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An innovative framework for performance analysis of members of supply chains

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Abstract
Purpose – An appropriate system for analysing performance of supply chains is an important requirement for the effective utilization of the supply chains. The purpose of this paper is to develop a conceptual model for the task of analysing the performance of members of supply chains.
Design/methodology/approach – A thorough literature review of the methodologies proposed earlier by various authors has been made. In this paper a multi criteria decision-making (MCDM) framework comprising of two MCDM approaches is proposed for analysing performance of supply chain members.
Findings – Performance analysis of members of supply chain and the process of decision making based on the outcome of the analysis is a MCDM process. Since human judgements are often vague, the application of fuzzy concepts is appropriate for analysing the performance of supply chains. The framework proposed in this paper was validated in a company manufacturing textiles.
Research limitations/implications – The methodologies proposed are of great use for large- and medium-sized enterprises. However, small organizations may not be able to allot enough resources to implement the methodologies proposed.
Practical implications – The framework developed can be applied for undertaking a comparative analysis of performance of members of supply chains. It can also be applied for the process of incorporation of new members into the supply chain.
Originality/value – Very few methods are available for analysing the performance of supply chains and the subject remains an under researched one. The major contribution of this paper is that it proposes a new framework.

Keywords Total quality management, Performance measurement, Competitive strategy, Customer services quality, Supply chain management, Business excellence
Paper type Research paper

1. Introduction
Supply chain is a network consisting of customers, retailers, wholesalers, manufacturers, suppliers and service providers (Hugos, 2003). The primary aim of supply chain is to maximize the overall value generated. Although there are many definitions in the literature, supply chain management (SCM) is primarily concerned with managing relationships with suppliers and customers in order to deliver the best customer value at the lowest cost (Stevens, 1989).

SCM emphasises effective and efficient flows of both information and physical items to meet customer requirements starting from the source of supply of raw materials through to the consumption of the product by the end customer. A periodic monitoring of the two flows through the supply chain network is very essential for smooth and

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efficient functioning of the network (Pagell, 2004; Power, 2005). The management of these flows requires close collaboration among the different parties in the supply chain, including raw materials suppliers, manufacturers, distributors and retailers in order to achieve the ultimate goal of satisfying customer requirements and reducing costs. Efficiency and effectiveness in a supply chain network initially ensures sustainability and then profitability, growth and competitiveness (Chen *et al.*, 2004; Tracey *et al.* 2005; Li *et al.*, 2006).

Highly competitive environments require that supply chain managers respond quickly to competitive challenges, inventory shortages, customer complaints, inaccurate order processing and unreliable transport situations (Smith *et al.*, 2005). In modern business environments characterized by ever increasing competition and economy globalization, manufacturers have been exploiting innovative technologies and strategies to achieve and sustain competitive advantage (Chandra and Kumar, 2000). Manufacturers face an increasing pressure of customers' requirements in product customization, quality improvement and demand responsiveness. On the other hand, they need to reduce production cost, shorten lead times and lower inventory levels to ensure profitability. In order to survive under these pressures, more and more enterprises are striving to develop long-term strategic partnerships with a few competent supply chain partners and collaborate with them in product development, inventory control, distribution and non-core process outsourcing (Chan and Qi, 2003).

The successful and efficient functioning of an organization is greatly influenced by the degree of efficiency of performance of the supply chains the organization is employing both for procuring raw materials and for transporting and distributing finished products. Hence, it is absolutely necessary that every organization constantly analyse and monitor the performance of the different supply chains the organization is making use of for getting raw materials and for distribution of finished products (Chan, 2003).

Performance analysis can provide important feedback information to enable supply chain managers to monitor implementation, reveal progress, enhance communication and diagnose problems. It can also provide insights about the effectiveness of the systems in place and procedures practiced, and help to identify success and potential opportunities. It can facilitate inter understanding and integration among the supply chain members. It can make an indispensable contribution to decision making in SCM, particularly in redesigning business goals and strategies, and in reengineering processes (Sharma and Bhagwat, 2007).

Performance analysis can also aid benchmarking activities in the organization. Benchmarking is the search for industrial best practices that lead to superior performance (Camp, 1989). Pioneered by Xerox, benchmarking has been widely adopted by companies as an improvement initiative (Port and Smith, 1992). Organizations operating in the industrial service business tend to imitate the best practices in the industry in order to stay competitive. This requires organizations to closely monitor changes in the environment, evaluate new technologies and best practices (Parast and Adams, 2012). Benchmarking has gained increased popularity in the last couple of decades, especially since its inclusion within the Malcolm Baldrige Award criteria (Sarkis and Talluri, 2004). Performance analysis and benchmarking are seen as integrative approaches, whereby the performance analysis acts as the source of information for benchmarking activities (Seol *et al.*, 2007).

As an indispensable management tool, performance analysis can provide the necessary assistance for performance improvement in pursuit of supply chain excellence. However, many critical drawbacks pervert the existing performance analysis methods from making a significant contribution to the development and improvement of supply chains. The major drawbacks with the existing methods are as follows: incapable to capture holistic aspects, lack of suitability to the different levels of measurement, complexity in methods, requirement of intricate details, inadequate to capture vagueness in human judgement, etc. It is necessary to build a suitable framework which can take into account the commonalities of practical supply chains when analysing performance.

Due to the vagueness of decision data especially for intangible aspects, the crisp data are inadequate for organizational decision making. Since human judgements including preferences are often vague and cannot be expressed by exact numerical values, the application of fuzzy concepts in performance analysis is the appropriate option. Furthermore we found TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) and VIKOR (the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje) have most desirable properties which address few challenges mentioned above such as robustness, capable to capture holistic aspects, suitability at different levels, simple to use and easy to implement. We developed a novel framework for the task of analysing the performance of member firms of supply chains by integrating the fuzzy logic the TOPSIS and the VIKOR. We also validated the framework in a textiles manufacturing company to demonstrate the feasibility and practicability of the framework.

The following sections of the paper are organized as follows. Performance analysis approaches used in supply chains are discussed in Section 2. The fuzzy approach to decision-making problems is discussed in Section 3. The conceptual basis of TOPSIS, extension of TOPSIS in fuzzy environment and the detailed procedural steps for applying the fuzzy TOPSIS approach for multi criteria decision-making (MCDM) problems are explained in Section 4. Similarly, the conceptual basis of VIKOR, extension of VIKOR in fuzzy environment and the detailed procedural steps for applying the fuzzy VIKOR approach for MCDM problems are explained in Section 5. The proposed framework for analysing the performance of individual members of supply chains is discussed in Section 6. The implementation of the proposed framework in a company from the textiles industry is illustrated in Section 7. Findings and recommendations are discussed in Section 8. Finally in Section 9, the paper will be ended with a conclusion.

2. Supply chain performance analysis approaches

From a global point of view, a system for performance analysis can be seen as a multi criteria instrument, made of a set of performance expressions, i.e. physical measures as well as performance evaluations, to be consistently organized with respect to the objectives of the organisation. A system for analysing performance is defined with respect to a global objective and at the end, provides one or a set of performance expressions in order to quantify the satisfaction of this objective. Generally, the considered global objective is broken down into elementary ones along organizational levels while the elementary performance expressions associated to the broken down objectives can be aggregated, providing information about the global satisfaction. This aggregation model can be a support for decision making (Berra *et al.*, 2000; Cliville *et al.*, 2007).

2.1 Beamon's supply chain performance indicators

Beamon (1999) identified and evaluated various individual supply chain performance indicators and proposed that resource, output and flexibility are vital components to the success of supply chain. The resource measures refer to such performance measures as total cost, distribution cost, inventory and return on investment. Output measures include customer responsiveness, the quality and quantity of final products. Flexibility measures refer to volume flexibility, delivery flexibility, mix flexibility and new product flexibility. In Beamon's framework, resource utilization and flexibility measurement has been emphasised. However, the value increase in supply chain is not emphasised enough.

2.2 Supply chain performance metrics

Gunasekaran *et al.* (2001) brought out a detailed list of the performance measures and metrics of SCM with the help of a framework that gives cohesive picture to address what needs to be measured and how it can be dealt with. The metrics discussed in this framework are classified into strategic, tactical and operational levels of management. These metrics are also distinguished as financial and non-financial so that a suitable costing method based on activity analysis can be applied.

Gunasekaran *et al.* (2004) pointed out that individual firms will have performance measurement needs that reflect the unique operations of their business and it was suggested that other measures desirable should be developed by firms and supply chain participants to reflect their unique needs.

2.3 Supply chain operations reference (SCOR) model

Supply Chain Council (1996), developed the SCOR model in 1996. In SCOR it is important to quantify the operational performance of similar companies and establish internal targets based on "best in class" results, e.g. supply chain operation performance analysis. SCOR proposed two dimensions of analysis: customer facing and internal facing. In customer facing dimension, reliability, responsiveness and flexibility are measured. Performance metrics include delivery performance, fill rate, perfect order fulfillment, order fulfillment lead time, supply chain response time and production flexibility. In internal facing dimension, costs and assets are measured. Performance metrics include cost of goods sold, value added productivity, warranty cost or returns processing cost, cash to cash cycle time, inventory days of supply and asset returns. Due to the complexity of the methodology suggested, very few industries implemented the model.

