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Evaluation and selection of resilient suppliers in fuzzy environment: Exploration of fuzzy-VIKOR

Anoop Kumar Sahu Saurav Datta S.S. Mahapatra

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Anoop Kumar Sahu, Saurav Datta and S.S. Mahapatra
Department of Mechanical Engineering, National Institute of Technology, Rourkela, India

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Abstract

Purpose – Supply chains (SCs) have become increasingly vulnerable to catastrophic events/disruptions that may be natural or man-made. Hurricanes, tsunamis and floods are natural disasters, whereas man-made disasters may be strikes, terrorist attacks, etc. Failure at any point in the SC network has the potential to cause the entire network to fail. SCs must therefore be properly designed to survive well in the disruption scenario. The capability of successful survival (of the firm's SC) against those adverse events/happenings is termed as resilience; and, the SC designed under resilience consideration is called a resilient SC. Effective supplier selection is considered as a key strategic consideration in SC management. It is felt that apart from considering traditional suppliers selection criterions, suppliers' resiliency strategy must be incorporated while selecting a potential supplier which can provide best support to the firm even in the disaster/disruption scenario. The purpose of this paper is to focus aspects of evaluation and selection of resilience supplier by considering general as well as resiliency strategy, simultaneously.

Design/methodology/approach – In this work, subjectivity associated with ill-defined (vague) evaluation information has been tackled through logical exploration of fuzzy numbers set theory. Application of VIKOR embedded with fuzzy mathematics has been utilized here. Sensitivity analysis has been performed to reflect the effect of decision-makers' (DM) risk bearing attitude in selecting the best potential supplier in a resilient SC. A case empirical example has also been presented.

Findings – The work attempts to focus on a decision-making procedural hierarchy towards effective supplier selection in a resilient SC. The work exhibits application potential of VIKOR method integrated with fuzzy set theory to select potential supplier based on general strategy as well as resiliency strategy. The final supplier selection score (obtained by considering general strategy) and that of obtained by analyzing resiliency strategy have been combined to get a final compromise solution. The decision-support framework thus reported here also considers DMs' risk bearing attitude.

Practical implications – The study bears significant impact to the industry managers who are trying to adapt resiliency strategy in their SC followed by potential supplier selection in the context of resilient SC.

Originality/value – Exploration of VIKOR embedded with fuzzy set theory towards suppliers' evaluation and selection by considering general and resiliency criteria both. The decision-support module (s) adapted in this paper considers DMs' risk bearing attitude to arrive the best compromise solution.

Keywords Decision-support systems, Supplier evaluation

Paper type Research paper

1. Research background

In the recent uncertain and turbulent marketplace, supply chain (SC) vulnerability has become a critical issue for many companies (Christopher and Peck, 2004). As the numbers and types of threats that can undermine a SC are now greater, organizations are facing greater challenges in managing risks than ever (Sheffi, 2005). These risks including natural disasters, terrorism, cyber-attacks, credit crunch and many more

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could yield to a drastic loss in productivity, revenue, competitive advantage, profitability, etc., if not managed properly, and that is why a resilient SC is of vital concern (Mensah and Merkuryev, 2014). In order to reduce aforesaid risks, SCs must be designed to incorporate event readiness, provide an efficient and effective response, and be capable of recovering to their original state or even better post the disruptive event (Ponomarov and Holcomb, 2009). This is the motive of SC resiliency. Resilience is, therefore, related to both the individual and organizational responses to turbulence and discontinuities (Bhamra *et al.*, 2011).

From the organizational perspective resilience has been defined in terms of adjustment to capacities or abilities. Some of the definitions are as follows:

(1) the capacity to adjust and maintain desirable functions under challenging or straining conditions (Weick *et al.*, 1999; Bunderson and Sutcliffe, 2002; Edmondson, 1999);

(2) a dynamic capacity of organizational adaptability that grows and develops over time (Wildavsky, 1988); and

(3) the ability to bounce back from disruptive events or hardship (Sutcliffe and Vogus, 2003).

In SCM, effective supplier selection/evaluation is considered to be a key strategic consideration in relation to the industrial purchasing process (Patton, 1997; Michaels *et al.*, 1995). Thus many companies are focussing on their core business activities where they are able to expand a competitive advantage and contracting out their non-core activities to capitalize on others' expertise, resulting in a greater reliance on suppliers and producers to deliver the right quantities to the right places at the right times in recent years due to the volatile market situation (Haldar *et al.*, 2012). Therefore, planning for disruption scenarios is nowadays becoming a crucial task in the supplier selection process to keep pace with serving a globally competitive market scenario. Thus, proactive planning for these types of event should be a priority for SC managers (Haldar *et al.*, 2014). Effective supplier selection not only improves overall SC performance (in terms of profitability of the company) but also makes an industry/company to be highly competitive in the unpredictable and volatile adverse business environments. A SC should be efficient enough in surviving well against unwanted happenings (disruptions) and thus resilient supplier selection is of utmost important. Therefore, while selecting a resilient supplier, resiliency strategies must be considered with high priority along with general supplier selection criterions.

2. State of art and problem statement

Literature is remarkably rich in attempting various issues of supplier/vendor selection in different decision-making scenarios of industry perspectives. Most of the past research dealt with general supplier selection criterions in which quality, cost, reliability, etc. were solely considered as prime supplier evaluation indices. Suppliers' selection under resiliency strategy was attempted to a very limited extent.

Shyur and Shih (2006) proposed a hybrid model for supporting vendor selection process in new task situations. The model explored the technique of analytic network process (ANP) and modified technique for order performance by similarity to ideal solution (TOPSIS). Kumar *et al.* (2006) addressed vendor selection problem (VSP) as a "fuzzy multi-objective integer programming VSP" formulation that incorporated three important goals: cost-minimization, quality-maximization and maximization of on-time-delivery-with the realistic constraints such as meeting the buyers' demand, vendors' capacity, vendors' quota flexibility, etc. In the aforesaid model, various input parameters were treated as vague with a linear membership function of fuzzy type. The approach provided a strong decision tool that facilitated vendor selection and their quota allocation under different degrees of information vagueness in the decision parameters of a SC modeling. Chen *et al.* (2006) presented a fuzzy-TOPSIS-based decision-making approach to deal with the supplier selection problem in SC system. Amid *et al.* (2006) developed a fuzzy multi-objective linear model to overcome the vagueness of decision information in a fuzzy-based supplier selection problem. An asymmetric fuzzy-decision-making technique was applied to enable the decision maker (DM) to assign different weights to various criteria.

