Benchmarking: An International Journal

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Received 14 March 2014
Revised 14 June 2014
Accepted 23 June 2014

Abstract

Purpose – The concept of agile supply chain (ASC) has become increasingly important as means of achieving a competitive edge in turbulent business environments. An ASC is a dynamic alliance of member enterprises, the adaptation of which is likely to introduce velocity, responsiveness and flexibility into the manufacturing system. In ASC management, supplier/partner selection is a key strategic concern; influenced by various agility-related criteria/attributes. Therefore, evaluation and selection of potential supplier in an ASC has become an important multi-criteria decision-making problem. The purpose of this paper is to report, a supplier selection procedure (module) in the context of ASC.

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

Findings – A case empirical example has been provided. It has been proved that the methodology would be fruitful in considering different evaluation criterion (indices); may be contradicting in nature like beneficial and cost criterions. The application of vague set theory has also been proved as a better option to work under uncertain (fuzzy) decision-making environment in comparison to fuzzy set theory.

Originality/value – The application of vague set theory in multi-criteria group decision making has been reported in literature to a limited extent. Application of vague set as a decision-making tool in agile supplier selection appears relative new and unexplored work area. The work has got remarkable managerial implications.

Keywords Operations management, Agility, Supplier evaluation, Agile supply chain (ASC), Decision support systems, Agile production, Supplier/partner selection, Vague set theory

Paper type Research paper

1. Introduction and prior state of art

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

Authors gratefully acknowledge the support rendered by Professor A. Gunasekaran, Editor-In-Chief, *Benchmarking, An International Journal*. Special thanks to the anonymous reviewers for their valuable constructive comments and suggestions to prepare the paper a good contributor.

Benchmarking: An International Journal
Vol. 23 No. 4, 2016
pp. 866-892

1463-5771
DOI 10.1108/BIJ-03-2014-0020

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

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

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

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

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

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

Shen and Yu (2009) considered the strategic and operational factors simultaneously to secure the efficacy of supplier selection (VS) on initial stage of new product development. Wang and Yang (2009) introduced AHP and fuzzy compromise programming to obtain a reasonable compromise solution for allocating order quantities among suppliers with their quantity discount rate offered. Boran *et al.* (2009) proposed application of TOPSIS method combined with intuitionistic fuzzy set to select appropriate supplier in group decision-making environment. Ebrahim *et al.* (2009) proposed the scatter search algorithm for supplier selection and order lot sizing under multiple price discount environment.

Sanayei *et al.* (2010) reported a research on group decision-making process for supplier selection with VIKOR under fuzzy environment. Chamodrakas *et al.* (2010) suggested an approach for decision support system enabling effective supplier selection processes in electronic marketplaces. The authors introduced an evaluation method with two stages: initial screening of the suppliers through the enforcement of hard constraints on the selection criteria and final supplier evaluation through the application of a modified variant of the Fuzzy Preference Programming method. Keskin *et al.* (2010) applied Fuzzy Adaptive Resonance Theory's classification ability to the supplier evaluation and selection area. Liao and Kao (2010) integrated the Taguchi loss function, AHP and multi-choice goal programming (MCGP) model for solving the supplier selection problem. Awasthi *et al.* (2010) presented a fuzzy multi-criteria approach for evaluating environmental performance of suppliers. Büyüközkan and Çifçi (2011) examined the problem of identifying an effective model based on sustainability principles for supplier selection operations in SCs. The paper developed an approach based on fuzzy ANP within multi-person decision-making schema under incomplete preference relations. Yucel and Guneri (2011) investigated on supplier section problem by using a weighted additive fuzzy programming approach. Dalalah *et al.* (2011) presented a hybrid fuzzy model for group MCDM in relation to supplier selection. A modified fuzzy DEMATEL model was presented to deal with the influential relationship between the evaluations criteria. Liao and Kao (2011) proposed integrated fuzzy TOPSIS and MCGP approach to solve the supplier selection problem.

Ertay *et al.* (2011) proposed a methodology, which was capable of evaluating and monitoring suppliers' performance, was constructed, using FAHP to weight the established decision criteria and ELECTRE III to evaluate, rank and classify performance of suppliers regarding relative criteria. The proposed methodology was applied to a real-life supplier-selection and classification problem of a pharmaceutical company.

