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Research Article

Novel Distance Measure in Fuzzy TOPSIS for Supply Chain Strategy Based Supplier Selection

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In today's highly competitive environment, organizations need to evaluate and select suppliers based on their manufacturing strategy. Identification of supply chain strategy of the organization, determination of decision criteria, and methods of supplier selection are appearing to be the most important components in research area in the field of supply chain management. In this paper, evaluation of suppliers is done based on the balanced scorecard framework using new distance measure in fuzzy TOPSIS by considering the supply chain strategy of the manufacturing organization. To take care of vagueness in decision making, trapezoidal fuzzy number is assumed for pairwise comparisons to determine relative weights of perspectives and criteria of supplier selection. Also, linguistic variables specified in terms of trapezoidal fuzzy number are considered for the payoff values of criteria of the suppliers. These fuzzy numbers satisfied the Jensen based inequality. A detailed application of the proposed methodology is illustrated.

1. Introduction

One of the functions that has been singled out as important in the coordination processes of the individual firms and supply chain is sourcing. Supplier selection and evaluation methods which are mostly based on quoted price, quality, business relations, lead time, and so forth constitute multicriteria or multiobjective decision making problems. Use of suitable criteria and appropriate methodologies are necessary to evaluate the performance of suppliers. Byun [1] presented analytic hierarchy process (AHP) approach for vendor selection in Korean automobiles. Muralidharan et al. [2] developed aggregation technique for combining group member's preferences into one consensus for supplier rating. Zhang et al. [3] made a review on supplier selection criteria. Firstly, appropriate measures and selection criteria need to be developed based on the organization's requirements. Then the organization will judge the supplier's ability to meet the requirements of the organization to select prospective suppliers. In this regard, Dulmin and Mininno [4] discussed the aspects of multicriteria decision aid methods, namely, PROMETHEE and GAIA, to supplier selection problems. Similarly, Ohdar and Ray [5] identified the attributes and factors relevant to the decision and measuring the performance of a supplier through fuzzy inference system of the MATLAB fuzzy logic tool box by considering the optimal set of fuzzy rules. On the other hand Venkata Subbaiah and Narayana Rao [6] considered thirty-three subcriteria under six main criteria in four decision hierarchy levels for supplier selection using AHP. Enyinda et al. [7] adopted analytic hierarchy process (AHP) model and implemented using Expert Choice Software for a supplier selection problem in a generic pharmaceutical organization. Elanchezhian et al. [8] adopted analytical network process (ANP) and TOPSIS method for selecting the best vendor. Kumar and Roy [9] adopted a hybrid model using analytic hierarchy process (AHP) and neural networks (NNs) theory to assess vendor performance. Yücel and Güneri [10] assessed the supplier selection factors through fuzzy positive ideal rating and negative ideal rating to handle ambiguity and fuzziness in supplier selection problem and developed a new weighted additive fuzzy programming approach. Yang and Jiang [11] proposed AHM (Analytic Hierarchy Method) and $M(1,2,3)$ methodology to evaluate the supply chains' overall performance. Prasad et al. [12] proposed and illustrated the methodology for evaluating the efficiency and performance of the suppliers using Data Envelopment Analysis (DEA) technique. Abbasi et al. [13] proposed a framework consisting of the network configuration in addition to the supplier selection phase and applier QFD/ANP to rank the relative importance of the key attributes in selection of suppliers. Galankashi et al. [14] evaluated suppliers based on balanced scorecard framework based on manufacturer's supply chain strategies. Mohite et al. [15] reviewed international journal articles regarding methods and tools that deal with decision making problems in supplier selection.

In decision making environment, specification of evaluation parameters is vague in nature and cannot be given precisely. Fuzzy set theory effectively incorporates imprecision and subjectivity into the model formulation and solution process. Chen et al. [16] adopted TOPSIS concept in fuzzy environment to determine the ranking order of the suppliers by considering the factors such as quality, price, and flexibility and delivery performance. Lee et al. [17] adopted fuzzy analytic hierarchy process (FAHP) to analyze the importance of multiple factors by incorporating the experts' opinions to select Thin Film Transistor Liquid Crystal Display (TFT-LCD) suppliers. Narayana Rao et al. [18] illustrated fuzzy outranking technique for selection of supplier using minimum and gamma operators for aggregating the concordance and discordance indices of the alternative suppliers to arrive at the ranking with credibility values. Yuan et al. [19] proposed DEA, AHP, and fuzzy set theory to evaluate the overall performance of suppliers' involvement in the production of a manufacturing company. Yuen and Lau [20] proposed a fuzzy analytic hierarchy process model for evaluating the software quality of vendors using fuzzy logarithmic least square method. Fuzzy logic finds applications in controlling and the concept has been discussed in an elaborate manner by a number of authors. Shaocheng et al. [21] have presented two control methods which are observer-dependent adaptive fuzzy output feedback. On the other hand Lian et al. [22] have proposed a direct adaptive robust state and output feedback controllers in order to control the output tracking for a class of indecisive systems. Chen et al. [23] have concentrated on an adaptive fuzzy tracking control for a group of uncertain single-input/single-output nonlinear strict-feedback systems. In addition to this, Tong et al. [24] put forward a control method based on an adaptive fuzzy output feedback for single-input/single-output nonlinear systems. Further, Chen and Zhang [25] have taken up the problem of globally stable adaptive backstepping output feedback tracking control of a group of nonlinear systems with anonymous high-frequency gain sign. This has been further extended when Precup and Hellendoorn [26] came forward with a survey about the latest developments of analysis and design of fuzzy control systems centred on industrial applications. Furthermore, Tong et al. [27] have come forth with couple of adaptive fuzzy output feedback control approaches for a section of uncertain stochastic nonlinear strict-feedback systems. Apart from this, Liu et al. [28] have dealt with the difficulties of the adaptive fuzzy tracking control for a section of tentative nonlinear MIMO systems with the external disturbances. Shirouyehzad et al. [29] present fuzzy logic controller as a strong and easy apprehension approach is applied to transform the quantitative variable to linguistic terms in order to measure the vendor's performance. And to add an idea further, Li et al. [30] have focused on reliable fuzzy H_∞ controller design for active suspension systems with actuator delay and fault. As an extension to this, Ranjbar-Sahraei et al. [31] had put forward an innovative decentralized adaptive scheme for multiagent formation control which is based on an integration of artificial potential functions with robust control techniques. Liu et al. [32] have endeavoured to deal with the problems of stability of tracking control for division of large-scale nonlinear systems with unmodelled dynamics by constructing a decentralized adaptive fuzzy output feedback approach. Li et al. [33] have taken into consideration the problem of adaptive fuzzy robust control for an order of single-input/single-output (SISO) stochastic nonlinear systems in the form of strict-feedback. As to add to this, the study of an adaptive fuzzy controller design for uncertain nonlinear systems has been conducted by Liu and Tong [34]. Li et al. [35] had dealt with the problem of fuzzy observer-based controller design. Hongyi Li et al. [36] led an investigation into the problem of dynamic output feedback control for interval type-2 (IT2) by building up a switched output feedback controller. Liu et al. [37] have built up an adaptive fuzzy controller for a group of nonlinear discrete-time systems where the functions are unknown and the disturbances are bounded. This work had been further extended when the adaptive fuzzy identification and related control problems for a class of multi-input-multioutput (MIMO) have been considered by Liu and Tong [38]. More and more, Liu and Tong [39] have explored an adaptive fuzzy controller design for a specific division of nonlinear multi-input-multioutput (MIMO) systems in an interconnected form. In addition to this, Li et al. [40] studied the menace of fuzzy control for nonlinear networked control systems with packet dropouts and uncertainties in parameters which are based on the interval type-2 fuzzy model based approach. To add an innovative idea, Zhang and Zhao [41] have constructed a kind of dynamic discrete switched dual channel closed loop supply chain (CLSC) model considering the time delay in remanufacturing alongside the uncertainties in the parameters of cost, gratuitous return rate, rates of remanufacturing/disposal, preference of the customer to the Internet channel, and the customer's demand under the Internet based on cost switching. Finally, this idea has been extended by Liu et al. [42] who have addressed an adaptive fuzzy optimal control design for a class of obscure nonlinear discrete-time systems. Optimization has been vividly discussed across the length and breadth of the mathematics circles. By putting into use the direct heuristic dynamic programming (DHDP), Gao and Liu [43] have tried to find a solution to the problem of optimal tracking control. Expósito-Izquiero et al. [44] have executed the problem of tactical berth allocation, wherein the vessels are assigned to given berth alongside the problem of Quay Crane Scheduling for which the work schedules of the quay cranes are ascertained. This work has further been extended by Saborido et al. [45] who have taken into consideration a model for portfolio selection proposed of late known as Mean-Downside Risk-Skewness (MDRS) model. Further, multicriteria decision making problems have been dealt with, with more carefulness and accuracy. Gul and Guneri [46] have put forward a fuzzy approach which enables experts to use linguistic variables for measuring two factors that use the parameters of matrix method and to reduce the inconsistency in making a decision. Joshi and Kumar [47] defined the Choquet integral operator for internal-valued intuitionistic hesitant fuzzy sets and also recommended the technique for order preference by similarity to ideal solution (TOPSIS) method with the help of Choquet integral operator in interval-valued intuitionistic hesitant fuzzy environment. Shen et al. [48] have proposed a new method of outranking sorting for group decision making by using intuitionistic fuzzy sets. There are three major supply chain strategies, namely, lean, agile, and leagile strategies. The lean strategy manufacturing focuses on cost reduction by eliminating nonvalue added activities, which leads to minimization/elimination of waste, increased business opportunities, and high competitive advantage. In case of agile strategy, the organization responds rapidly to changes in demand, both in terms of volume and variety by embracing organizational structures, information point in the material, systems, and logistics processes. The leagile strategy responds positively to a volatile demand downstream yet providing level scheduling upstream from the market place. The two differentiated supply chain strategies (lean/agile) are based on the product characteristics, manufacturing characteristics, and decision drivers.

