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# Application of integrated TOPSIS in ASC index: partners benchmarking perspective

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## Abstract

**Purpose** – In the rapidly changing business environment, companies must align with suppliers to streamline operations, as well as working together to achieve a level of agility beyond individual companies (Lin *et al.*, 2006). Today's more dynamic business environment increases the need for greater agility in supply chains, which increases both the importance and frequency of supplier/partner evaluation and benchmarking decision making. The purpose of this paper is to develop a multiple criterion appraisement index (model/module) for supplier/partner alternative firm benchmarking perspective under similar agile supply chain architecture.

**Design/methodology/approach** – In this reporting, evaluation information against subjectivity (uncertain environment) indices has been transformed mathematical dimensionless numbers by fuzzy-based computation module. A new interval-valued fuzzy number set conjunction with modified "technique for order preference by similarity to ideal solution" methodology has been explored from benchmarking (ranking order of firm under similar criterion) point of view of supplier firms.

**Findings** – In this context, a novel "fuzzy mathematical equation" has been developed in perceptive to compute the priority weights and appropriateness ratings of first-level measures which reduced the acquisition of supplementary priority weights and appropriateness ratings assessment in linguistic terms from group decision makers (DMs) for first-level indices. An empirical case study has been carried to ranking order the candidate partner/supplier alternative via collective index (CI) value. Lower value of "CI" reflected higher degree of performance extent. The authors found out the effectiveness and validity of proposed methodology for constructed appraisement module.

**Originality/value** – This research work shall be valuable for that organization which volunteer to obtain the ranking order of partner/supplier alternative (benchmark) under similar agile supply chain architecture in accordance to group DMs' comprehensive information for select best one supplier for own firm. In this reporting, a novel fuzzy mathematical equation has been developed in order to compute the important weights as well as priority rating of first-level indices/measure which reduced the supplementary important weights and priority rating assessment from group DMs in linguistic terms in order to obtain the measures rating and weights.

**Keywords** Benchmarking, Agility, Supplier evaluation, Agile supply chain (ASC), Interval-valued fuzzy number set (IVFNS), Supplier/partner evaluation

**Paper type** Research paper

## 1. Introduction

Supply chain management is known as active management that maximizes customer value and achieves a sustainable competitive advantage. It represents a conscious effort by the supply chain firms to develop and run supply chains in the most effective and efficient ways (Sahu *et al.*, 2012b, c, 2014a, c). Supply chain management covers

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everything, e.g. product development, sourcing, production and logistics, as well as the information systems needed to coordinate these activities. Supply chain loosely related to group of companies formed to enable collaboration to achieve mutually agreed on goals (Christopher, 2000). The importance of time has been recognized as a competitive weapon which paid the need to concert the integrated concept of supply chain management in order to obtain higher satisfactory level of customer toward firm (Stalk, 1988). Last decades, among few integrated concept of SC, the concept of agility has been found out so effective to obtain the much more satisfactory of customer toward organization. Therefore, agility is defined as the ability of an enterprise to rapidly respond to change in market and customer's demands (Sharp *et al.*, 1999). Agility is an ability of enterprises to meet the demands of customers for ever-shorter delivery times is called agility (Stalk and Thomas, 1990). Agile supply chain (ASC) can be considered to be structure under the goals of satisfying customers and employees within which every organization can design its own business strategies, organization, processes and information systems and agility is defined as the ability of a supply chain to rapidly respond to changes in market and customer demands (Sharp *et al.*, 1999; Lin *et al.*, 2006). Agility aligns index exploit in purpose to measure the intensity levels of agility enable-attributes, while other measuring methods (Youssuf, 1993; Yusuf *et al.*, 2001; Lin *et al.*, 2006). Lat decades in diverging trend, it has been soughed that the effectiveness and energeticness of manufacturing firm mostly depend on the upstream attached supplier/partners agent in SC management context. In this context, a decision support system (DSS) (multi criterion hierarchical index/modules couple with interval-valued fuzzy numbers (IVFNs)-technique for order preference by similarity to ideal solution (TOPSIS) method) has been proposed to managers of individual firm. In order that, managers could evaluate-select the best supplier/partner for own firm under uncertain agile SC indices.

## 2. State of arts

The state of arts section aligned the literature reviews section in regard to fuzzy logic application in supplier benchmarking and selection in ASC arena.

Goldman *et al.* (1991) suggested that agility have four underlying components of agility including delivering value to the customers, being ready for change, valuing human knowledge and skills, and forming virtual partnerships. Markland *et al.* (1995) expressed that ASC provides the link from suppliers to customers in the planning, manufacturing and controlling of raw materials and products. Zimmermann (1996) found out the broad scope of the applications of fuzzy set theory, engineering design emerges as an important activity in today's organizations that has lacked tools that manage the great amount of imprecise information that is usually encountered.

Christopher (2000) explained that an ASC thus should possess the ability to respond appropriately to changes occurring in its business environment. Additionally, author also explained that many businesses have adopted the concept of ASCs or networks in order to respond efficiently and effectively to increasingly dynamic and volatile markets. De Boer *et al.* (2001) expressed that very few studies have given much attention to criteria formulation for partner selection in ASC. Yang and Li (2002) defined that foundation of the ASC lies in the integration of customer sensitivity, organization, processes, networks and information systems. Yang and Li (2002) explained a cases study to validate the model and approach with regard to the efficiency of the method to measure agility index. Tsourveloudis and Valavanis (2002)

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designed some IF-THEN rules for measuring enterprise agility based on fuzzy logic in order to overcome the vagueness of the agility assessment.

Lin and Chen (2004) offered a fuzzy decision-making framework to tackle the supply partner selection problem. Sarkar and Mohapatra (2006) articulated that however, frequently changing customer demands create increased uncertainty and ambiguity for this decision-making process. Thus, the importance of the supplier selection process has increased as has its complexity. Yigin *et al.* (2007) considered agile supply chain management (ASCM) can be considered as one of the most important aspects of production planning and control. Yigin *et al.* (2007) explained that most researchers in ASC have typically proposed their own subjective criteria without giving adequate evidence. Additionally expressed that an ASC needs to be highly flexible and to be able to be reconfigured quickly in response to changes in the unpredictable business environment.

Sahu *et al.* (2012b) explained a performance appraisal is a systematic and periodic process that assesses an individual's performance and productivity in relation to certain pre-established criteria and organizational objectives. Aishwarya and Balaji (2013) attempted to validate a tool, agile supply chain transformation matrix and implemented methodology for a systematic approach to achieve agility in the supplier-buyer supply chain. Sahu *et al.* (2014a, b, c) articulated that multi-criteria decision-making (MCDM) is concerned with structuring and solving decision and planning problems involving multiple criteria. The purpose is to support decision makers (DMs) facing such problems. Typically, there does not exist a unique optimal solution for such problems and it is necessary to use DM's preferences to differentiate between solutions. Solving can be interpreted in different ways. It could correspond to choosing the "best" alternative from a set of available. Sahu *et al.* (2012b, c, 2014a, c) elaborated that performance measures (indices) are always tied to a goal or an objective (the target). Performance measures quantitatively an important about the products, services and the processes that produce them. It is a tool to help in understanding, managing and improving what organizations do.

## 3. A summary of literature reviews

After conducting the sufficient literature survey in regard to benchmarking and supplier selection problem in arena of ASC. Where, merely two research gaps existed in broaden way.

### *3.1 First research gap*

Articulated that solely minority of published manuscripts dealt with multi-level evaluation appraisement index/module (aligned subjectivity) in arena of ASC. Therefore, there is s mitigation of an exploration of new multi-level hierarchical modules/indexes aligning measures and their interrelated metrics combined with new MCDM methods, tool and software, etc., in order to solve supplier benchmarking and selection problem in integrated concept of SC management (agile) (Sahu *et al.*, 2012a, 2013, 2014b, 2015).

### *3.2 Second research gap*

There is a mitigation of new mathematical equation conjunctive with fuzzy logic tool which can reduce the problem solving complexity of multi hierarchical appraisement (decision making) index and as well as provide the assistance to developed DSS in arena of MCDM (Sahu *et al.*, 2012a, b, c, 2013, 2014a, b, c, 2015).

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In this context, in purpose to compensate aforementioned research gaps, a novel fuzzy mathematical equation has been developed in perceptive to compute the priority weights and appropriateness ratings of first-level measures which reduced the acquisition of supplementary priority weights and appropriateness ratings assessment in linguistic terms from group DMs. And finally, a DSS (multi criterion hierarchical index/modules couple with IVFNS-TOPSIS method) has been applied to ranking order the suppliers for facilitating the managers of the firm for benchmarking and selection of best supplier firm among all/preferred in arena of agile SC index.