2.4 Balanced score card approach

Kaplan and Norton (1992) proposed the balanced score card (BSC), as a means to evaluate corporate performance from four different perspectives: the financial, the internal business process, the customer and the learning and growth. Bhagwat and Sharma (2007) applied the BSC to analyse the performance of supply chains. The various supply chain metrics developed by Gunasekaran *et al.* (2001) were grouped into the four different perspectives of BSC. They recommended that the perspectives should be revised periodically and updated as necessary. The measures included in the given BSC should be tracked and traced over time and integrated explicitly into the strategic SCM process. This method suffers from the limitation that it is very cumbersome to collect all data relevant to the supply chain from the different work and cost centres and to consolidate them.

2.5 Analytic hierarchy process (AHP)

The AHP proposed by Saaty (1980) is a systematic procedure for representing the elements of any problem, hierarchically. AHP uses pair-wise comparison of the same hierarchy elements in each level (criteria or alternatives) using a scale indicating the importance of one element over another with respect to a higher level element. AHP enjoys the advantages of being a simple and easy to implement method. However, it suffers from limitations like the rank reversal problem and limitation in the use of the nine point scale. Chan (2003) adopted the AHP for analysing the performance of supply chains and made use of Expert Choice (1999), the commonly used AHP software for this purpose. Chan and Qi (2003) developed a fuzzy AHP for analysing the performance of supply chains. They employed a geometric scale of triangular fuzzy numbers to quantify the comparison ratios of AHP. Sharma and Bhagwat (2007) proposed an integrated BSC – AHP approach which aimed to analyse the performance of supply chain from the following four perspectives: finance, customer, internal business process, and learning and growth.

Performance analysis of members of supply chain and the process of decision making based on the outcome of the analysis is a MCDM process. In this paper a MCDM framework is proposed for analysing the performance of individual members of supply chains. The framework comprises of two approaches. The first approach is based on the fuzzy logic and the TOPSIS and the second approach is based on the fuzzy logic and the VIKOR. The proposed framework has also been implemented in a textiles manufacturing company for analysing the performance of the supply chain members.

Decision makers usually are more confident making linguistic judgements than crisp value judgements. This phenomenon results from the inability to explicitly state their preferences owing to the fuzzy nature of the comparison process. The linguistic expressions of fuzzy theory are regarded as natural representations of preferences or judgements. Characteristics such as satisfaction, fairness and dissatisfaction indicate the applicability of fuzzy set theory in capturing the preference structures of decision makers, while fuzzy set theory aids in measuring the ambiguity of the concepts associated with subjective human judgements (Asady and Zendehnam, 2007).

The TOPSIS proposed by Hwang and Yoon (1981), is capable of ranking a finite number of feasible alternatives in order of preference according to the features of each attribute of every alternative. The basic concept of TOPSIS technique is that the selected alternative will have the shortest Euclidean distance from the ideal solution and the farthest Euclidean distance from the anti ideal solution. The VIKOR developed by Opricovic and Tzeng (2002 and 2004) for multi criteria optimization of systems, focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria. Both TOPSIS and VIKOR have good conceptual basis and are simple to learn, understand and implement. In the case of both the methods, the procedural steps are less time consuming with or without the use of computers and hence the proposed framework can be a very convenient tool for practicing managers to carry out the performance analysis of members of supply chains.

3. Fuzzy approach

Expressions such as "not very clear", "probably so" and "very likely" are often encountered in real life as well as organizational situations, and more or less represent some degree of uncertainty of human assessment. In order to deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory. A fuzzy set is a class of objects with a continuum of grades of membership. It is a set with a smooth boundary. Such a set is characterized by a membership function which assigns to each object a grade of membership ranging between zero and one (Zadeh, 1965). A fuzzy set is an extension of a crisp set. Crisp sets only allow full membership or non-membership at all, whereas fuzzy sets allow partial membership. In other words, an element may partially belong to a fuzzy set (Ertugrul and Karakasoglu, 2006).

Fuzzy sets and fuzzy logic are powerful mathematical tools for modelling uncertain systems in industry, nature and humanity; and facilitators for commonsense reasoning in decision making in the absence of complete and precise information. Fuzzy logic provides numerical information on the situation where there is no certainty and it helps to get more realistic results on defining the existence of a relation in between (Gunari *et al.*, 2009). Their role is significant when applied to complex phenomena not easily described by traditional mathematical models, especially when the goal is to find a good approximate solution (Bojadziev and Bojadziev, 1998). Fuzzy sets theory providing a more widely frame than classic sets theory, has been contributing to capability of reflecting real world (Ertugrul and Tus, 2007). Modelling using fuzzy sets has proven to be an effective way for formulating decision problems where the information available is subjective and imprecise (Zimmermann, 1992). Fuzzy sets also provide the flexibility required to represent and handle the uncertainty and imprecision resulting from a lack of knowledge or ill-defined information.

A linguistic variable is a variable whose values are not numbers, but words or sentences in a natural or artificial language. In other words, they are variables with lingual expression as their values (Zadeh, 1975; Dombi and Gera, 2005). As an illustration, age is a linguistic variable if its values are assumed to be fuzzy variables labelled young, not young, very young, not very young, etc., rather than the numbers 0,1,2,3, etc. The concept of a linguistic variable appears as a useful means for providing approximate characterization of phenomena that are too complex or ill defined to be considered in conventional quantitative terms (Zadeh, 1975).

A set in classical set theory always has a sharp boundary because membership in a set is a black and white concept – an object either completely belongs to the set or does not belong to the set at all (Yen and Langari, 2006). In the classical set theory, the truth value of a statement can be given by the membership function as $\mu_A(x)$:

$$\mu_A(x) = \begin{cases} 1 & if \quad x \in A, \\ 0 & if \quad x \notin A. \end{cases}$$

Fuzzy numbers are a subset of real numbers and they represent the expansion of the idea of a confidence interval. A fuzzy set $\tilde{A}$ in a universe of discourse X can be defined mathematically by a membership function $\mu_{\tilde{A}}(x)$ which assigns each element x in the universe of discourse 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 $\tilde{A}$. The nearer the value of $\mu_{\tilde{A}}(x)$ to unity, the higher the grade of membership of x in $\tilde{A}$ (Kaufmann and Gupta, 1991).

Due to their conceptual and computation simplicity, triangular fuzzy numbers are useful in promoting representation and information processing in fuzzy environment. A triangular fuzzy number $\tilde{A}$ can be defined by a triplet (a, b, c). The membership function $\mu_{\tilde{A}}(x)$is defined as:

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-a}{b-a}, & a \leqslant x \leqslant b \\ \frac{x-c}{b-c}, & b \leqslant x \leqslant c \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where a, b, c are real numbers and $a < b < c$. The value of x at b gives the maximal grade of $\mu_{\tilde{A}}(x)$, i.e. $\mu_{\tilde{A}}(x) = 1$; it is the most probable value of the evaluation data. The value of x at a gives the minimal grade of $\mu_{\tilde{A}}(x)$, i.e. $\mu_{\tilde{A}}(x) = 0$; it is the least probable value of the evaluation data. Constants a and c are the lower and upper bounds of the available area for the evaluation data. These constants reflect the fuzziness of the evaluation data. The narrower the interval [*a,c*], the lower is the fuzziness of the evaluation data.

The distance between two triangular fuzzy numbers can be calculated by vertex method:

$$d_v = \sqrt{\frac{1}{3}\left[(a_1-a_2)^2+(b_1-b_2)^2+(c_1-c_2)^2\right]} \tag{2}$$

Basic arithmetic operations on triangular fuzzy numbers $A_1=(a_1,\ b_1,\ c_1)$, where $a_1 \leqslant b_1 \leqslant c_1$, and $A_2=(a_2,\ b_2,\ c_2)$, where $a_2 \leqslant b_2 \leqslant c_2$, can be shown as follows:

$$\text{Addition:}\quad A_1 \oplus A_2 = (a_1+a_2,\ b_1+b_2,\ c_1+c_2) \tag{3}$$

$$\text{Subtraction:}\quad A_1 \Theta A_2 = (a_1-c_2,\ b_1-b_2,\ c_1-a_2) \tag{4}$$

Multiplication: if k is a scalar:

$$k \otimes A_1 = \begin{cases} (ka_1, kb_2, kc_1),\ k>0 \\ (kc_1, kb_2, ka_1),\ k<0 \end{cases} \tag{5}$$

$$A_1 \otimes A_2 \cong (a_1a_2, b_1b_2, c_1c_2),\ \text{if}\ \ a_1 \geqslant 0,\ a_2 \geqslant 0 \tag{6}$$

$$\text{Division: } A_1 \phi A_2 \cong \left(\frac{a_1}{c_2}, \frac{b_1}{b_2}, \frac{c_1}{a_2}\right),\ \text{if}\ a_1 \geqslant 0,\ a_2 \geqslant 0. \tag{7}$$

Although multiplication and division operations on triangular fuzzy numbers do not necessarily yield a triangular fuzzy number, triangular fuzzy number approximations can be conveniently used for many practical applications (Kaufmann and Gupta, 1998; Asady and Zendehnam, 2007). Triangular fuzzy numbers are appropriate for quantifying the vague information about most decision problems. The primary reason for using triangular fuzzy numbers can be stated as their intuitive and computational efficient representation (Karsak, 2002). The evaluators can be asked to conduct their judgements, and each linguistic variable can be indicated by a triangular fuzzy number within a scale range (Wu *et al.*, 2009).

4. Hybrid approach 1 – fuzzy TOPSIS

4.1 TOPSIS

Hwang and Yoon (1981) introduced the TOPSIS for solving the MCDM problems. Different competing alternatives are sorted in decreasing order of closeness coefficient which is calculated with respect to distance of a given alternative from both positive and negative ideal solution concurrently. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from negative ideal solution (Abo Sinna and Amer, 2005; Jahanshahloo *et al.*, 2006; Shih *et al.*, 2007).

