An integrated approach of Fuzzy AHP and Fuzzy TOPSIS in modeling supply chain coordination

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In improving overall supply chain performance, coordination of supply chain of trading partner plays a crucial role. For allocating the components or services to trading partner, it would be significant to analyze level of coordination in their supply chain. This paper presents how Analytic Hierarchy Process and Technique for Order Preference by Similarity to Ideal Solution in Fuzzy environment can be integrated for a more consistent evaluation and prioritization of trading partner based on four coordination criteria namely joint decision-making, information sharing, use of information technology tools, and resource sharing determined by factor analysis of survey data and expert opinion. A case study of Indian automotive parts manufacturing company is described to illustrate the application of the proposed method. Fuzzy AHP is used to calculate relative weights of each coordination criterion and then partners are ranked based on closeness coefficient, calculated for each partner using Fuzzy TOPSIS.

Keywords: supply chain coordination; partner prioritization; Fuzzy logic; Fuzzy AHP; Fuzzy TOPSIS.

1. Introduction

A supply chain consists of a number of organizations acting together with each organization dependent on performance of other organizations in the chain. There are different people, entities, and process in a supply chain interacting with each other to achieve supply chain objectives. Each member of supply chain needs to perform specific functions or activities in value addition process. Performance of supply chain could be improved if supply chain is integrated and the concerned activities are properly coordinated. Supply chain coordination plays a critical role in integrating different actors of any supply chain resulting in enhancement in its performance. There are number of mechanisms by which the supply chain partners can coordinate with each other. With the global competition, managing uncertainties and complexities to coordinate supply chain is a challenging task. Partner prioritization in a supply chain is a multi-criteria decision problem and has important role in chain performance. The conventional methods of partner selection have limitation in dealing with the imprecise or vague nature of linguistic assessment. To overcome this limitation, Fuzzy multi-criteria decision-making method is adopted. In this paper, a methodology is proposed to prioritize trading partner.
based on coordination mechanisms using multi-criteria decision-making in the Fuzzy environment.

This paper illustrates how Fuzzy AHP and Fuzzy TOPSIS can be integrated to allow for a more consistent evaluation and prioritization of supply chain partner. The methodology is demonstrated through a case study of an automotive parts manufacturer in India. After determining the coordination criteria, Fuzzy AHP and Fuzzy TOPSIS methods are applied to the problem and results are presented.

2. Literature review

Coordination across supply chain includes integrated planning and control over all inter-organizational processes and activities in the supply chain (Stock, Greis, & Kasarda, 2000). Main objective of supply chain coordination is to coordinate the independent players to work together as a whole to pursue the common goal of chain profitability in changing market conditions. Supply chain coordination can be defined as identifying interdependent supply chain activities between supply chain members and develop mechanisms for managing them (Arshinder, Kanda, & Deshmukh, 2008). Coordination is realized when a decision-maker in the supply chain, acting rationally, makes decisions that are efficient for the supply chain as a whole (Gupta & Weerawat, 2006). The purpose of coordination in a supply chain is to align all the activities working jointly as a unified system and then stimulate the overall supply chain performance (Arshinder et al., 2008). Importance of coordination has been realized by many authors for organizations to streamline supply chain operations, identify interdependencies and mutually define goals, to share risks and rewards, access to resources, and to gain competitive advantage (Arshinder, Kanda, & Deshmukh, 2006; Chopra & Meindl, 2004; Min, 2001). Coordination mechanisms offer tools to execute supply chain objectives by successfully managing interactions between people, processes, and entities for improving overall system performance (Fugate, Sahin, & Mentzer, 2006; Li & Wang, 2007; Xu & Beamon, 2006). There are number of mechanisms by which the supply chain partners may coordinate with each other. The appropriate use of coordination mechanisms is expected to increase efficiency and effectiveness in the operations, the actors, and the supply chain (Sandberg & Bildsten, 2011). Therefore, the selection of supply chain coordination mechanisms (SCCMs) essentially has impact on the performance of the whole supply chain. Because of the multi-dimensional criteria, the selection of appropriate SCCM in a given situation remains a difficult task for supply chain managers. This paper is an attempt to explore various issues pertaining to supply chain coordination and use integrated approach of Fuzzy AHP and Fuzzy TOPSIS to prioritize coordination mechanisms and then prioritize trading partner based on coordination mechanisms.