## 4. Problem formulation

In today's competitive edge, enterprises has become more conscious to explore decision-making tool and techniques for partner/supplier evaluation in ASC extent due to the leverage of constrained unified objectives such as creating the satisfactory consumer's response, better partner enterprises image, enhancing productivity and minimize the loss (maximize profit). Today's assessment as well as benchmarking of best partner/supplier in ASC is a complex, difficult as well as complicated but indeed to perform this task. In this context, entitled multiple subjective (measures and their interrelated metrics) has been developed with the help of extensive literature review of several manuscripts pertaining to partner/supplier evaluation in ASC extent. Subsequently, explored of IVFNS theory conjunction with modified TOPSIS methodology to effective appraisement and assessment of potential candidate suppliers/partner in ASC. Subjective appraisement indices have been evaluated in terms of performance extent as well as priority importance and priority appropriate rating assessed by the DMs as linguistic information. In order to remove a raised uncertainty, ambiguity and vagueness in linguistic evaluation information, at this stage fuzzy logic has been adapted to transform linguistic information into appropriate fuzzy numbers. The judgment of the expert panels (linguistic preferences) have been transformed into IVFNs. The concept of IVFNs in conjunction with modified TOPSIS methodology has been explored toward benchmarking of the preferred candidate alternatives. Finally, an empirical case study has been carried out to provide a better make out the proposed measures of partner/supplier evaluation in ASC. The raking order of preferred alternative industries has been derived in accordance with ascending value of the "collective index (CI)". Lower value of "CI" reflects higher degree of performance extent.

## 5. TOPSIS methodology

The TOPSIS method was first proposed by Hwang and Yoon (1981). It is based on the concept of positive ideal solution (PIS) as well as negative ideal solution (NIS) (anti-ideal solution). The PIS is a solution that minimizes the cost criteria and maximizes the benefit criteria; whereas, the NIS maximizes the cost criteria and minimizes the benefit criteria. The so-called benefit criteria are those whose maximum values are proffered; while, the cost criteria are those whose minimum values are desired. The best alternative is the one, which is placed at closest to the PIS and farthest distance from the NIS.

Suppose a MCDM problem has $m$ alternatives $(A_1, \ldots, A_m)$ and $n$ decision criteria $(C_1, \ldots, C_n)$. Each alternative is evaluated with respect to $n$ criteria. All the ratings assigned to the alternatives with respect to each criterion form a decision matrix denoted by $X=(x_{ij})_{mn}$. Let $W=(w_1, w_2, \ldots, w_n)$ be the relative weight vector about the criteria, satisfying $\sum_{j=1}^{n} w_j = 1$. Then, the TOPSIS method is summarized as follows:

*Step 1*: normalize the decision matrix $X=(x_{ij})_{mn}$ using the following equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}, \quad i = 1, 2, 3, \ldots, m, \ , \quad j = 1, 2, 3, \ldots, n \tag{1}$$

here, $r_{ij}$ is the normalized criterion rating.

*Step 2*: calculate the weighted normalized decision matrix $v=(v_{ij})_{mn}$. Here, $w_j$ is the relative weight of the $j$th criterion or attribute, and $\sum_{j=1}^{n} w_j = 1$.

*Step 3*: determine the PIS and NIS by:

$$A* = \{v_1^*, \ldots, v_n^*.\} = \left\{ \left( \max_i v_{ij}(j \in \Omega_b]., \left( \min_i v_{ij}(j \in \Omega_c]._j \right\} \tag{2}$$

$$A^- = \{v_1^-, \ldots, v_n^-.\} = \left\{ \left( \max_i v_{ij}(j \in \Omega_b]., \left( \min_i v_{ij}(j \in \Omega_c]._j \right\} \tag{3}$$

here, $\Omega_b$ and $\Omega_c$ are the sets of benefit criteria and cost criteria, respectively.

*Step 4*: calculate the Euclidean distances of each alternative from the PIS and the NIS, respectively:

$$D_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v^*)_{ij}^2}, \quad i = 1, 2, 3, \ldots, m \tag{4}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v^*)_{ij}^2}, \quad i = 1, 2, 3, \ldots, m \tag{5}$$

*Step 5*: calculate the relative closeness of each alternative with respect to the ideal solution. The relative closeness of the alternative $A_i$ with respect to $A^*$ is defined by:

$$RC_i = \frac{D_i -}{D_i^* + D_i^-}, \quad i = 1, 2, 3, \ldots, m \tag{6}$$

*Step 6*: rank the alternatives according to their relative closeness to the ideal solution. The bigger the $RC_i$, the better the alternative $A_i$ is. The best alternative is the one which is having the greatest relative closeness to the ideal solution.

## 6. Fuzzy set theory

The fuzzy set theory was first introduced by Zadeh (1965) for dealing with problems in which a source of vagueness is present. It has been considered as a modeling language to approximate situations in which fuzzy phenomena and fuzzy criteria exist. In a universe of discourse $X$, a fuzzy subset $A$ of $X$ is a set defined by a membership function $f_A(x)$ representing a mapping which maps each element $x$ in $X$ to a real number in the closed interval [0, 1]. Here, the value of $f_A(x)$ for the fuzzy set $A$ is called the membership value (or the grade of the membership) of $x$ in X. The membership value represents the degree of $x$ belonging to the fuzzy set $A$. The greater $f_A(x)$ the stronger is the grade of membership for $X$ in $A$.

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The linguistic value could be used for approximate reasoning within the framework of fuzzy set theory (Zadeh, 1965, 1975; Zimmermann, 1996) for handling effectively the ambiguity involved in the evaluation data and the vague property of linguistic expression; and normal trapezoidal or triangular fuzzy numbers could be used to characterize the fuzzy values of quantitative data and linguistic terms used in approximate reasoning. The operations of fuzzy numbers can be understood using the extension principle (Tanaka, 1997).

### *6.1 Interval-valued fuzzy numbers sets (IVFNS)*

According to Gorzalczany (1987) an IVFS defined on (−∞, +∞) is given by:

$$A = \left\{ \left( x, \mu_A^L(x), \mu_A^U(x) \right] \right) \right\} \quad (7)$$

$$\mu_A^L, \mu_A^U : X \to [0, 1] \quad \forall x \in X, \mu_A^L \leqslant \mu_A^U$$

$$\mu_A(x) = \mu_A^L(x), \mu_A^U(x)$$

$$A = \left\{ \left( x, \mu_A(x) \right) \right\}, \quad x \in (-\infty, \infty)$$

here, $\mu_A^L$ the lower is limit of degree of membership and $\mu_A^U$ is the upper limit of the membership degree.

Given two IVFNs $N_x = \left[N_x^-, N_x^+\right]$ and $M_x = \left[M_x^-, M_x^+\right]$, according to [10, 29], we have:

*Definition 1.* If ∈(+, *x*) then $N.M(x,y) = [N_x^- .M_x^-, N_x^+ .M_x^+]$ for a positive non-fuzzy number $(v), v.M(x,y) = [v.M_y^-, N_x^+ .v.M_x^+]$.

*Definition 2.* The subtraction and division operations between two triangular interval-valued fuzzy number (TIVFNs) $\tilde{N}$ and $\tilde{M}$ are as follows (Kuo, 2011):

$$\tilde{N} - \tilde{M} = \left[N_1, N_1'\right); N_2; \left(N_3', N_3\right)\right] - \left[M_1, M_1'\right); M_2; \left(M_3', M_3\right)\right]$$

$$[N_1 - M_3, N'_1 - M'_3); N_2 - M_2; (N'_3 - M'_1, N_3 - M_1)]$$

and:

$$\tilde{N} \div \tilde{M} = [N_1, N'_1); N_2; (N'_3, N_3)] \div [M_1, M'_1); M_2; (M'_3, M_3)]$$

$$[N_1 \div M_3, N'_1 \div M'_3); N_2 \div M_2; (N'_3 \div M'_1, N_3 \div M_1)]$$

*Definition 3.* The intersection of two IVFSs (Gorzalczany, 1987) is defined as the minimum of their respective lower and upper bounds of their membership intervals. Given two intervals of [0, 1] an $N_x = [N_x^-; N_x^+] \subset [0, 1], M_y = [M_y^-; M_y^+] \subset [0, 1]$ the minimum of both intervals is an interval $K = \text{Min}\left(N_x, M_y\right) = [\text{Min}(N_x^-; M_y^-), \text{Min}(N_x^+; M_y^+)]$.

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*Definition 4.* The union of two IVFSs (Mousavi *et al.*, 2012) is defined as the maximum of their respective lower and upper bounds of their membership intervals. Given two intervals of [0, 1] and $N_x = [N_x^-; N_x^+] \subset [0,1], M_y = [M_y^-; M_y^+] \subset [0,1]$, the maximum of both intervals is $K = \text{Max}(N_x, M_y) = [\text{Max}(N_x^-; M_y^-), \text{Max}(N_x^+; M_y^+)]$.