Zouggari and Benyoucef (2012) presented an efficient decision-making approach for group multi-criteria supplier selection problem, which clubbed supplier selection process with order allocation for dynamic SCs to cope market variations. Fuzzy-AHP method was used first for supplier selection through four classes (CLASS I: performance strategy, CLASS II: quality of service, CLASS III: innovation and CLASS IV: risk), which were qualitatively meaningful. Thereafter, using simulation-based fuzzy TOPSIS technique, the criteria application was quantitatively evaluated for order allocation among the selected suppliers. Büyüközkan (2012) proposed a decision model for supplier performance evaluation by considering various environmental performance criteria. An integrated, fuzzy group decision-making approach was adopted to evaluate green supplier alternatives. More precisely, a FAHP was applied to determine the relative weights of the evaluation criteria and an axiomatic design-based fuzzy group decision-making approach was applied to rank the green suppliers. Pitchipoo *et al.* (2012) developed an appropriate hybrid model by integrating the AHP and grey relational analysis (GRA) for supplier evaluation and selection, which comprises three stages. In Stage I, the most influential criteria were selected by mutual-information-based feature selection. Stage II focussed on the determination of the weights of the attributes using AHP, while Stage III was used for the determination of the best supplier using GRA.

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

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

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

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

Supplier/partner selection is, therefore, considered as a fundamental issue in SCM as it contributes significantly to overall SC performance. However, such decision making is problematic due to the need to consider both tangible and intangible factors, which cause vagueness, ambiguity and complexity (Yucel and Guneri, 2011; Wu and Barnes, 2011, 2013). At the same time, the vagueness of the information in this type of problem makes decision making more complicated (Amid *et al.*, 2006; Yang, 2010). Consequently, many researchers have realized the application potential of fuzzy set theory (FST) as offering an efficient means of handling this uncertainty effectively and of converting human judgments into meaningful results (Wu and Barnes, 2013; Yang, 2010; Yucel and Guneri, 2011; Zadeh, 1965; Amid *et al.*, 2006). As an example, Wu and Barnes (2013) proposed a fuzzy intelligent approach for partner selection in ASCs by using FST in combination with RBF-ANN. The work included an empirical application of the model with data from 84 representative companies within the Chinese electrical components and equipment industry, to demonstrate its suitability for helping organizational decision makers (DMs) in partner selection.

Agility in SCs is the capability to effectively and efficiently respond to the dynamic as well as turbulent market expectations. An ASC needs to be highly flexible and to be able to be reconfigured quickly in response to changes in the volatile business environment. The successful operation of an ASC largely depends upon the firm's ability to select the most appropriate potential partners/suppliers in any given situation (Wu and Barnes, 2010, 2013; Christopher, 2000).

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

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

2. Vague set theory

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

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

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

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

$$A = \sum_{i=l}^{n} [t_A(u_i), 1-f_A(u_i)]/u_i \quad (u \in U) \tag{2}$$

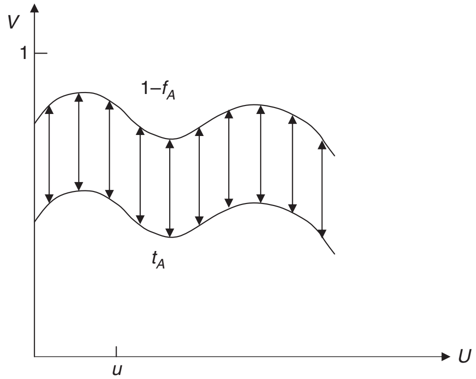

Figure 1.
Vague set

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

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

$$\begin{aligned} x \wedge y &= \left[\min\left(t_x, t_y\right),\ \min\left(1-f_x,\ 1-f_y\right)\right] \\ &= \left[\min\left(t_x, t_y\right),\ 1-\max\left(f_x,\ f_y\right)\right] \end{aligned} \tag{3}$$

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

$$\begin{aligned} x \vee y &= \left[\max\left(t_x, t_y\right),\ \max\left(1-f_x,\ 1-f_y\right)\right] \\ &= \left[\min\left(t_x, t_y\right),\ 1-\max\left(f_x,\ f_y\right)\right] \end{aligned} \tag{4}$$