As there has been limited research in supply chain strategy based supplier evaluation and selection, this study aims to evaluate supplier evaluation and selection based on the supply chain strategy of the organization through new distance measure in TOPSIS under fuzzy environment. The proposed methodology is illustrated by considering the supply chain strategy of the apparel manufacturing company for evaluation and selection of the prospective suppliers of the company. New distance measure in fuzzy TOPSIS is explained in Section 2. Supply chain selection method is presented in Section 3. Illustrative example is presented in Section 4. Finally, the conclusions are summarized with future scope in Section 5.

2. Novel Distance Measure

In this section, a novel distance measure for trapezoidal fuzzy numbers using their centroid of centroids is put forward. Figure 1 shows the general trapezoidal fuzzy number with left and right spreads. The trapezoid is partitioned into three plane figures thus forming three triangles ARC, RCS, and CSD, wherein the centroids of the triangles are G_1, G_2, and G_3, respectively, from which $G_{\widetilde{A}}$ is the centroid of the centroids G_1, G_2, and G_3.

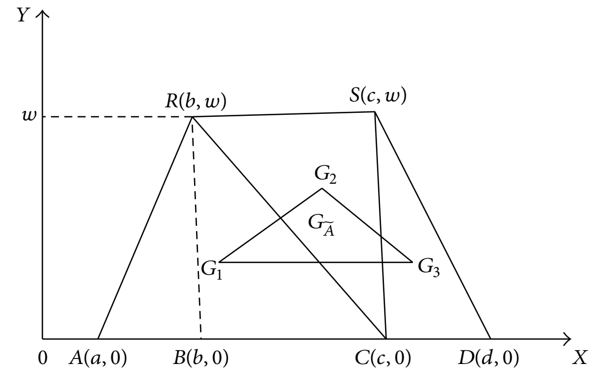

Figure 1: Trapezoidal fuzzy number.

Consider trapezoidal fuzzy numbers $\widetilde{A} = (a_1, a_2, a_3, a_4)$ and $\widetilde{B} = (b_1, b_2, b_3, b_4)$ with centroid of centroids points $(cc_{\widetilde{A}}, c'c'_{\widetilde{A}})$ and $(cc_{\widetilde{B}}, c'c'_{\widetilde{B}})$ and left and right spreads $(l_{\widetilde{A}}, r_{\widetilde{A}})$ and $(l_{\widetilde{B}}, r_{\widetilde{B}})$, respectively. Sum of the distances from positive ideal solution (D^+) and the sum of the distances from negative ideal solution (D^-) are given as follows:

$$D^+ = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^+\right), \quad i = 1, 2, 3, \ldots, m,$$
$$D^- = \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^-\right), \quad i = 1, 2, 3, \ldots, m, \tag{1}$$

$\widetilde{v}_j^- = \min_i(v_{ij1})$ and $\widetilde{v}_j^+ = \max_i(v_{ij4})$.

The distance measure of two trapezoidal fuzzy numbers $(\widetilde{A}, \widetilde{B})$ is

$$d\left(\widetilde{A}, \widetilde{B}\right) = \max\left\{\left|cc_{\widetilde{A}} - cc_{\widetilde{B}}\right|, \left|l_{\widetilde{A}} - l_{\widetilde{B}}\right|, \left|r_{\widetilde{A}} - r_{\widetilde{B}}\right|\right\}, \tag{2}$$

where $cc_{\widetilde{A}} = (a_1 + 2a_2 + 5a_3 + a_4)/9$; $cc_{\widetilde{B}} = (b_1 + 2b_2 + 5b_3 + b_4)/9$; $c'c'_{\widetilde{A}} = 4w/9$; $c'c'_{\widetilde{B}} = 4w/9$; $l_{\widetilde{A}} = a_2 - a_1$ and $r_{\widetilde{A}} = a_4 - a_3$; $l_{\widetilde{B}} = b_2 - b_1$ and $r_{\widetilde{B}} = b_4 - b_3$.

A numerical illustration for novel distance measure for two trapezoidal fuzzy numbers is determined in Appendix A.4.

3. Supplier Evaluation and Selection

The proposed methodology for supplier evaluation and selection is explained in the following steps.

Step 1 (establish evaluation index system of supplier performance). An organization has to identify criteria for supplier selection to evaluate whether the supplier fits its supply chain strategy. The total performance of the supplier depends on the capabilities in criteria and the relative importance given to them. In this paper, balanced scorecard framework proposed by Galankashi et al. [14] is considered as evaluation index system of suppliers' performance is considered.

Step 2 (determine important weights of perspectives). In this paper, four balanced scorecard perspectives, namely, financial perspective, customer perspective, internal business perspective, and learning and growth perspective of supplier evaluation, are considered. These perspectives are prioritized based on lean, agile, and leagile strategies using fuzzy LLSM. Fuzzy logarithmic least square method (LLSM) developed by Wang et al. [49] is employed with trapezoidal fuzzy numbers $\widetilde{w} = (a^L, a^{M1}, a^{M2}, a^U)$ of fuzzy pairwise comparison matrices to obtain the vector of trapezoidal fuzzy weights $\widetilde{w} = (\widetilde{w}_1, \widetilde{w}_2, \ldots, \widetilde{w}_i)^{\mathrm{T}}$ through the optimization model of fuzzy LLSM. The optimization model is as follows:

$$\begin{aligned}
\min \quad & f \\
& = \sum_{i=1}^{n}\sum_{j=1,j\neq i}^{n}\left(\left(\ln w_i^L - \ln w_j^U - \ln a_{ij}^L\right)^2 + \left(\ln w_i^{M1} - \ln w_j^{M1} - \ln a_{ij}^{M1}\right)^2 + \left(\ln w_i^U - \ln w_j^L - \ln a_{ij}^U\right)^2 + \left(\ln w_i^{M2} - \ln w_j^{M2} - \ln a_{ij}^{M2}\right)^2\right) \\
\text{subject to} \quad & w_i^L + \sum_{j=1,j\neq i}^{n} w_j^U \geq 1, \\
& w_i^U + \sum_{j=1,j\neq i}^{n} w_j^L \leq 1, \\
& \sum_{i=1}^{n}\left(w_j^L + w_i^U\right) = 2, \\
& \sum_{i=1}^{n}\left(w_j^{M1} + w_i^{M2}\right) = 2, \\
& 0 < w_i^L \leq w_i^{M1} \leq w_i^{M2} \leq w_i^U < 1.
\end{aligned} \tag{3}$$

Considering the trapezoidal fuzzy weight of the ith criteria, $(\widetilde{w}_i) = (w_i^L, w_i^{M1}, w_i^{M2}, w_i^U)$.

Step 3 (determine important weights of criteria). Criteria of supplier evaluation under each perspective are prioritized using fuzzy LLSM.

Step 4 (determine global weights). Global weights are obtained by multiplying the weights of the criteria with respective weights of the perspective. Hence, global weights of supplier evaluation are obtained under each strategy.

Step 5 (decision matrix). Decision matrix represents the payoff values of the criteria of the alternative suppliers. In this paper, payoff values in terms of trapezoidal fuzzy number are considered.

Step 6. Construct the normalized decision matrix using the following equations

For beneficial criteria,

$$r_{ij} = \frac{x_{ij}}{\max\left(x_{ij}\right)}. \tag{4}$$

For nonbeneficial criteria,

$$r_{ij} = \frac{\min\left(x_{ij}\right)}{x_{ij}}, \tag{5}$$

where r_{ij} is the normalized value of x_{ij}.

This normalization procedure is adopted to transform various attribute dimensions into nondimensional attributes to facilitate comparisons across criteria. The normalization is done to bring all the criteria values between 0 and 1.

Step 7. Develop the weighted normalized decision matrix

$$v_{ij} = w_j \cdot r_{ij}, \tag{6}$$

where w_j is the priority weight (importance) of jth criterion.

Step 8. Determine the positive and the negative ideal solutions and compute the distance of each replacement from FPIS and FNIS from the following relations:

$$\begin{aligned}
A^+ &= \left(\widetilde{v}_1^+, \widetilde{v}_2^+, \ldots, \widetilde{v}_n^+\right), \\
A^- &= \left(\widetilde{v}_1^-, \widetilde{v}_2^-, \ldots, \widetilde{v}_n^-\right),
\end{aligned} \tag{7}$$

where $\widetilde{v}_j^- = \min_i(v_{ij1})$, $\widetilde{v}_j^+ = \max_i(v_{ij4})$, $i = 1, 2, 3, \ldots, m$, and $j = 1, 2, 3, \ldots, n$. The index v_{ij1} and v_{ij4}, 1 and 4, determine the first and fourth elements in a trapezoidal fuzzy number, respectively,

$$\begin{aligned}
D^+ &= \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^+\right), \quad i = 1, 2, 3, \ldots, m, \\
D^- &= \sum_{j=1}^{n} d\left(\widetilde{v}_{ij}, \widetilde{v}_j^-\right), \quad i = 1, 2, 3, \ldots, m.
\end{aligned} \tag{8}$$

D^+ denotes the distance between the alternatives and the positive ideal solution; D^- denotes the distance between the alternatives and the negative ideal solution.

Step 9. Calculate the relative closeness (CC_i) to the ideal solution,

$$CC_i = \frac{D^-}{D^+ + D^-}. \quad (9)$$

Relative closeness values of the suppliers selection of each strategy are to be determined.

4. Illustrative Example

The evaluation of the supplier's performance using the proposed methodology is depicted with numerical example in this paper.

4.1. Hierarchy of Evaluation Index System of Supplier's Performance. Goal, criterion layer, and subcriterion layer are the three layers that the hierarchy of supplier's evaluation is organized into. The balanced scorecard perspectives of financial perspective (FP), customer perspective (CP), internal business perspective (IBP), and learning and growth perspective (LGP) are taken into account at criterion level. Subcriteria falling under each criterion are given as below: subcriteria under financial perspective (FP), asset turnover (AT), inventory turnover (I.T), return on net asset (ROA), and return on equity (ROE); subcriteria coming under the purview of cost perspective (CP) are customer satisfaction (CS), customer loyalty level (CL), length of relationship (LR), and number of complaints (NC); subcriteria which come under internal business perspective (IBP) are on time deliveries (OTD), sigma level (SL), new product development (NPD), and process time (PT); subcriteria coming under learning and growth perspective (LGP) are employee capabilities (EC), team performance (TP), employee satisfaction (ES), and infrastructure (IT). Data required for finding the relative importance of perspectives and criteria have been accumulated from discussions with the managers of purchase, logistics, quality control, and production departments of the manufacturing organization. Figure 2 represents the hierarchy of assessment index system of supplier performance.