Gencer and Gurpinar (2007) used ANP in supplier selection problem. Liao and Rittscher (2007) developed a multi-objective supplier selection model under stochastic demand conditions. Stochastic supplier selection was determined with simultaneous consideration of the total cost, the quality rejection rate, the late delivery rate and the flexibility rate, involving constraints of demand satisfaction and capacity. Araz and Ozkarahan (2007) described a supplier evaluation and management methodology for strategic sourcing, in which suppliers were assessed considering supplier's co-design capabilities and categorized based on overall performances, potential reasons for differences in performance of supplier groups were identified and performances of the suppliers were improved by applying supplier development programs. A multi-criteria sorting method based on the PROMETHEE methodology was introduced to facilitate suppliers' selection decision making.

Sanayei *et al.* (2008) proposed an integrated approach of multi-attribute utility theory and linear programming (LP) towards rating and choosing the best suppliers and defining the optimum-order quantities among selected ones in order to maximize total additive utility. Özgen *et al.* (2008) developed a technique through integration of the analytic hierarchy process (AHP) and a multi-objective possibilistic linear programming to account for all tangible, intangible, quantitative and qualitative factors which needed to evaluate and select suppliers and to define the optimum-order quantities assigned to each. In order to model the uncertainties encountered in the integrated supplier evaluation and order allocation methodology, fuzzy theory was adopted. Demirtas and Ustun (2008) proposed an integrated approach of ANP and multi-objective mixed integer linear programming to consider both tangible and intangible factors in choosing the best suppliers and define the optimum quantities among selected suppliers to maximize the total value of purchasing and minimize the budget and defect rate. Ng (2008) proposed a weighted linear program for the multi-criteria supplier selection problem. The said model for multi-criteria supplier selection problem could be easily implemented with a spreadsheet package. The model could be widely applied to practical situations and did not require the user with any optimization background. Ha and Krishnan (2008) outlined a hybrid method, incorporating multiple techniques into an evaluation process, in order to select competitive suppliers in a SC. It enabled a purchaser to do single sourcing and multiple sourcing by calculating a combined supplier score, which accounted for both qualitative and quantitative factors that impact on SC performance. By performing a cluster analysis, it drew a supplier map so as to position suppliers within the qualitative and quantitative dimensions of performance efficiency, and to select a portfolio of suppliers from supplier segments, which were different in performance with regard to key factors. Chou and Chang (2008) presented a strategy-aligned fuzzy simple multi-attribute rating technique (SMART) approach for solving the supplier/VSP from the perspective of strategic management of the SC. The proposed system utilized OM/SC strategy to identify supplier selection criteria. A fuzzy SMART was applied to evaluate the alternative suppliers, and dealt with the ratings of both qualitative and quantitative criteria. The final DM incorporated the supply risks of individual suppliers into final decision making.

Razmi *et al.* (2009) developed a fuzzy ANP model to evaluate the potential suppliers and select the best one(s) with respect to the vendor important factors. The authors augmented the model with a non-LP model to elicit eigenvectors from fuzzy comparison matrices. Hybridization of these two concepts could model supplier selection problem in all circumstances and reached the optimal choice. Lee proposed an analytical approach to select suppliers under a fuzzy environment. A fuzzy analytic hierarchy process (FAHP) model, which incorporated the benefits, opportunities, costs and risks concept was constructed to evaluate various aspects of suppliers. Önüt *et al.* (2009) developed a supplier evaluation approach based on the ANP and the TOPSIS methods to help a telecommunication company in the GSM sector in Turkey under the fuzzy environment where the vagueness and subjectivity were handled with linguistic terms parameterized by triangular fuzzy numbers. Boran *et al.* (2009) proposed TOPSIS method combined with intuitionistic fuzzy set to select appropriate supplier in group decision-making environment. Intuitionistic fuzzy weighted averaging operator was utilized to aggregate individual opinions of DMs for rating the importance of criteria and alternatives.

Liao and Kao (2010) proposed an approach integrating Taguchi loss function, AHP and multi-choice goal programming (GP) model for solving the supplier selection problem. The advantage of this proposed method was that it allowed DMs to set multiple aspiration levels for the decision criteria. Sanayei *et al.* (2010) proposed a hierarchy multi-criteria decision making (MCDM) model based on fuzzy sets theory and VIKOR method to deal with the supplier selection problems in the SC system. Bhattacharya *et al.* (2010) proposed a concurrent engineering approach integrating AHP with quality function deployment (QFD) in combination with cost factor measure to rank and subsequently select candidate-suppliers under multiple, conflicting-in-nature criteria environment within a value-chain framework. Engineering requirements and customer requirements governing the selection decision were identified.

Amid *et al.* (2011) proposed a weighted max-min model for fuzzy multi-objective supplier selection in a SC. In another reporting, Amin *et al.* (2011) applied fuzzy strengths, weaknesses, opportunities and threats (SWOT) analysis and fuzzy LP in the context of supplier selection. Kilincci and Onal (2011) investigated a supplier selection problem of a washing machine company in Turkey and used a FAHP-based methodology towards selecting the best supplier firm providing the most customer satisfaction for the criteria determined.

Erdem and Gocen (2012) generated a decision-support system (DSS) for the improvement of supplier evaluation and order allocation decisions in a SC. Initially, an AHP model was developed for qualitative and quantitative evaluation of suppliers. Based on these evaluations, a GP model was developed for order allocation among suppliers. The models were integrated into a DSS that provided a dynamic, flexible and fast decision-making environment.

Aforesaid literature survey depicts a considerable amount of grasp to the extent body of past research carried out by pioneers on various aspects of supplier selection problems. Different DSS thus proposed by previous researchers have been well documented.

Apart from objective (quantitative) evaluation criterions; different supplier selection modules have also been proposed considering subjective (qualitative) evaluation indices. Incorporation of "green issues" into traditional supplier selection (green supplier selection) has also been highlighted. However, very little work has been reported so far in consideration with resilient supplier selection. The following section provides the brief reference of two reporting found in existing literature source on resilient supplier selection.

Haldar *et al.* (2012) incorporated an analytical framework for SC design to help the DMs to select a suitable supplier under a disruption scenario. The supplier's weights were initially determined using the TOPSIS and AHP methodology for general selection criteria. A cut-off value for the supplier weight was assigned and the suppliers which were above this cut-off value were selected for the primary selection process. Using AHP-QFD methodology the manufacturer's critical criteria and resiliency criteria were integrated into the selection process, to determine the subjective factor measures for each of the primary selected suppliers. Different cost factors were unified using a normalizing technique to determine the objective factor measure for each of the suppliers. Finally, a supplier selection index was calculated in which the DM's attitude played an important role. In another reporting, Haldar *et al.* (2014) developed a quantitative approach for strategic supplier selection under a fuzzy environment in a disaster scenario. This paper presented an integrated fuzzy group decision-making approach based on a fuzzy technique for order preference by similarity to the ideal solution integrated with the aggregate fuzzy weight method to rank the suppliers of a manufacturing system. Using this approach, organizations could devise resiliency plans to alleviate the vulnerability of a SC system.