*Definition 5.* Absolute value: $|N_x| = \text{Max}\{|N_x^-|, |N_x^+|\}$.

*Definition 6.* Let $\tilde{N}$ and $\tilde{M}$ be two TIVFNs $\tilde{N} = [N_1, N'_1); N_2; (N'_3, N_3)]$ and $\tilde{N} = [M_1, M'_1); M_2; (M'_3, M_3)]$ can then be represented as follows:

$$h\left(\tilde{N}\right) = \frac{N_1 + N'_1 + N_2 + N'_3 + N_3}{6} \tag{8}$$

and:

$$h\left(\tilde{N}\right) = \frac{M_1 + M'_1 + N_2 + M'_3 + N_3}{6}, \tag{9}$$

We say $\tilde{N} > \mathrm{M}'$ if $\mathrm{h}(\tilde{N}) > \mathrm{h}(\mathrm{M}')$.

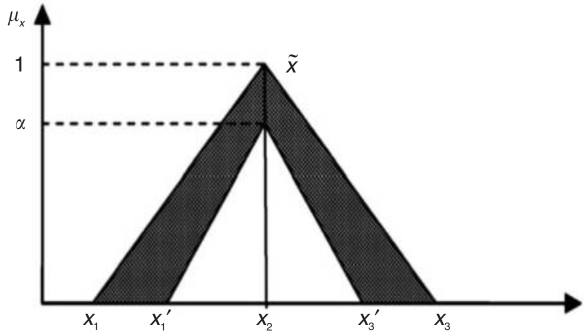
### *6.2 Interval-valued (IV) fuzzy modified TOPSIS method*

A MCDM problem can be concisely articulated in a decision matrix, whose component indicates the evaluation or a value of an alternative with respect to a criterion. This paper develops the decision matrix format to the IV fuzzy decision matrix; that is, the DMs are expected to assign an extent of membership grades that capture the degree of the alternative satisfying the criterion according to their judgments. In some cases, determining precisely of this evaluation is difficult, and the membership value can be expressed as an interval consisting of real numbers. Zadeh (1975) introduced the concept of the linguistic variable which is fruitful in dealing with these situations that are too complex or ill-defined to be reasonably described in conventional quantitative expressions and then convert into related fuzzy numbers.

Modeling a phenomenon in the traditional linguistic approach is not clear enough because of its presentation in the form of ordinary fuzzy sets (Cornelis *et al.*, 2006; Grzegorzewski, 2004). Thus, it is more appropriate to represent this degree of certainty by an interval form. In addition, in the fuzzy sets theory, it is often difficult for an expert to exactly quantify his or her opinion as a number in interval [0, 1]. For this purpose, this paper considers the performance rating and criteria weights as linguistic variables and then transforms into IVFNs, which are the generalization of ordinary fuzzy sets.

Let $\tilde{X} = [x_{ij}]_{m \times n}$ be a fuzzy decision matrix for the MCDM problem, in which ($A_1$,$A_2$, …, $A_m$) are $m$ possible alternatives and ($C_1$,$C_2$, …, $C_n$) are $n$ criteria. Therefore, the performance of alternative $A_i$ with respect to criterion $C_i$ is denoted a $\tilde{x}_{ij}$. As illustrated in Figure 1, $\tilde{x}_{ij}$ and $\tilde{w}_j$ are expressed in TIVFNs:

$$\begin{cases} (x_1, x_2, x_3) \\ (x'_1, x'_2, x'_3) \end{cases}$$




**Source:** Vahdani *et al.* (2013)

**Figure 1.** Triangular interval-valued fuzzy number (TIVFN)

The $\tilde{x}$ can be also expressed as $\tilde{x} = [(x_1, x'_1); x_2; (x'_3, x_3)]$. It is worth noting that the use of TIVNFs gives an opportunity to experts or (DMs) to define lower and upper bounds values as an interval for matrix's elements and weights of criteria. In addition to this, in a group decision environment with $K$ persons, the importance of the criteria and the rating of alternatives with respect to each criterion can be computed by:

$$\tilde{x}_{ij} = \frac{1}{k}\left[\tilde{x}_{ij}^1 + \tilde{x}_{ij}^2 +, \ldots, +\tilde{x}_{ij}^k\right] \tag{10}$$

$$\tilde{w}_{ij} = \frac{1}{k}\left[\tilde{w}_{ij}^1 + \tilde{w}_{ij}^2 +, \ldots, +\tilde{w}_{ij}^k\right] \tag{11}$$

Equations (10) and (11) represent the average values of $\tilde{x}_{ij}$ and $\tilde{w}_{ij}$ denoted by experts, where (+) is the "sum operator" and is applied to the IVFNs as defined in Definition 1. So, the output is an IVFN. Now, the proposed VIFM-TOPSIS method can be presented as follows.

*Step 1*: sub-criterion subjective priority rating and weights aggregation operator.

This operator has developed with following the average fuzzy rule (Vahdani *et al.*, 2013; Sahu *et al.*, 2015) in perceptive to solve the hierarchical framework (module) which aligned criterions and their interrelated criterions). With the help of this operator, we can compute the priority rating and weights of respective platform on the basis of their sub-criterion assessment (priority rating and weights):

$$\frac{\sum r_{ij}}{C_{nij}} = \frac{r_{ij\,1} + r_{ij\,2} + r_{ij\,3} + r_{ij\,4} + r_{ij\,5}, \ldots, r_{nij}}{C_{ij\,1} + C_{ij\,2} + C_{ij\,3} + C_{ij\,4} + C_{ij\,5}, \ldots, C_{nij}} \tag{12}$$

In above equation, $\sum r_{ij}$ denoted as submission of appropriateness priority rating of sub criterion under an individual main criterion and $C_{nij}$ denoted as number of sub criterion against $j$th index at (second, third, etc.) which is under index $i$th at main criterion level.

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Correspondingly:

$$\frac{\sum w_{ij}}{C_{nij}} = \frac{w_{ij\,1}+w_{ij\,2}+w_{ij\,3}+w_{ij\,4}+w_{ij\,5},\ \ldots,\ w_{nij}}{C_{ij\,1}+C_{ij\,2}+C_{ij\,3}+C_{ij\,4}+C_{ij\,5},\ \ldots,\ C_{nij}} \tag{13}$$

In above equation, $\sum w_{ij}$ denoted as submission of priority weights of sub criterion under an individual main criterion and $C_{nij}$ denoted as number of sub criterion against $j$th index at (second, third, etc.) which is under index $i$th at main criterion level.

*Step 2*: given $\tilde{x}_{ij} = \left[a_{ij}, a'_{ij}\right);\ b_{ij};\ \left(c'_{ij}, c_{ij}\right)\right]$. The normalized performance rating can be calculated by:

$$\tilde{n}_{ij} = \left[\left(\frac{a_{ij}}{c_j^+}, \frac{a'_{ij}}{c_j^+}\right);\ \frac{b_{ij}}{c_j^+};\ \left(\frac{c'_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right)\right], \quad i = 1,\ \ldots,\ n, \quad j \in \boldsymbol{\Omega}_b \tag{14}$$

$$\tilde{n}_{ij} = \left[\left(\frac{a_j^-}{c'_{ij}}, \frac{a_j^-}{c_{ij}}\right);\ \frac{a_j^-}{b_{ij}};\ \left(\frac{a_j^-}{a'_{ij}}, \frac{a_j^-}{a_{ij}}\right)\right], \quad i = 1,\ \ldots,\ n, \quad j \in \boldsymbol{\Omega}_c \tag{15}$$

$$c_j^+ = \underset{i}{\mathrm{Max}} c_{ij}, \quad j \in \boldsymbol{\Omega}_b$$

$$a_j^- = \underset{i}{\mathrm{Min}} a_{ij}, \quad j \in \boldsymbol{\Omega}_c$$

Here, $\boldsymbol{\Omega}_b$ and $\boldsymbol{\Omega}_c$ are associated with benefit and cost criteria, respectively. Hence, the normalized matrix $\tilde{N} = \left(n_{ij}\right)_{n \times m}$ can be obtained. The above-mentioned normalization method is to preserve the property that the ranges of normalized interval numbers fall within the interval [0, 1].