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

$$\overline{x} = [f_{\mathrm{x}},\ 1-t_x] \tag{5}$$

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

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

$$A \cap B = \sum_{i=1}^{n} \left\{[t_A(u_i),\ 1-f_A(u_i)] \wedge [t_B(u_i),\ 1-f_B(u_i)]\right\}/u_i \tag{6}$$

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

$$A \cup B = \sum_{i=1}^{n} \left\{[t_A(u_i),\ 1-f_A(u_i)] \vee [t_B(u_i),\ 1-f_B(u_i)]\right\}/u_i \tag{7}$$

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

$$\overline{A} = \sum_{i=1}^{n} [f_A(u_i), \quad 1-t_A(u_i)]/u_i \tag{8}$$

2.2 Similarity measure between vague sets

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

$$S(x, y) = 1-\frac{d(x, y)}{\sqrt{2}} \tag{9}$$

here:

$$d(x, y) = \sqrt{(t_x-t_y)^2 + (1-f_x-(1-f_y))^2} = \sqrt{(t_x-t_y)^2 + (f_x-f_y)^2} \tag{10}$$

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

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

$$S(A,B) = \frac{1}{n}\sum_{i=1}^{n} S(\mu_A(u_i), \mu_B(u_i)) \tag{11}$$

2.3 Comparison between vague sets

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

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

$$P(x \geqslant y) = \frac{\text{Max}(0,\ L(x)+L(y)-\text{Max}(0,\ 1-f_x-t_x))}{L(x)+L(y)}, \tag{12}$$

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

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

Property 1. $0 \leqslant P(x \geqslant y) \leqslant 1$.

Property 2. If $P(x \geqslant y)=P(y \geqslant x)$, then $P(x \geqslant y)=P(y \geqslant x)=0.5$.

Property 3. $P(x \geqslant y)+P(y \geqslant x)=1$.

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

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

$$P(A \geqslant B) = \frac{1}{n} \sum_{i=1}^{n} P\left(\mu_A(u_i) \geqslant \mu_B(u_i)\right) \tag{13}$$

2.4 Defuzzification of vague value and weighted sum of vague values

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

$$\text{Dfzz}(x) = t_x/(t_x + f_x). \tag{14}$$

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

$$\bar{x} = \sum_{i=1}^{n} w_i \times x_i = \left[\sum_{i=1}^{n} w_i \times t_i, \ 1 - \sum_{i=1}^{n} w_i \times f_i\right], \tag{15}$$

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

3. Agile supplier selection module: exploration of vague set theory

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

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

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

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

For every DMs in the decision-making group, we can get a vector of attribute weights and a preference matrix of supplier alternatives. Namely,

$W^k = \{W_1^k, W_2^k, \ldots, W_n^k\}$ $(k=1,\ldots,K)$ is the vector of attribute weights given by kth DM, where, $W_j^k = (t_{W_j^k}, 1-f_{W_j^k})$ $(j=1,\ldots,n)$ is a vague variable. The preference matrix given by kth DM is written as:

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

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

Step 3: calculate weighted decision matrix of kth DM.

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

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

where:

$$M_{ij}^k = W_j^k \wedge R_{ij}^k \quad (i=1, \ldots, m; j=1, \ldots, n). \tag{16}$$

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

Step 4: adjust the importance degree of DMs according to the preference accordance in the decision group.

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

$$S_{pq} = S(M^p, M^q) = \frac{1}{m}\sum_{i=1}^{m} S(M_i^p, M_i^q). \tag{17}$$

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

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

Obviously, S is found to be a symmetric matrix. Using the line sum of S get the similarity weights vector, $h = \{h^1, h^2, \ldots, h^K\}$, where:

$$h^k = \frac{\sum_{q=1,\, q \neq k}^{K} S_{kq}}{\sum_{p=1}^{K}\sum_{q=1\,,\, q \neq p}^{K} S_{pq}} = \frac{\sum_{q=1}^{K} S_{kq} - 1}{\sum_{p=1}^{K}\sum_{q=1}^{K} S_{pq} - K}. \tag{18}$$