In the present work, an efficient DSS has been adapted to facilitate evaluation and selection of resilient suppliers in fuzzy context. Apart from general strategies of suppliers (namely, product quality C_1, product reliability C_2, product functionality C_3, extent of customer satisfaction C_4 and product price C_5); resiliency strategies like investment in capacity buffers R_1, responsiveness R_2, capacity for holding strategic inventory stocks for crises R_3 have also been considered. Since most of the evaluation criterions are subjective in nature; which invites some kind of ambiguity and vagueness, the said DSS has to rely on DMs' subjective evaluation information expressed in linguistic terminologies. Linguistic expert data have been transformed into appropriate trapezoidal fuzzy numbers. Next, an improved fuzzy-VIKOR method has been adapted towards evaluating the ranking order of candidate suppliers based on general strategy only. In this computation, the ranking order has been derived in view of the "VIKOR INDEX, Q" (adapted from the theory of VIKOR method) of individual supplier alternatives. Moreover, based on the resiliency strategy, performance ranking order of alternative suppliers has been obtained in view of their "overall suitability index (OSI)". The final "supplier selection score (SSS)" has thus been obtained by utilizing supplier selection indices based on aforesaid two strategies i.e. general as well as resiliency strategies; thus, providing the ultimate choice to the best supplier. In computing "SSS", DMs' risk bearing attitude has been incorporated. Sensitivity analysis has been carried out to show how the variation of decision-making attitude influences the choice of the potential supplier. A case empirical illustration has also been provided here.

3. Methodology

The work explores a decision-support framework combining VIKOR method which has been extended (improved) to operate in fuzzy environment. The following sections deal with the traditional VIKOR-based MCDM approach and the improved VIKOR method towards exploring fuzzy-VIKOR in the said supplier selection problem. To start with fuzzy-VIKOR, the basic understanding on fuzzy preliminaries (fuzzy sets and fuzzy numbers, notations of fuzzy numbers, fuzzy operational rules and defuzzification formulae of fuzzy numbers) are indeed necessary. These could be found in Carlsson and Fuller (2000), Chen (2000), Chen and Hwang (1992), Li (2003), Zimmermann (1991), Bagis (2003), Carlsson and Fuller (2000), Cerrada (2005), Hu (2006), Medaglia *et al.* (2002), Simon (2005), Wang and Chuu (2004), Yang and Bose (2006), and Zimmermann and Zysno (1985).

3.1 The VIKOR method

Opricovic (1998) and Opricovic and Tzeng (2002) developed VIKOR, the Serbian name: *Vlse Kriterijumska Optimizacija I Kompromisno Resenje*, means multi-criteria optimization and compromise solution (Chu *et al.*, 2007). The VIKOR method was developed for multi-criteria optimization of complex systems (Opricovic and Tzeng, 2004). This method focusses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting criteria, which can help the DMs to reach a final decision. 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).

According to Opricovic and Tzeng (2004), the multi-criteria measure for compromise ranking is developed from the PL_p metric used as an aggregating function in a compromise programming method (Yu, 1973). The various J alternatives are denoted as $a_1, a_2, ..., a_J$. For alternative a_j, the rating of the ith aspect is denoted by f_{ij}, i.e. f_{ij} is the value of ith criterion function for the alternative a_j; n is the number of criteria. Development of the VIKOR method started with the following form of L_p-metric:

$$L_{p,j} = \left\{ \sum_{i=1}^{n} \left[w_i \left(f_i^* - f_{ij} \right) / \left(f_i^* - f_i^- \right) \right]^p \right\}^{\frac{1}{p}}, 1 \leqslant p \leqslant \infty; j = 1, 2, \ ..., \ J. \quad (1)$$

Within the VIKOR method $L_{1,j}$ (as S_j) and $L_{\infty,j}$ (as R_j) are used to formulate the ranking measure. The $L_{1,j}$ is interpreted as "concordance" and can provide DMs with information about the maximum group "utility" or "majority". Similarly, $L_{\infty,j}$ is interpreted as "discordance" and provides DMs with information about the minimum individual regret of the "opponent" (Sanayei *et al.*, 2010).

3.2 The fuzzy-VIKOR

A systematic approach to extend the VIKOR as proposed by Sanayei *et al.* (2009, 2010) has been explored here to solve the resilient supplier selection problem under a fuzzy environment. In this module the importance weights of various criteria and the ratings of criteria have also been considered as linguistic variables (assuming all criterions are subjective/qualitative in nature). Because linguistic assessments merely approximate the subjective judgment of DMs, it has been felt that linear trapezoidal membership functions could be adequate for capturing the vagueness of these linguistic assessments.

In fact, supplier selection in SC system is a group multiple criteria decision-making problem, which may be described by means of the following sets (Chen *et al.*, 2006):

(1) a set of K DMs called $E = \{D_1, D_2, D_3, \ldots, D_K\}$;

(2) a set of m possible suppliers called $A = \{A_1, A_2, A_3 \ldots, A_m\}$;

(3) a set of n criteria, $C = \{C_1, C_2, C_3, \ldots, C_n\}$, with which supplier performances are measured; and

(4) a set of performance ratings of A_i ($i = 1, 2, 3, \ldots, m$) with respect to criteria C_j ($j = 1, 2, 3, \ldots, n$), called $X = \{x_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\}$.

The main steps of the algorithms are:

Step 1: identify the objectives of the decision-making process and define the problem scope.

Decision making is the process of defining the decision goals, gathering relevant information and selecting the optimal alternative (Hess and Siciliano, 1996). Thus, the first step is defining the decision goal that here is to evaluate and select a favorable resilient supplier/s. Making precise statement of the problem will help to narrow it. Giving clear and careful thought to this first step is very vital to selecting process. The way in which the process is defined will deterministic the character of all the other steps.

Step 2: arrange the decision-making group and define and describe a finite set of relevant attributes.

In supplier evaluation and selection process a number of DMs (experts) from different functional areas within the company are involved. So with considering the problem scope defined in previous section and its entire dimension, a group of DMs must be formed.

Supplier selection first requires identification of decision attributes (criteria) then evaluation scales/metrics are determined in order to measure appositeness of supplier. These criteria must be defined according to the corporate strategies, company's competitive situation, the level of buyer-supplier integration (Ghodsypour and O'Brien, 1998) and type of product which be outsourced.

Step 3: identify the appropriate linguistic variables.

In this step, the appropriate linguistic variables for the importance weight of criteria, and the fuzzy rating for alternatives with regard to each criterion have been defined; these linguistic variables can be expressed in positive trapezoidal fuzzy numbers, as in Tables II-III. It is suggested that the DMs should use the linguistic variables shown in Tables II-III to evaluate the importance of the criteria and the ratings of alternatives with respect to qualitative criteria.

Step 4: pull the DMs' opinions to get the aggregated fuzzy weight (AFW) of criteria, and aggregated fuzzy rating of alternatives and construct a fuzzy decision matrix.