*Step 3*: determine the weighted normalized matrix. By considering the different importance of each criterion, we can construct the weighted normalized fuzzy decision matrix as:

$$\tilde{V} = \left[v_{ij}\right]_{n \times m} \tag{16}$$

here:

$$\tilde{v}_{ij} = \tilde{w}_{ij} \times n_{ij}. \tag{17}$$

According to Definition 1, the "multiplication operator" can be applied as:

$$\tilde{v}_{ij} = \left[\left[\left(\tilde{w}_{1j} \times n_{1ij}\tilde{w}_{1j} \times n'_{1ij}\right); \tilde{w}_{2j} \times n_{2ij}; \left(\tilde{w}_{3j} \times n_{3ij}\tilde{w}_{3j} \times n'_{3ij}\right)\right]\right] \tag{18}$$

*Step 4*: determine the PIS and NIS. The values for $A^*$ and $A^-$ are defined as follows with respect to Equations (17) or (18):

$$A^* = \{v_1^*, \ldots, v_n^*.\} = \left\{ \max_i v_{ij} \,(j \in \Omega_b], \left(\min v_{ij}(j \in \Omega_c]_j \right. \right\} \tag{19}$$

$$A^- = \{v_1^-, \ldots, v_n^-.\} = \left\{ \left(\min_i v_{ij} \,(j \in \Omega_b], \left(\max v_{ij}(j \in \Omega_c]_j \right. \right. \right\} \tag{20}$$

here, $\Omega_b$ and $\Omega_c$ are the sets of benefit criteria and cost criteria. Obviously, $A^*$ indicates the most preferable alternative or the PIS. Similarly, $A^-$ indicates the least preferable alternative or the NIS.

*Step 4*: construct ideal separation matrix ($D^*$) and anti-ideal separation matrix $D^*$ which are defined as follows:

$$D^* = \left[d_{ij}^*\right] = \begin{bmatrix} \left|\tilde{v}_{11} - \tilde{v}_1^*\right| & \left|\tilde{v}_{12} - \tilde{v}_2^*\right| & \left|\tilde{v}_{13} - \tilde{v}_3^*\right| & \left|\tilde{v}_{1n} - \tilde{v}_n^*\right| \\ \left|\tilde{v}_{22} - \tilde{v}_2^*\right| & \left|\tilde{v}_{22} - \tilde{v}_2^*\right| & \left|\tilde{v}_{33} - \tilde{v}_3^*\right| & \left|\tilde{v}_{2n} - \tilde{v}_n^*\right| \\ & & & \\ \left|\tilde{v}_{m1} - \tilde{v}_1^*\right| & \left|\tilde{v}_{m2} - \tilde{v}_2^*\right| & \left|\tilde{v}_{m3} - \tilde{v}_3^*\right| & \left|\tilde{v}_{mn} - \tilde{v}_n^*\right| \end{bmatrix} \tag{21}$$

According to Definition 2, the "subtraction operator" can be applied as:

$$D^* = \left[d_{ij}^*\right]$$

$$= \begin{bmatrix} \left[\left(v_{1(1,1)}, v'_{1(1,1)}\right); v_{2(1,1)}; \left(v'_{3(1,1)}, v_{3(1,1)}\right)\right] - \left[\left(v_{1(1)}^*, v_{1(1)}^*\right); v_{2(1)}^*; \left(v_{3(1)}^*, v_{3(1)}^*\right)\right] \ldots \\ \left[\left(v_{1(1,n)}, v'_{1(1,n)}\right); v_{2(1,n)}; \left(v'_{3(1,n)}, v_{3(1,n)}\right)\right] - \left[\left(v_{1(n)}^*, v_{1(n)}^*\right); v_{2(n)}^*; \left(v_{3(n)}^*, v_{3(n)}^*\right)\right] \\ \ldots \\ \ldots \\ \left[\left(v_{1(m,1)}, v'_{1(m,1)}\right); v_{2(m,1)}; \left(v'_{3(m,1)}, v_{3(m,1)}\right)\right] - \left[\left(v_{1(1)}^*, v_{1(1)}^*\right); v_{2(1)}^*; \left(v_{3(1)}^*, v_{3(1)}^*\right)\right] \ldots \\ \left[\left(v_{1(m,n)}, v'_{1(m,n)}\right); v_{2(m,n)}; \left(v'_{3(m,n)}, v_{3(m,n)}\right)\right] - \left[\left(v_{1(n)}^*, v_{1(n)}^*\right); v_{2(n)}^*; \left(v_{3(n)}^*, v_{3(n)}^*\right)\right] \end{bmatrix} \tag{22}$$

$$D^- = \left[d_{ij}^-\right] = \begin{bmatrix} \left|\tilde{v}_{11} - \tilde{v}_1^-\right| & \left|\tilde{v}_{12} - \tilde{v}_2^-\right| & \left|\tilde{v}_{13} - \tilde{v}_3^-\right| & \left|\tilde{v}_{1n} - \tilde{v}_n^-\right| \\ \left|\tilde{v}_{22} - \tilde{v}_2^-\right| & \left|\tilde{v}_{22} - \tilde{v}_2^-\right| & \left|\tilde{v}_{33} - \tilde{v}_3^-\right| & \left|\tilde{v}_{2n} - \tilde{v}_n^-\right| \\ . & . & . & . \\ \left|\tilde{v}_{m1} - \tilde{v}_1^-\right| & \left|\tilde{v}_{m2} - \tilde{v}_2^-\right| & \left|\tilde{v}_{m3} - \tilde{v}_3^-\right| & \left|\tilde{v}_{mn} - \tilde{v}_n^-\right| \end{bmatrix} \tag{23}$$

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According to Definition 2, the "subtraction operator" can be applied as:

$$D^- = \left[d_{ij}^-\right]$$

$$= \begin{bmatrix} \left[\left(v_{1(1,1)}, v'_{1(1,1)}\right); v_{2(1,1)}; \left(v'_{3(1,1)}, v_{3(1,1)}\right)\right] - \left[\left(v_{1(1)}^-, v_{1(1)}^-\right); v_{2(1)}^-; \left(v_{3(1)}^-, v_{3(1)}^-\right)\right] \ldots \\ \left[\left(v_{1(1,n)}, v'_{1(1,n)}\right); v_{2(1,n)}; \left(v'_{3(1,n)}, v_{3(1,n)}\right)\right] - \left[\left(v_{1(n)}^-, v_{1(n)}^-\right); v_{2(n)}^-; \left(v_{3(n)}^-, v_{3(n)}^-\right)\right] \\ \ldots \\ \ldots \\ \left[\left(v_{1(m,1)}, v'_{1(m,1)}\right); v_{2(m,1)}; \left(v'_{3(m,1)}, v_{3(m,1)}\right)\right] - \left[\left(v_{1(1)}^-, v_{1(1)}^-\right); v_{2(1)}^-; \left(v_{3(1)}^-, v_{3(1)}^-\right)\right] \ldots \\ \left[\left(v_{1(m,n)}, v'_{1(m,n)}\right); v_{2(m,n)}; \left(v'_{3(m,n)}, v_{3(m,n)}\right)\right] - \left[\left(v_{1(n)}^-, v_{1(n)}^-\right); v_{2(n)}^-; \left(v_{3(n)}^-, v_{3(n)}^-\right)\right] \end{bmatrix} \tag{24}$$

With respect to Definition 5, ideal separation matrix ($D^*$) and anti-ideal separation matrix ($D^-$) are converted into a matrix with absolute numbers which are presented as follows:

$$D^* = \begin{bmatrix} d_{11}^* & d_{12}^* & \ldots & d_{1n}^* \\ d_{21}^* & d_{22}^* & \ldots & d_{2n}^* \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1}^* & d_{m2}^* & \ldots & d_{mn}^* \end{bmatrix}, \tag{25}$$

and:

$$D^- = \begin{bmatrix} d_{11}^- & d_{12}^- & \ldots & d_{1n}^- \\ d_{21}^- & d_{22}^- & \ldots & d_{2n}^- \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1}^- & d_{m2}^- & \ldots & d_{mn}^- \end{bmatrix}, \tag{26}$$

*Step 5*: calculate CI. This index is calculated by:

$$\Gamma_i\left(D^*, D^-\right) = \left(\sum_{l=1(A)}^{L} \frac{d_{ij}^*}{d_{ij}^-}\right)^{1/L} + z_{ij'} \quad \forall_i = 1, 2, \ldots, m. \tag{27}$$

Here, the first summation $\left(\sum A\right)$ refers to all $j$ for which $d_{ij}^- > 0$ while $(z_{ij'})$ refers to all $j$ for which $d_{ij}^- = 0$. Further, $z_{ij'}$ can be calculated such that $z_{ij'} = \left(\left(\max_{j'}\left(d_{ij}^*/d_{ij}^-\right)\right)\right)^{1/\max_j w_j}$ for which $d_{ij}^- > 0$ and $w_j$ for $d_{ij}^- = 0$:

$$\varsigma_i\left(D^*, D^-\right) = \left(\sum_{l=1}^{L} d^*_{ij}\right)^{1/m} + \left(\sum_{l=1(A)}^{L} \frac{1}{d_{ij}^-}\right)^{1/L} + Q_{ij'}, \quad \forall_i = 1, 2, \ldots, m. \tag{28}$$

Here, the second summation $\left(\sum A\right)$ refers to all $j$ for which $d_{ij}^- > 0$ while $(Q_{ij'})$ refers

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to all $j$ for which $d_{ij}^{-}=0$. Further, $Q_{ij'}$ can be calculated such that $Q_{ij'}=((\min_{j'}(d_{ij'}^{-})))^{1/\max_j w_j}$ for which $d_{ij}^{-}>0$ and $w_j$ for $d_{ij}^{-}=0$.