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

Step 5: adjust the weights vectors of the DMs' by both subjective and objective weights vectors. Use Equation (14) to get the precise value $w=\{w^1, w^2, \ldots, w^K\}$ of the subjective weights vector $D=(D^1, D^2, \ldots, D^K)$,
where:

$$w^k = t_{D^k}/\left(t_{D^k}+f_{D^k}\right). \tag{19}$$

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

$$d^k = a \times w^k + (1-a) \times h^k, \quad k = 1, 2, \ \ldots, \ K. \tag{20}$$

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

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

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

here:

$$G_{ij} = \sum_{k=1}^{K} d^k \times M_{ij}^k = \left[\sum_{k=1}^{k} d^k \times t_{M_{ij}^k}, \ 1-\sum_{k=1}^{k} d^k \times f_{M_{ij}^k}\right], \tag{21}$$

which is obtained by *Definition 11*.

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

Step 7: calculate the probability matrix of all supplier alternatives:

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

here:

$$P_{il} = P(G_i \geqslant G_l) = \frac{1}{n}\sum_{j=1}^{n} P\left(G_{ij} \geqslant G_{lj}\right), \tag{22}$$

which is obtained by *Definition 9*.

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

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

$$e_i = \frac{\sum_{l=1}^{m} P_{il} + \frac{m}{2} - 1}{m(m-1)} \tag{23}$$

when e_i is bigger, the ranking order of A_i is better. Otherwise, the ranking order is worse.

According to the above procedure, appropriate ranking order of all supplier alternatives can be determined and the best one can easily be selected from among a set of feasible supplier alternatives.

4. Case illustration

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

The step by step evaluation schemes have been presented below.

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

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

Step 2: for collection of DMs' opinion (or judgment); linguistic variables have been utilized in order to express suitability of performance as well as priority importance

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

Source: Luo *et al.* (2009)

Table I.
Hierarchy criteria of the supplier selection in agile supply chain

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

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

Step 4: weighted decision matrix has then been calculated for all candidate suppliers. According to Equation (16), the obtained weighted decision matrix which has been shown in Table VI.

Step 5: in this step, the importance degree of DMs needs to be adjusted. According to Equation (17), the preference accordance matrix corresponding to five DMs have been computed as follows:

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

According to Equation (18), the similarity weights vector of four DMs has been obtained, which appears as: $h = \{ 0.2090 \quad 0.2005 \quad 0.2005 \quad 0.2090 \quad 0.1811 \}$ It is also called objective weights vector.

Step 6: the weight vector of four DMs has been adjusted here. According to Equation (19), the precise value of the subjective weight vectors D has been obtained as follows:

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

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

Assume that $\alpha = 0.5$, it means that the subjective weights have been assumed to have the same importance as objective weights. Using Equation (20), adjusted weight vector has been obtained as follows: $\mathrm{d} = \{ 0.2049 \quad 0.2173 \quad 0.2173 \quad 0.2049 \quad 0.1556 \}$.

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

Source: Zhang *et al.* (2009)

Table II. Linguistic scale (for collecting expert opinion) and corresponding vague representation