The procedure of TOPSIS can be expressed in a series of steps (Sen and Yang, 1998; Olson, 2004; Yang and Hung, 2007):

(1) Normalise the decision matrix: the normalization of the decision matrix is done using the following transformation for each r_{ij}:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{n} x_{kj}^2}},\ i = 1, \ldots, n;\ j = 1, \ldots, m \tag{8}$$

Multiply the columns of the normalized decision matrix by the associated weights. The weighted and normalized decision matrix is obtained as:

$$V_{ij} = w_j \times r_{ij}; i = 1, \ldots, n;\ j = 1, \ldots, m \tag{9}$$

where w_j represents the weight of the jth criterion.

(2) Determine the ideal and negative ideal alternatives: the ideal and negative ideal alternatives are determined, respectively, as follows:

$$A^* = \{v_1^*, v_2^*, \ldots, v_m^*\} = \{(\max_j v_{ij} | j \epsilon \Omega_b), (\min_j v_{ij} | j \epsilon \Omega_c)\} \tag{10}$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_m^-\} = \{(\min_j v_{ij} | j \epsilon \Omega_b), (\max_j v_{ij} | j \epsilon \Omega_c)\} \tag{11}$$

where Ω_b is the set of benefit criteria and Ω_c is the set of cost criteria.

(3) Obtain the distances of the existing alternatives from ideal and negative ideal alternatives: the two Euclidean distances for each alternative are, respectively, calculated as:

$$d_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^*\right)^2},\ i = 1, \ldots, n \tag{12}$$

$$d_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2},\ i = 1, \ldots, n \tag{13}$$

(4) Calculate the closeness coefficient to the ideal alternatives: the closeness coefficient to the ideal alternatives can be defined as:

$$C_i = \frac{d_i^-}{d_i^+ - d_i^-},\ i = 1, \ldots, m,\ 0 \leqslant C_i \leqslant 1 \tag{14}$$

(5) Rank the alternatives: according to the closeness coefficient to the ideal alternatives, the bigger is the C_i, the better is the alternative A_i.

4.2 Extension of TOPSIS in fuzzy environment

In the classical TOPSIS method, the weights of the criteria and the ratings of alternatives are known precisely and crisp values are used in the evaluation process. However, since crisp data are inadequate to model real life decision problems, the fuzzy

TOPSIS method is recommended where the weights of criteria and ratings of alternatives are evaluated by linguistic variables represented by fuzzy numbers.

The detailed algorithm of the fuzzy TOPSIS method is described in Appendix 1.

5. Hybrid approach 2 – fuzzy VIKOR

5.1 VIKOR

VIKOR, the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje, means multi criteria optimization and compromise solution (Chu *et al.*, 2007). Opricovic and Tzeng (2002; 2004) developed the VIKOR method for multi criteria optimization of complex systems. VIKOR method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria. Here, the compromise solution is a feasible solution which is the closest to the ideal, and a compromise means an agreement established by mutual concessions (Opricovic and Tzeng, 2007). It introduces the multi criteria ranking index based on the particular measure of "closeness" to the "ideal" solution (Opricovic, 1998).

The multi criteria measure for compromise ranking is developed from the *Lp* – metric that is used as an aggregating function in compromise programming (Yu, 1973; Zeleny, 1982). The compromise ranking algorithm of VIKOR consists of the following steps:

Step 1: determine the best (aspired/desired levels) and worst values (tolerable/worst levels). Assuming that *j*th criterion represents a benefit, then the best values for setting all the criteria functions (aspired/desired levels) are $\left\{X_i^* \middle| j = 1, 2, \ldots, n\right\}$ and the worst values (tolerable/worst levels) are $\left\{X_i^- \middle| j = 1, 2, \ldots, n\right\}$, respectively.

Step 2: compute the gaps $\{S_i|i=1,2,[\ldots],m\}$ and $\{R_i|i=1,2,[\ldots],m\}$ from the *Lp* – metric by normalization. The relationships are presented in Equations (16) and (17):

$$d_i^p = \left\{\sum_{j=1}^{n}\left(w_j\frac{\left|X_j^* - X_{ij}\right|}{\left|X_j^* - X_j^-\right|}\right)^P\right\},\ i = 1, 2, \ldots, m, \tag{15}$$

$$S_i = d_i^{p=1} = \sum_{j=1}^{n}\left(w_j\frac{\left|X_j^* - X_{ij}\right|}{\left|X_j^* - X_j^-\right|}\right),\ i = 1, 2, \ldots, m, \tag{16}$$

$$R_i = d_i^{p=\infty} = \max_j\left\{w_j\frac{\left|X_j^* - X_{ij}\right|}{\left|X_j^* - X_j^-\right|}, j = 1, 2, \ldots, n\right\},\ i = 1, 2, \ldots, m, \tag{17}$$

where $S_i, Ri \in [0, 1]$ and 0 denotes the best (i.e. achieving aspired/desired level) and 1 denotes the worst situations.

Step 3: compute the gaps $\{Q_i|i = 1, 2, [\ldots], m\}$ for ranking. The relation is defined as in Equation (18), where $S^* = \min_i S_i$ (the best S^* can be set to zero), $S^- = \max_i S_i$ (the worst S^- can be set equal to one); $R^* = \min_i R_i$ (the best R^* can be set to equal zero),

$R^{-} = \max_i R_i$ (the worst R^{-} can be set equal to one) and $v \in [0, 1]$ is introduced as the weight of the strategy:

$$Q_i = v\left[\frac{(S_i - S^*)}{S^- - S^*}\right] + (1 - v)\left[\frac{(R_i - R^*)}{R^- - R^*}\right],\ i = 1, 2, \ldots, m, \tag{18}$$

Step 4: rank and improve the alternatives, sort by values S, R and Q, in decreasing order and reduce the gaps in the criteria. The results are three ranking lists, with the best alternatives having the lowest value.

Step 5: propose a compromise solution. For a given criteria weight, the alternatives (a'), are the best ranked by measure Q (minimum) if the following two conditions are satisfied:

[C_1] Acceptable advantage:

$$Q(a'') - Q(a') \geqslant DQ \tag{19}$$

where a'' is the alternative with second position in the ranking list by Q; $DQ = 1/(J-1)$; J is the number of alternatives.

[C_2] Acceptable stability in decision making: Alternative a' must also be the best ranked by S or/and R.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed.

5.2 Extension of VIKOR method in a fuzzy environment

Based on the concept of fuzzy logic and the VIKOR method, the fuzzy VIKOR method has been developed to provide a rational, systematic process to arrive at a ranking list of all possible alternatives in MCDM problems and to discover a best solution and a compromise solution that can be used to resolve MCDM problems.

The detailed algorithm of the fuzzy VIKOR method is described in Appendix 2.

6. Performance analysis of supply chain members by hybrid approaches

The proposed fuzzy MCDM framework explained above can be employed for the task of performance analysis of individual members of supply chains which is a MCDM problem. The different supply chain members, the performance of which need to be analysed are listed out. A group of people who are experts in the field are identified and they are made members of the committee of decision makers. This committee identifies the list of evaluation criteria based on which the different individual members of supply chain are to be evaluated.

The decision makers use the linguistic weighting methodology to assess the importance of the various criteria arrived at. The decision makers then evaluate the different supply chain members under analysis based on the criteria arrived at and award linguistic ratings. These linguistic ratings are converted into the corresponding triangular fuzzy numbers.

The first approach of the proposed MCDM framework, i.e. the fuzzy TOPSIS approach is applied to the evaluation data which is in the form of triangular fuzzy numbers. The outcome of the fuzzy TOPSIS procedure is a ranking list of the different supply chain members subjected to the analysis. Similarly the second approach of the MCDM framework, i.e. the fuzzy VIKOR approach is also applied to the evaluation data which is in the form of triangular fuzzy numbers. Similar to the fuzzy TOPSIS procedure, the fuzzy VIKOR procedure also produces a ranking list of the different supply chain members subjected to the analysis. In addition, the fuzzy VIKOR procedure also recommends a compromise solution in case the best ranked firm does not enjoy acceptable advantage. An organization can thus carry out an analysis of the performance of individual members of supply chains employed by it and get a ranking list using the proposed framework.

7. Implementation of the proposed framework in a textiles manufacturing company

Gunasekaran *et al.* (2004) recommended that additional research and practitioner-driven initiatives are needed in the area of SCM performance measurement and that creative efforts are needed to design new measures and new programmes for assessing the performance of supply chain as a whole as well as the performance of each organization that is a part of the supply chain. It was also suggested that industry consortiums, consultants and researchers could be helpful in promoting SCM performance measurement generally, and in developing measures and measurement techniques specifically.

The proposed MCDM framework comprising of fuzzy TOPSIS and fuzzy VIKOR approaches for performance analysis of individual members of supply chains was implemented in a textiles manufacturing company located in the southern part of India. The company is in the textiles manufacturing business for the past 18 years. The major products produced are cotton fabrics and garments. The textiles manufacturing company is outsourcing the task of transporting its products to other parts of India. It is making use of the services of six transporting firms for this purpose. A ranking list based on the performance of these six transporting firms will be of great use to the textiles manufacturing company.

A committee of five decision makers was formed, comprising of five experts commanding good expertise and experience in the textiles and logistics sectors. The range of experience of the five decision makers is 20-35 years. The decision makers undertook a study of the existing literature on performance analysis of supply chains and made a careful consideration of all major factors and issues relevant to the textiles and transportation sectors. The committee of decision makers identified 12 criteria on the basis of which to analyse the six transporting firms. The 12 criteria listed in Table II are a subset of the comprehensive list of metrics identified by Gunasekaran *et al.* (2001). The decision makers made use of the linguistic weighting variables shown in Table I to assess the importance of criteria. The weights for importance of criteria suggested by the decision makers are shown in Table II.