Finally, the CI is calculated as follows:

$$\mathrm{CI}_i=\Gamma_i+\varsigma_i \tag{29}$$

*Step 6*: rank the preference order. The best satisfied alternative can be decided according to the preference ranking order of $\Gamma_i$ and $\varsigma_i$. The minimum value of the CI indicates better performance for alternative $A_i$.

According to the IV fuzzy decision matrix, the new MCDM method is presented that may reflect both subjective judgments and objective information in real life situations. The proposed VIFM-TOPSIS method is based on concepts of the PIS and the NIS for solving decision-making problems by considering multiple judges and multiple criteria in an uncertain environment. It is a generalized form of the ordinary fuzzy sets by using the TIVFNs. The presented method provides with a useful way to deal with fuzzy MCDM problems in a more flexible and intelligent manner due to the fact that it utilizes IVFNS rather than ordinary fuzzy sets to represent the alternative rating with respect to criteria and the weights of criteria. Moreover, the new relative closeness (i.e. CI) is presented by considering two indices in order to discriminate successfully and clearly among alternatives in the ranking process along with its simplicity and flexibility in respect to subjective or objective criteria.

The usefulness of the aforesaid approach has been summarized below (Vahdani *et al.*, 2013):

(1) A new version of fuzzy sets in IV form has been adapted, which provides more flexibility and better representation uncertainties than traditional fuzzy sets because of the fact that TIVFNs have been utilized.

(2) A new relative closeness (i.e. CI) based on two indices has been computed that considers the relative distance of alternatives from the reference points effectively.

(3) In the said IVFM-TOPSIS method for each criterion, the alternatives rating and the criteria weights can be expressed with linguistic variables and then transformed into a generalized form of ordinary fuzzy sets.

(4) The method constructs the ideal separation and anti-ideal separation matrix based on the operations between TIVFNs to distinguish among the alternatives in the decision-making problem better than the previous studies based on Euclidean distances of each alternative from the PIS and the NIS.

(5) The effect of weights of criteria, which can be highly important in the ranking process of alternatives in MCDM problems, is clearly regarded by using new indices in the evaluations rather than the previous studies.

(6) The IVFN-TOPSIS method can deal with the situations, in which fuzzy and non-fuzzy evaluations are required. In fact, the proposed method assists the experts or DMs to take data in the form of linguistic terms, TIVFNs, and/or crisp numbers in MCDM problems. This leads to more realistic and reliable decision-making process than the existing ones.

The flow chart for evaluation and benchmarking of partner/supplier in ASC context has been revealed by Figure 2.

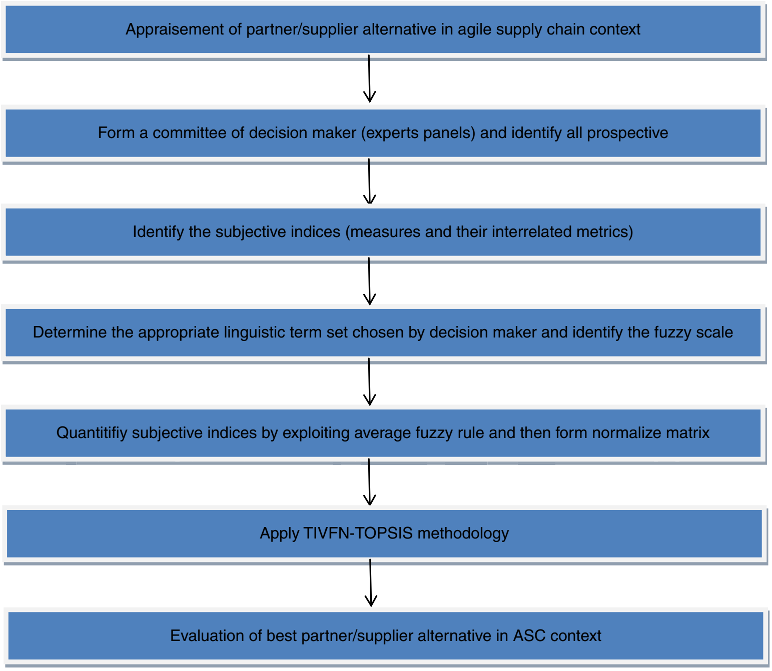


**Figure 2.**
The flow chart for evaluation and benchmarking of partner/supplier in agile supply chain context

## 7. Empirical research: data analyses

The multi hierarchical performance appraisement platform/model toward selection of appropriate partner in ASC context has been developed in this manuscript shown in Table I. The double-level model consists of various indices: measures and their interrelated metrics, where production and logistics management($C_1$), partnership management($C_2$), financial capability($C_3$), technology and knowledge management($C_4$), marketing capability ($C_5$), industrial and organizational competitiveness($C_6$), and human resource management($C_7$) have been considered as the single-level indices followed by their interrelated metrics. A modified TOPSIS methodology conjunction with TIVFNS proposed by Vahdani *et al.* (2013), has been adapted here in order to evaluate a ranking order of partner/supplier alternatives in ASC (Table II).

Empirical research has been carried out to verify application credentials of said approach toward finding the best alternative under fuzzy environment. In this research, we assume that a committee of five DMs (experts group) such as ($DM_1$, $DM_2$, $DM_3$, $DM_4$, $DM_5$) has been constructed from miscellaneous department of several companies. Also, assume that there are four alternative industries such as $A_1$, $A_2$, $A_3$, $A_4$.

In this paper, priority weights against individual measures/indices and corresponding performance extent (appropriateness ratings) have been obtained via linguistic information, provided by the expert group; which have been further transformed into TIVFNs. Here, these linguistic variables for appropriateness ratings as well as priority weights assignment against several indices has been expressed in fuzzy numbers by 1-7 scale as pointed out in Tables III-IV, respectively. The procedural steps of the proposed platform benchmarking followed by results of empirical data analysis have been summarized as follows.

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| Goal, $C$ | Measures, $C_i$ | Mertices, $C_{ij}$ |
|---|---|---|
| Evaluation of partner/ supplier | Production and logistics management, $C_1$ | Production volume flexibility, $C_{1,1}$ |
| | | Variety of product/service, $C_{1,2}$ |
| | | Order lead time, $C_{1,3}$ |
| | | Responsiveness to customers' needs, $C_{1,4}$ |
| | | Delivery capacity and reliability, $C_{1,5}$ |
| | Partnership management, $C_2$ | Information available on supplier, $C_{2,1}$ |
| | | Essay communication, $C_{2,2}$ |
| | | Willing to invest in sales training, $C_{2,3}$ |
| | | Data information, $C_{2,4}$ |
| | | Foreign experience, $C_{2,5}$ |
| | Financial sapability, $C_3$ | Technical capability, $C_{3,1}$ |
| | | Knowledge of local business practices, $C_{3,2}$ |
| | | Information systems and communication, $C_{3,3}$ |
| | | Special skills that you can learn from partners, $C_{3,4}$ |
| | Technology and knowledge management, $C_4$ | Variation in price, $C_{4,1}$ |
| | | Rapid market entry, $C_{4,2}$ |
| | | General reputation, $C_{4,3}$ |
| | Marketing capability, $C_5$ | Industry attractiveness, $C_{5,1}$ |
| | | Strategic orientation, $C_{5,2}$ |
| | | Bargaining power or buyers, $C_{5,3}$ |
| | Industrial and organizational competitiveness, $C_6$ | Corporate culture, $C_{6,1}$ |
| | | Human resource management skill, $C_{6,2}$ |
| | | Quality of management team, $C_{6,3}$ |
| | Human resource management, $C_7$ | Learning ability, $C_{7,1}$ |
| | | Organizational leadership, $C_{7,2}$ |
| | | Product and market expertise, $C_{7,3}$ |
| | | Quality of management team, $C_{7,4}$ |

**Source**: Chong and David (2010)

**Table I.** A partner/supplier evaluation module

*Step 1*: collection of expert judgment (in linguistic terms) on account of priority weight and appropriateness rating of individual evaluation indices.