4.2. Relative Weights of Balanced Scorecard Perspectives. The supply chain strategy of the manufacturer is the most important factor to be taken into account as far as the evaluation of the suppliers is concerned. The competitive strategy of the manufacturer is considered by their supply chain strategy and it is quintessential in the process of selecting supplier. Relative weights of financial, customer, internal business, and learning and growth perspectives falling under lean, agile, and leagile manufacturing strategies are regulated via fuzzy LLSM making use of fuzzy pairwise comparison matrices. Fuzzy pairwise comparison matrices are prepared based on the discussions with the managers of purchase, logistics, quality control, and production departments so that the relative importance of the perspectives is assessed based on the supply chain strategy. Intensity of relative importance of criteria is imparted with the linguistic variables as detailed herewith: very low (VL), low (L), medium low (ML), medium high (MH), high (H), very high (VH), and full (F). Trapezoidal fuzzy numbers of the linguistic variables are shown in Table 1.

Table 1: Trapezoidal fuzzy numbers of linguistic variable.

Linguistic variables	Trapezoidal fuzzy numbers
Low importance (L)	(1, 2, 3, 5)
Medium low importance (ML)	(1, 3, 5, 7)
Medium high importance (MH)	(3, 5, 7, 9)
High importance (H)	(5, 7, 9, 11)
Very high importance (VH)	(7, 9, 10, 12)

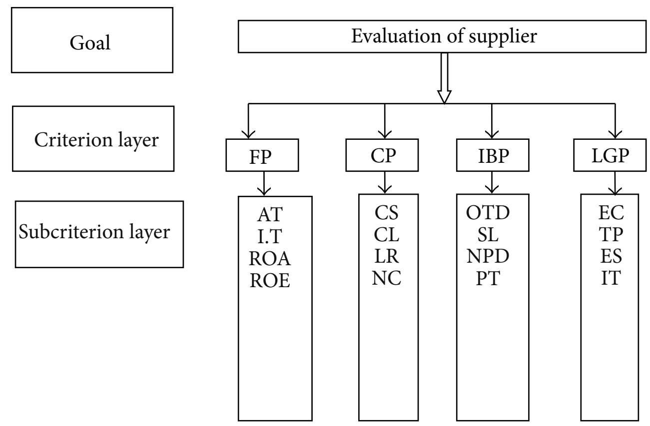

Figure 2: Hierarchy of evaluation index system of supplier performance.

Fuzzy pairwise comparison matrix of perspectives under lean strategy is shown in Table 2.

Fuzzy pairwise comparison matrix of perspectives under agile strategy is shown in Table 3.

Fuzzy pairwise comparison matrix of perspectives under leagile strategy is shown in Table 4.

The lingo code has been developed so as to solve fuzzy LLSM optimization model taking into consideration the fuzzy pairwise comparison matrix of perspectives under each strategy. Relative weights of the perspectives under each strategy in terms of trapezoidal fuzzy numbers are shown in Table 5.

Table 5 displays fuzzy weights of the perspectives. In case of lean strategy, financial perspective with a crisp weight of ((0.45 + 0.59 + 0.63 + 0.65)/4 = 0.58) has been prioritized as the most important perspective followed by customer perspective (0.2625), internal business perspective (0.1075), and learning growth perspective (0.05).

In case of agile strategy, customer perspective with a crisp weight of (0.535) has been prioritized as the most important perspective followed by financial perspective (0.2525), internal business perspective (0.1625), and learning and growth perspective (0.0452).

In case of leagile, customer perspective with a crisp weight of (0.3625) has been prioritized as the most important perspective followed by financial perspective (0.3375), internal business perspective (0.24), and learning and growth perspective (0.05). Fuzzy pairwise comparison matrix of criteria under each perspective is shown in Table 6.

Table 2: Fuzzy pairwise comparison matrix of perspectives under lean strategy.

Perspectives	Perspectives			
	FP	CP	IBP	LGP
Financial perspective (FP)	(1, 1, 1, 1)	(1, 3, 5, 7)	(3, 5, 7, 9)	(7, 9, 10, 12)
Customer perspective (CP)	(1/7, 1/5, 1/3, 1)	(1, 1, 1, 1)	(1, 3, 5, 7)	(3, 5, 7, 9)
Internal business perspective (IBP)	(1/9, 1/7, 1/5, 1/3)	(1/7, 1/5, 1/3, 1)	(1, 1, 1, 1)	(1, 3, 5, 7)
Learning and growth perspective (LGP)	(1/12, 1/10, 1/9, 1/7)	(1/9, 1/7, 1/5, 1/3)	(1/7, 1/5, 1/3, 1)	(1, 1, 1, 1)

Table 3: Fuzzy pairwise comparison matrix of perspectives under agile strategy.

Perspectives	Perspectives			
	FP	CP	IBP	LGP
Financial perspective (FP)	(1, 1, 1, 1)	(1/7, 1/5, 1/3, 1)	(1, 2, 3, 5)	(3, 5, 7, 9)
Customer perspective (CP)	(1, 3, 5, 7)	(1, 1, 1, 1)	(1, 3, 5, 7)	(5, 7, 9, 11)
Internal business perspective (IBP)	(1/5, 1/3, 1/2, 1)	(1/7, 1/5, 1/3, 1)	(1, 1, 1, 1)	(3, 5, 7, 9)
Learning and growth perspective (LGP)	(1/9, 1/7, 1/5, 1/3)	(1/11, 19, 1/7, 1/5)	(1/9, 1/7, 1/5, 1/3)	(1, 1, 1, 1)

The fuzzy pairwise comparison matrix of the criteria for each perspective is used to find the relative weights of each of the criteria.

4.3. Relative Weights of Criteria. Putting into use the fuzzy pairwise comparison matrices, the relative weights of the criteria under each perspective are determined and they are shown in Table 6. These matrices are prepared in terms of trapezoidal fuzzy numbers based on the discussions with the managers from the departments of purchase, logistics, quality control, and production in order to assess the relative importance of the criteria of the respective perspective. Relative weights of the criteria in the form of trapezoidal numbers are shown in Table 7.

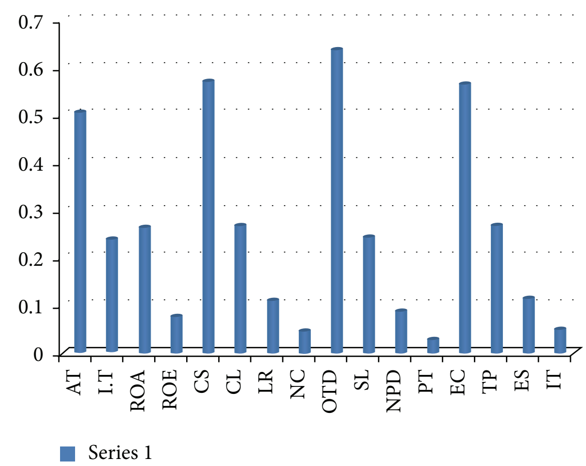

Figure 3: Relative weights of criteria.

As for the financial perspective, asset turnover (AT) with a crisp weight of (0.505) has been prioritized as the most important criteria followed by inventory turnover (I.T) (0.27), return on assets (0.265), and return on equity (0.0775). When it comes to customer perspective, customer satisfaction (CS) with a crisp weight of (0.57) has been prioritized as the most important criteria followed by customer loyalty level (CL) (0.2675), length of relationship (LR) (0.11), and number of complaints (NC) (0.0452). And for internal business perspective, on time deliveries (OTD) with a crisp weight of (0.6375) have been prioritized as the most important criteria that are followed by sigma level (SL) (0.2675), new product development (NPD) (0.08), and process time (PT) (0.02). When we consider the learning and growth perspective, employee capabilities (EC) with a crisp weight of (0.565) have been prioritized as the most important criteria followed by team performance (TP) (0.2675), employee satisfaction (ES) (0.115), and IT infrastructure (0.04). Asset turnover (AT), customer satisfaction (CS), on time delivery (OTD), and employer capability (EC) can be considered as critical criteria since these factors impact the strategy of the manufacturing organization. Figure 3 represents the relative weights of the criteria.

Global weights of the criteria under three strategies are determined as shown in Table 8. In case of lean, financial perspective and asset turnover (AT) with a crisp weight of (0.31075) have been prioritized as the most important criteria followed by return on assets (ROA) (0.165), inventory turnover (I.T) (0.162), and return on equity (ROE) (0.046). In case of customer perspective, customer satisfaction (CS) with a crisp weight of (0.15) has been prioritized as the most important criteria followed by customer loyalty level (CL) (0.079), length of relationship (LR) (0.032), and number of complaints (NC) (0.01). In case of internal business perspective, on time deliveries (OTD) with a crisp weight of (0.07) had been prioritized as the most important criteria followed by sigma level (0.02), new product development (0.01), and process time (0.003). In case of learning and growth perspective, employee capabilities (EC) with a crisp weight of (0.026) have been prioritized as the most important criteria followed by team performance (0.01), employee satisfaction (ES) (0.005), and infrastructure (IT) (0.002). Under such conditions the critical criteria taken into account are asset turnover (AT), customer satisfaction (CS), on time delivery (OTD), and employer capability (EC) since they can affect the manufacturing organization's strategy.

Table 4: Fuzzy pairwise comparison matrix of perspectives under leagile strategy.

Perspectives	Perspectives			
	FP	CP	IBP	LGP
Financial perspective (FP)	(1, 1, 1, 1)	(1/9, 1/7, 1/5, 1/3)	(3, 5, 7, 9)	(5, 7, 9, 11)
Customer perspective (CP)	(1, 3, 5, 7)	(1, 1, 1, 1)	(1/7, 1/5, 1/3, 1)	(1, 2, 3, 5)
Internal business perspective (IBP)	(1/9, 1/7, 1/5, 1/3)	(1, 3, 5, 7)	(1, 1, 1, 1)	(5, 7, 9, 11)
Learning and growth perspective (LGP)	(1/11, 19, 1/7, 1/5)	(1/5, 1/3, 1/2, 1)	(1/11, 19, 1/7, 1/5)	(1, 1, 1, 1)

Table 5: Fuzzy weights of the perspectives.