For importance of criteria		For ratings of firms	
Linguistic variables	Triangular fuzzy numbers	Linguistic variables	Triangular fuzzy numbers
Very low (VL)	(0,0,0.2)	Very poor (VP)	(0,0,2)
Low (L)	(0.1,0.2,0.3)	Poor (P)	(1,2,3)
Medium low (ML)	(0.2,0.35,0.5)	Medium poor (MP)	(2,3.5,5)
Medium (M)	(0.4,0.5,0.6)	Fair (F)	(4,5,6)
Medium high (MH)	(0.5,0.65,0.8)	Medium good (MG)	(5,6.5,8)
High (H)	(0.7,0.8,0.9)	Good (G)	(7,8,9)
Very high (VH)	(0.8,1.0,1.0)	Very good (VG)	(8,10,10)

Table I. Definitions of linguistic variables

Table II. The importance of criteria by the five decision makers and the fuzzy weights

Evaluation criteria	Decision makers D_1	D_2	D_3	D_4	D_5	Fuzzy weights
Lead time (C_1)	VH	VH	H	H	VH	(0.76, 0.92, 0.96)
Reliability (C_2)	VH	VH	VH	H	VH	(0.78, 0.96, 0.98)
Flexibility (C_3)	H	VH	VH	H	MH	(0.70, 0.85, 0.92)
Defect free delivery (C_4)	H	MH	VH	M	MH	(0.58, 0.72, 0.82)
Experience (C_5)	M	MH	M	M	MH	(0.44, 0.56, 0.68)
Innovativeness (C_6)	M	M	ML	MH	M	(0.38, 0.50, 0.62)
Technology upgradation (C_7)	ML	ML	VL	M	M	(0.24, 0.34, 0.48)
Brand value (C_8)	ML	ML	L	M	ML	(0.22, 0.35, 0.48)
Tariff (C_9)	ML	ML	MH	MH	ML	(0.32, 0.47, 0.62)
Capacity (C_{10})	H	H	MH	M	H	(0.60, 0.71, 0.82)
Market share (C_{11})	VL	L	ML	L	VL	(0.08, 0.15, 0.30)
Expansion capability (C_{12})	L	L	VL	VL	L	(0.06, 0.12, 0.26)

The decision makers made use of the linguistic rating variables shown in Table I to evaluate the ratings of transporting firms with respect to each criteria. The ratings of the six transporting firms by the decision makers under the various criteria are shown in Table III.

7.1 Fuzzy TOPSIS calculations

- Step 1: the linguistic valuations marked by the decision makers for the weights of the evaluation criteria and for the six alternatives are available in OTables II-IV, respectively.
- Step 2: the values of the fuzzy decision matrix and the fuzzy weights of the criteria are calculated using Equations (26) and (22) and are shown in Table V.
- Step 3: the fuzzy decision matrix is normalized using Equation (23) and the normalized fuzzy decision matrix is constructed as shown in Table VI.
- Step 4: the fuzzy weights of the criteria are incorporated and the weighted normalized fuzzy decision matrix is formed using Equation (24) and is shown in Table VII.
- Step 5: the fuzzy positive ideal solution (A^*) and the fuzzy negative ideal solution (A^-) are noted down and are incorporated in Tables VIII and IX, respectively.
- Step 6: the distances of the six alternatives from the fuzzy positive ideal solution (A^*) and the fuzzy negative ideal solution (A^-) are calculated and are listed in Tables VIII and IX, respectively.
- Step 7: the values of $d_i^*, d_i^- \textit{ and } C_i$ for the six firms are calculated using Equations (25)-(27) and are shown in Table X.
- Step 8: the fuzzy TOPSIS method recommends the ranking order $A_3 > A_1 > A_4 > A_5 > A_6 > A_2$. A_3 emerges as the best ranked firm followed by A_1 and A_4.

7.2 Fuzzy VIKOR calculations

Step 1: the linguistic valuations marked by the decision makers for the weights of the evaluation criteria and for the six alternatives are available in Tables II and III, respectively.

Table III. The rating of firms by decision makers under various evaluation criteria

Transporting firms	Decision makers	Evaluation criteria											
		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
A_1	D_1	G	VG	MG	G	VG	F	F	G	MP	MG	G	VG
	D_2	VG	G	G	F	VG	MG	MG	G	P	G	VG	MG
	D_3	G	G	MG	F	VG	G	F	G	VP	VG	G	VG
	D_4	VG	VG	MG	MG	G	MG	F	G	P	G	VG	G
	D_5	G	G	F	G	VG	MG	G	VG	MP	G	G	G
A_2	D_1	F	MG	MP	P	G	MP	MP	F	F	G	F	VP
	D_2	G	G	P	P	VG	MP	P	G	P	VG	G	P
	D_3	MG	MG	VP	MP	G	P	VP	MG	P	G	MG	P
	D_4	F	F	MP	MP	VG	F	P	G	MP	VG	MG	P
	D_5	MG	G	P	P	G	P	P	F	F	G	F	MP
A_3	D_1	G	G	F	G	MG	MG	MG	MG	G	F	F	F
	D_2	G	VG	MG	VG	G	G	G	G	VG	F	MG	MP
	D_3	VG	G	F	G	MG	MG	VG	VG	G	G	MG	P
	D_4	VG	G	MG	VG	MG	MG	VG	G	G	MG	F	MP
	D_5	G	VG	F	G	G	G	G	G	G	F	MG	F
A_4	D_1	G	VG	F	F	MG	G	F	G	G	F	F	MP
	D_2	G	G	F	G	G	MG	G	F	VG	F	MG	P
	D_3	VG	G	G	G	F	G	MG	G	G	F	MP	P
	D_4	G	VG	F	F	MG	MG	G	G	G	F	F	MP
	D_5	VG	G	F	G	F	G	G	MG	MG	F	MP	P
A_5	D_1	G	G	P	VG	P	G	MG	G	G	G	MG	G
	D_2	G	G	P	G	VP	F	MG	G	F	G	G	VG
	D_3	F	G	P	G	VP	F	F	F	G	MG	MG	VG
	D_4	G	F	MP	VG	VP	G	MG	F	F	G	F	G
	D_5	F	G	F	VG	P	F	G	F	F	MG	F	MG
A_6	D_1	G	G	G	G	P	VG	G	P	G	MP	P	MP
	D_2	VG	G	VG	G	VP	G	F	F	F	P	P	MP
	D_3	G	G	G	G	P	MG	F	MP	G	MP	VP	F
	D_4	VG	G	MG	F	VP	G	F	P	G	F	VP	F
	D_5	VG	G	G	G	VP	MG	G	MP	F	MP	VP	MG

	A_1	A_2	A_3	A_4	A_5	A_6
C_1	(7.4,8.8,9.4)	(5.0,6.2,7.4)	(7.4,8.8,9.4)	(7.4,8.8,9.4)	(5.8,6.8,7.8)	(7.6,9.2,9.6)
C_2	(7.4,8.8,9.4)	(5.6,6.8,8.0)	(7.4,8.8,9.4)	(7.4,8.8,9.4)	(6.4,7.4,8.4)	(7.0,8.0,9.0)
C_3	(5.2,6.5,7.8)	(1.2,2.2,3.6)	(4.4,5.6,6.8)	(4.6,5.6,6.6)	(1.8,2.9,4.0)	(6.8,8.1,9.0)
C_4	(5.4,6.5,7.6)	(1.4,2.6,3.8)	(7.4,8.8,9.4)	(5.8,6.8,7.8)	(7.6,9.2,9.6)	(6.4,7.4,8.4)
C_5	(7.8,9.6,9.8)	(7.4,8.8,9.4)	(5.8,7.1,8.4)	(5.0,6.2,7.4)	(0.4,0.8,2.4)	(0.4,0.8,2.4)
C_6	(5.2,6.5,7.8)	(2.0,3.2,4.4)	(5.8,7.1,8.4)	(6.2,7.4,8.6)	(5.2,6.2,7.2)	(6.4,7.8,8.8)
C_7	(4.8,5.9,7.0)	(1.0,1.9,3.2)	(7.0,8.5,9.2)	(6.0,7.1,8.2)	(5.2,6.5,7.8)	(5.2,6.2,7.2)
C_8	(7.2,8.4,9.2)	(5.4,6.5,7.6)	(6.8,8.1,9.0)	(6.0,7.1,8.2)	(5.2,6.2,7.2)	(2.0,3.2,4.4)
C_9	(1.2,2.2,3.6)	(2.4,3.5,4.6)	(7.2,8.4,9.2)	(6.8,8.1,9.0)	(5.2,6.2,7.2)	(5.8,6.8,7.8)
C_{10}	(6.8,8.1,9.0)	(7.4,8.8,9.4)	(4.8,5.9,7.0)	(4.0,5.0,6.0)	(6.2,7.4,8.6)	(2.2,3.5,4.8)
C_{11}	(7.4,8.8,9.4)	(5.0,6.2,7.4)	(4.6,5.9,7.2)	(3.4,4.7,6.0)	(5.0,6.2,7.4)	(0.4,0.8,2.4)
C_{12}	(7.0,8.5,9.2)	(1.0,1.9,3.2)	(2.6,3.8,5.0)	(1.4,2.6,3.8)	(7.0,8.5,9.2)	(3.4,4.7,6.0)