A committee of fives DMs: $DM_1$, $DM_2$, $DM_3$, $DM_4$, $DM_5$ has been constructed. The team members have been instructed to express their subjective preferences (valuation score) in linguistic terms against evaluation indices constructed index shown in Table I. Linguistic preferences have been transformed into IV triangular fuzzy number in accordance with the scale chosen (Tables III-IV). The linguistic data, appropriateness ratings and priority weights of various indices has been assessed by the DMs shown in Tables V-VI), for alternative $A_1$, $A_2$ and $A_3$, $A_4$, respectively.

*Step 2*: approximation of linguistic evaluation information using IV triangular fuzzy numbers.

Using the concept of IVFNs in fuzzy set theory, the linguistic variables have been transformed into corresponding appropriateness fuzzy ratings as well priority

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| Measures,($C_i$) | Definition (refer: bibliography sources) |
|---|---|
| Production and logistics management, $C_1$ | It covers all activities pertain to the supply for production processes and delivery of goods to the distribution warehouse/material receiving enterprises |
| Partnership management, $C_2$ | It is a business strategy for improving communication between companies and their channel partners/supplier |
| Financial capability, $C_3$ | It is a financial ability of partner/supplier firm to supply the material to their partners firm for contracted time |
| Technology and knowledge management, $C_4$ | Technology stands for the capability of a partner to ready the good quality of goods under the limited schedule time. And knowledge management is the exploration of experience and work force skill to lay this task to the effective and appreciable end |
| Marketing capability, $C_5$ | It refers to ability of the partner/supplier to fulfill the turbulence demand of enterprises |
| Industrial and organizational competitiveness, $C_6$ | It is a ability of a partner to offer products and services that meet the quality standards of the local and world markets at reasonable prices |
| Human resource management, $C_7$ | It stands for the management of a workforce or human resources of supplier industry |

**Table II.**
Definition of measures of a partner/supplier evaluation module

| Linguistic variables | Triangular interval-valued fuzzy numbers |
|---|---|
| Very Poor (VP) | [(0,0);0;(1,1.5)] |
| Poor (P) | [(0,0.5);1;(2.5,3.5)] |
| Moderately Poor (MP) | [(0,1.5);3;(4.5,5.5)] |
| Fair (F) | [(2.5,3.5);5;(6.5,7.5)] |
| Moderately Good (MG) | [(4.5,5.5);7;(8,9.5)] |
| Good (G) | [(5.5,7.5);9;(9.5,10)] |
| Very Good (VG) | [(8.5,9.5);10;(10,10)] |

**Table III.**
Definitions of linguistic variables for the appropriateness ratings

| Linguistic variables | Triangular interval-valued fuzzy numbers |
|---|---|
| Very Low (VL) | [(0,0);0;(0.1,0.15)] |
| Low (L) | [(0,0.05);0.1;(0.25,0.35)] |
| Medium Low (ML) | [(0,0.15);0.3;(0.45,0.55)] |
| Medium (M) | [(0.25,0.35);0.5;(0.65,0.75)] |
| Medium High (MH) | [(0.45,0.55);0.7;(0.8,0.95)] |
| High (H) | [(0.55,0.75);0.9;(0.95,1.0)] |
| Very High (VH) | [(0.85,0.95);1.0;(1.0, 1.0)] |

**Table IV.**
Definitions of linguistic variables for the priority weights of each criterion

weights via indicator scale as shown in Tables III-IV). Next, based on simple fuzzy average rule (AFR); aggregated performance ratings and weights has computed for second-level metrics.

Then, Equations (12)-(13), has been followed to obtain the appropriateness rating and priority weights of measures (first-level hierarchy indices).

Thus, the situation appears toward solving a feasible solution from the decision-making matrix, involving a number of alternatives candidate industries corresponding

| Indices, $C_i$ | Alternatives | $C_{ij}$ | Linguistic judgment of the DMs DM$_1$ | DM$_2$ | DM$_3$ | DM$_4$ | DM$_5$ |
|---|---|---|---|---|---|---|---|
| $C_1$ | $A_1$ | $C_{1,1}$ | VG | VG | VG | G | G |
| | | $C_{1,2}$ | G | VG | VG | VG | G |
| | | $C_{1,3}$ | VG | VG | VG | G | G |
| | | $C_{1,4}$ | G | VG | VG | G | VG |
| | | $C_{1,5}$ | VG | VG | VG | G | G |
| | $A_2$ | $C_{1,1}$ | G | MG | G | G | VG |
| | | $C_{1,2}$ | MG | G | G | G | VG |
| | | $C_{1,3}$ | G | MG | G | G | VG |
| | | $C_{1,4}$ | G | MG | G | G | VG |
| | | $C_{1,5}$ | VG | MG | G | G | G |
| | $A_3$ | $C_{1,1}$ | VG | VG | VG | G | G |
| | | $C_{1,2}$ | VG | VG | VG | G | G |
| | | $C_{1,3}$ | G | VG | VG | VG | G |
| | | $C_{1,4}$ | VG | VG | VG | G | G |
| | | $C_{1,5}$ | G | VG | VG | G | VG |
| | $A_4$ | $C_{1,1}$ | VG | VG | G | G | G |
| | | $C_{1,2}$ | G | VG | VG | G | G |
| | | $C_{1,3}$ | G | VG | VG | G | G |
| | | $C_{1,4}$ | VG | G | VG | G | G |
| | | $C_{1,5}$ | G | VG | VG | G | G |
| $C_2$ | $A_1$ | $C_{2,1}$ | G | G | G | MG | MG |
| | | $C_{2,2}$ | MG | G | G | MG | G |
| | | $C_{2,3}$ | MG | G | G | G | MG |
| | | $C_{2,4}$ | G | G | G | MG | MG |
| | | $C_{2,5}$ | G | G | G | MG | MG |
| | $A_2$ | $C_{2,1}$ | G | MG | VG | MG | MG |
| | | $C_{2,2}$ | G | MG | VG | MG | MG |
| | | $C_{2,3}$ | VG | MG | G | MG | MG |
| | | $C_{2,4}$ | G | MG | VG | MG | MG |
| | | $C_{2,5}$ | G | MG | VG | MG | MG |
| | $A_3$ | $C_{2,1}$ | G | VG | VG | VG | VG |
| | | $C_{2,2}$ | VG | VG | G | VG | VG |
| | | $C_{2,3}$ | G | VG | VG | VG | VG |
| | | $C_{2,4}$ | G | VG | VG | VG | VG |
| | | $C_{2,5}$ | VG | G | VG | VG | VG |
| | $A_4$ | $C_{2,1}$ | G | G | G | G | G |
| | | $C_{2,2}$ | G | G | G | G | G |
| | | $C_{2,3}$ | G | G | G | G | G |
| | | $C_{2,4}$ | G | G | G | G | G |
| | | $C_{2,5}$ | G | G | G | G | G |
| $C_3$ | $A_1$ | $C_{3,1}$ | VG | G | MG | F | MP |
| | | $C_{3,2}$ | VG | G | MG | F | MP |
| | | $C_{3,3}$ | G | VG | MG | F | MP |
| | $A_2$ | $C_{3,1}$ | VG | VG | G | G | MG |
| | | $C_{3,2}$ | VG | VG | G | G | MG |
| | | $C_{3,3}$ | VG | VG | G | G | MG |
| | $A_3$ | $C_{3,1}$ | G | G | MG | MG | MG |
| | | $C_{3,2}$ | G | G | MG | MG | MG |
| | | $C_{3,3}$ | G | G | MG | MG | MG |
| | $A_4$ | $C_{3,1}$ | VG | VG | G | G | G |
| | | $C_{3,2}$ | VG | VG | G | G | G |
| | | $C_{3,3}$ | VG | VG | G | G | G |
| $C_4$ | $A_1$ | $C_{4,1}$ | G | VG | MG | VG | G |

(*continued*)