Strategy	Weights of the perspectives			
	FP	CP	IBP	LGP
Lean (LE)	(0.45, 0.59, 0.63, 0.65)	(0.14, 0.24, 0.26, 0.41)	(0.06, 0.09, 0.1, 0.18)	(0.04, 0.04, 0.042, 0.06)
Agile (AG)	(0.15, 0.19, 0.27, 0.4)	(0.29, 0.51, 0.64, 0.7)	(0.1, 0.12, 0.17, 0.26)	(0.043, 0.046, 0.046, 0.046)
Leagile (LA)	(0.27, 0.33, 0.34, 0.41)	(0.14, 0.25, 0.53, 0.53)	(0.14, 0.14, 0.29, 0.39)	(0.051, 0.054, 0.054, 0.06)

In case of agile financial perspective, asset turnover (AT) with a crisp weight of (0.11) had been prioritized as the most important criteria followed by return on assets (ROA) (0.08), inventory turnover (I.T) (0.07), and return on equity (ROE) (0.02). In case of customer perspective, customer satisfaction (CS) with a crisp weight of (0.31) has been prioritized as the most important criteria followed by customer loyalty level (CL) (0.15), length of relationship (LR) (0.06), and number of complaints (NC) (0.025). In case of internal business perspective, on time deliveries (OTD) with a crisp weight of (0.108) have been prioritized as the most important criteria followed by sigma level (SL) (0.04), new product development (NPD) (0.01), and process time (0.004). In case of learning and growth perspective, employee capabilities (EC) with a crisp weight of (0.02) had been prioritized as the most important criteria followed by team performance (0.01), employee satisfaction (0.005), and infrastructure (IT) (0.002). Asset turnover (AT), customer satisfaction (CS), on time delivery (OTD), and employer capability (EC) can be considered as critical criteria that affect the strategy of the manufacturing organization.

While using leagile financial perspective, asset turnover (AT) with a crisp weight of (0.185) had been prioritized as the most important criteria followed by return on assets (ROA) (0.09), inventory turnover (I.T) (0.105), and return on equity (ROE) (0.02). In case of customer perspective, customer satisfaction (CS) with a crisp weight of (0.198) has been prioritized as the most important criteria followed by customer loyalty level (CL) (0.195), length of relationship (LR) (0.045), and number of complaints (NC) (0.01). In case of internal business perspective, on time deliveries (OTD) with a crisp weight of (0.15) have been prioritized as the most important criteria followed by sigma level (0.04), new product development (NPD) (0.01), and process time (0.005). In case of learning and growth perspective, employee capabilities (EC) with a crisp weight of (0.03) have been prioritized as the most important criteria followed by team performance (TP) (0.01), employee satisfaction (ES) (0.006), and infrastructure (IT) (0.003). Asset turnover (AT), customer satisfaction (CS), on time delivery (OTD), and employer capability (EC) can be considered as critical criteria that affect the strategy of the manufacturing organization. Figures 4, 5, and 6 represent the global weights of lean, agile, and leagile strategy.

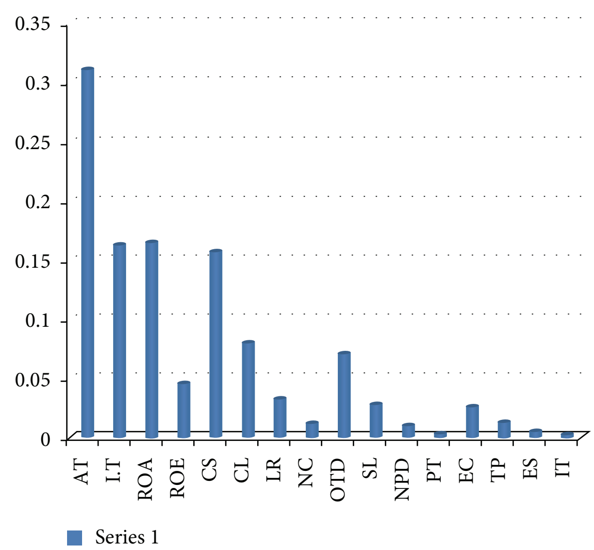

Figure 4: Global weights of criteria, lean strategy.

4.4. Decision Matrix for Each Strategy. Data has been collected on 16 criterions in terms of linguistic variables via semistructured interview with the stakeholders' organization in this segment and the decision matrix is shown in Table 9.

4.5. Normalized Decision Matrix. Normalized decision matrix is formed as in decision matrix in Step 6. The entries of the normalized decision matrix are presented in Table 10.

4.6. Weighed Normalized Decision Matrix. The weighed up normalized matrix for each strategy has been determined and discussed in Step 7. Weighted normalized decision matrix is presented for lean, agile, and leagile strategies, respectively.

Table 6: Fuzzy pairwise comparison matrices of criteria.

Perspective	Criteria				
		AT	I.T	ROA	ROE
FP	AT	(1, 1, 1, 1)	(1, 2, 3, 5)	(1, 3, 5, 7)	(3, 5, 7, 9)
	I.T	(1/5, 1/3, 1/2, 1)	(1, 1, 1, 1)	(1, 2, 3, 5)	(1, 3, 5, 7)
	ROA	(1/7, 1/5, 1/3, 1)	(1/5, 1/3, 1/2, 1)	(1, 1, 1, 1)	(1, 2, 3, 5)
	ROE	(1/9, 1/7, 1/5, 1/3)	(1/7, 1/5, 1/3, 1)	(1/5, 1/3, 1/2, 1)	(1, 1, 1, 1)
		CS	CL	LR	NC
CP	CS	(1, 1, 1, 1)	(1, 3, 5, 7)	(3, 5, 7, 9)	(5, 7, 9, 11)
	CL	(1/7, 1/5, 1/3, 1)	(1, 1, 1, 1)	(1, 3, 5, 7)	(3, 5, 7, 9)
	LR	(1/9, 1/7, 1/5, 1/3)	(1/7, 1/5, 1/3, 1)	(1, 1, 1, 1)	(1, 3, 5, 7)
	NC	(1/11, 1/9, 1/7, 1/5)	(1/9, 1/7, 1/5, 1/3)	(1/7, 1/5, 1/3, 1)	(1, 1, 1, 1)
		OTD	SL	NPD	PT
IBP	OTD	(1, 1, 1, 1)	(3, 5, 7, 9)	(5, 7, 9, 11)	(7, 9, 10, 12)
	SL	(1/9, 1/7, 1/5, 1/3)	(1, 1, 1, 1)	(3, 5, 7, 9)	(5, 7, 9, 11)
	NPD	(1/11, 1/9, 1/7, 1/5)	(1/9, 1/7, 1/5, 1/3)	(1, 1, 1, 1)	(3, 5, 7, 9)
	PT	(1/12, 1/10, 1/9, 1/7)	(1/11, 1/9, 1/7, 1/5)	(1/9, 1/7, 1/5, 1/3)	(1, 1, 1, 1)
		EC	TP	ES	IT
LGP	EC	(1, 1, 1, 1)	(1, 2, 3, 5)	(3, 5, 7, 9)	(7, 9, 10, 12)
	TP	(1/5, 1/3, 1/2, 1)	(1, 1, 1, 1)	(1, 2, 3, 5)	(3, 5, 7, 9)
	ES	(1/9, 1/7, 1/5, 1/3)	(1/5, 1/3, 1/2, 1)	(1, 1, 1, 1)	(1, 2, 3, 5)
	IT	(1/12, 1/10, 1/9, 1/7)	(1/9, 1/7, 1/5, 1/3)	(1/5, 1/3, 1/2, 1)	(1, 1, 1, 1)

Table 7: Fuzzy relative weights of the criteria.

Perspective	Criteria	Fuzzy weight	Crisp weights
FP	AT	(0.32, 0.53, 0.53, 0.64)	0.505
	I.T	(0.15, 0.27, 0.27, 0.39)	0.24
	ROA	(0.09, 0.14, 0.14, 0.69)	0.265
	ROE	(0.06, 0.07, 0.07, 0.11)	0.0775
CP	CS	(0.42, 0.6, 0.6, 0.66)	0.57
	CL	(0.15, 0.25, 0.25, 0.42)	0.2675
	LR	(0.06, 0.1, 0.1, 0.18)	0.11
	NC	(0.04, 0.04, 0.04, 0.06)	0.045
IBP	OTD	(0.53, 0.59, 0.70, 0.73)	0.6375
	SL	(0.17, 0.22, 0.26, 0.32)	0.2425
	NPD	(0.06, 0.08, 0.09, 0.12)	0.0875
	PT	(0.02, 0.02, 0.03, 0.04)	0.0275
LGP	EC	(0.45, 0.58, 0.58, 0.65)	0.565
	TP	(0.16, 0.26, 0.26, 0.39)	0.2675
	ES	(0.07, 0.11, 0.11, 0.17)	0.115
	IT	(0.04, 0.05, 0.05, 0.06)	0.05

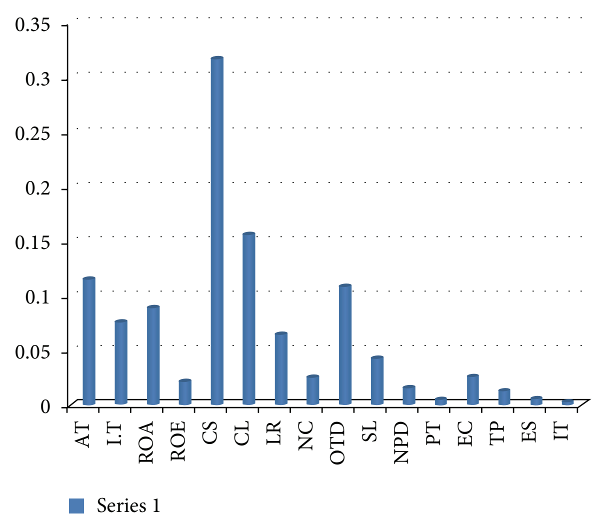

Figure 5: Global weights of criteria, agile strategy.