	Decision makers				
	DM_1	DM_2	DM_3	DM_4	DM_5
Linguistic weights	H	VH	VH	H	MH

Table III. Decision maker's importance weight

Table IV.
Criteria weights (in linguistic terms) as given by the expert group

Performance indicators/criterions (C_{ij})	Linguistic weights DM$_1$	DM$_2$	DM$_3$	DM$_4$	DM$_5$
Integration ability, C_{11}	H	H	M	M	H
Strategic programming, C_{12}	VH	MH	VH	H	H
R&D investment, C_{13}	H	H	MH	H	MH
Manufacture adaption level, C_{14}	M	VH	VH	H	H
Throughput capacity, C_{15}	VH	H	VH	H	H
Environment adaption ability, C_{16}	VH	MH	MH	H	MH
Production techniques level, C_{17}	VH	H	M	M	M
Learning organization, C_{18}	H	H	H	VH	VH
Product response time, C_{19}	M	MH	MH	VH	VH
Compatible cooperation culture, $C_{1,10}$	VH	MH	MH	H	H
Liquidity ratio, C_{21}	VH	VH	MH	M	VH
Inventory turnover, C_{22}	VH	VH	MH	MH	MH
Net assets value per share, C_{23}	H	H	H	H	H
Earnings per share of stock, C_{24}	MH	MH	H	H	H
Net operating margin, C_{25}	M	VH	M	VH	MH
Asset/liability ratio, C_{26}	VH	VH	MH	VH	MH
Net profits growth rates, C_{27}	H	H	H	VH	VH
Assets rates of increment, C_{28}	MH	M	MH	M	MH
Accounts receivable turnover, C_{29}	MH	MH	MH	MH	MH
Stockholders' equity ratio, $C_{2,10}$	VH	H	VH	H	H
Cash flow per share, $C_{2,11}$	H	H	H	H	H
Debt/equity ratio, $C_{2,12}$	H	H	VH	M	VH
Human resource quality, C_{31}	H	H	MH	M	VH
General reputation, C_{32}	H	H	MH	M	M
Fixed assets scope, C_{33}	MH	MH	VH	MH	VH
Information sharing level, C_{34}	VH	MH	H	H	H
IT level, C_{35}	VH	VH	H	MH	H
Value of trademark, C_{36}	MH	VH	H	MH	H
Product quality, C_{37}	MH	VH	H	M	MH
Quality/Cost, C_{38}	VH	H	VH	VH	VH
Service quality, C_{39}	VH	MH	MH	H	H

Step 7: the whole decision matrix has been generated now. Using Equation (21), the integrated decision matrix of four DMs has been obtained as shown in Table VII.

Step 8: in this step, the probability matrix has been computed. Using the Equation (22), the probability matrix of five supplier alternatives has been obtained as follows:

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

Step 9: finally, the order vector of five alternative suppliers has been determined. Using the Equation (23), the order vector has been obtained as follows: $e = \{ 0.2050 \quad 0.1999 \quad 0.1796 \quad 0.2145 \quad 0.2010 \}$.

The ranking order of alternative suppliers appears as follows: A4 > A1 > A5 > A2 > A3.

Performance indicators/criterions (C_{ij})	Supplier(s)	Linguistic ratings DM$_1$	DM$_2$	DM$_3$	DM$_4$	DM$_5$
Integration ability, C_{11}	A1	MG	F	G	MG	VG
	A2	VG	VG	G	G	G
	A3	G	G	MG	MG	G
	A4	G	MP	F	F	MP
	A5	G	G	VG	VG	G
Strategic programming, C_{12}	A1	F	G	G	F	G
	A2	MG	VG	G	F	G
	A3	VG	MG	MG	MG	MG
	A4	G	G	VG	G	VG
	A5	MG	VG	MG	VG	MG
R&D investment, C_{13}	A1	F	G	G	G	F
	A2	G	VG	MG	VG	VG
	A3	G	MP	MG	MP	G
	A4	VG	VG	VG	G	G
	A5	MG	VG	G	G	VG
Manufacture adaption level, C_{14}	A1	F	G	G	G	G
	A2	MG	G	MG	G	VG
	A3	VG	G	MG	VG	VG
	A4	VG	G	VG	VG	VG
	A5	G	G	F	MG	MG
Throughput capacity, C_{15}	A1	G	MG	F	VG	MG
	A2	F	VG	F	MP	VG
	A3	F	G	G	MP	MP
	A4	VG	G	G	G	G
	A5	G	G	MG	VG	MG
Environment adaption ability, C_{16}	A1	MG	VG	MG	MG	G
	A2	G	G	MG	MG	G
	A3	MG	F	MP	F	F
	A4	MP	MP	G	G	F
	A5	VG	G	G	MG	MG
Production techniques level, C_{17}	A1	G	MG	MG	MG	MG
	A2	G	VG	G	G	G
	A3	G	VG	VG	G	G
	A4	G	MG	G	G	G
	A5	G	MG	MG	F	F
Learning organization, C_{18}	A1	VG	VG	G	F	F
	A2	VG	G	MG	VG	VG
	A3	MG	MG	MG	MP	MP
	A4	G	VG	G	VG	G
	A5	VG	G	VG	VG	VG
Product response time, C_{19}	A1	G	MG	G	G	G
	A2	G	MG	G	MG	F
	A3	VG	VG	G	F	F
	A4	G	MG	G	VG	G
	A5	G	VG	VG	G	G
Compatible cooperation culture, $C_{1,10}$	A1	VG	MG	G	G	G
	A2	MP	G	F	G	F
	A3	MG	G	MG	G	MG
	A4	G	G	VG	G	G
	A5	MP	F	F	G	G
Liquidity ratio, C_{21}	A1	G	VG	MG	VG	F
	A2	VG	G	MG	F	VG
	A3	MP	P	MG	F	MP