**Table V.** Priority rating against individual second-level indices as given by the DMs

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| Indices, $C_i$ | Alternatives | $C_{ij}$ | Linguistic judgment of the DMs $DM_1$ | $DM_2$ | $DM_3$ | $DM_4$ | $DM_5$ |
|---|---|---|---|---|---|---|---|
| | | $C_{4,2}$ | G | VG | MG | VG | G |
| | | $C_{4,3}$ | VG | VG | MG | G | G |
| | $A_2$ | $C_{4,1}$ | G | G | VG | G | G |
| | | $C_{4,2}$ | VG | G | VG | G | G |
| | | $C_{4,3}$ | G | G | VG | G | G |
| | $A_3$ | $C_{4,1}$ | MG | G | G | F | MG |
| | | $C_{4,2}$ | G | MG | G | F | MG |
| | | $C_{4,3}$ | MG | G | G | F | MG |
| | $A_4$ | $C_{4,1}$ | G | G | VG | G | VG |
| | | $C_{4,2}$ | G | G | VG | G | VG |
| | | $C_{4,3}$ | G | G | VG | G | VG |
| $C_5$ | $A_1$ | $C_{5,1}$ | VG | G | VG | G | G |
| | | $C_{5,2}$ | VG | G | VG | G | G |
| | | $C_{5,3}$ | VG | G | VG | G | G |
| | $A_2$ | $C_{5,1}$ | VG | MG | F | F | MP |
| | | $C_{5,2}$ | MG | VG | F | F | MP |
| | | $C_{5,3}$ | MG | VG | F | F | MP |
| | $A_3$ | $C_{5,1}$ | G | G | G | G | MG |
| | | $C_{5,2}$ | G | G | G | G | MG |
| | | $C_{5,3}$ | MG | G | G | G | G |
| | $A_4$ | $C_{5,1}$ | G | G | MG | MG | MG |
| | | $C_{5,2}$ | G | G | MG | MG | MG |
| | | $C_{5,3}$ | G | G | MG | MG | MG |
| $C_6$ | $A_1$ | $C_{6,1}$ | MG | G | G | G | G |
| | | $C_{6,2}$ | G | G | MG | G | G |
| | | $C_{6,3}$ | MG | G | G | G | G |
| | $A_2$ | $C_{6,1}$ | G | VG | G | G | VG |
| | | $C_{6,2}$ | G | VG | G | G | VG |
| | | $C_{6,3}$ | G | VG | G | G | VG |
| | $A_3$ | $C_{6,1}$ | F | G | G | G | G |
| | | $C_{6,2}$ | F | G | G | G | G |
| | | $C_{6,3}$ | G | G | F | G | G |
| | $A_4$ | $C_{6,1}$ | G | VG | MG | MG | G |
| | | $C_{6,2}$ | G | VG | MG | MG | G |
| | | $C_{6,3}$ | G | VG | MG | MG | G |
| $C_7$ | $A_1$ | $C_{7,1}$ | F | VG | G | G | G |
| | | $C_{7,2}$ | F | VG | G | G | G |
| | | $C_{7,3}$ | VG | F | G | G | G |
| | | $C_{7,4}$ | F | VG | G | G | G |
| | $A_2$ | $C_{7,1}$ | F | G | F | F | MG |
| | | $C_{7,2}$ | F | G | F | F | MG |
| | | $C_{7,3}$ | F | G | F | F | MG |
| | | $C_{7,4}$ | F | G | F | F | MG |
| | $A_3$ | $C_{7,1}$ | G | VG | G | VG | VG |
| | | $C_{7,2}$ | G | VG | G | VG | VG |
| | | $C_{7,3}$ | G | VG | G | VG | VG |
| | | $C_{7,4}$ | G | VG | G | VG | VG |
| | $A_4$ | $C_{7,1}$ | F | MG | F | G | G |
| | | $C_{7,2}$ | MG | F | F | G | G |
| | | $C_{7,3}$ | F | MG | F | G | G |
| | | $C_{7,4}$ | MG | F | F | G | G |

**Table V.**

| Indices, $C_i$ | $C_{ij}$ | Linguistic judgment of the DMs<br>$DM_1$ | $DM_2$ | $DM_3$ | $DM_4$ | $DM_5$ |
|---|---|---|---|---|---|---|
| $C_1$ | $C_{1,1}$ | MH | H | ML | H | H |
| | $C_{1,2}$ | MH | H | ML | H | H |
| | $C_{1,3}$ | H | MH | ML | H | H |
| | $C_{1,4}$ | MH | H | ML | H | H |
| | $C_{1,5}$ | H | H | ML | MH | H |
| $C_2$ | $C_{2,1}$ | H | VH | H | M | VH |
| | $C_{2,2}$ | VH | H | H | VH | VH |
| | $C_{2,3}$ | H | VH | H | M | VH |
| | $C_{2,4}$ | VH | H | H | M | VH |
| | $C_{2,5}$ | H | VH | H | VH | VH |
| $C_3$ | $C_{3,1}$ | VH | ML | H | M | VH |
| | $C_{3,2}$ | VH | ML | H | M | VH |
| | $C_{3,3}$ | VH | ML | H | M | VH |
| $C_4$ | $C_{4,1}$ | ML | H | H | M | H |
| | $C_{4,2}$ | ML | H | H | M | H |
| | $C_{4,3}$ | ML | H | H | M | H |
| $C_5$ | $C_{5,1}$ | VH | MH | VH | H | H |
| | $C_{5,2}$ | VH | MH | VH | H | H |
| | $C_{5,3}$ | VH | MH | VH | H | H |
| $C_6$ | $C_{6,1}$ | H | H | H | H | H |
| | $C_{6,2}$ | H | H | H | H | H |
| | $C_{6,3}$ | H | H | H | H | H |
| $C_7$ | $C_{7,1}$ | H | H | H | VH | VH |
| | $C_{7,2}$ | H | H | H | VH | VH |
| | $C_{7,3}$ | VH | H | H | H | VH |
| | $C_{7,4}$ | VH | H | H | H | VH |

**Table VI.** Priority weight against individual second-level indices as given by the DMs

to a set of evaluation criteria:

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_2 & C_4 & C_5 \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} \end{bmatrix} \end{array}$$

*Step 3*: normalization. All of the indices have been assumed benefit in nature and expressed in terms of IV triangular fuzzy numbers but ranges of normalized interval numbers fall within the interval [0, 1]. Therefore, normalization has been led by exploring Equations (14)-(15).

*Step 4*: construction of weighted normalized decision matrix.

The weighted normalized IV fuzzy decision matrix has been found out in consideration with different importance of each measure/indices assessed by DMs; we have constructed the weighted normalized fuzzy decision matrix by exploring Equations (16)-(18), and the normalized weighted matrix has been furnished in Table VII.

*Step 5*: determination of PIS and NIS.

All of the performance indices/metrics have been assumed beneficial in nature and computation of positive ideal $A^*$ and NISs $A^-$ has been carried out by using Equations (19)-(20). Results have been pointed out in Table VIII.

*Step 6*: ideal separation matrix ($d^*$) and anti-ideal separation matrix ($d^-$).

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Table VII.
Computed weighted normalized fuzzy decision matrix

| Indices, $C_i$ | Alternatives | Weights normalized matrix |
|---|---|---|
| $C_1$ | $A_1$ | [(0.307,0.513);0.710;(0.804,0.900)] |
| | $A_2$ | [(0.248,0.443);0.651;(0.763,0.891)] |
| | $A_3$ | [(0.307,0.513);0.710;(0.804,0.900)] |
| | $A_4$ | [(0.281,0.490);0.696;(0.795,0.900)] |
| $C_2$ | $A_1$ | [(0.311,0.503);0.705;(0.810,0.931)] |
| | $A_2$ | [(0.336,0.503);0.688;(0.792,0.922)] |
| | $A_3$ | [(0.482,0.683);0.843;(0.901,0.950)] |
| | $A_4$ | [(0.336,0.563);0.774;(0.865,0.950)] |
| $C_3$ | $A_1$ | [(0.176,0.303);0.462;(0.593,0.723)] |
| | $A_2$ | [(0.273,0.435);0.612;(0.724,0.842)] |
| | $A_3$ | [(0.206,0.347);0.530;(0.662,0.825)] |
| | $A_4$ | [(0.281,0.457);0.639;(0.747,0.850)] |
| $C_4$ | $A_1$ | [(0.247,0.435);0.630;(0.743,0.851)] |
| | $A_2$ | [(0.232,0.435);0.644;(0.758,0.860)] |
| | $A_3$ | [(0.171,0.325);0.518;(0.656,0.800)] |
| | $A_4$ | [(0.255,0.457);0.658;(0.766,0.860)] |
| $C_5$ | $A_1$ | [(0.436,0.656);0.846;(0.912,0.990)] |
| | $A_2$ | [(0.234,0.371);0.540;(0.667,0.792)] |
| | $A_3$ | [(0.345,0.561);0.774;(0.865,0.980)] |
| | $A_4$ | [(0.319,0.498);0.702;(0.808,0.960)] |
| $C_6$ | $A_1$ | [(0.292,0.533);0.774;(0.874,0.990)] |
| | $A_2$ | [(0.369,0.623);0.846;(0.922,1.000)] |
| | $A_3$ | [(0.270,0.503);0.738;(0.846,0.950)] |
| | $A_4$ | [(0.314,0.533);0.756;(0.855,0.980)] |
| $C_7$ | $A_1$ | [(0.369,0.589);0.790;(0.873,0.950)] |
| | $A_2$ | [(0.235,0.390);0.583;(0.718,0.840)] |
| | $A_3$ | [(0.489,0.722);0.902;(0.951,1.000)] |
| | $A_4$ | [(0.275,0.457);0.658;(0.776,0.890)] |

We computed ideal separation matrix ($d^*$) and anti-ideal separation matrix ($d^-$) with the help of Equations (21)-(26) and absolute value from Definition 5 to convert the matrix into a scrip value matrix as shown in Table IX.