Let the fuzzy rating and importance weight of the kth DM be $\tilde{x}_{ijk} = \left(x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4}\right)$ and $\tilde{w}_{jk} = \left(w_{jk1}, w_{jk2}, w_{jk3}, w_{jk4}\right)$; $i = 1, 2, \ldots, m$; $j = 1, 2, \ldots, n$, respectively. Hence, the aggregated fuzzy ratings of $\left(\tilde{x}_{ij}\right)$ alternatives with respect to each criterion can be calculated as:

$$\tilde{x}_{ij} = \left(x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4}\right), \tag{2}$$

here:

$$x_{ij1} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk1}, x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk2}, x_{ij3} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk3}, x_{ij4} = \frac{1}{K}\cdot\sum_{k=1}^{K} x_{ijk4}$$

The AFWs $(\tilde{w}_j)$ of each criterion can be calculated as:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}) \tag{3}$$

$$w_{j1} = \frac{1}{K}\sum_{k=1}^{K} w_{jk1}, w_{j2} = \frac{1}{K}\sum_{k-1}^{K} w_{jk2},\ w_{j3} = \frac{1}{K}\sum_{k=1}^{K} w_{jk3},\ w_{j4} = \frac{1}{K}\sum_{k=1}^{K} w_{jk4}$$

A supplier selection problem can be concisely expressed in matrix format as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \vdots & \tilde{x}_{mn} \end{bmatrix}, \quad \tilde{W} = [\tilde{w}_1, \tilde{w}_2,\ ...,\ \tilde{w}_n],$$

where $\tilde{x}_{ij}$ the rating of alternative A_i with respect to C_j, $\tilde{w}_j$ the importance weight of the jth criterion holds, $\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$; $i = 1, 2,\ ...,\ m$; $j = 1, 2,\ ...,\ n$ are linguistic variables can be approximated by positive trapezoidal fuzzy numbers.

Step 5: defuzzifying the fuzzy decision matrix and fuzzy weight of each criterion into crisp values.

Also the crisp value of the fuzzy number $\tilde{A} = (a_1, a_2, a_3, a_4)$ based on center of area method can be expressed by following relation (Sanayei *et al.*, 2010):

$$\text{defuzz}(\widehat{A}) = \frac{\int x \cdot \mu(x)dx}{\int \mu(x)dx}$$

$$= \frac{\int_{a_1}^{a_2} (x - a_1/a_2 - a_1) \cdot xdx + \int_{a_2}^{a_3} xdx + \int_{a_3}^{a_4} (a_4 - x/a_4 - a_3) \cdot xdx}{\int_{a_1}^{a_2} (x - a_1/a_2 - a_1)dx + \int_{a_2}^{a_3} dx + \int_{a_3}^{a_4} (a_4 - x/a_4 - a_3)dx}$$

$$= \frac{-a_1a_2 + a_3a_4 + \frac{1}{3}(a_4 - a_3)^2 - \frac{1}{3}(a_2 - a_1)^2}{-a_1 - a_2 + a_3 + a_4}. \tag{4}$$

Step 6: determine the best f_j^* and the worst f_j^- values of all criterion ratings, $j = 1, 2, 3, ..., n$:

$$f_j^* = \max_i\ x_{ij}; \tag{5}$$

$$f_j^- = \min_i\ x_{ij}. \tag{6}$$

Step 7: compute the values S_i and R_i by the relations:

$$S_i = \sum_{j=1}^{n} w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right) \tag{7}$$

$$R_i = \max_j \; w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right) \quad (8)$$

Step 8: compute the values Q_i by the relations:

$$Q_i = v\left(\left(S_i - S^*\right)/\left(S^- - S^*\right)\right) + (1-v)\left(\left(R_i - R^*\right)/\left(R^- - R^*\right)\right) \quad (9)$$

here, $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \max_i R_i$, $R^- = \max_i R_i$ and ν is introduced as a weight for the strategy of maximum group utility, whereas 1−ν is the weight of the individual regret.

Step 9: rank the alternatives, sorting by the values S, R and Q in ascending order.

Step 10: propose as a compromise solution the alternative ($A^{(1)}$)which is the best ranked by the measure Q (minimum) if the following two conditions are satisfied.

C_1. Acceptable advantage:

$$Q(A^{(2)}) - Q(A^{(1)}) \geqslant DQ, \quad (10)$$

where, $A^{(2)}$ is the alternative with second position in the ranking list by Q; $DQ = 1/(J-1)$.

C_2. Acceptable stability in decision making.

The alternative $A^{(1)}$ must also be the best ranked by S or/and R. This compromise solution is stable within a decision-making process, which could be the strategy of maximum group utility (when $v > 0.5$ is needed), or "by consensus" $v \approx 0.5$, or "with veto" ($v < 0.5$). Here, v is the weight of decision-making strategy of maximum group utility.

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

(1) alternatives $A^{(1)}$and $A^{(2)}$ if only the condition C_2 is not satisfied.

(2) OR

(3) alternatives $A^{(1)}$, $A^{(2)}$, ... $A^{(M)}$ if the condition C_1 is not satisfied; $A^{(M)}$ is determined by the relation $Q(A^{(M)}) - Q(A^{(1)}) < DQ$ for maximum M (the positions of these alternatives are "in closeness").

4. Proposed decision-support framework

It has been assumed that a company wishes to develop a proactive resiliency strategy to rank potential suppliers as its commitment to the global marketplace. A finite number of candidate suppliers have been identified for this analysis. From different functional areas, five DMs (experts) participated towards evaluating the suppliers. The criteria set for supplier evaluation has been based upon general strategy as well as suppliers' resiliency strategy. Under general strategy the following criterions have been considered as the suppliers' evaluation indices: product quality, (C_1); reliability of the product, (C_2); functionality of the product, (C_3); extent of customer satisfaction, (C_4); product price, (C_5). Apart from general strategy, the following have been considered under resiliency strategy namely, investment in capacity buffers, (R_1) responsiveness, (R_2) capacity for holding strategic inventory stocks for crises, (R_3). Thus, the combined selection criterions for resilient supplier selection has been depicted in Table I; adapted from the work by Haldar *et al.* (2014). Table II represents the set of linguistic variables and corresponding fuzzy representative scale (0, 1) for assigning priority weights

Category	Evaluation index (C_i)	Definition
General strategy	Product quality, (C_1)	It is defined as a group of features and characteristics of a saleable good which determine its desirability and can be controlled by a manufacturer to meet certain basic requirements
	Reliability of the product, (C_2)	It is defined as an ability of product to consistently perform its intended or required function in limited period of time under prescribed operating condition
	Functionality of the product, (C_3)	It refers to the purpose for that product is designed to fulfill customer expectation
	Extent of customer satisfaction, (C_4)	It measures that how well the expectations of a customer concerning a product or service provided by your company have been met
	Product price, (C_5)	It refers to the sum of all costs associated with the production of a specific quantity of a good or service
Resiliency strategy	Investment in capacity buffers, (R_1)	It refers to ability of individual firm to investment the money for reserve the excess product as a safeguard against unforeseen shortages or demands
	Responsiveness, (R_2)	This is the willingness to respond to customer needs with the help of several medium i.e. answering their phone or e-mail requests quickly, by acknowledging them quickly
	Capacity for holding strategic inventory stocks for crises, (R_3)	It is defined as a capacity of firm to holding a large stock of essential materials and goods to withstand a long period of scarcity caused by a natural disaster, war or strike action