(*continued*)

Table V. Criteria rating (expressed in linguistic term) as given by the expert group against individual alternative suppliers

Performance indicators/criterions (C_{ij})	Supplier(s)	Linguistic ratings DM$_1$	DM$_2$	DM$_3$	DM$_4$	DM$_5$
	A4	G	MG	VG	F	VG
	A5	MG	F	MG	F	G
Inventory turnover, C_{22}	A1	VG	G	G	MG	G
	A2	G	G	G	MG	G
	A3	MG	G	G	VG	MG
	A4	VG	VG	G	G	G
	A5	MP	MP	MG	F	F
Net assets value per share, C_{23}	A1	F	G	MG	MG	MG
	A2	VG	MG	G	G	MG
	A3	VG	VG	G	VG	G
	A4	G	MP	G	F	F
	A5	F	F	MP	MP	P
Earnings per share of stock, C_{24}	A1	VG	VG	G	VG	VG
	A2	G	G	F	F	MP
	A3	F	G	F	G	VG
	A4	G	MG	MG	G	VG
	A5	G	VG	VG	G	G
Net operating margin, C_{25}	A1	G	G	G	G	G
	A2	G	VG	G	VG	G
	A3	MG	MG	MG	MG	G
	A4	G	G	G	G	F
	A5	G	G	VG	VG	G
Asset/liability ratio, C_{26}	A1	VG	G	VG	MG	MG
	A2	F	F	MP	MP	MP
	A3	F	MG	MG	F	MP
	A4	G	G	G	VG	VG
	A5	G	MG	MG	MG	VG
Net profits growth rates, C_{27}	A1	G	VG	G	G	G
	A2	MG	MG	G	G	F
	A3	G	VG	G	G	G
	A4	VG	G	G	G	G
	A5	G	G	F	F	G
Assets rates of increment, C_{28}	A1	VG	G	VG	VG	G
	A2	MG	MG	G	G	VG
	A3	VG	G	G	G	G
	A4	G	VG	VG	VG	G
	A5	G	F	G	F	MG
Accounts receivable turnover, C_{29}	A1	G	F	G	G	MG
	A2	G	VG	G	G	MG
	A3	MP	G	F	MP	MP
	A4	G	MG	MG	G	MG
	A5	G	G	VG	G	VG
Stockholders' equity ratio, $C_{2,10}$	A1	MG	G	MG	MG	G
	A2	G	VG	G	G	G
	A3	G	MG	G	G	G
	A4	G	VG	VG	G	G
	A5	MG	MG	F	F	F
Cash flow per share, $C_{2,11}$	A1	VG	G	G	G	VG
	A2	VG	G	G	G	VG
	A3	G	MP	MP	F	F
	A4	G	VG	VG	VG	F
	A5	G	F	MG	MG	G
Debt/equity ratio, $C_{2,12}$	A1	G	VG	G	G	G

Table V. (*continued*)