Table IV.
Fuzzy ratings of the six firms

	A_1	A_2	A_3	A_4	A_5	A_6	Weight
C_1	(7,8.8,10)	(4,6.2,9)	(7,8.8,10)	(7,8.8,10)	(4,6.8,9)	(7,9.2,10)	(0.7,0.92,1)
C_2	(7,8.8,10)	(4,6.8,9)	(7,8.8,10)	(7,8.8,10)	(4,7.4,9)	(7,8,9)	(0.7,0.96,1)
C_3	(4,6.5,9)	(0,2.2,5)	(4,5.6,8)	(4,5.6,9)	(1,2.9,6)	(5,8.1,10)	(0.5,0.85,1)
C_4	(4,6.5,9)	(1,2.6,5)	(7,8.8,10)	(4,6.8,9)	(7,9.2,10)	(4,7.4,9)	(0.4,0.72,1)
C_5	(7,9.6,10)	(7,8.8,10)	(5,7.1,9)	(4,6.2,9)	(0,0.8,3)	(0,0.8,3)	(0.4,0.56,0.8)
C_6	(4,6.5,9)	(1,3.2,6)	(5,7.1,9)	(5,7.4,9)	(4,6.2,9)	(5,7.8,10)	(0.2,0.5,0.8)
C_7	(4,5.9,9)	(0,1.9,5)	(5,8.5,10)	(4,7.1,9)	(4,6.5,9)	(4,6.2,9)	(0,0.34,0.6)
C_8	(7,8.4,10)	(4,6.5,9)	(5,8.1,10)	(4,7.1,9)	(4,6.2,9)	(1,3.2,6)	(0.1,0.35,0.6)
C_9	(0,2.2,5)	(1,3.5,6)	(7,8.4,10)	(5,8.1,10)	(4,6.2,9)	(4,6.8,9)	(0.2,0.47,0.8)
C_{10}	(5,8.1,10)	(7,8.8,10)	(4,5.9,9)	(4,5,6)	(5,7.4,9)	(1,3.5,6)	(0.4,0.71,0.9)
C_{11}	(7,8.8,10)	(4,6.2,9)	(4,5.9,8)	(2,4.7,8)	(4,6.2,9)	(0,0.8,3)	(0,0.15,0.5)
C_{12}	(5,8.5,10)	(0,1.9,5)	(1,3.8,6)	(1,2.6,5)	(5,8.5,10)	(2,4.7,8)	(0,0.12,0.3)

Table V.
TOPSIS: fuzzy decision matrix and weights of criteria

	A_1	A_2	A_3	A_4	A_5	A_6
C_1	(0.7,0.88,1)	(0.4,0.62,0.9)	(0.7,0.88,1)	(0.7,0.88,1)	(0.4,0.68,0.9)	(0.7,0.92,1)
C_2	(0.7,0.88,1)	(0.4,0.68,0.9)	(0.7,0.88,1)	(0.7,0.88,1)	(0.4,0.74,0.9)	(0.7,0.8,0.9)
C_3	(0.4,0.65,0.9)	(0,0.22,0.5)	(0.4,0.56,0.8)	(0.4,0.56,0.9)	(0.1,0.29,0.6)	(0.5,0.81,1)
C_4	(0.4,0.65,0.9)	(0.1,0.26,0.5)	(0.7,0.88,1)	(0.4,0.68,0.9)	(0.7,0.92,1)	(0.4,0.74,0.9)
C_5	(0.7,0.96,1)	(0.7,0.88,1)	(0.5,0.71,0.9)	(0.4,0.62,0.9)	(0,0.08,0.3)	(0,0.08,0.3)
C_6	(0.4,0.65,0.9)	(0.1,0.32,0.6)	(0.5,0.71,0.9)	(0.5,0.74,0.9)	(0.4,0.62,0.9)	(0.5,0.78,1)
C_7	(0.4,0.59,0.9)	(0,0.19,0.5)	(0.5,0.85,1)	(0.4,0.71,0.9)	(0.4,0.65,0.9)	(0.4,0.62,0.9)
C_8	(0.7,0.84,1)	(0.4,0.65,0.9)	(0.5,0.81,1)	(0.4,0.71,0.9)	(0.4,0.62,0.9)	(0.1,0.32,0.6)
C_9	(0,0.22,0.5)	(0.1,0.35,0.6)	(0.7,0.84,1)	(0.5,0.81,1)	(0.4,0.62,0.9)	(0.4,0.68,0.9)
C_{10}	(0.5,0.81,1)	(0.7,0.88,1)	(0.4,0.59,0.9)	(0.4,0.5,0.6)	(0.5,0.74,0.9)	(0.1,0.35,0.6)
C_{11}	(0.7,0.88,1)	(0.4,0.62,0.9)	(0.4,0.59,0.8)	(0.2,0.47,0.8)	(0.4,0.62,0.9)	(0,0.08,0.3)
C_{12}	(0.5,0.85,1)	(0,0.19,0.5)	(0.1,0.38,0.6)	(0.1,0.26,0.5)	(0.5,0.85,1)	(0.2,0.47,0.8)

Table VI.
TOPSIS: normalised fuzzy decision matrix

Table VII. TOPSIS: weighted normalised fuzzy decision matrix

	A_1	A_2	A_3	A_4	A_5	A_6
C_1	(0.49,0.81,1)	(0.28,0.570,0.9)	(0.49,0.81,1)	(0.49,0.81,1)	(0.28,0.626,0.9)	(0.49,0.846,1)
C_2	(0.49,0.845,1)	(0.28,0.653,0.9)	(0.49,0.845,1)	(0.49,0.845,1)	(0.28,0.710,0.9)	(0.49,0.768,0.9)
C_3	(0.2,0.553,0.9)	(0,0.187,0.5)	(0.2,0.476,0.8)	(0.2,0.476,0.9)	(0.05,0.247,0.6)	(0.25,0.689,1)
C_4	(0.16,0.468,0.9)	(0.04,0.187,0.5)	(0.28,0.634,1)	(0.16,0.49,0.9)	(0.28,0.662,1)	(0.16,0.533,0.9)
C_5	(0.28,0.538,0.8)	(0.28,0.493,0.8)	(0.2,0.398,0.72)	(0.16,0.347,0.72)	(0,0.045,0.24)	(0,0.045,0.24)
C_6	(0.08,0.325,0.72)	(0.02,0.16,0.48)	(0.1,0.355,0.72)	(0.1,0.37,0.72)	(0.08,0.31,0.72)	(0.1,0.39,0.8)
C_7	(0,0.201,0.54)	(0,0.065,0.3)	(0,0.289,0.6)	(0,0.241,0.54)	(0,0.221,0.54)	(0,0.211,0.54)
C_8	(0.07,0.294,0.6)	(0.04,0.228,0.54)	(0.05,0.284,0.6)	(0.04,0.249,0.54)	(0.04,0.217,0.54)	(0.01,0.112,0.36)
C_9	(0,0.103,0.4)	(0.02,0.165,0.48)	(0.14,0.395,0.8)	(0.1,0.381,0.8)	(0.08,0.291,0.72)	(0.08,0.32,0.72)
C_{10}	(0.2,0.575,0.9)	(0.28.0.625,0.9)	(0.16,0.42,0.81)	(0.16,0.355,0.54)	(0.2,0.525,0.81)	(0.04,0.249,0.54)
C_{11}	(0,0.132,0.5)	(0,0.093,0.45)	(0,0.089,0.4)	(0,0.071,0.4)	(0,0.093,0.45)	(0,0.012,0.15)
C_{12}	(0,0.102,0.3)	(0,0.023,0.15)	(0,0.046,0.18)	(0,0.031,0.15)	(0,0.102,0.3)	(0,0.056,0.24)

Table VIII.
TOPSIS: distances between A^* and A_i $(i = 1, 2, 3)$

	A^*	A_1	A_2	A_3	A_4	A_5	A_6
C_1	1.000	0.314	0.488	0.314	0.314	0.472	0.308
C_2	1.000	0.308	0.461	0.308	0.308	0.452	0.329
C_3	1.000	0.532	0.798	0.564	0.555	0.737	0.469
C_4	1.000	0.577	0.782	0.466	0.570	0.000	0.558
C_5	0.800	0.336	0.349	0.420	0.455	0.713	0.713
C_6	0.800	0.500	0.611	0.481	0.477	0.505	0.468
C_7	0.600	0.418	0.496	0.390	0.405	0.411	0.414
C_8	0.600	0.353	0.390	0.366	0.383	0.393	0.463
C_9	0.800	0.656	0.610	0.447	0.471	0.511	0.502
C_{10}	0.900	0.446	0.392	0.512	0.570	0.461	0.657
C_{11}	0.500	0.358	0.373	0.378	0.385	0.373	0.451
C_{12}	0.300	0.208	0.251	0.237	0.248	0.208	0.226

Table IX.
TOPSIS: distances between A_i $(i = 1, 2, 3)$ and A^-

	A^-	A_1	A_2	A_3	A_4	A_5	A_6
C_1	0.280	0.530	0.400	0.530	0.530	0.410	0.543
C_2	0.280	0.542	0.418	0.542	0.542	0.436	0.471
C_3	0.000	0.621	0.308	0.550	0.599	0.473	0.716
C_4	0.040	0.559	0.279	0.666	0.565	0.675	0.572
C_5	0.000	0.580	0.566	0.489	0.471	0.141	0.141
C_6	0.020	0.442	0.278	0.450	0.454	0.439	0.501
C_7	0.000	0.333	0.177	0.384	0.342	0.337	0.335
C_8	0.010	0.380	0.331	0.376	0.336	0.329	0.211
C_9	0.000	0.239	0.293	0.521	0.543	0.552	0.457
C_{10}	0.040	0.592	0.616	0.500	0.348	0.534	0.313
C_{11}	0.000	0.299	0.265	0.237	0.235	0.265	0.087
C_{12}	0.000	0.183	0.088	0.107	0.089	0.183	0.142

Table X.
TOPSIS: d_i^*, d_i^- and C_i

	A_1	A_2	A_3	A_4	A_5	A_6
d_i^*	5.004	6.003	4.885	5.141	5.694	5.557
d_i^-	5.298	4.014	5.353	5.052	4.773	4.488
$d_i^* + d_i^-$	10.30	10.02	10.24	10.19	10.47	10.05
C_i	0.514	0.401	0.523	0.496	0.456	0.447
Rank	2	6	1	3	4	5

Step 2: the linguistic valuations available in Tables II and III are converted into corresponding triangular fuzzy numbers using Equations (28) and (29) and are given in Tables II and IV, respectively.