Source: Haldar *et al.* (2014)

Table I.
Resilient supplier selection criterions

Linguistic terms (for priority weights)	Generalized trapezoidal fuzzy numbers
Very Low (VL)	(0, 0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.3, 0.4, 0.5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)
Medium High (MH)	(0.5, 0.6, 0.7, 0.8)
High (H)	(0.7, 0.8, 0.8, 0.9)
Very High (VH)	(0.8, 0.9, 1, 1)

Table II.
Linguistic variables and corresponding fuzzy representative scale (0, 1) for assigning priority weights

against individual supplier selection criterions (under general as well as resiliency strategy both). The set of linguistic variables and corresponding fuzzy representative scale (0, 10) for assigning (appropriateness) ratings against individual supplier selection criterions (under general as well as resiliency strategy both) have been shown in Table III. The transformation of linguistic variable into fuzzy number is a logical approach to avoid inherent uncertainty, imprecision and incompleteness that arise due to subjective human (expert) judgment. Here each fuzzy number is represented by the trapezoidal membership function (generalized trapezoidal fuzzy numbers). The entire decision making-module has been made consisting of the following three steps.

Step 1: determination of "VIKOR INDEX, Q_i" of supplier alternatives under general strategy.

Step 2: determination of "OSI" of supplier alternatives under resiliency strategy.

Step 3: determination of final "SSS" followed by ranking of the supplier alternatives. In this step, suppliers are ranked individually on the basis of general strategy and resiliency strategy. Finally, these two choices are combined for final ranking of the suppliers.

5. Case empirical research

The procedural steps of the said decision-support module could be well understood through the following case empirical research. Table II exhibits a seven-member linguistic terms set (Very Low (VL); Low (L); Medium Low (ML); Medium (M); Medium High (MH); High (H) and Very High (VH)) by exploring which, DMs have been instructed to assign priority importance (weight) against individual supplier selection criterions. Similarly, DMs have been asked to use another seven-member linguistic terms set (Table III) (Very Poor (VP); Poor (P); Medium Poor (MP); Fair (F); Medium Good (MG); Good (G); Very Good (VG)) to provide ratings of different evaluation criterions for each alternative suppliers.

Step 1: in this step, the "VIKOR INDEX, Q_i" of individual supplier alternatives under general strategy have been computed by exploring improved fuzzy-VIKOR. The importance weights against individual evaluation indices (C_1, C_2, C_3, C_4 and C_5) as assigned by DMs have been furnished in Table IV, and corresponding AFWs of each criterion have also been computed based on Equation (3). Table V represents appropriateness ratings (expressed in linguistic terminology) against individual evaluation indices as assigned by DMs (for alternative S_1, S_2, S_3, S_4, S_5, respectively) and corresponding aggregated fuzzy ratings (AFR) (computed using Equation (2)). The decision matrix has thus been obtained and shown in Table VI. The normalized decision matrix has been formed using the formulae as provided in Li (2003, 2007) and furnished in Table VII.

Linguistic terms (for ratings)	Generalized trapezoidal fuzzy numbers
Very Poor (VP)	(0, 0, 0, 1)
Poor (P)	(0, 1, 2, 3)
Medium Poor (MP)	(2, 3, 4, 5)
Fair (F)	(4, 5, 5, 6)
Medium Good (MG)	(5, 6, 7, 8)
Good (G)	(7, 8, 9, 10)
Very Good (VG)	(9, 10, 10, 10)

Table III. Linguistic variables and corresponding fuzzy representative scale (0, 10) for assigning (appropriateness) ratings

Evaluation indices	Importance weight expressed in linguistic terms					
	DM1	DM2	DM3	DM4	DM5	AFW
C_1	H	H	M	H	H	(0.640,0.740,0.740,0.840)
C_2	VH	VH	VH	H	H	(0.760,0.860,0.920,0.960)
C_3	H	H	MH	H	MH	(0.620,0.720,0.760,0.860)
C_4	M	VH	H	H	H	(0.660,0.760,0.780,0.860)
C_5	VH	H	VH	H	H	(0.740,0.840,0.880,0.940)

Table IV. Importance weights against individual evaluation indices as assigned by DMs and corresponding aggregated fuzzy weights (AFW) of each criterion

Evaluation indices	Appropriateness rating against individual 2nd-level evaluation indices DM1	DM2	DM3	DM4	DM5	AFR
For alternative S_1						
C_1	MG	F	G	MG	VG	(6.000,7.000,7.600,8.400)
C_2	F	G	MG	F	G	(5.400,6.400,7.000,8.000)
C_3	F	G	G	G	F	(5.800,6.800,7.400,8.400)
C_4	F	G	G	G	G	(6.400,7.400,8.200,9.200)
C_5	G	MG	F	VG	MG	(6.000,7.000,7.600,8.400)
For alternative S_2						
C_1	VG	VG	G	G	G	(7.800,8.800,9.400,10.00)
C_2	MG	VG	G	F	G	(6.400,7.400,8.000,8.800)
C_3	G	VG	MG	VG	VG	(7.800,8.800,9.200,9.600)
C_4	MG	G	MG	G	VG	(6.600,7.600,8.400,9.200)
C_5	F	VG	F	MP	VG	(5.600,6.600,6.800,7.400)
For alternative S_3						
C_1	G	MG	MG	MG	G	(5.800,6.800,7.800,8.800)
C_2	VG	MG	MG	MG	MG	(5.800,6.800,7.600,8.400)
C_3	G	MP	MG	MP	G	(4.600,5.600,6.600,7.600)
C_4	VG	G	MG	VG	VG	(7.800,8.800,9.200,9.600)
C_5	F	G	G	MP	MP	(4.400,5.400,6.200,7.200)
For alternative S_4						
C_1	G	MP	F	F	MP	(3.800,4.800,5.400,6.400)
C_2	G	G	VG	G	VG	(7.800,8.800,9.400,10.00)
C_3	VG	VG	VG	G	G	(8.200,9.200,9.600,10.00)
C_4	VG	G	VG	VG	VG	(8.600,9.600,9.800,10.00)
C_5	VG	MG	G	G	G	(7.000,8.000,8.800,9.600)
For alternative S_5						
C_1	G	G	VG	VG	G	(7.800,8.800,9.400,10.00)
C_2	MG	VG	MG	VG	MG	(6.600,7.600,8.200,8.800)
C_3	MG	VG	MG	G	VG	(7.000,8.000,8.600,9.200)
C_4	G	G	F	MG	MG	(5.600,6.600,7.400,8.400)
C_5	G	G	MG	VG	MG	(6.600,7.600,8.400,9.200)

Table V. Appropriateness rating against individual evaluation indices as assigned by DMs and corresponding aggregated fuzzy ratings (AFR)

From Table VII, the crisp values for the decision matrix and weight of each criterion (under general strategy) have been computed (using Equation (4)) as shown in Table VIII. The best and the worst values of all criterion ratings have been determined as follows:

$$f_1^* = 0.898,\ f_2^* = 0.898, f_3^* = 0.922, f_4^* = 0.945, f_5^* = 0.536$$

$$f_1^- = 0.510,\ f_2^- = 0.670, f_3^- = 0.610, f_4^- = 0.700, f_5^- = 0.788$$

The values of S, R and Q have been computed for all suppliers and shown in Table IX. The ranking order of candidate suppliers by S, R and Q in decreasing order has been shown in Table X.