Weighted normalized decision matrix of the decision matrix for lean strategy is represented in Table 11.

Table 12 represents the weighted normalized decision matrix of the decision matrix for agile.

Table 13 represents the weighted normalized decision matrix of the decision matrix for leagile.

4.7. Positive and Negative Ideal Solutions. The fuzzy positive ideal solution, (A^+), and fuzzy negative ideal Solution, (A^-), for lean, agile, and leagile strategy have been determined as discussed in Step 8. The positive and negative ideal solutions of lean, agile, and leagile strategy are shown in the Appendices A.1, A.2, and A.3. The distance from (A^+) to each criterion and (A^-) to each criterion is shown in Tables 14 and 15, respectively.

Table 15 represents the distance from (A^-) to each criterion.

The relative proximity coefficients for four suppliers under the strategies lean, agile, and leagile are shown in Table 16.

Relative weights of the suppliers under three strategies are obtained by normalizing the closeness coefficient values.

Table 8: Global weights of the criteria.

Strategy	Criteria	Strategy Lean	Agile	Leagile
FP	AT	(0.144, 0.312, 0.371, 0.416)	(0.048,0.01007, 0.1431, 0.256)	(0.09, 0.17, 0.18, 0.3)
	I.T	(0.067, 0.159, 0.170, 0.253)	(0.0225, 0.0513, 0.0729, 0.156)	(0.04, 0.08, 0.09, 0.15)
	ROA	(0.04, 0.083, 0.088, 0.449)	(0.0135, 0.0266, 0.0378, 0.276)	(0.02, 0.05, 0.05, 0.3)
	ROE	(0.027, 0.041, 0.044, 0.072)	(0.009, 0.0133, 0.0189, 0.044)	(0.01, 0.02, 0.02, 0.04)
CP	CS	(0.058, 0.144, 0.156, 0.271)	(0.1218, 0.306, 0.384, 0.462)	(0.06, 0.15, 0.32, 0.35)
	CL	(0.021, 0.06, 0.065, 0.172)	(0.0435, 0.1275, 0.16, 0.294)	(0.02, 0.06, 0.13, 0.22)
	LR	(0.008, 0.024, 0.026, 0.073)	(0.0174, 0.051, 0.064, 0.126)	(0.008, 0.03, 0.053, 0.09)
	NC	(0.005, 0.009, 0.0104, 0.025)	(0.012, 0.0204, 0.0256, 0.042)	(0.006, 0.01, 0.02, 0.03)
IBP	OTD	(0.031, 0.053, 0.07, 0.131)	(0.053, 0.071, 0.12, 0.19)	(0.07, 0.098, 0.17, 0.28)
	SL	(0.0102, 0.0198, 0.026, 0.057)	(0.017, 0.026, 0.044, 0.0832)	(0.017, 0.031, 0.037, 0.08)
	NPD	(0.004, 0.007, 0.009, 0.021)	(0.006, 0.009, 0.015, 0.0312)	(0.0084, 0.01, 0.02, 0.04)
	PT	(0.0012, 0.0018, 0.003, 0.0072)	(0.002, 0.0024, 0.0051, 0.01)	(0.003, 0.004, 0.005, 0.01)
LGP	EC	(0.018, 0.023, 0.024, 0.039)	(0.019, 0.027, 0.027, 0.029)	(0.02, 0.031, 0.031, 0.039)
	TP	(0.0064, 0.0104, 0.0109, 0.0234)	(0.007, 0.012, 0.012, 0.018)	(0.008, 0.01, 0.01, 0.02)
	ES	(0.0028, 0.0044, 0.0046, 0.0102)	(0.003, 0.005, 0.005, 0.008)	(0.004, 0.006, 0.006, 0.01)
	IT	(0.0016, 0.002, 0.0021, 0.0036)	(0.0017, 0.0023, 0.0023, 0.0028)	(0.002, 0.003, 0.003, 0.004)

Table 9: Decision matrix.

Suppliers	Criteria			
	AT	IT	ROA	PR
S_1	L (1, 2, 3, 5)	MH (3, 5, 7, 9)	H (5, 7, 9, 11)	MH (3, 5, 7, 9)
S_2	H (5, 7, 9, 11)	H (5, 7, 9, 11)	L (1, 2, 3, 5)	H (5, 7, 9, 11)
S_3	ML (1, 3, 5, 7)	ML (1, 3, 5, 7)	L (1, 2, 3, 5)	ML (1, 3, 5, 7)
S_4	H (5, 7, 9, 11)	MH (3, 5, 7, 9)	ML (1, 3, 5, 7)	ML (1, 3, 5, 7)
	CS	NOC	NRP	NNC
S_1	VH (7, 9, 10, 12)	VH (7, 9, 10, 12)	L (1, 2, 3, 5)	MH (3, 5, 7, 9)
S_2	H (5, 7, 9, 11)	VH (7, 9, 10, 12)	MH (3, 5, 7, 9)	VH (7, 9, 10, 12)
S_3	H (5, 7, 9, 11)	MH (3, 5, 7, 9)	L (1, 2, 3, 5)	MH (3, 5, 7, 9)
S_4	H (5, 7, 9, 11)	VH (7, 9, 10, 12)	MH (3, 5, 7, 9)	H (5, 7, 9, 11)
	OTD	NPD	PT	AMB
S_1	VH (7, 9, 10, 12)	VH (7, 9, 10, 12)	ML (1, 3, 5, 7)	ML (1, 3, 5, 7)
S_2	L (1, 2, 3, 5)	H (5, 7, 9, 11)	MH (3, 5, 7, 9)	VH (7, 9, 10, 12)
S_3	L (1, 2, 3, 5)	VH (7, 9, 10, 12)	MH (3, 5, 7, 9)	MH (3, 5, 7, 9)
S_4	VH (7, 9, 10, 12)	ML (1, 3, 5, 7)	H (5, 7, 9, 11)	VH (7, 9, 10, 12)
	EC	ES	ITI	SMI
S_1	VH (7, 9, 10, 12)	MH (3, 5, 7, 9)	MH (3, 5, 7, 9)	VH (7, 9, 10, 12)
S_2	MH (3, 5, 7, 9)	H (5, 7, 9, 11)	MH (3, 5, 7, 9)	H (5, 7, 9, 11)
S_3	H (5, 7, 9, 11)	MH (3, 5, 7, 9)	VH (7, 9, 10, 12)	ML (1, 3, 5, 7)
S_4	ML (1, 3, 5, 7)	VH (7, 9, 10, 12)	L (1, 2, 3, 5)	L (1, 2, 3, 5)

Ranking of suppliers under three strategies based on the normalized coefficient values is shown in Table 17.

In case of lean manufacturing strategy, it can be noted that, among the four given suppliers (S_1, S_2, S_3, and S_4), "S_4" has the highest weight of 0.1084. Therefore, it must be selected as the best supplier to satisfy the goals and objectives of the lean manufacturing organization. While using agile manufacturing strategy, it can also be noted that, among the four given suppliers (S_1, S_2, S_3, and S_4), "S_1" has the highest weight of 0.106. Therefore, it must be selected as the best supplier to satisfy the goals and objectives of the agile manufacturing organization. In case of leagile manufacturing strategy, it can also be noted that, among the four given suppliers (S_1, S_2, S_3, and S_4), "S_2" has the highest weight of 0.0.0878. Therefore, it must be selected as the best supplier to satisfy the goals and objectives of the leagile manufacturing organization. Supplier "S_4" may not be suitable for lean, agile, and leagile manufacturing organizations. Supplier 4, "S_4",

Table 10: Normalized decision matrix.

Suppliers	Criteria			
	AT	I.T	ROA	ROE
S_1	(0.09, 0.18, 0.27, 0.45)	(0.27, 0.45, 0.63, 0.81)	(0.45, 0.63, 0.81, 1)	(0.27, 0.45, 0.63, 0.81)
S_2	(0.45, 0.63, 0.81, 1)	(0.45, 0.63, 0.81, 1)	(0.09, 0.18, 0.27, 0.45)	(0.45, 0.63, 0.81, 1)
S_3	(0.09, 0.27, 0.45, 0.63)	(0.09, 0.27, 0.45, 0.63)	(0.09, 0.18, 0.27, 0.45)	(0.09, 0.27, 0.45, 0.63)
S_4	(0.45, 0.63, 0.81, 1)	(0.27, 0.45, 0.63, 0.81)	(0.09, 0.27, 0.45, 0.63)	(0.27, 0.45, 0.63, 0.81)
	CS	CL	LR	NC
S_1	(0.58, 0.75, 0.83, 1)	(0.25, 0.3, 0.33, 0.42)	(0.11, 0.22, 0.33, 0.55)	(0.25, 0.41, 0.58, 0.75)
S_2	(0.41, 0.58, 0.75, 0.91)	(0.25, 0.3, 0.33, 0.42)	(0.33, 0.55, 0.77, 1)	(0.58, 0.75, 0.83, 1)
S_3	(0.41, 0.58, 0.75, 0.91)	(0.33, 0.42, 0.6, 1)	(0.11, 0.22, 0.33, 0.55)	(0.25, 0.41, 0.58, 0.75)
S_4	(0.41, 0.58, 0.75, 0.91)	(0.25, 0.3, 0.33, 0.42)	(0.33, 0.55, 0.77, 1)	(0.41, 0.58, 0.75, 0.91)
	OTD	SL	NPD	PT
S_1	(0.58, 0.75, 0.83, 1)	(0.58, 0.75, 0.83, 1)	(0.14, 0.2, 0.33, 1)	(0.08, 0.25, 0.41, 0.58)
S_2	(0.08, 0.16, 0.25, 0.41)	(0.41, 0.58, 0.75, 0.91)	(0.11, 0.14, 0.2, 0.33)	(0.58, 0.75, 0.83, 1)
S_3	(0.08, 0.16, 0.25, 0.41)	(0.58, 0.75, 0.83, 1)	(0.11, 0.14, 0.2, 0.33)	(0.25, 0.41, 0.58, 0.75)
S_4	(0.58, 0.75, 0.83, 1)	(0.08, 0.25, 0.41, 0.58)	(0.09, 0.11, 0.14, 0.2)	(0.58, 0.75, 0.83, 1)
	EC	TP	ES	IT
S_1	(0.58, 0.75, 0.83, 1)	(0.25, 0.41, 0.58, 0.75)	(0.25, 0.41, 0.58, 0.75)	(0.58, 0.75, 0.83, 1)
S_2	(0.25, 0.41, 0.58, 0.75)	(0.58, 0.75, 0.83, 1)	(0.25, 0.41, 0.58, 0.75)	(0.41, 0.58, 0.75, 0.92)
S_3	(0.41, 0.58, 0.75, 0.92)	(0.25, 0.41, 0.58, 0.75)	(0.58, 0.75, 0.83, 1)	(0.08, 0.25, 0.41, 0.58)
S_4	(0.08, 0.25, 0.41, 0.58)	(0.58, 0.75, 0.83, 1)	(0.08, 0.25, 0.41, 0.58)	(0.08, 0.16, 0.25, 0.41)

Table 11: Weighted normalized decision matrix, lean strategy.

