sale costs and backorder costs.

Transportation cost

Transportation cost consists of all supply chain transportation costs. In agile strategy some extra transportation cost may be imposed to increase responsiveness.

Supply cost

Supply costs consist of: sourcing, supplier evaluation, material, quality control, order cost and etc.

Process cost

Process costs include *i*) the cost of capital investment on manufacturing equipment such as machines, tools, and material handling, *ii)* the operating cost which consists of machine utilization, operators running machines, *iii)* workers on the shop floor responsible for other tasks such as maintenance, transportation, quality control, and cleaning and *iv)* indirect cost, which consists of energy, engineers, and personnel officering, production planning and etc.

5. Case Study

A manufacturing company desires to select an appropriate strategy to improve long term performance of its supply chain. The proposed method is applied to determine the best strategy in this case study. The computational procedure of which is summarized as follows:

Step 1: Three decision-makers use the linguistic weighting variables shown in Fig 3 to assess the importance of the criteria. The aggregated importance weights of the criteria determined by these decision makers are shown in Table 2.

Step 2: the decision-makers use the linguistic rating variables to evaluate the ratings of candidates with respect to each criterion. The ratings of the five candidates by the decision makers under the various criteria are shown in Table 2.

Step 3: Then the linguistic evaluations shown in Tables 2 and 3 are converted into triangular fuzzy numbers to construct the fuzzy decision matrix and determine the fuzzy weight of each criterion, as in Table 4.

Step 4: The normalized fuzzy-decision matrix is constructed as in Table 5.

Step 5: Weighted normalized fuzzy-decision matrix is constructed as in Table 6.

Step 6: Determine FPIS and FNIS as:

$$A^* = \begin{bmatrix} (0.71,0.71,0.71)\,(0.56,0.56,0.56)\,(0.24,0.24,0.24)\,(0.56,0.56,0.56) \\ (0.16,0.16,0.16)\,(0.08,0.08,0.08)\,(0.24,0.24,0.24)\,(0.78,0.78,0.78) \\ (0.56,0.56,0.56)\,(1,1,1)\,(0.56,0.56,0.56)(0.11,0.11,0.11) \end{bmatrix}$$

$$A^- = \begin{bmatrix} (0.03,0.03,0.03)\,(0.1,0.1,0.1)\,(0,0,0)\,(0.03,0.03,0.03)\,(0,0,0)\,(0,0,0) \\ (0.01,0.01,0.01)\,(0.03,0.03,0.03)\,(0.04,0.04,0.04)\,(0.04,0.04,0.04) \\ (0.03,0.03,0.03)\,(0,0,0) \end{bmatrix}$$

Step 7: Calculate the distance of each strategy from FPIS and FNIS with respect to each criterion, respectively, as Tables 7 and 8.

Step 8: Calculate d_i^* , d_i^- of three possible strategies A_i as Table 9.

Table 2: Linguistic variable for importance weight of criteria

First level criteria	Importance weight	Second level criteria	Importance weight	Third level criteria	Importance weight
Cost	Fairly High	Inventory cost	Medium		
		Shortage cost	Low		
		Process cost	Low		
		Supply cost	High		
		Transportation cost	Very Very Low		
Responsiveness	Fairly Low	Flexibility	Medium	Product type flexibility	Fairly Low
				Volume flexibility	Fairly High
				Manpower flexibility	Very Low
				Supply flexibility	Fairly Low
				Transportation flexibility	Very very Low
		Total lead-time	Fairly High		
		Innovation	High		

Table 3: Ratings of the five candidates by decision-makers under various criteria

Criteria	Strategies		
	Lean	Agile	Leagile
Inventory cost	Very High	Very Low	Fairly High
Shortage cost	Fairly High	High	High
Process cost	High	Fairly Low	Fairly High
Supply cost	High	Fairly Low	Medium
Transportation cost	High Fairly	Low	Medium
Total lead-time	Fairly Low	Fairly High	Medium
Innovation	Very Low	Fairly High	Medium
Product type flexibility	Low	High	High
Volume flexibility	Fairly Low	Very High	Fairly High
Manpower flexibility	Medium	High	Fairly High
Supply flexibility	Fairly Low	Fairly High	Fairly High
Transportation flexibility	Medium	High	Medium