Step 2: in this step, the "OSI" of individual supplier alternatives under resiliency strategy has been determined. A disrupted SC network requires dynamic evaluation of strategic planning. Three strategic planning criterions have been considered in developing resiliency in the SC system namely, R_1, R_2 and R_3 as shown in Table I. The priority weight (expressed in linguistic terms) of each of the three resiliency criteria given by the individual DMs have been tabulated in Table XI. Table XI also represents the AFW_{Ri} of the resiliency criteria (R_1, R_2 and R_3) computed using Equation (3). Now, each DM rates each alternative with respect to each criterion and the data have been tabulated (Tables XII-XVI). Due to the fact that the expert judgments partially depend on personal preference, the DMs' recommendations have been expressed through linguistic terminologies which have further been transformed into appropriate generalized trapezoidal fuzzy numbers. By applying Equation (2), the weighted

2nd-level indices	Aggregated fuzzy rating (AFR) against individual evaluation indices for alternative suppliers S_1	S_2	S_3	S_4	S_5
C_1	(6.000,7.000,7.600,8.400)	(7.800,8.800,9.400,10.00)	(5.800,6.800,7.800,8.800)	(3.800,4.800,5.400,6.400)	(7.800,8.800,9.400,10.00)
C_2	(5.400,6.400,7.000,8.000)	(6.400,7.400,8.000,8.800)	(5.800,6.800,7.600,8.400)	(7.800,8.800,9.400,10.00)	(6.600,7.600,8.200,8.800)
C_3	(5.800,6.800,7.400,8.400)	(7.800,8.800,9.200,9.600)	(4.600,5.600,6.600,7.600)	(8.200,9.200,9.600,10.00)	(7.000,8.000,8.600,9.200)
C_4	(6.400,7.400,8.200,9.200)	(6.600,7.600,8.400,9.200)	(7.800,8.800,9.200,9.600)	(8.600,9.600,9.800,10.00)	(5.600,6.600,7.400,8.400)
C_5	(6.000,7.000,7.600,8.400)	(5.600,6.600,6.800,7.400)	(4.400,5.400,6.200,7.200)	(7.000,8.000,8.800,9.600)	(6.600,7.600,8.400,9.200)

Table VI. The decision matrix

2nd-level indices	Normalized fuzzy rating (NFR) against individual evaluation indices for alternative suppliers S_1	S_2	S_3	S_4	S_5
C_1	(0.600,0.700,0.760,0.840)	(0.780,0.880,0.940,1.000)	(0.580,0.680,0.780,0.880)	(0.380,0.480,0.540,0.640)	(0.780,0.880,0.940,1.000)
C_2	(0.540,0.640,0.700,0.800)	(0.640,0.740,0.800,0.880)	(0.580,0.680,0.760,0.840)	(0.780,0.880,0.940,1.000)	(0.660,0.760,0.820,0.880)
C_3	(0.580,0.680,0.740,0.840)	(0.780,0.880,0.920,0.960)	(0.460,0.560,0.660,0.760)	(0.820,0.920,0.960,1.000)	(0.700,0.800,0.860,0.920)
C_4	(0.640,0.740,0.820,0.920)	(0.660,0.760,0.840,0.920)	(0.780,0.880,0.920,0.960)	(0.860,0.960,0.980,1.000)	(0.560,0.660,0.740,0.840)
C_5	(0.524,0.579,0.629,0.733)	(0.595,0.647,0.667,0.786)	(0.611,0.710,0.815,1.000)	(0.458,0.500,0.550,0.629)	(0.478,0.524,0.579,0.667)

Table VII. The normalized decision matrix

	Criteria C_1	C_2	C_3	C_4	C_5
Weight	0.740	0.872	0.740	0.764	0.848
S_1	0.724	0.670	0.710	0.780	0.619
S_2	0.898	0.764	0.882	0.794	0.678
S_3	0.730	0.714	0.610	0.882	0.788
S_4	0.510	0.898	0.922	0.945	0.536
S_5	0.898	0.778	0.818	0.700	0.564

Table VIII. Crisp values for decision matrix and weight of each criterion (under general strategy)

	Suppliers S_1	S_2	S_3	S_4	S_5
S	2.500	1.556	2.809	0.740	1.562
R	0.872	0.478	0.848	0.740	0.764
Q	0.92	0.19	0.97	0.33	0.56

Table IX. The values of S, R and Q for all suppliers aggregated fuzzy rating ($WAFR_{DMi}$) (for individual DMs) against each of the alternatives have been determined and shown in Tables XII-XVI, respectively. WAFRs of alternative suppliers by each of the five DMs for the three resiliency criteria have been tabulated in Table XVII. Now, the OSI_{Ri} of each of the alternatives has been determined and shown in Table XVII.

Using the equation given by Sanayei *et al.* (2010), $E = \left(-a_1a_2 + a_3a_4 + (1/3)(a_4 - a_3)^2 - (1/3)(a_2 - a_1)^2\right)/(-a_1 - a_2 + a_3 + a_4)$, the OSI has been determined from the defuzzified value concept of the trapezoidal fuzzy number (a_1, a_2, a_3, a_4).

Now values of VIKOR INDEX (Q_i) of the alternatives for general strategy and OSI_{Ri} for resiliency strategy have been normalized (Q_{Ni}, and OSI_{NRi}, respectively) to get the ranking order of supplier alternatives based on aforementioned two strategies (Table XVIII).