Step 3: the fuzzy best value (FBV) and fuzzy worst value (FWV) for the 12 criteria used are calculated using Equations (32) and (33), respectively, and are shown in Table XI.

Step 4: using Equations (34)-(39), $\tilde{S}_i, \tilde{R}_i, \tilde{S}^*, \tilde{S}^-, \tilde{R}^*$ and $\tilde{R}^-$ are calculated and are shown in Tables XII and XIII. Using Equation (40), $\tilde{Q}_i$ values are calculated and are shown in Table XIV.

Step 5: $\tilde{S}_i$, $\tilde{R}_i$ and $\tilde{Q}$ are defuzzified and are shown in Tables XII and XIV.

		$\tilde{f}_j^*$			$\tilde{f}_j^-$	
C_1	7.6	9.2	9.6	5.0	6.2	7.4
C_2	7.4	8.8	9.4	5.6	6.8	8.0
C_3	6.8	8.1	9.0	1.2	2.2	3.6
C_4	7.6	9.2	9.6	1.4	2.6	3.8
C_5	7.8	9.6	9.8	0.4	0.8	2.4
C_6	6.4	7.8	8.8	2.0	3.2	4.4
C_7	7.0	8.5	9.2	1.0	1.9	3.2
C_8	7.2	8.4	9.2	2.0	3.2	4.4
C_9	7.2	8.4	9.2	1.2	2.2	3.6
C_{10}	7.4	8.8	9.4	2.2	3.5	4.8
C_{11}	7.4	8.8	9.4	0.4	0.8	2.4
C_{12}	7.0	8.5	9.2	1.0	1.9	3.2

Table XI. VIKOR: fuzzy best value and fuzzy worst value

m		$\tilde{S}_i$		S_i	Rank		$\tilde{R}_i$		R_i	Rank
A_1	1.045	1.487	1.583	1.372	2	0.320	0.470	0.620	0.470	2
A_2	3.883	5.009	5.832	4.908	6	0.780	0.960	0.980	0.907	6
A_3	0.941	1.310	1.399	1.217	1	0.300	0.389	0.428	0.372	1
A_4	1.292	1.880	2.187	1.786	3	0.392	0.509	0.606	0.502	3
A_5	2.557	3.545	4.005	3.369	5	0.625	0.749	0.852	0.742	5
A_6	1.808	2.659	3.183	2.550	4	0.600	0.710	0.820	0.710	4

Table XII. VIKOR: S_i and R_i and the ranks of the firms

$\tilde{S}^*$	0.941	1.310	1.399
$\tilde{S}^-$	3.883	5.009	5.832
$\tilde{R}^*$	0.300	0.389	0.428
$\tilde{R}^-$	0.780	0.960	0.980

Table XIII. VIKOR: $\tilde{S}^*$, $\tilde{S}^-$, $\tilde{R}^*$ and $\tilde{R}^-$

m		$\tilde{Q}_i$		Q_i	Rank
A_1	0.039	0.095	0.195	0.110	2
A_2	1.000	1.000	1.000	1.000	6
A_3	0.000	0.000	0.000	0.000	1
A_4	0.155	0.182	0.250	0.196	3
A_5	0.613	0.617	0.678	0.636	5
A_6	0.460	0.463	0.556	0.493	4

Table XIV. VIKOR: Q_i and ranks of the firms

Step 6: the rankings for the six firms under consideration are marked based on S_i, R_i and Q_i. The rankings based on S_i and R_i are available in Table XII and the rankings based on Q_i are available in Table XIV. All the three parameters, namely S_i, R_i and Q_i have returned the same ranking of the six firms considered. The ranking is $A_3 > A_1 > A_4 > A_6 > A_5 > A_2$.

Since all the three parameters, S_i, R_i and Q_i have returned the same ranking, there is acceptable stability in decision making. The firm A_3 which has been ranked first by S_i, R_i as well as Q_i is the best performing firm.

Step 7: since $m = 6$, DQ $= 1/(m–1)$ yields a value of 0.20. So, the best ranked firm A_3 does not enjoy "Acceptable advantage". Hence, the set of "Compromise solutions" is proposed. It consists of three firms A_3, A_1 and A_4.

8. Discussions

It is essential that every organization constantly analyse and monitor the performance of different supply chains, the organization is making use of, for getting raw materials and for distribution of finished products. Many critical drawbacks pervert the existing performance analysis methods from making a significant contribution to the development and improvement of supply chains. The major drawbacks with the existing methods are: incapable to capture holistic aspects, lack of suitability to the different levels of measurement, complexity in methods, requirement of intricate details, inadequate to capture vagueness in human judgement, etc.

The MCDM framework proposed in this paper, comprising of fuzzy TOPSIS approach and fuzzy VIKOR approach, once incorporated and institutionalized into the organizations can be an effective tool for practicing managers of organizations to analyse and monitor the performance of supply chains employed by the organizations. The framework is simple to learn and implement. The procedural steps are less time consuming both with or without the use of computers. The framework is free from accusations of bias and it is very much suitable for standardization.

The task of performance analysis in supply chains in practice, is often influenced by uncertainty, and in such situations, incorporation of fuzzy approach is the appropriate way to provide a systematic and efficient framework for the purpose. The proposed framework is capable of enabling practicing managers carry out performance analysis in a systematic, consistent and productive manner. The TOPSIS approach has advantages like, it is easy to understand, it has a simple conceptual basis and the computation procedure is not long. The major advantage of the VIKOR approach is that it also recommends a compromise solution in case the best ranked alternative does not enjoy acceptable advantage.

For effective performance analysis and improvement, the measurement goals must represent organizational goals and should reflect a balance between financial and non-financial measures that can be related to strategic, tactical and operational levels of decision making and control. Performance of members of supply chains is a crucial factor in supply chain partnering and integration. Supply chain partnering is a collaborative relationship which recognizes some degree of interdependence and cooperation. Such a partnering emphasises direct long-term association encouraging mutual planning and problem-solving efforts. To bring about improved performance in supply chain and move closer to attainment of the goal of supply chain optimization, performance analysis and improvement studies must be done throughout the supply chain. All participants in the supply chain should be involved and committed to common goals, such as customer satisfaction throughout the supply chain and enhanced competitiveness. A performance measurement programme for a supply chain should be complete, should cover all the individual participants and should be tailored to varying needs of participants.

9. Conclusions

The continuously evolving and dynamic nature of the supply chain networks presents many opportunities for organizations which they can successfully leverage for achieving their objectives. Organisations need to look to continuous improvement in their supply chain operations as a tool to enhance their core competitiveness and financial outcome. Many companies have failed in maximizing the potential of their supply chains because they have often failed to develop and establish suitable systems to analyse the performance of the members of the supply chain so that perfect integration among different members of the supply chain can be facilitated.

The proposed framework has a few limitations. It can be used to analyse the comparative performance of the different supply chain members employed and to obtain a ranking list based on the performance of the members. However, it cannot be used to obtain scores on the absolute performance of the members of the supply chain. The performance analysis exercise by employing the proposed framework will be able to bring about the real picture in the supply chain only if experienced and competent managers who have sufficient expertise in the relevant sectors are appointed to the committee of decision makers. Large organizations are unlikely to find it difficult to identify such competent people from among their own talent pool or from other organizations on deputation. However, small and very small scale organizations may find it difficult to identify experts from within their ranks and they also may not be in a position to utilize the services of external experts.

There is a need to explore the suitability of employing other emerging MCDM methodologies like the PROMETHEE, ELECTRE, data envelopment analysis and goal programming for the task of anlysing the performance of supply chains. There is a need to direct research efforts in this direction in future.

Environmental responsibility is becoming more and more important for organizations as the emphasis on the environmental protection by stakeholders, including stockholders, governments, customers, employees, competitors and communities, keeps increasing. The framework proposed in this paper can also be suitably amended to analyse the green performance of the various members of the supply chain.

References

Abo Sinna, M.A. and Amer, A.H. (2005), "Extension of TOPSIS for multi objective large scale non linear programming problems", *Applied mathematics and Computation*, Vol. 162 No. 1, pp. 243-256.

Asady, B. and Zendehnam, A. (2007), "Ranking fuzzy numbers by distance minimizing", *Applied Mathematical Modeling*, Vol. 31 No. 11, pp. 2589-2598.

Beamon, M.B. (1999), "Measuring supply chain performance", *International Journal of Operations and Production Management*, Vol. 19 No. 3, pp. 275-292.