Performance indicators/criterions (C_{ij})	Supplier(s)	Linguistic ratings DM$_1$	DM$_2$	DM$_3$	DM$_4$	DM$_5$
	A2	MG	G	G	G	G
	A3	G	VG	G	VG	G
	A4	G	G	G	G	G
	A5	G	MG	G	MG	G
Human resource quality, C_{31}	A1	G	G	G	G	G
	A2	G	VG	G	G	G
	A3	MG	G	VG	VG	VG
	A4	MG	G	G	G	F
	A5	VG	G	VG	VG	G
General reputation, C_{32}	A1	F	G	MG	MG	MG
	A2	VG	G	VG	VG	G
	A3	G	G	G	G	G
	A4	G	G	G	G	G
	A5	G	G	VG	G	F
Fixed assets scope, C_{33}	A1	MG	MG	MG	MG	G
	A2	VG	G	VG	VG	G
	A3	MG	G	MG	G	G
	A4	MG	G	MG	MG	MG
	A5	MG	F	G	F	G
Information sharing level, C_{34}	A1	G	G	MG	F	G
	A2	G	MG	MP	MP	MP
	A3	G	G	VG	F	G
	A4	MG	MG	G	G	MP
	A5	G	G	VG	G	G
IT level, C_{35}	A1	F	F	G	G	F
	A2	VG	G	G	G	VG
	A3	G	G	G	G	G
	A4	MG	MG	G	G	G
	A5	VG	G	VG	VG	G
Value of trademark, C_{36}	A1	F	VG	MG	MG	G
	A2	G	G	G	G	F
	A3	MP	MP	F	F	F
	A4	VG	G	G	G	G
	A5	F	G	VG	F	MG
Product quality, C_{37}	A1	G	VG	MG	MG	MG
	A2	VG	MG	MG	MG	MG
	A3	MG	VG	G	G	G
	A4	G	MG	G	G	F
	A5	G	VG	G	G	G
Quality/cost, C_{38}	A1	G	G	G	G	VG
	A2	G	G	MG	G	G
	A3	G	G	MG	VG	VG
	A4	MG	F	F	MG	MG
	A5	VG	G	G	G	MG
Service quality, C_{39}	A1	G	G	G	F	F
	A2	MG	G	G	G	VG
	A3	MG	VG	MG	MG	G
	A4	VG	G	VG	VG	G
	A5	VG	G	VG	G	G

Table V.

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

Table VI.
Weighted decision matrix for the set of candidate suppliers

Performance indicators/criterions (C_{ij})	Supplier(s)	Weighted decision information				
		DM_1	DM_2	DM_3	DM_4	DM_5
C_{11}	A1	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
	A4	(0.6,0.9)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)
	A5	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
C_{12}	A1	(0.4,0.5)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A3	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A4	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)
	A5	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
C_{13}	A1	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
	A3	(0.6,0.9)	(0.3,0.4)	(0.5,0.6)	(0.3,0.4)	(0.5,0.6)
	A4	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
	A5	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
C_{14}	A1	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A3	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A4	(0.4,0.5)	(0.6,0.9)	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)
	A5	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)
C_{15}	A1	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
	A2	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.3,0.4)	(0.6,0.9)
	A3	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)	(0.3,0.4)	(0.3,0.4)
	A4	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A5	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
C_{16}	A1	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A3	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)
	A4	(0.3,0.4)	(0.3,0.4)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)
	A5	(0.9,1)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.5)
C_{17}	A1	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A3	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A4	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A5	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
C_{18}	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.9,1.0)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.3,0.4)	(0.3,0.4)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)	(0.6,0.9)
	A5	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)	(0.9,1.0)
C_{19}	A1	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A2	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)
	A3	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A4	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)
	A5	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
$C_{1,10}$	A1	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A2	(0.3,0.4)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)
	A4	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A5	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)
C_{21}	A1	(0.6,0.9)	(0.9,1.0)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A2	(0.9,1.0)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.9,1.0)

(*continued*)

Performance indicators/criterions (C_{ij})	Supplier(s)	Weighted decision information DM$_1$	DM$_2$	DM$_3$	DM$_4$	DM$_5$
	A3	(0.3,0.4)	(0.1,0.3)	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)
	A4	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.9,1.0)
	A5	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
C_{22}	A1	(0.9,1.0)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A3	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A4	(0.9,1.0)	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A5	(0.3,0.4)	(0.3,0.4)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
C_{23}	A1	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A4	(0.6,0.9)	(0.3,0.4)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)
	A5	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)	(0.3,0.4)	(0.1,0.3)
C_{24}	A1	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)
	A3	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)
	A4	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A5	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
C_{25}	A1	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
	A2	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
	A3	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)
	A4	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)
	A5	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)
C_{26}	A1	(0.9,1.0)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.4,0.5)	(0.4,0.5)	(0.3,0.4)	(0.3,0.4)	(0.3,0.4)
	A3	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)
	A4	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.5,0.6)
	A5	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
C_{27}	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A5	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)
C_{28}	A1	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A2	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A3	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A4	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A5	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
C_{29}	A1	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A2	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A3	(0.3,0.4)	(0.5,0.6)	(0.4,0.5)	(0.3,0.4)	(0.3,0.4)
	A4	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A5	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
$C_{2,10}$	A1	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A3	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A4	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)
	A5	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
$C_{2,11}$	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
	A3	(0.6,0.9)	(0.3,0.4)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)
	A5	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)

(*continued*)

Table VI.