Table X. The ranking of the suppliers by S, R and Q in decreasing order

	Ranking order of candidate suppliers (under general strategy)				
	1	2	3	4	5
By S	S_4	S_2	S_5	S_1	S_3
By R	S_2	S_4	S_5	S_3	S_1
By Q	S_2	S_4	S_5	S_1	S_3

Table XI. The initial DM weight and aggregated weight of criteria under the resiliency strategy

Evaluation indices	Importance weight expressed in linguistic terms					
	DM1	DM2	DM3	DM4	DM5	AFW_{Ri}
R_1	VH	MH	H	H	H	(0.680,0.780,0.820,0.900)
R_2	VH	H	M	M	M	(0.540,0.640,0.660,0.740)
R_3	H	H	H	VH	VH	(0.740,0.840,0.880,0.940)

Table XII. Weighted-aggregated rating of alternatives by DM1 for resiliency criteria

Decision-maker DM1				
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	$WAFR_{DM1}$
S_1	MG	MG	VG	(4.253,5.640,6.387,7.507)
S_2	G	G	VG	(5.067,6.587,7.373,8.600)
S_3	MG	MG	MG	(3.267,4.520,5.507,6.880)
S_4	MP	G	G	(3.440,4.727,5.713,7.100)
S_5	VG	G	VG	(5.520,7.107,7.647,8.600)

Table XIII. Weighted-aggregated rating of alternatives by DM2 for resiliency criteria

Decision-maker DM2				
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	$WAFR_{DM2}$
S_1	VG	MG	VG	(5.160,6.680,7.207,8.107)
S_2	G	VG	G	(4.933,6.453,7.300,8.600)
S_3	F	VG	MG	(3.760,5.113,5.620,6.773)
S_4	MP	MG	VG	(3.573,4.860,5.567,6.607)
S_5	G	MG	G	(4.213,5.600,6.640,8.107)

6. Sensitivity analysis

Sensitivity analysis makes the supplier selection process more robust. A trade-off between general selection criteria and resiliency criteria have been done using "sensitivity analysis", where, a "SSS" has been measured for each of the candidate suppliers. Here, the SSS has been computed using the method proposed by Ray *et al.* (2010). Figure 1 shows optimal region for both the suppliers:

$$(\mathrm{SSS})_i = \left[\alpha \times \mathrm{CR}_{N_i} + (1-\alpha)\mathrm{OSI}_{NR_i}\right] \tag{11}$$

In this computation, the Q_{Ni} values are the normalized Q_i (obtained from fuzzy-VIKOR analysis considering general strategy) and the OSI_{NRi} values are the normalized OSI for each supplier alternative and they are integrated into the supplier selection process to determine the SSS. Here, the choice of α is an important issue. The sensitivity plot has been exhibited in Figure 1. For any value of $0 \leqslant \alpha \leqslant 1$, S_2 is the best option. If we consider alternative suppliers except S_2, when $0 \leqslant \alpha < 0.2$, S_5 is the best; when $0.2 < \alpha \leqslant 1$, S_4 is the best.

Application potential of aforesaid fuzzy-VIKOR has been compared to that of fuzzy-TOPSIS (Chen and Hwang, 1992; Hwang and Yoon, 1981; Lai and Hwang, 1994;

	Decision-maker DM3			
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	$\mathrm{WAFR}_{\mathrm{DM3}}$
S_1	MG	MG	G	(3.760,5.080,6.093,7.507)
S_2	MG	G	MG	(3.627,4.947,5.947,7.373)
S_3	MP	VG	MG	(3.307,4.593,5.347,6.473)
S_4	G	G	G	(4.573,6.027,7.080,8.600)
S_5	G	MG	VG	(4.707,6.160,6.933,8.107)

Table XIV. Weighted-aggregated rating of alternatives by DM3 for resiliency criteria

	Decision-maker DM4			
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	$\mathrm{WAFR}_{\mathrm{DM4}}$
S_1	MG	MG	F	(3.020,4.240,4.920,6.253)
S_2	MG	G	VG	(4.613,6.067,6.827,8.000)
S_3	F	MG	MP	(2.300,3.420,4.080,5.340)
S_4	G	G	VG	(5.067,6.587,7.373,8.600)
S_5	MG	F	VG	(4.073,5.427,5.947,7.013)

Table XV. Weighted-aggregated rating of alternatives by DM4 for resiliency criteria

	Decision-maker DM5			
Criteria	R_1	R_2	R_3	
Criteria weight	(0.680,0.780,0.820,0.900)	(0.540,0.640,0.660,0.740)	(0.740,0.840,0.880,0.940)	$\mathrm{WAFR}_{\mathrm{DM5}}$
S_1	G	MG	F	(3.473,4.760,5.467,6.853)
S_2	G	G	VG	(5.067,6.587,7.373,8.600)
S_3	F	G	MP	(2.660,3.847,4.520,5.833)
S_4	F	G	MG	(3.400,4.687,5.400,6.773)
S_5	MG	F	VG	(4.073,5.427,5.947,7.013)

Table XVI. Weighted-aggregated rating of alternatives by DM5 for resiliency criteria

Table XVII. Aggregated overall suitability index (OSI_{Ri}) of the alternatives for the resiliency strategy

Criteria	Decision makers					Overall aggregated fuzzy rating (AFR_O)	Overall suitability index (OSI_{Ri})
	$WAFR_{DM1}$	$WAFR_{DM2}$	$WAFR_{DM3}$	$WAFR_{DM4}$	$WAFR_{DM5}$		
S_1	(4.253,5.640,6.387,7.507)	(5.160,6.680,7.207,8.107)	(3.760,5.080,6.093,7.507)	(3.020,4.240,4.920,6.253)	(3.473,4.760,5.467,6.853)	(3.933,5.280,6.015,7.245)	5.612
S_2	(5.067,6.587,7.373,8.600)	(4.933,6.453,7.300,8.600)	(3.627,4.947,5.947,7.373)	(4.613,6.067,6.827,8.000)	(5.067,6.587,7.373,8.600)	(4.661,6.128,6.964,8.235)	6.487
S_3	(3.267,4.520,5.507,6.880)	(3.760,5.113,5.620,6.773)	(3.307,4.593,5.347,6.473)	(2.300,3.420,4.080,5.340)	(2.660,3.847,4.520,5.833)	(3.059,4.299,5.015,6.260)	4.658
S_4	(3.440,4.727,5.713,7.100)	(3.573,4.860,5.567,6.607)	(4.573,6.027,7.080,8.600)	(5.067,6.587,7.373,8.600)	(3.400,4.687,5.400,6.773)	(4.011,5.377,6.227,7.536)	5.785
S_5	(5.520,7.107,7.647,8.600)	(4.213,5.600,6.640,8.107)	(4.707,6.160,6.933,8.107)	(4.073,5.427,5.947,7.013)	(4.073,5.427,5.947,7.013)	(4.517,5.944,6.623,7.7680	6.198

Li, 2003, 2007; Haldar *et al.*, 2014) on the same supplier selection problem. Results have been depicted in Table XIX and Figure 2. By comparing results of fuzzy-TOPSIS and fuzzy-VIKOR, the best alternative is S_2. It has been observed that aforesaid two approaches providing compatible results. However, slight difference that has been noticed (on ranking order of alternative suppliers based on general strategy only) is due the working principle of TOPSIS in contrast to VIKOR. TOPSIS is based on aggregating function representing "closeness to ideal". In TOPSIS the chosen alternative should have the "shortest distance" from the ideal solution and the "farthest distance" from the "negative-ideal". The TOPSIS method introduces two reference points, but it does not consider the relative importance of the distances from these points (Chu *et al.*, 2007).