Table 4: Fuzzy-decision matrix and fuzzy weight of criteria

Criteria	Inventory cost	Shortage cost	Process cost	Supply cost	Transportation cost	Total lead-time
Lean	(0.7,0.8,0.9)	(0.5,0.6,0.7)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.6,0.7)	(0.3,0.4,0.5)
Agile	(0.1,0.2,0.3)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.3,0.4,0.5)	(0.1,0.3,0.5)	(0.3,0.5,0.7)
Leagile	(0.5,0.6,0.7)	(0.5,0.7,0.9)	(0.5,0.6,0.7)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.4,0.5)
Weight	(0.3,0.5,0.7)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0,0.1,0.1)	(0.5,0.6,0.7)

Criteria	Innovation	Product type flexibility	Volume flexibility	Manpower flexibility	Supply flexibility	Transportation flexibility
Lean	(0.1,0.2,0.3)	(0.1,0.3,0.5)	(0.3,0.4,0.5)	(0.3,0.5,0.7)	(0.3,0.4,0.5)	(0.3,0.5,0.7)
Agile	(0.5,0.6,0.7)	(0.5,0.7,0.9)	(0.7,0.8,0.9)	(0.5,0.7,0.9)	(0.5,0.6,0.7)	(0.5,0.7,0.9)
Leagile	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.5,0.6,0.7)	(0.5,0.6,0.7)	(0.5,0.6,0.7)	(0.3,0.5,0.7
Weight	(0.5,0.7,0.9)	(0.1,0.2,0.3)	(0.5,0.6,0.7)	(0,0.1,0.2)	(0.1,0.2,0.3)	(0,0,0.1)

Table 5: Normalized Fuzzy-decision matrix and fuzzy weight of criteria

Criteria	Inventory cost	Shortage cost	Process cost	Supply cost	Transportation cost	Total lead-time
Lean	(0.78,0.89,1)	(0.56,0.67,0.78)	(0.56,0.78,1)	(0.56,0.78,1)	(0.56,0.67,0.78)	(0.43,0.57,0.71)
Agile	(0.11,0.22,0.33)	(0.56,0.78,1)	(0.11,0.33,0.56)	(0.33,0.44,0.56)	(0.11,0.33,0.56)	(0.43,0.71, 1)
Leagile	(0.56,0.67,0.78)	(0.56,0.78,1)	(0.56,0.67,0.78)	(0.33,0.56,0.78)	(0.33,0.56,0.78)	(0.43,0.57,0.71)
Weight	(0.33,0.56,0.78)	(0.11,0.33,0.56)	(0.56,0.78,1)	(0.11,0.33,0.56)	(0,0.11,0.11)	(0.56,0.67,0.78)

Criteria	Innovation	Product type flexibility	Volume flexibility	Manpower flexibility	Supply flexibility	Transportation flexibility
Lean	(0.14,0.29,0.43)	(0.11,0.33,0.56)	(0.33,0.44,0.56)	(0.33,0.56,0.78)	(0.43,0.57,0.71)	(0.33,0.56,0.78)
Agile	(0.71,0.86,1)	(0.56,0.78,1)	(0.78,0.89,1)	(0.56,0.78,1)	(0.71,0.86,1)	(0.56,0.78,1)
Leagile	(0.43,0.71,1)	(0.56,0.78,1)	(0.56,0.67,0.78)	(0.56,0.67,0.78)	(0.71,0.86,1)	(0.33,0.56,0.78)
Weight	(0.56,0.78,1)	(0.14,0.29,0.43)	(0.71,0.86,1)	(0,0.14,0.29)	(0.14,0.29,0.43)	(0,0,0.14)