Berra, L., Mauris, G., Haurat, A. and Foulloy, L. (2000), "Global vision and performance indicators for an industrial improvement approach", *Computers in Industry*, Vol. 43 No. 3, pp. 211-225.

Bhagwat, R. and Sharma, M.K. (2007), "Performance measurement of supply chain management: a balanced score card approach", *Computers and Industrial Engineering*, Vol. 53 No. 1, pp. 43-62.

Bojadziev, G. and Bojadziev, M. (1998), *Fuzzy Sets and Fuzzy Logic Applications*, World Scientific, Singapore.

Camp, R.C. (1989), *Benchmarking: The Search for Industry Best Practices that Lead to Superior Performance*, ASQC Quality Press, Milwauke, WI.

Chandra, C. and Kumar, S. (2000), "Supply chain management in theory and practice: a passing fad or a fundamental change?", *Industrial Management and Data Systems*, Vol. 100 No. 3, pp. 100-114.

Chan, F.T.S. (2003), "Performance measurement in a supply chain", *International Journal of Advanced Manufacturing Technology*, Vol. 21 No. 7, pp. 534-548.

Chan, F.T.S. and Qi, H.J. (2003), "An innovative performance measurement method for supply chain management", *Supply Chain Management: An International Journal*, Vol. 8 No. 3, pp. 209-223.

Chen, I.J., Paulraj, A. and Lado, A.A. (2004), "Strategic purchasing, supply management and firm performance", *Journal of Operations Management*, Vol. 22 No. 5, pp. 505-523.

Chu, M.T., Shyu, J., Tzeng, G.H. and Khosla, R. (2007), "Comparison among three analytical methods for knowledge communities group decision analysis", *Expert Systems with Applications*, Vol. 33 No. 4, pp. 1011-1024.

Cliville, V., Berra, L. and Mauris, G. (2007), "Quantitative expression and aggregation of performance measurements based on the MACBETH multi-criteria method", *International Journal of Production Economics*, Vol. 105 No. 1, pp. 171-189.

Dombi, J. and Gera, Z. (2005), "The approximation of piecewise linear membership functions and lukasiewicz operators", *Fuzzy Sets and Systems*, Vol. 154 No. 2, pp. 275-286.

Ertugrul, I. and Karakasoglu, N. (2006), "Fuzzy TOPSIS method for academic member selection in engineering faculty", *International Joint Conferences on Computer, Information, and Systems Sciences and Engineering (CIS^{2}E 06), Bridgeport, 4-14 December*.

Ertugrul, I. and Tus, A. (2007), "Interactive fuzzy linear programming and an application sample at a textile firm", *Fuzzy Optimization and Decision Making*, Vol. 6 No. 1, pp. 29-49.

Expert Choice (1999), Expert Choice Inc., Pittsburgh, PA, available at: www.expertchoice.com

Gunari, A.F., Cengiz, M. and Seker, S. (2009), "A fuzzy ANP approach to shipyard location selection", *Expert Systems with Applications*, Vol. 36 No. 4, pp. 7992-7999.

Gunasekaran, A., Patel, C. and Tirtirlogu, E. (2001), "Performance measures and metrics in a supply chain environment", *International Journal of Production and Operations Management*, Vol. 21 Nos 1/2, pp. 71-87.

Gunasekaran, A., Patel, C., Ronald, E. and McGaughey, R. (2004), "A framework for supply chain performance measurement", *International Journal of Production Economics*, Vol. 87 No. 3, pp. 333-348.

Hugos, M. (2003), *Essentials of Supply Chain Management*, Wiley, New York, NY.

Hwang, C.L. and Yoon, K. (1981), *Multiple Attributes Decision Making Methods and Applications*, Springer, Berlin and Heidelberg.

Jahanshahloo, G.R., Lotfi, F.H. and Izadikhah, M. (2006), "Extension of TOPSIS method for decision making problems with fuzzy data", *Applied Mathematics and Computation*, Vol. 181 No. 2, pp. 1544-1551.

Kaplan, R. and Norton, D. (1992), "The balanced scorecard: measures that drive performance", *Harvard Business Review*, Vol. 70 No. 1, pp. 71-99.

Karsak, E.E. (2002), "Distance based fuzzy MCDM approach for evaluating flexible manufacturing system alternatives", *International Journal of Production Research*, Vol. 40 No. 13, pp. 3167-3181.

Kaufmann, A. and Gupta, M.M. (1991), *Introduction to Fuzzy Arithmetic: Theory and Application*, Van Nostrand Reinhold, New York, NY.

Kaufmann, A. and Gupta, M.M. (1998), *Fuzzy Mathematical Models in Engineering and Management Science*, North Holland, Amsterdam.

Li, S., Ragunathan, B., Ragunathan, T.S. and Subba Rao, S. (2006), "The impact of supply chain management practices on competitive advantage and organizational performance", *Omega*, Vol. 34 No. 2, pp. 107-124.

Opricovic, S. (1998), *Multi Criteria Optimization of Civil Engineering Systems*, Faculty of Civil Engineering, Belgrade.

Opricovic, S. and Tzeng, G.H. (2002), "Multicriteria planning of post earthquake sustainable reconstruction", *Computer Aided Civil and Infrastructure Engineering*, Vol. 17 No. 3, pp. 211-220.

Opricovic, S. and Tzeng, G.H. (2004), "Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS", *European Journal of Operations Research*, Vol. 156 No. 2, pp. 445-455.

Opricovic, S. and Tzeng, G.H. (2007), "Extended VIKOR method in comparison with outranking methods", *European Journal of Operations Research*, Vol. 178 No. 2, pp. 514-529.

Pagell, M. (2004), "Understanding the factors that enable and inhibit the integration of operations, purchasing and logistics", *Journal of Operations Management*, Vol. 22 No. 5, pp. 459-487.

Parast, M.M. and Adams, S.G. (2012), "Corporate social responsibility, benchmarking, and organizational performance in the petroleum industry: a quality management perspective", *International Journal of Production Economics*, Vol. 139 No. 2, pp. 447-458.

Port, O. and Smith, G. (1992), "Beg, borrow and benchmark", *Businessweek*, Vol. 30, November, pp. 74-75.

Power, D. (2005), "Supply chain management integration and implementation: a literature review", *Supply Chain Management: An International Journal*, Vol. 10 No. 4, pp. 252-263.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw Hill, New York, NY.

Sarkis, J. and Talluri, S. (2004), "Performance based clustering for benchmarking of US airports", *Transportation Research Part A: Policy and Practice*, Vol. 38 No. 5, pp. 329-346.

Sen, P. and Yang, J.B. (1998), *Multiple Criteria Decision Support in Engineering Design*, Springer Verlag, London.

Seol, H., Choi, J., Park, G. and Park, Y. (2007), "A framework for benchmarking service process using data envelopment analysis and decision tree", *Expert Systems with Applications*, Vol. 32 No. 2, pp. 432-440.

Sharma, M.K. and Bhagwat, R. (2007), "An integrated BSC-AHP approach for supply chain management evaluation", *Measuring Business Excellence*, Vol. 11 No. 3, pp. 57-68.

Shih, H.S., Shyur, H.J. and Stanley Lee, E. (2007), "An extension of TOPSIS for group decision making", *Mathematical and Computer Modelling*, Vol. 45 Nos 7/8, pp. 801-813.

Smith, M.F., Lancioni, R.A. and Oliva, T.A. (2005), "The effects of management inertia on the supply chain performance of produce to stock firms", *Industrial Marketing Management*, Vol. 34 No. 1, pp. 614-628.

Stevens, G.C. (1989), "Integrating the supply chain", *International Journal of Physical Distribution and Materials Management*, Vol. 23 No. 2, pp. 102-107.

Supply Chain Council (1996), *Supply Chain Operations Reference Model*, Supply-Chain Council, Chicago, IL.

Tracey, M., Lim, J.S. and Vonderembse, M.A. (2005), "The impact of supply chain management capabilities on business performance", *Supply Chain Management: An International Journal*, Vol. 10 No. 3, pp. 179-191.

Wu, Y.H., Tzeng, G.H. and Chen, Y.H. (2009), "A fuzzy MCDM approach for evaluating banking performance based on balanced scorecard", *Expert Systems with Applications*, Vol. 36 No. 6, pp. 10135-10147.

Yang, T. and Hung, C.C. (2007), "Multiple attribute decision making methods for plant layout design problem", *Robotics and Computer Integrated Manufacturing*, Vol. 23 No. 1, pp. 126-137.

Yen, J. and Langari, R. (2006), *Fuzzy Logic – Intelligence, Control and Information*, Pearson Education, New Delhi.

Yoon, K. (1981), "System selection by multiple attribute decision making", PhD dissertations, Kansas State University, Manhattan.

Yu, P.L. (1973), "A class of solutions for group decision problems", *Management Science*, Vol. 19 No. 8, pp. 936-946.

Zadeh, L.A. (1965), "Fuzzy sets", *Information Control*, Vol. 8 No. 1, pp. 338-353.

Zadeh, L.A. (1975), "The concept of a linguistic variable and its application to approximate reasoning-I", *Information Sciences*, Vol. 8 No. 3, pp. 199-249.

Zeleny, M. (1982), *Multiple Criteria Decision Making*, McGraw Hill, New York, NY.

Zimmermann, H.J. (1992), *Fuzzy Set Theory and its Applications*, Kluwer, Boston, MA.

Further reading

Chen, C.T. (2000), "Extensions of TOPSIS for group decision making under fuzzy environment", *Fuzzy Sets Systems*, Vol. 114 No. 1, pp. 1-9.