Suppliers	Q_i (lower-is-better)	Q_{Ni}	Ranking order (based on general strategy) fuzzy-VIKOR	OSI_{Ri} (higher-is-better)	OSI_{NRi}	Ranking order (based on resiliency strategy
S_1	0.92	0.207	4	5.612	0.865	4
S_2	0.19	1.000	1	6.487	1.000	1
S_3	0.97	0.196	5	4.658	0.718	5
S_4	0.33	0.576	2	5.785	0.892	3
S_5	0.56	0.339	3	6.198	0.955	2

Note: Combining selections based on general strategy as well as resiliency strategy

Table XVIII. Supplier selection score (SSS_i)

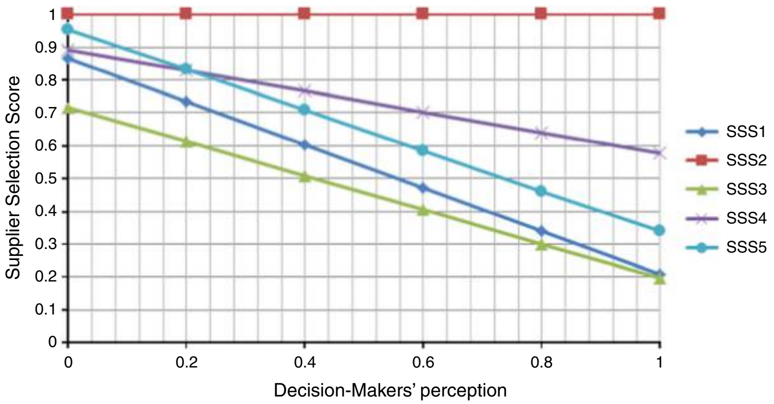

Figure 1. Sensitivity analysis plot (fuzzy-VIKOR)

Suppliers	CR_i (higher-is-better)	CR_{Ni}	Ranking order (based on general strategy) fuzzy TOPSIS	OSI_{Ri} (higher-is-better)	OSI_{NRi}	Ranking order (based on resiliency strategy
S_1	0.379	0.512	4	5.612	0.865	4
S_2	0.657	0.889	2	6.487	1.000	1
S_3	0.312	0.422	5	4.658	0.718	5
S_4	0.740	1.000	1	5.785	0.892	3
S_5	0.640	0.865	3	6.198	0.955	2

Note: Combining selections based on general strategy as well as resiliency strategy

Table XIX. Supplier selection score (SSS_i)

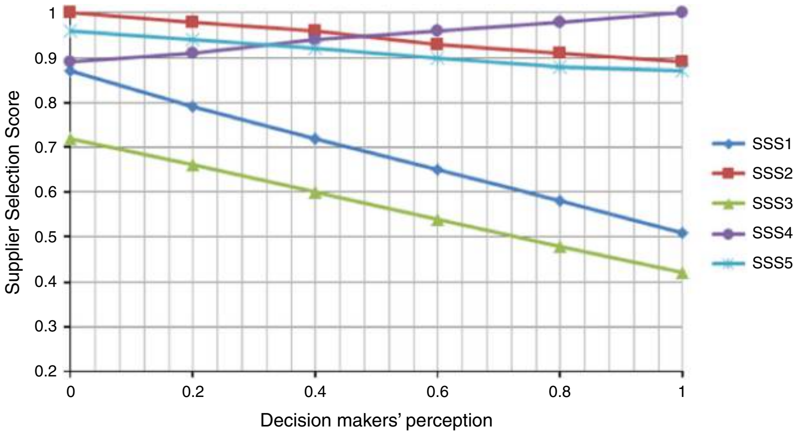

Figure 2.
Sensitivity analysis plot (fuzzy-TOPSIS)

7. Managerial implication

SC network is expected to deliver the right products (or services) on right time, with the required specifications, at the right place and to the right customer. Nowadays, SCs are facing numerous business challenges due to market globalization; and as a consequence, SCs are becoming much more complicated due to adaptation of modern business philosophies like lean, agile as well as leagile in order to survive successfully in the highly competitive and turbulent marketplace. The implementation of aforesaid philosophies or practices in turn brings enhanced level of risks, since SCs have become more vulnerable to disturbances (Christopher and Towill, 2000; Norrman *et al.*, 2004; Tang, 2006). Once an SC is affected by a disturbance, its performance is jeopardized, e.g., short-term financial performance is reduced, losing competitiveness (Ji and Zhu, 2008). In order to survive, organizations and their SCs must be resilient; they must develop the ability to react to an unforeseen disturbance and to return quickly to their original stable state or move to a new, more advantageous one after suffering the said disturbances (Carvalho and Cruz Machado, 2007; Ji and Zhu, 2008; Peck, 2005). To help organizations become more resilient and, eventually, less vulnerable to disturbances, adequate design strategies reflecting contingency and mitigation policies must be defined (Machado *et al.*, 2009). It is widely known that the overall performance of a SC is influenced by effective supplier selection. Therefore, to avail competitive advantage not only in stability but also to survive against unwanted disruptions; resilient supplier selection is of immense importance. To this end, forgoing work attempts to focus on a decision-making procedural hierarchy towards effective supplier selection in a resilient SC. The work exhibits application potential of VIKOR method integrated with fuzzy set theory to select potential supplier based on general strategy as well as resiliency strategy. The final SSS (obtained by considering general strategy) and that of obtained by analyzing resiliency strategy have been combined to get a final compromise solution. The decision-support framework thus reported here also considers DMs' risk bearing attitude. The study bears significant impact to the industry managers who are trying to adapt resiliency strategy in their SC followed by potential supplier selection in the context of resilient SC.

8. Conclusion

The contribution of the present work has been summarized below:

(1) development of an efficient decision-support framework towards resilient supplier selection by considering general as well as resiliency strategy both;

(2) exploration of fuzzy set theory in order to tackle ambiguity and vagueness associated with DMs' linguistic evaluation information (expert judgment);

(3) application feasibility of fuzzy-VIKOR has been tested and compared with fuzzy-TOPSIS for supplier selection under general strategy;

(4) aggregation of SSS obtained by considering general strategy and resiliency strategy, respectively, to compute a unique supplier selection index (supplier suitability index) to determine the most favorable supplier alternative;

(5) consideration of decision-making attitude (risk bearing attitude) of DMs in evaluating the final ranking score; and

(6) sensitivity analysis reflects how variation of decision-making attitude influences selection of supplier alternatives.

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Corresponding author
Saurav Datta can be contacted at: sdatta@nitrkl.ac.in