Table 6: Weighted normalized Fuzzy-decision matrix

Criteria	Inventory cost	Shortage cost	Process cost	Supply cost	Transportation cost	Total lead-time
Lean	(0.19,0.42,0.78)	(0.04,0.19,0.43)	(0.22,0.52,1)	(0.04,0.22,0.56)	(0,0.08,0.11)	(0.1,0.22,0.4)
Agile	(0.03,0.11,0.26)	(0.04,0.22,0.56)	(0.04,0.22,0.56)	(0.03,0.13,0.31)	(0,0.04,0.08)	(0.1,0.27,0.56)
Leagile	(0.13,0.32,0.6)	(0.04,0.22,0.56)	(0.22,0.44,0.78)	(0.03,0.16,0.43)	(0,0.07,0.11)	(0.1,0.22,0.4)
Criteria	Innovation	Product type flexibility	Volume flexibility	Manpower flexibility	Supply flexibility	Transportation flexibility
Lean	(0.03,0.13,0.31)	(0,0.03,0.13)	(0.03,0.12,0.31)	(0,0.03,0.12)	(0.01,0.05,0.17)	(0,0,0.06)
Agile	(0.17,0.38,0.71)	(0.01,0.07,0.24)	(0.08,0.24,0.56)	(0,0.04,0.16)	(0.01,0.08,0.24)	(0,0,0.08)
Leagile	(0.1,0.32,0.71)	(0.01,0.07,0.24)	(0.06,0.18,0.43)	(0,0.03,0.12)	(0.01,0.08,0.24)	(0,0,0.06)

Table 7: Distances between alternatives and A* with respect to each criterion

Criteria	Inventory cost	Shortage cost	Process cost	Supply cost	Transportation cost	Total lead-time
d (lean,A)*	0.40	0.37	0.53	0.35	0.07	0.34
d(agile,A)*	0.65	0.35	0.76	0.42	0.08	0.31
d(leagile,A)*	0.47	0.35	0.57	0.39	0.07	0.34
Criteria	Innovation	Product type flexibility	Volume flexibility	Manpower flexibility	Supply flexibility	Transportation flexibility
d (lean,A)*	0.57	0.19	0.42	0.12	0.18	0.07
d(agile,A)*	0.37	0.16	0.33	0.12	0.16	0.06
d(leagile,A)*	0.42	0.16	0.37	0.12	0.16	0.07

Table 8: Distances between alternatives and A- with respect to each criterion

Criteria	Inventory cost	Shortage cost	Process cost	Supply cost	Transportation cost	Total lead-time
$d(lean,A^-)$	0.50	0.24	0.62	0.33	0.08	0.18
$d(agile,A^-)$	0.14	0.31	0.31	0.17	0.05	0.28
$d(leagile,A^-)$	0.38	0.31	0.49	0.25	0.08	0.18
Criteria	Innovation	Product type flexibility	Volume flexibility	Manpower flexibility	Supply flexibility	Transportation flexibility
$d(lean,A^-)$	0.17	0.08	0.17	0.07	0.10	0.04
$d(agile,A^-)$	0.45	0.14	0.33	0.09	0.14	0.05
$d(leagile,A^-)$	0.43	0.14	0.25	0.07	0.14	0.04

Table 9: Computations of di* , di- and CCi

	d_i^*	d_i^-	$d_i^- + d_i^*$	CC_i
Lean	3.595964	2.565158	6.161122	0.416346
Agile	3.768472	2.464395	6.232867	0.395387
Leagile	3.479794	2.750983	6.230777	0.541515

Step 9: Calculate the closeness coefficient of each strategy as:
CC_{Lean}=0.416346, CC_{Agile}=0.395387, $CC_{Leagile}$=0.541515

Step 10: According to the closeness coefficients of five strategies and the approval status level, we know that using presented model, strategies **Lean** and **Agile** belong to Class III, witch the assessment statuses of them are “recommend with low risk”, And strategy **Leagile** belongs to Class IV. This means that its assessment status is “approved”. Accordingly, strategy Leagile is preferred to Agile and Lean and the ranking order of five strategies is leagile> lean>agile because $CC_{Leagile} > CC_{Lean} > CC_{Agile}$.

5.1. Sensitivity analysis

Sensitivity analysis is an important concept for the effective use of any quantitative decision model [38]. In the present work sensitivity analysis is done to find out the changes in the decision making model for lean, agile and leagile supply chain paradigms with variation in the expert opinion with respect to cost and responsiveness. Overall objective of sensitivity analysis is to see the robustness of proposed framework due to variation in the experts’ opinion in assigning the weights during comparison. Figure 5 indicates how the supply chain strategy’s ranking varies with changing the priority of responsiveness.