Suppliers	Criteria			
	AT	I.T	ROA	ROE
S_1	(0.013, 0.06, 0.10, 0.18)	(0.013, 0.06, 0.10, 0.18)	(0.013, 0.06, 0.10, 0.18)	(0.013, 0.06, 0.10, 0.18)
S_2	(0.06, 0.19, 0.30, 0.42)	(0.06, 0.19, 0.30, 0.42)	(0.06, 0.19, 0.30, 0.42)	(0.06, 0.19, 0.30, 0.42)
S_3	(0.013, 0.08, 0.17, 0.26)	(0.013, 0.08, 0.17, 0.26)	(0.013, 0.08, 0.17, 0.26)	(0.013, 0.08, 0.17, 0.26)
S_4	(0.06, 0.19, 0.30, 0.416)	(0.06, 0.19, 0.30, 0.416)	(0.06, 0.19, 0.30, 0.416)	(0.06, 0.19, 0.30, 0.416)
	CS	CL	LR	NC
S_1	(0.03, 0.1, 0.13, 0.3)	(0.03, 0.1, 0.13, 0.3)	(0.03, 0.1, 0.13, 0.3)	(0.03, 0.1, 0.13, 0.3)
S_2	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)
S_3	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)
S_4	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)	(0.02, 0.08, 0.12, 0.25)
	OTD	SL	NPD	PT
S_1	(0.02, 0.04, 0.06, 0.1)	(0.02, 0.04, 0.06, 0.1)	(0.02, 0.04, 0.06, 0.1)	(0.02, 0.04, 0.06, 0.1)
S_2	(0.002, 0.008, 0.02, 0.05)	(0.002, 0.008, 0.02, 0.05)	(0.002, 0.008, 0.02, 0.05)	(0.002, 0.008, 0.02, 0.05)
S_3	(0.002, 0.008, 0.02, 0.05)	(0.002, 0.008, 0.02, 0.05)	(0.002, 0.008, 0.02, 0.05)	(0.002, 0.008, 0.02, 0.05)
S_4	(0.02, 0.04, 0.05, 0.1)	(0.02, 0.04, 0.05, 0.1)	(0.02, 0.04, 0.05, 0.1)	(0.02, 0.04, 0.05, 0.1)
	EC	TP	ES	IT
S_1	(0.01, 0.017, 0.02, 0.04)	(0.01, 0.017, 0.02, 0.04)	(0.01, 0.017, 0.02, 0.04)	(0.01, 0.017, 0.02, 0.04)
S_2	(0.005, 0.009, 0.01, 0.03)	(0.005, 0.009, 0.01, 0.03)	(0.005, 0.009, 0.01, 0.03)	(0.005, 0.009, 0.01, 0.03)
S_3	(0.007, 0.01, 0.018, 0.04)	(0.007, 0.01, 0.018, 0.04)	(0.007, 0.01, 0.018, 0.04)	(0.007, 0.01, 0.018, 0.04)
S_4	(0.001, 0.005, 0.009, 0.02)	(0.001, 0.005, 0.009, 0.02)	(0.001, 0.005, 0.009, 0.02)	(0.001, 0.005, 0.009, 0.02)

needs to improve in respect of critical criteria, namely, asset turnover (AT), customer satisfaction (CS), on time delivery (OTD), and employer capability (EC), to align with the manufacturing strategy of vendee organization. Variation of the relative closeness values of suppliers under lean, agile, and leagile strategies is shown in Figure 7.

5. Conclusion

The relative weights of balanced scorecard prospective and their criteria have been obtained through the proposed new distance measure in TOPSIS in this theory. The adoption of trapezoidal fuzzy numbers aims at determining the relative

Table 12: Weighted normalized decision matrix, agile strategy.

Supplier	Criteria			
	AT	I.T	ROA	ROE
S_1	(0.005, 0.02, 0.04, 0.1)	(0.005, 0.02, 0.04, 0.1)	(0.005, 0.01, 0.03, 0.28)	(0.002, 0.005, 0.01, 0.03)
S_2	(0.02, 0.06, 0.1, 0.3)	(0.009, 0.03, 0.06, 0.16)	(0.0009, 0.005, 0.01, 0.13)	(0.004, 0.006, 0.01, 0.04)
S_3	(0.005, 0.02, 0.06, 0.16)	(0.001, 0.01, 0.03, 0.1)	(0.0009, 0.005, 0.01, 0.13)	(0.0008, 0.0027, 0.009, 0.03)
S_4	(0.02, 0.06, 0.1, 0.26)	(0.005, 0.02, 0.04, 0.13)	(0.0009, 0.0081, 0.01, 0.17)	(0.002, 0.005, 0.01, 0.03)
	CS	CL	LR	NC
S_1	(0.07, 0.23, 0.31, 0.46)	(0.011, 0.039, 0.05, 0.12)	(0.002, 0.011, 0.09, 0.07)	(0.003, 0.008, 0.02, 0.03)
S_2	(0.04, 0.18, 0.29, 0.42)	(0.011, 0.039, 0.05, 0.12)	(0.006, 0.03, 0.04, 0.13)	(0.006, 0.015, 0.02, 0.04)
S_3	(0.04, 0.18, 0.29, 0.42)	(0.01, 0.052, 0.09, 0.29)	(0.002, 0.011, 0.09, 0.07)	(0.003, 0.008, 0.02, 0.03)
S_4	(0.04, 0.18, 0.29, 0.42)	(0.011, 0.039, 0.05, 0.12)	(0.006, 0.03, 0.04, 0.13)	(0.0041, 0.011, 0.02, 0.03)
	OTD	SL	NPD	PT
S_1	(0.029, 0.05, 0.09, 0.19)	(0.01, 0.02, 0.03, 0.08)	(0.0008, 0.002, 0.006, 0.03)	(0.0001, 0.0006, 0.002, 0.005)
S_2	(0.004, 0.01, 0.03, 0.08)	(0.008, 0.017, 0.03, 0.07)	(0.0006, 0.001, 0.004, 0.009)	(0.00116, 0.0018, 0.004, 0.01)
S_3	(0.004, 0.01, 0.03, 0.08)	(0.01, 0.02, 0.03, 0.08)	(0.0006, 0.001, 0.004, 0.009)	(0.0005, 0.0009, 0.002, 0.008)
S_4	(0.029, 0.05, 0.09, 0.19)	(0.001, 0.007, 0.01, 0.03)	(0.0005, 0.0009, 0.002, 0.006)	(0.00116, 0.0018, 0.004, 0.01)
	EC	TP	ES	IT
S_1	(0.01, 0.02, 0.022, 0.029)	(0.001, 0.004, 0.006, 0.01)	(0.00075, 0.002, 0.0029, 0.006)	(0.0009, 0.001, 0.0019, 0.0028)
S_2	(0.004, 0.01, 0.015, 0.02)	(0.004, 0.009, 0.0099, 0.018)	(0.0007, 0.002, 0.003, 0.006|)	(0.0006, 0.001, 0.0017, 0.002)
S_3	(0.007, 0.01, 0.02, 0.026)	(0.001, 0.004, 0.006, 0.01)	(0.001, 0.003, 0.004, 0.008)	(0.0001, 0.0005, 0.0009, 0.001)
S_4	(0.001, 0.006, 0.01, 0.016)	(0.004, 0.009, 0.0099, 0.018)	(0.00024, 0.001, 0.002, 0.004)	(0.00013, 0.0003, 0.0005, 0.001)

Table 13: Weighted normalized decision matrix, leagile strategy.