*Step 7*: computation of values $\Gamma_i$, $\varsigma_i$ and $\mathrm{CI}_i$.

The values of $\Gamma_i$, $\varsigma_i$ and $\mathrm{CI}_i$ have been computed using Equations (27)-(29), and presented in Table X and Figure 3.

*Step 8*: determination of the final ranking order of alternative industries.

Finally, ranking order brought in accordance to ascending value of CI. Consequence showed that third partner alternative ($A_3$) should be best choice as per the assessments of DMs; whereas, the fourth alternative ($A_4$) is the second-best choice. The second alternative ($A_2$) is the third-best choice at the other end of spectrum, third alternative ($A_1$) is the worst choice from the prospective of selection.

## 8. Managerial implication

In this reporting, subjectivity of appropriateness rating as well as priority weight against supplier/partner evaluation criterions/indices have been assessed by expert panels which have finally been tackled by exploiting IVFNS theory conjunction with modified TOPSIS methodology. This methodology observed to be of quite efficient, simple and flexible of solving such a MCDM problem which dealt with the subjective evaluation information in an efficient manner.

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| Indices, $C_i$ | Alternatives | Positive ideal solution | Negative ideal Solutions |
|---|---|---|---|
| $C_1$ | $A_1$ | [(0.73,0.87);0.96;(0.98,1)] | [(0.59,0.75);0.88;(0.93,0.99)] |
| | $A_2$ | | |
| | $A_3$ | | |
| | $A_4$ | | |
| $C_2$ | $A_1$ | [(0.79,0.91);0.98;(0.99,1)] | [(0.51,0.67);0.8;(0.87,0.97)] |
| | $A_2$ | | |
| | $A_3$ | | |
| | $A_4$ | | |
| $C_3$ | $A_1$ | [(0.67,0.83);0.94;(0.97,1)] | [(0.42,0.55);0.68;(0.77,0.85)] |
| | $A_2$ | | |
| | $A_3$ | | |
| | $A_4$ | | |
| $C_4$ | $A_1$ | [(0.67,0.83);0.94;(0.97,1)] | [(0.45,0.59);0.74;(0.83,0.93)] |
| | $A_2$ | | |
| | $A_3$ | | |
| | $A_4$ | | |
| $C_5$ | $A_1$ | [(0.67,0.83);0.94;(0.97,1)] | [(0.36,0.47);0.6;(0.71,0.80)] |
| | $A_2$ | | |
| | $A_3$ | | |
| | $A_4$ | | |
| $C_6$ | $A_1$ | [(0.67,0.83);0.94;(0.97,1)] | [(0.49,0.67);0.82;(0.89,0.95)] |
| | $A_2$ | | |
| | $A_3$ | | |
| | $A_4$ | | |
| $C_7$ | $A_1$ | [(0.73,0.87);0.96;(0.98,1)] | [(0.35,0.47);0.62;(0.74,0.84)] |
| | $A_2$ | | |
| | $A_3$ | | |
| | $A_4$ | | |

**Table VIII.** Computed positive ideal and negative ideal solutions

The main aim of this research to facilitate the managers of individual firm from DSS (multi criterion hierarchical index/modules couple with IVFNS-TOPSIS method) in order that, managers can evaluate-select the best supplier/partner for own firm under uncertain agile SC indices.

## 9. Conclusions

Fuzzy multi-indices analysis under the group decision-making process provides an effective efficient way to modeling a multiple indices framework for the appraisement and selection of best alternatives. ASCM is the combine of agile conception and SCM, which makes enterprises work together through collaborative manage and improves the agility enterprises, even whole SCM. This paper considered multiple subjective performance indices for the appraisement of appropriate supplier/partner in ASC. Due to fuzziness associated with DMs (expert panel) subjective evaluation; this paper utilized an approach based on IV fuzzy set theory combined with TOPSIS method. The contribution of this research has been the exploration of IVFNs in conjunction with modified TOPSIS analytical methodology toward appraisement of appropriate supplier/partner in ASC. The proposed methodology enables the committee to incorporate and aggregate multiple fuzzy information assessed by DMs regarding multiple information attributes. The case study depicts fruitfulness of the said approach. This approach can also be applied to any MCDM problem which involves

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| Indices, $C_i$ | Alternatives | ($d^*$) | ($d^-$) |
|---|---|---|---|
| $C_1$ | $A_1$ | 0.270 | 0.410 |
| | $A_2$ | 0.990 | 0.990 |
| | $A_3$ | 1.000 | 1.000 |
| | $A_4$ | 1.000 | 1.000 |
| $C_2$ | $A_1$ | 0.490 | 0.470 |
| | $A_2$ | 0.970 | 0.970 |
| | $A_3$ | 1.000 | 1.000 |
| | $A_4$ | 1.000 | 1.000 |
| $C_3$ | $A_1$ | 0.580 | 0.430 |
| | $A_2$ | 0.990 | 0.990 |
| | $A_3$ | 0.970 | 0.970 |
| | $A_4$ | 1.000 | 0.970 |
| $C_4$ | $A_1$ | 0.350 | 0.540 |
| | $A_2$ | 1.000 | 1.000 |
| | $A_3$ | 0.930 | 0.930 |
| | $A_4$ | 1.000 | 1.000 |
| $C_5$ | $A_1$ | 0.330 | 0.640 |
| | $A_2$ | 0.800 | 0.800 |
| | $A_3$ | 0.990 | 0.990 |
| | $A_4$ | 0.970 | 0.970 |
| $C_6$ | $A_1$ | 0.320 | 0.500 |
| | $A_2$ | 1.000 | 1.000 |
| | $A_3$ | 0.950 | 0.950 |
| | $A_4$ | 0.980 | 0.980 |
| $C_7$ | $A_1$ | 0.450 | 0.600 |
| | $A_2$ | 0.840 | 0.840 |
| | $A_3$ | 1.000 | 1.000 |
| | $A_4$ | 0.890 | 0.890 |

**Table IX.** Computed positive ideal separation matrix ($d^*$)and anti-ideal separation matrix ($d^-$)

| Alternatives | $\Gamma_i$ | $\varsigma_i$ | $\mathrm{CI}_i$ | Ranking order |
|---|---|---|---|---|
| $A_1$ | 0.801 | 2.395 | 3.195 | *4.00* |
| $A_2$ | 1.000 | 2.012 | 3.012 | *3.00* |
| $A_3$ | 1.000 | 2.001 | 3.001 | *1.00* |
| $A_4$ | 1.004 | 2.007 | 3.011 | *2.00* |

**Table X.** Computed values of $\Gamma_i$, $\varsigma_i$ and $\mathrm{CI}_i$ by proposed IVFN-TOPSIS method

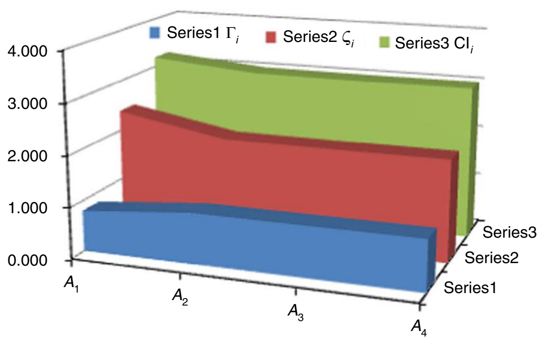


**Figure 3.** Bar chart analysis depicted ranking order in accordance with computed values of $\Gamma_i$, $\varsigma_i$ and $\mathrm{CI}_i$

uncertainty as well as vagueness due to subjectivity of the evaluation criterions. Finally, an empirical study has led in order to exhibit finally; an empirical study has led in order to exhibit the feasibility, effectiveness and validity of the proposed methodology revealed in Figure 3. The main contributions of the aforesaid research have been highlighted below:

(1) developed a "novel average fuzzy rule-based equation" in perceptive to direct compute an priority weights and appropriateness rating of first-level measures; which reduced the need to collect the extra subjective information on contrary of first-level measures from expert panels;

(2) explored of IVFNs in conjunction with modified TOPSIS methodology toward appraisement and evaluation-selection of appropriate supplier/partner in ASC context;

(3) adaptated the subjective indices dealt with uncertainty which tackled by DM perceptions; and

(4) developed the MCDM module for appraisement and selection of appropriate supplier/partner in ASC context.

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