Y-axis represents the value of closeness coefficient calculated by fuzzy TOPSIS method considering the relative priority of responsiveness with respect to cost ($X_{R/C}$). As shown in Figure 5, by increasing the value of $X_{R/C}$ the sequence of solutions is changed. Accordingly, there are four segments with different sequences of solutions as follows:

1) If the priority of responsiveness is very lower than priority of cost (almost $X_{R/C}<0.2$), lean strategy is the best solution. In other words, in a competitive market where cost is market winner, lean strategy is the best solution. In this situation the ranking order of alternatives is: Agile<Leagile<Lean.
2) If the relative priority of responsiveness with respect to cost is fairly low or near to medium (almost $0.2 \le X_{R/C} < 0.5$), leagile strategy is the best solution. In this case, since cost is more important than responsiveness, lean strategy is preferred to agile. In this situation, the ranking order of alternatives is: Agile<Lean<Leagile.
3) If the relative priority of responsiveness with respect to cost is medium or fairly high (almost $0.5 \le X_{R/C} < 0.75$), leagile strategy is still the best solution. By increasing the priority of responsiveness in comparison with previous case, agile strategy is preferred to lean. In this case, the ranking order of alternatives is: Lean<Agile<Leagile.
4) If the priority of responsiveness is very higher than priority of cost (almost $X_{R/C}>0.75$), agile strategy is the best solution. In other words, in a competitive market where responsiveness is market winner criterion, agile strategy is the best solution. In this situation the ranking order of alternatives is: Lean<Leagile<Agile.

As result shown, where the priority of responsiveness is higher than cost, agile and leagile strategies are preferred to lean because responsiveness is the most important criteria for leagile and agile supply chain [10]. In contrast, where cost is more important than responsiveness, lean and leagile strategies are preferred to agile.

5.2. Backward Process

The strategic/tactical revisions can be developed through a forward–backward process. The forward–backward process interacts hierarchies in order to direct and control the likely future towards the desired future [39]. The forward process provides a hierarchy for the assessment of the state of the likely strategy choice. In turn, the backward planning process provides the hierarchy for controlling and steering the forward process towards the desired strategy by using a composite scenario that is a combination of the alternatives in the forward hierarchy. As depicted in figure 6, the backward process consists of four levels: (1) desired strategy choice, (2) strategy choices, (3) state variables, (4) policies. The composite scenario is represented by state variables, i.e. profit, quality, delivery speed, flexibility, customer satisfaction, and risk. During the implementation period of supply chain strategy, the state variables themselves must be prioritized first and then with respect to each strategy alternative in order to achieve a composite measurement. The composite value of this reconfigurable AHP will be used as a degree of convergence between the likely and desired strategy identified in the backward process.

The forth level includes polices i.e. i) cost reduction to increase profit and market share, ii) market and costumer needs study to identify future needs and react them rapidly, iii) training to reduce risk and increase flexibility iv) information system development to increase delivery speed and precise, v) internal process reengineering to reduce costs and increase quality and risk and vi) product redesign to increase customer satisfaction and quality. In backward process, important rate of each strategy is concluded from forward process. The priorities of state variables and polices in the backward hierarchy can be quantified from pair wise comparisons which can be performed for all elements at each level with respect to the next higher-level elements. All of pair wise comparisons are done upon experts' opinion.Finally, the preferences of each policy is achieved, the problem is then transferred to how their requirements can meet the resources available. In this regard, a trading off between the derived priorities and required resources for each policy is essential to maximize the performance of the proposed strategy. One of the effective approaches to resource allocation is the knapsack method, which can be linearly formulated as the following (0–1) integer problem.

$$\boldsymbol{Max}\ Z = \sum_{i=1}^{n} P_i X_i$$

Subject to:

$$\sum_{i=1}^{n} R_{ij} X_i \le B_j$$

$$P_i \text{ and } R_{ij} \ge 0$$

$$X_i = \begin{cases} 1 & if\ alternative\ i\ is\ selected \\ 0 & otherwise \end{cases}$$

$$i = 1, \dots, n$$

$$j = 1, \dots, m$$

Where X_i is the ith alternative policy for supply chain strategy, Pi is the priority of the ith policy obtained through solving the AHP model, and R_{ij} is the expected amount of jth resource required by the ith policy. B_j is the available amount of the jth resource at the company. There are n alternatives, which require m resources.