Suppliers	Criteria			
	AT	I.T	ROA	ROE
S_1	(0.0081, 0.0306, 0.05, 0.1)	(0.01, 0.03, 0.05, 0.12)	(0.009, 0.03, 0.04, 0.3)	(0.003, 0.009, 0.01, 0.03)
S_2	(0.04, 0.1, 0.15, 0.3)	(0.02, 0.05, 0.07, 0.15)	(0.002, 0.009, 0.01, 0.14)	(0.005, 0.01, 0.02, 0.04)
S_3	(0.008, 0.04, 0.08, 0.18)	(0.004, 0.02, 0.04, 0.09)	(0.002, 0.009, 0.01, 0.14)	(0.0009, 0.005, 0.009, 0.03)
S_4	(0.04, 0.1, 0.14, 0.3)	(0.01, 0.04, 0.05, 0.12)	(0.002, 0.014, 0.02, 0.12)	(0.0027, 0.009, 0.01, 0.03)
	CS	CL	LR	NC
S_1	(0.03, 0.11, 0.26, 0.35)	(0.005, 0.02, 0.04, 0.09)	(0.0008, 0.006, 0.01, 0.05)	(0.0015, 0.0041, 0.01, 0.02)
S_2	(0.02, 0.09, 0.24, 0.31)	(0.005, 0.02, 0.04, 0.09)	(0.002, 0.01, 0.03, 0.09)	(0.003, 0.0075, 0.01, 0.03)
S_3	(0.02, 0.09, 0.24, 0.31)	(0.006, 0.02, 0.08, 0.22)	(0.0008, 0.006, 0.01, 0.05)	(0.0015, 0.0041, 0.01, 0.02)
S_4	(0.02, 0.09, 0.24, 0.31)	(0.005, 0.02, 0.04, 0.09)	(0.003, 0.01, 0.03, 0.09)	(0.002, 0.005, 0.015, 0.027)
	OTD	SL	NPD	PT
S_1	(0.04, 0.07, 0.14, 0.28)	(0.009, 0.02, 0.03, 0.08)	(0.001, 0.002, 0.006, 0.04)	(0.00024, 0.001, 0.002, 0.005)
S_2	(0.0056, 0.01, 0.04, 0.11)	(0.006, 0.01, 0.02, 0.07)	(0.0009, 0.001, 0.004, 0.01)	(0.001, 0.003, 0.004, 0.01)
S_3	(0.0056, 0.01, 0.04, 0.11)	(0.009, 0.02, 0.03, 0.08)	(0.0009, 0.001, 0.004, 0.01)	(0.0007, 0.0016, 0.0029, 0.007)
S_4	(0.04, 0.07, 0.14, 0.28)	(0.001, 0.007, 0.01, 0.03)	(0.0007, 0.001, 0.002, 0.008)	(0.001, 0.003, 0.004, 0.01)
	EC	TP	ES	IT
S_1	(0.01, 0.02, 0.025, 0.039)	(0.002, 0.004, 0.005, 0.01)	(0.001, 0.002, 0.003, 0.007)	(0.00116, 0.002, 0.004)
S_2	(0.005, 0.01, 0.02, 0.03)	(0.004, 0.007, 0.008, 0.02)	(0.001, 0.002, 0.003, 0.007)	(0.0008, 0.001, 0.002, 0.003)
S_3	(0.008, 0.01, 0.02, 0.03)	(0.002, 0.004, 0.005, 0.01)	(0.002, 0.004, 0.005, 0.01)	(0.00016, 0.0007, 0.001, 0.002)
S_4	(0.001, 0.007, 0.01, 0.02)	(0.004, 0.007, 0.008, 0.02)	(0.0003, 0.001, 0.002, 0.005)	(0.0001, 0.0004, 0.0007, 0.001)

weights of perspectives and criteria for adequate comprehension of linguistic variables adopted in pairwise comparisons. This study can be extended to measure the performance of the supplier using fuzzy logic controller; furthermore this paper presents a robust methodology in order to value the suppliers based on the supply chain strategy. This study can be spread to other domains of decision making for evaluation and ranking of alternatives. On the other hand, by reducing the subjective judgment in prioritizing the factors/subfactors, the performance of the proposed method can be improved. Viewing the theory, it can be determined that the supplier's rank is based on the manufacturing strategy of the organization that

TABLE 14: Distance from A^+ to criteria.

Criteria	Lean				Agile				Leagile			
	$d(A^+, A_1)$	$d(A^+, A_2)$	$d(A^+, A_3)$	$d(A^+, A_4)$	$d(A^+, A_1)$	$d(A^+, A_2)$	$d(A^+, A_3)$	$d(A^+, A_4)$	$d(A^+, A_1)$	$d(A^+, A_2)$	$d(A^+, A_3)$	$d(A^+, A_4)$
1	0.3296	0.1559	0.2779	0.1559	0.2215	0.1516	0.2003	0.1516	0.2886	0.2474	0.2803	0.2474
2	0.1498	0.1197	0.1795	0.1498	0.1155	0.1033	0.1281	0.1155	0.1369	0.1307	0.1426	0.1369
3	0.3777	0.4006	0.4006	0.3811	0.2476	0.2587	0.2587	0.1155	0.2852	0.2967	0.2967	0.2944
4	0.0433	0.0363	0.0512	0.0432	0.0281	0.0247	0.0315	0.0281	0.0374	0.0363	0.0385	0.0374
5	0.1415	0.1563	0.1563	0.1563	0.1742	0.2097	0.2097	0.2097	0.2694	0.2854	0.2854	0.2854
6	0.1454	0.1454	0.133	0.1454	0.2372	0.2372	0.194	0.2372	0.2132	0.2132	0.2041	0.2132
7	0.0595	0.0529	0.0595	0.0529	0.1084	0.0838	0.1084	0.0838	0.0879	0.0841	0.0879	0.0841
8	0.0236	0.0206	0.0236	0.0217	0.0249	0.0177	0.0249	0.0204	0.0287	0.0276	0.0287	0.0282
9	0.0733	0.1131	0.1131	0.0733	0.0986	0.1617	0.1617	0.0986	0.2372	0.2731	0.2731	0.2372
10	0.0377	0.0403	0.0377	0.0498	0.0468	0.0504	0.0468	0.0647	0.0723	0.0741	0.0723	0.0778
11	0.0180	0.0179	0.0179	0.0186	0.0234	0.0263	0.0263	0.0274	0.0392	0.0395	0.0395	0.0396
12	0.0057	0.0047	0.0052	0.004	0.0080	0.0060	0.0072	0.0060	0.0097	0.0091	0.0095	0.0091
13	0.0196	0.0264	0.0222	0.0305	0.0092	0.0148	0.0104	0.0193	0.0319	0.0353	0.0336	0.0369
14	0.0168	0.0143	0.0063	0.0080	0.0113	0.0080	0.0113	0.0080	0.0188	0.0177	0.0188	0.0177
15	0.0021	0.0024	0.0031	0.0034	0.0051	0.0051	0.0038	0.0060	0.0093	0.0093	0.0087	0.0096
16	0.0021	0.0024	0.0031	0.0034	0.0009	0.0011	0.0011	0.0022	0.0033	0.0038	0.0038	0.0038

Table 15: Distance from A^- to criteria.

Criteria	Lean				Agile				Leagile			
	$d(A^-, A_1)$	$d(A^-, A_2)$	$d(A^-, A_3)$	$d(A^-, A_4)$	$d(A^-, A_1)$	$d(A^-, A_2)$	$d(A^-, A_3)$	$d(A^-, A_4)$	$d(A^-, A_1)$	$d(A^-, A_2)$	$d(A^-, A_3)$	$d(A^-, A_4)$
1	0.0870	0.2540	0.1320	0.2540	0.0792	0.1466	0.1008	0.1466	0.086	0.154	0.108	0.154
2	0.0978	0.1202	0.0828	0.0987	0.0855	0.1033	0.0693	0.0855	0.064	0.077	0.054	0.064
3	0.3777	0.1782	0.1782	0.2432	0.2476	0.1152	0.1152	0.1584	0.259	0.121	0.121	0.166
4	0.0306	0.0363	0.0255	0.0306	0.0198	0.0238	0.0162	0.0198	0.019	0.023	0.016	0.019
5	0.1415	0.1296	0.1296	0.1296	0.2365	0.2010	0.2010	0.2010	0.084	0.078	0.078	0.078
6	0.0507	0.0507	0.133	0.0507	0.069	0.069	0.194	0.069	0.049	0.049	0.142	0.049
7	0.0315	0.0529	0.0315	0.0529	0.0517	0.0838	0.0517	0.0838	0.033	0.051	0.033	0.051
8	0.0127	0.0163	0.0127	0.0149	0.0126s	0.0197	0.0126	0.0170	0.010	0.013	0.010	0.012
9	0.0729	0.0362	0.0362	0.0729	0.0904	0.0479	0.0479	0.0904	0.138	0.072	0.072	0.138
10	0.0354	0.0323	0.0354	0.0167	0.0468	0.0428	0.0768	0.022	0.049	0.045	0.049	0.023
11	0.0180	0.0051	0.0051	0.0029	0.0234	0.0059	0.0059	0.0032	0.033	0.009	0.009	0.005
12	0.0029	0.0047	0.0036	0.0047	0.0037	0.0058	0.0046	0.0058	0.003	0.005	0.004	0.005
13	0.0193	0.0153	0.0178	0.0127	0.0198	0.0128	0.0170	0.0081	0.013	0.011	0.012	0.009
14	0.0112	0.0143	0.0112	0.0143	0.0065	0.0082	0.0065	0.0082	0.009	0.011	0.009	0.011
15	0.0049	0.0049	0.0063	0.0040	0.0031	0.0031	0.0039	0.0025	0.004	0.004	0.005	0.003
16	0.00185	0.0017	0.00122	0.0009	0.00172	0.0014	0.0007	0.0005	0.001	0.001	0.001	0.0008

Table 16: Relative closeness values of suppliers.

Suppliers	Strategy		
	Lean	Agile	Leagile
S_1	0.40714	0.422915	0.327423
S_2	0.420363	0.395528	0.290509
S_3	0.359041	0.385537	0.28506
S_4	0.433801	0.409921	0.311546

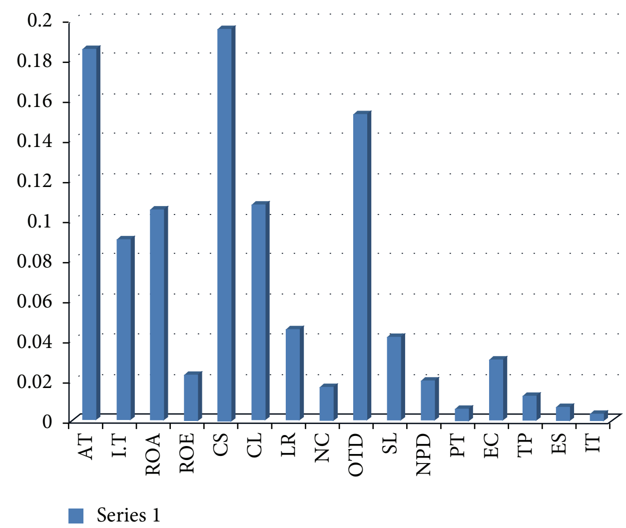

Figure 6: Global weights of criteria, leagile strategy.