Table VI.

Performance indicators/criterions (C_{ij})	Supplier(s)	Weighted decision information				
		DM_1	DM_2	DM_3	DM_4	DM_5
$C_{2,12}$	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A2	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A4	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A5	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
C_{31}	A1	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
	A3	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.9,1.0)
	A4	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A5	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
C_{32}	A1	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A3	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A4	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A5	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
C_{33}	A1	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A2	(0.5,0.6)	(0.5,0.6)	(0.9,1.0)	(0.5,0.6)	(0.6,0.9)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A4	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)
	A5	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
C_{34}	A1	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.6,0.9)
	A2	(0.6,0.9)	(0.5,0.6)	(0.3,0.4)	(0.3,0.4)	(0.3,0.4)
	A3	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.6,0.9)
	A4	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.3,0.4)
	A5	(0.6,0.9)	0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)
C_{35}	A1	(0.4,0.5)	(0.4,0.5)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)
	A2	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A4	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A5	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
C_{36}	A1	(0.4,0.5)	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A2	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.4,0.5)
	A3	(0.3,0.4)	(0.3,0.4)	(0.4,0.5)	(0.4,0.5)	(0.4,0.5)
	A4	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)
	A5	(0.4,0.5)	(0.6,0.9)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)
C_{37}	A1	(0.5,0.6)	(0.9,1.0)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A2	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.5,0.6)
	A3	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)
	A4	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.4,0.5)	(0.4,0.5)
	A5	(0.5,0.6)	(0.9,1.0)	(0.6,0.9)	(0.4,0.5)	(0.5,0.6)
C_{38}	A1	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.9,1.0)
	A2	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A3	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)	(0.9,1.0)	(0.9,1.0)
	A4	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)	(0.5,0.6)	(0.5,0.6)
	A5	(0.9,1.0)	(0.6,0.9)	(0.6,0.9)	(0.6,0.9)	(0.5,0.6)
C_{39}	A1	(0.6,0.9)	(0.5,0.6)	(0.5,0.6)	(0.4,0.5)	(0.4,0.5)
	A2	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A3	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)
	A4	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)
	A5	(0.9,1.0)	(0.5,0.6)	(0.5,0.6)	(0.6,0.9)	(0.6,0.9)

5. Managerial implication

In the present work, an attempt has been made to give empirical confirmation to make manufacturing managers a practical methodology for selecting suitable suppliers/partners in perspective of ASC. A comprehensive criteria list (in relation to agile suppliers' performance evaluation) has been adapted here. The information

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

Table VII.
The integrated decision matrix

collected from the decision-making group could be utilized in enriching the extent of customer and industrial cooperation which is treated as one of the key agile dimension.

In the recent highly volatile marketplace, ASC needs to be highly flexible so that the customer requirement in terms of product quality, quantity and product variety within a particular time period can satisfactorily be fulfilled. This entire event is somewhat related to selection of appropriate supplier/partner. Therefore, the need for developing an agile supplier/partner selection process is definitely a challenging task. The selection model presented in this work has been aimed to aid DMs/industry management towards successful survival in turbulent and competitive business environment. It has been proved that the methodology would be beneficial in considering different evaluation criterion (indices); may be contradicting in nature like beneficial and cost criterions. The application vague set theory has also been proved as a better option to work under uncertain (fuzzy) environment in comparison to FST. The methodology used in this work has been found useful for structuring decision information in the DM's intellect. A key feature of the conceptual model presented in this work is the usage of the integrated decision matrix, which increases the visibility of the assessment of each potential supplier's strength and weakness. This provides an opportunity for DMs to make more rational judgments.

6. Conclusions

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

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

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