Olson, D.L. (2004), "Comparison of weights in TOPSIS models", *Mathematical and Computer Modelling*, Vol. 40 Nos 7/8, pp. 721-727.

Appendix 1. The algorithm of the fuzzy TOPSIS method

The algorithm of the fuzzy TOPSIS method is described in the following steps:

Step 1: generate the list of all feasible alternatives. Form a committee of decision makers who are experts in the field commanding good expertise and experience. The committee of decision makers arrives at the list of evaluation criteria to be considered for determining the ranking of alternatives. Define linguistic variables and their corresponding triangular fuzzy numbers for the weight of criteria and the rating of alternatives, respectively.

Step 2: aggregate the weights of the various evaluation criteria.

If the fuzzy ratings of all decision makers are described as triangular fuzzy numbers $\tilde{R}_k = (a_k, b_k, c_k), k = 1, 2, \ldots, K.$, then the aggregated fuzzy rating can be determined as $\tilde{R} = (a, b, c), k = 1, 2, \ldots, K,$ Here:

$$a = \min_k\{a_k\},\ b = \frac{1}{K}\sum_{k=1}^{K} b_k,\ c = \max_k\{c_k\} \tag{A1}$$

If the fuzzy rating and importance weight of the kth decision maker are $\tilde{x}_{ijk} = \left(a_{ijk}, b_{ijk}, c_{ijk}\right)$ and $\tilde{w}_{ijk} = \left(w_{jk1}, w_{jk2}, w_{jk3}\right),\ i = 1, 2, \ldots, m,\ j = 1, 2, \ldots, n,$ respectively, then the aggregated fuzzy ratings $(\tilde{x}_{ij})$ of alternatives with respect to each criterion can be found as $\left(\tilde{x}_{ij}\right) = \left(a_{ij}, b_{ij}, c_{ij}\right)$. Here:

$$a_{ij} = \min_k\left\{a_{ijk}\right\},\ b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk},\ c_{ij} = \max_k\left\{c_{ijk}\right\} \tag{A2}$$

Then the aggregated fuzzy weights $\left(\tilde{w}_{ij}\right)$ of each criterion are calculated as: $\left(\tilde{w}_j\right) = \left(w_{j1}, w_{j2}, w_{j3}\right)$. Here:

$$w_{j1} = \min_k\left\{w_{jk1}\right\},\ w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2},\ w_{j3} = \max_k\left\{w_{jk3}\right\} \tag{A3}$$

Construct the fuzzy decision matrix as:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n]$$

Step 3: normalise the fuzzy decision matrix that is constructed and obtain the normalized fuzzy decision matrix as $\tilde{R}$:

$$\tilde{R} = \left[\tilde{r}_{ij}\right]_{m\times n} \quad i = 1, 2, \ldots, m;\ j = 1, 2, \ldots, n \tag{A4}$$

where $\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), c_j^* = \max_i c_{ij}$

Step 4: form the weighted normalized decision matrix as:

$$\tilde{V} = \left[\tilde{v}_{ij}\right]_{m\times n} i = 1, 2, \ldots, m; j = 1, 2, \ldots, n; \tilde{v}_{ij} = \tilde{w}_j(.)\tilde{r}_{ij} \tag{A5}$$

where $\tilde{w}_j$represents the importance weight of criterion C_j.

Step 5: determine the fuzzy positive ideal solution (FPIS, A*) and fuzzy negative ideal solution (FNIS, A^-):

$$A^* = \left(\tilde{v}_1^*, \tilde{v}_2^*, \ldots \tilde{v}_n^*\right) \text{ and } A^- = \left(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-\right),$$

where $\tilde{v}_j^* = \max_i\{v_{ij3}\}$ and $\tilde{v}_j^- = \min_i\{v_{ij1}\}$ $i = 1, 2, \ldots m,\ j = 1, 2, \ldots n.$

Step 6: calculate the distance of each alternative from FPIS and FNIS as:

$$d_i^* = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^*\right),\ i = 1, 2, \ldots,\ m \tag{A6}$$

$$d_i^- = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^-\right),\ i = 1, 2, \ldots,\ m \tag{A7}$$

where $d_v(.,.)$ is the distance measurement between two fuzzy numbers.

Step 7: the closeness coefficient of each alternate can be calculated as:

$$C_i = \frac{d_i^-}{d_i^* + d_i^-},\ i = 1, 2, \ldots,\ m \tag{A8}$$

Step 8: as per Equations (27) an alternative A_i would be closer to FPIS and farther from FNIS as C_i approaches the value of 1. The ranking of the alternatives can be finalised, based on the values of closeness coefficients of alternatives.

Appendix 2. The algorithm of the fuzzy VIKOR method

The algorithm of the fuzzy VIKOR method is described in the following steps:

Step 1: generate the list of all feasible alternatives. Form a committee of decision makers who are experts in the field commanding good expertise and experience. The committee of decision makers arrives at the list of evaluation criteria to be considered for determining the ranking of alternatives. Define linguistic variables and their corresponding triangular fuzzy numbers for the weight of criteria and the rating of alternatives, respectively.

Step 2: integrate decision makers' preferences and opinions. The decision is derived by aggregating the fuzzy weight of criteria and fuzzy rating of alternatives from n decision makers calculated as:

$$\tilde{w}_j = \frac{1}{n}\left[\sum_{e=1}^{n} \tilde{w}_j^e\right],\ j = 1, 2, \ldots, k \tag{A9}$$

In addition, the preferences and opinions of n decision makers with respect to j criterion for the importance weight of each criterion and the rating of each alternative in the ith alternative can be calculated by:

$$\tilde{x}_{ij} = \frac{1}{n}\left[\sum_{e=1}^{n} \tilde{x}_{ij}^{e}\right],\ i = 1, 2, \ldots, m \tag{A10}$$

Calculate the fuzzy weighted average and construct the normalized fuzzy decision matrix:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1k} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mk} \end{bmatrix} \tag{A11}$$

$$i = 1, 2, \ldots, m;\ \ j = 1, 2, \ldots, k$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_k],\ j = 1, 2, \ldots, k \tag{A12}$$

where $\tilde{x}_{ij}$ is the rating of alternative A_i with respect to criterion C_j and $\tilde{w}_j$ is the importance weight of the jth criterion.

Step 3: determine the FBV and FWV:

$$\tilde{f}_j^* = \max_i \tilde{x}_{ij} \tag{A13}$$

$$\tilde{f}_j^- = \min_i \tilde{x}_{ij} \tag{A14}$$

Step 4: calculate the values $\tilde{S}_i$,$\tilde{R}_i$, $\tilde{S}^*$, $\tilde{S}^-$, $\tilde{R}^*$, $\tilde{R}^-$and $\tilde{Q}_i$

$$\tilde{S}_i = \sum_{j=1}^{k} \tilde{w}_j\left(\tilde{f}_j^* - \tilde{x}_{ij}\right) / \left(\tilde{f}_j^* - \tilde{f}_j^-\right) \tag{A15}$$

$$\tilde{R}_i = \max_j\left[\tilde{w}_j\left(\tilde{f}_j^* - \tilde{x}_{ij}\right) / \left(\tilde{f}_j^* - \tilde{f}_j^-\right)\right] \tag{A16}$$

where $\tilde{S}_i$ is A_i with respect to all criteria calculated by the sum of the distance for the FBV, and $\tilde{R}_i$ is A_i with respect to the jth criterion, calculated by maximum distance of FBV:

$$\tilde{S}^* = \min_i \tilde{S}_i \tag{A17}$$

$$\tilde{S}^- = \max_i \tilde{S}_i \tag{A18}$$

$$\tilde{R}^* = \min_i \tilde{R}_i \tag{A19}$$

$$\tilde{R}^- = \max_i \tilde{R}_i \tag{A20}$$

$$\tilde{Q}_i = v\left(\tilde{S}_i - \tilde{S}^*\right) / \left(\tilde{S}^- - \tilde{S}^*\right) + (1-v)\left(\tilde{R}_i - \tilde{R}^*\right) / \left(\tilde{R}^- - \tilde{R}^*\right) \tag{A21}$$

Here, $\tilde{S}^*$ is the minimum value of $\tilde{S}_i$, which is the maximum majority rule or maximum group utility, and $\tilde{R}^*$ is the minimum value of $\tilde{R}_i$, which is the minimum individual regret of the opponent.

Step 5: defuzzify triangular fuzzy number $\tilde{Q}_i$ and rank the alternatives, sorting by the value Q_i in ascending order. Consequently, the smaller the value of Q_i, the better the alternative.

Step 6: determine a compromise solution. Assume that the two conditions given below are acceptable. Then by using the index Q_i, determine a compromise solution (a') as a single optimal solution.

[C_1] Acceptable advantage:

$$Q(a'') - Q(a') \geqslant DQ \tag{A22}$$

$$DQ = 1/m - 1 \quad (DQ = 0.25 \text{if} m \geqslant 4) \tag{A23}$$

[C_2] Acceptable stability in decision making:

Under this condition $Q(a')$must be $S(a')$ or/and $R(a')$.

If [C_1] is not accepted and $Q\left(a^{(m)}\right) - Q(a') < DQ$, then $a^{(m)}$ and a' are the same compromise solution. However, a' does not have a comparative advantage, so the compromise solutions $a', a'', \ldots, a^{(m)}$ are the same. If the [$C2$] is not accepted, the stability in decision making is deficient, although a' has a comparative advantage. Hence, compromise solutions of a' and a'' are the same.

Step 7: select the best alternative. Choose $Q(a')$ as the best solution with the minimum of Q_i.

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