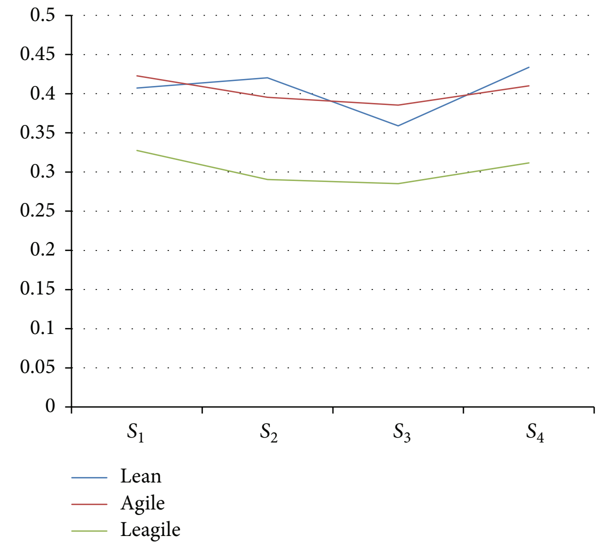

Figure 7: Relative closeness values of suppliers under lean, agile, and leagile strategies.

conducts the purchase. In the strategies of supply chain of lean and agile type, cost is the winner in the market since it is the market qualifier whereas the service levels emerge as market winners in case of agile and leagile strategies and the service levels are the market qualifiers in respect of lean strategy.

Appendix

A. Determine Positive and Negative Ideal Solutions

A.1. Set of Positive and Negative Ideal Solutions of Lean. Consider

$$A^{+} = \{(0.42, 0.42, 0.42, 0.42), (0.25, 0.25, 0.25, 0.25), (0.44, 0.44, 0.44, 0.44)\ (0.07, 0.07, 0.07, 0.07) \cdot (0.27, 0.27, 0.27, 0.27)\ (0.17, 0.17, 0.17, 0.17) \cdot (0.07, 0.07, 0.07, 0.07), (0.03, 0.03, 0.03, 0.03) \cdot (0.131, 0.131, 0.131, 0.131) \cdot (0.06, 0.06, 0.06, 0.06)\ (0.02, 0.02, 0.02, 0.02), (0.007, 0.007, 0.007, 0.007)\ (0.04, 0.04, 0.04, 0.04) \cdot (0.0234, 0.0234, 0.0234, 0.0234) \cdot (0.01, 0.01, 0.01, 0.01), (0.004, 0.004, 0.004, 0.004)\},$$

$$A^{-} = \{(0.01, 0.01, 0.01, 0.01), (0.01, 0.01, 0.01, 0.01), (0.0036, 0.0036, 0.0036, 0.0036) \cdot (0.002, 0.002, 0.002, 0.002) \cdot (0.002, 0.002, 0.002, 0.002) \cdot (0.005, 0.005, 0.005, 0.005) \cdot (0.0009, 0.0009, 0.0009, 0.0009), (0.001, 0.001, 0.001, 0.001) \cdot (0.0024, 0.0024, 0.0024, 0.0024) \cdot (0.0008, 0.0008, 0.0008, 0.0008) \cdot (0.0004, 0.0004, 0.0004, 0.0004), (0.00009, 0.00009, 0.00009, 0.00009) \cdot (0.001, 0.001, 0.001, 0.001) \cdot (0.0016, 0.0016, 0.0016, 0.0016) \cdot (0.0002, 0.0002, 0.0002, 0.0002), (0.00001, 0.00001, 0.00001, 0.00001)\}. \quad (A.1)$$

A.2. Set of Positive and Negative Ideal Solutions of Agile. Consider

$$A^{+} = \{(0.26, 0.26, 0.26, 0.26), (0.16, 0.16, 0.16, 0.16), (0.28, 0.28, 0.28, 0.28)\ (0.04, 0.04, 0.04, 0.04)$$

Table 17: Relative weights ranks for lean, agile, and leagile.

Supplier	Relative weights		Relative weights		Relative weights	
	Lean	Rank	Agile	Rank	Leagile	Rank
S_1	0.101785	3	0.105729	1	0.0726	3
S_2	0.105091	2	0.098882	3	0.087856	1
S_3	0.08976	4	0.096384	4	0.071265	4
S_4	0.10845	1	0.10248	2	0.077887	2

$$\begin{aligned}
&\cdot(0.46,0.46,0.46,0.46)\,(0.29,0.29,0.29,0.29)\\
&\cdot(0.13,0.13,0.13,0.13)\,,(0.04,0.04,0.04,0.04)\\
&\cdot(0.19,0.19,0.19,0.19)\,(0.08,0.08,0.08,0.08)\\
&\cdot(0.03,0.03,0.03,0.03)\,,(0.01,0.01,0.01,0.01)\\
&\cdot(0.029,0.029,0.029,0.029)\\
&\cdot(0.018,0.018,0.018,0.018)\\
&\cdot(0.008,0.008,0.008,0.008)\\
&\cdot(0.0028,0.0028,0.0028,0.0028)\}\,,\\
A^{-}&=\{(0.0045,0.0045,0.0045,0.0045)\\
&\cdot(0.0018,0.0018,0.0018,0.0018)\\
&\cdot(0.0009,0.0009,0.0009,0.0009)\\
&\cdot(0.00081,0.00081,0.00081,0.00081)\\
&\cdot(0.0492,0.0492,0.0492,0.0492)\\
&\cdot(0.011,0.011,0.011,0.011)\\
&\cdot(0.00187,0.00187,0.00187,0.00187)\\
&\cdot(0.0025,0.0025,0.0025,0.0025)\\
&\cdot(0.004,0.004,0.004,0.004)\\
&\cdot(0.0016,0.0016,0.0016,0.0016)\\
&\cdot(0.00054,0.00054,0.00054,0.00054)\\
&\cdot(0.00016,0.00016,0.00016,0.00016)\\
&\cdot(0.00152,0.00152,0.00152,0.00152)\\
&\cdot(0.00175,0.00175,0.00175,0.00175)\\
&\cdot(0.00024,0.00024,0.00024,0.00024)\\
&\cdot(0.000136,0.000136,0.000136,0.000136)\}\,.
\end{aligned} \tag{A.2}$$

A.3. Set of Positive and Negative Ideal Solutions of Leagile. Consider

$$\begin{aligned}
A^{+}&=\{(0.3,0.3,0.3,0.3)\,(0.15,0.15,0.15,0.15)\\
&\cdot(0.3,0.3,0.3,0.3)\,(0.04,0.04,0.04,0.04)\\
&\cdot(0.35,0.35,0.35,0.35)\,(0.22,0.22,0.22,0.22)\\
&\cdot(0.09,0.09,0.09,0.09)\,(0.03,0.03,0.03,0.03)\\
&\cdot(0.28,0.28,0.28,0.28)\,(0.08,0.08,0.08,0.08)\\
&\cdot(0.04,0.04,0.04,0.04)\,(0.01,0.01,0.01,0.01)\\
&\cdot(0.039,0.039,0.039,0.039)\\
&\cdot(0.02,0.02,0.02,0.02)\,(0.01,0.01,0.01,0.01)\\
&\cdot(0.004,0.004,0.004,0.004)\}\,,\\
A^{-}&=\{(0.0081,0.0081,0.0081,0.0081)\\
&\cdot(0.0036,0.0036,0.0036,0.0036)\\
&\cdot(0.0018,0.0018,0.0018,0.0018)\\
&\cdot(0.0009,0.0009,0.0009,0.0009)\\
&\cdot(0.0246,0.0246,0.0246,0.0246)\\
&\cdot(0.005,0.005,0.005,0.005)\\
&\cdot(0.00088,0.00088,0.00088,0.00088)\\
&\cdot(0.0015,0.0015,0.0015,0.0015)\\
&\cdot(0.0056,0.0056,0.0056,0.0056)\\
&\cdot(0.00136,0.00136,0.00136,0.00136)\\
&\cdot(0.000756,0.000756,0.000756,0.000756)\\
&\cdot(0.00024,0.00024,0.00024,0.00024)\\
&\cdot(0.005,0.005,0.005,0.005)\\
&\cdot(0.002,0.002,0.002,0.002)\\
&\cdot(0.00032,0.00032,0.00032,0.00032)\\
&\cdot(0.00016,0.00016,0.00016,0.00016)\}\,.
\end{aligned} \tag{A.3}$$

A.4. Numerical Illustration for Novel Distance Measure. Consider two trapezoidal fuzzy numbers $(5.6, 7.83, 8.46, 9)$ and $(9, 9, 9, 9)$. Put $\widetilde{A}_1 = (5.6, 7.83, 8.46, 9)$ and $\widetilde{A}_2 = (9, 9, 9, 9)$. From Section 2 the centroid of centroids of $\widetilde{A}_1$ and $\widetilde{A}_2$ is

$$\begin{aligned}
cc_{\widetilde{A}_1}&=\left(\frac{5.6+2\,(7.83)+5\,(8.46)+9}{9},\frac{4\,(1)}{9}\right)\\
&=(8.06,0.444)\,;
\end{aligned}$$

$$cc_{\widetilde{A}_2} = \left(\frac{9+2(9)+5(9)+9}{9}, \frac{4(1)}{9}\right) = (9, 0.444);$$
$$c'c'_{\widetilde{A}_1} = \frac{4}{9};$$
$$c'c'_{\widetilde{A}_2} = \frac{4}{9}. \tag{A.4}$$

Therefore, considering the centroid of centroids for each trapezoidal fuzzy number, $(cc_{\widetilde{A}_1}, c'c'_{\widetilde{A}_1}) = (8.06, 0.444)$ and $(cc_{\widetilde{A}_2}, c'c'_{\widetilde{A}_2}) = (9, 0.444)$. Left and right spreads are $(l_{\widetilde{A}_1}, r_{\widetilde{A}_1}) = (7.83 - 5.6, 9 - 8.46) = (2.23, 0.54)$ $(l_{\widetilde{A}_2}, r_{\widetilde{A}_2}) = (9 - 9, 9 - 9) = (0, 0)$. The distance measure for trapezoidal fuzzy numbers is

$$\begin{aligned} d(\widetilde{A}_1, \widetilde{A}_2) &= \max\left\{\left|cc_{\widetilde{A}_1} - cc_{\widetilde{A}_2}\right|, \left|l_{\widetilde{A}_1} - l_{\widetilde{A}_2}\right|, \left|r_{\widetilde{A}_1} - r_{\widetilde{A}_2}\right|\right\} \\ &= \max\{|8.06 - 9|, |2.23 - 0|, |0.54 - 0|\} = 2.23. \end{aligned} \tag{A.5}$$

Thus the distance between trapezoidal fuzzy numbers is 2.23.

Competing Interests

The authors declare that there are no competing interests regarding the publication of this paper.

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