The objective is to find the optimal assignment of resources to policies so that it maximizes the sum of resource utilization. This can justify the selection of the best policies considering resources limitations.

The requirements for the case study as mentioned in Table 9 are expected to be the budget, the time, expert operator, equipment. As each alternative selection creates a source of risk, the strategic risk level is also considered as another resource parameter for each alternative. The knapsack method can be linked to the manufacturing choices obtained from the AHP model for their resource allocations.

6. Conclusions

This paper investigates lean and agile concepts in the supply chain and represents a FMADM model to select the best supply chain strategy according to system characteristics. Due to the complexity of the decision making process in selecting the best supply chain strategy, a hierarchical model is used in this paper to determine the relative importance of each alternative.

The proposed method provides more information for strategy selection and evaluation in supply chain system. The systematic framework for strategy selection in a fuzzy environment presented in this paper can be easily used to different type of supply chains. However, improving the approach for solving strategy selection problem and developing a group decision support system in a fuzzy environment can be considered as a topic for future research.

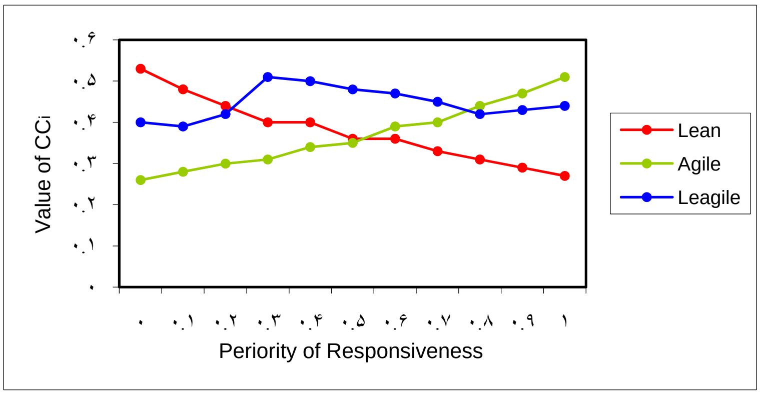

Figure 5: Variation in priority of supply chain paradigms with changes in weight assigned to responsiveness with respect to cost

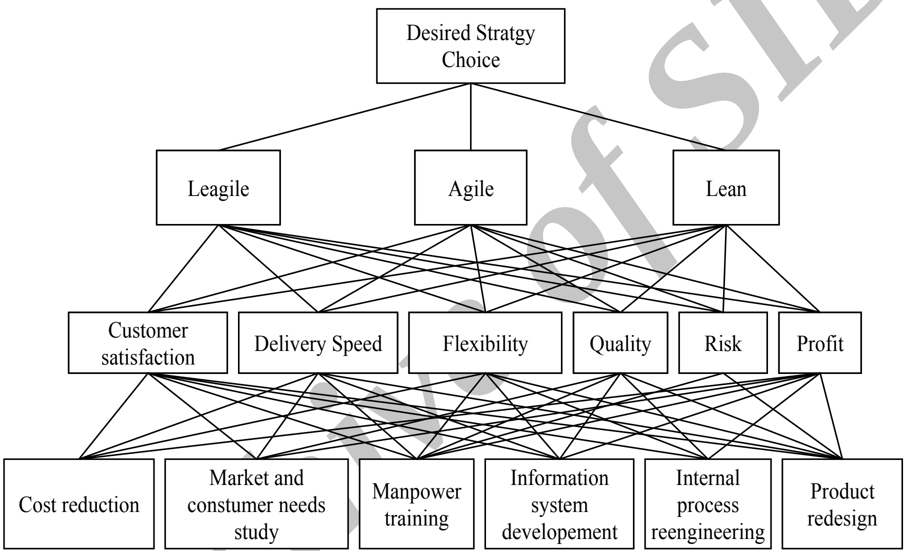

Figure 6: Backward hierarchy for the desired strategy choice

Table 10: Matrix of required and available resources for the strategic plan

Strategy	Investment ($)	Required Time	Expert Operators	Extra Equipment	Strategic Risk Level
Lean	200	5	10	15	5
Leagile	300	15	20	25	10
Agile	400	30	35	40	25
Available resources/ Upper allowance limit	400	20	35	40	20

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