2.1. Fuzzy Logic

To manage vagueness and uncertainty in decision-making, Zadeh (1965) proposed Fuzzy set theory. Modeling using Fuzzy sets has proven to be an effective way for formulating decision problems, where the information available is subjective and imprecise (Zimmermann, 1992). Fuzzy numbers stand for a specific range for a specific value. Due to this specific range, it is easier for the evaluator to indicate his/her preference. The preference of the expert is in many practical cases is uncertain, which makes it difficult to make a numerical comparison (Torfi, Farahani, & Rezapour, 2010). In short, a single linguistic rating will be translated into a Fuzzy number consisting of multiple
numbers. This way, the linguistic rating is reflected as a range. Both triangular and trapezoidal Fuzzy numbers can be used for Fuzzy theory. Balli and Korukoglu (2009) argue that it is often convenient to use triangular Fuzzy numbers (TFNs) because of the ease of computation. In present application, it is often convenient to work with TFNs because of their computational simplicity, and they are useful in promoting representation and information processing in a Fuzzy environment. TFNs can be defined as a triplet \((l, m, u)\), where the parameters \(l\), \(m\), and \(u\), respectively, indicate the smallest possible value, the most promising value, and the largest possible value that describe a Fuzzy event and the membership function can be defined by Equation (1) (Chang, 1996).

\[
\mu_M(x) = \begin{cases} 
0 & x < l; \\
\frac{x-l}{m-l} & l \leq x \leq m; \\
\frac{m-x}{u-m} & m \leq x \leq u; \\
0 & x > u. 
\end{cases}
\]

(1)

Deng (1999) discusses this mathematical representation of a TFN \(M\) that is depicted by Balli and Korukoglu (2009) as shown in Figure 1.

Next sections present an overview of both techniques including important steps and previous applications of these in the research work.

2.2. Fuzzy analytic hierarchy process (FAHP)

To overcome conventional AHP limitations, Van Laarhoven and Pedrycz (1983) proposed FAHP, which is the combination of analytic hierarchy process (AHP) and Fuzzy theory. Fuzzy AHP makes it possible to use linguistic ratings in the calculations by giving it a certain range. It is observed that decision-makers are more positive to give interval judgments than fixed-value judgments (Buyukozkan & Ruan, 2008). Balli and Korukoglu (2009) recognize that fuzziness in AHP contributes by being able to represent vague data. There are numerous studies, which applied the Fuzzy AHP in various applications. Chang (1996) introduces an approach for handling Fuzzy AHP, with the

Figure 1. A triangular Fuzzy number.
use of TFNs for pairwise comparison scale of Fuzzy AHP, and the use of the extent analysis method for determining synthetic extent values of the pairwise comparisons. Wang and Yang (2009) investigate supplier selection in a quantity discount environment using multi-objective linear programming, which involve AHP and Fuzzy theory. Lee (2009) used FAHP for supplier selection with the consideration of benefits, opportunities, costs, and risks. Mehdi, Hamid, and Hossein (2010) used Fuzzy AHP for selecting engineering partners. Ramík and Perzina (2010) introduced an extension of the AHP with feedback between criteria. Kilincci and Onal (2011) utilized Fuzzy AHP approach for supplier selection in a washing machine company. It seems to be first time to use integrated approach of Fuzzy AHP and Fuzzy TOPSIS in prioritizing trading partners based on coordination mechanisms criteria. In the research work, Chang’s (1992) extent analysis on Fuzzy AHP is used for selecting trading partners to improve coordination in supply. The outlines of the Chang’s extent analysis method on Fuzzy AHP used to compute relative weight of the each criterion has been explained in the following section.

2.2.1. Chang’s extent analysis

Let $X = \{x_1, x_2, x_3, \ldots, x_n\}$ an object set and $G = \{g_1, g_2, g_3, \ldots, g_n\}$ be a goal set. According to the method of Chang’s (1992) extent analysis, each criterion is taken and extent analysis for each goal $g_i^*$ is performed, respectively. Therefore, $m$ extent analysis values for each criterion can be obtained using following notation (Kahraman et al., 2004); $M_{g_1}^1, M_{g_2}^2, M_{g_3}^3, M_{g_4}^4, \ldots, M_{g_n}^m$, where $g_i$ is the goal set ($i = 1, 2, 3, 4, 5, \ldots, n$) and $M_{g_i}^j$ ($j = 1, 2, 3, 4, 5, \ldots, m$), All are TFNs. The steps of Chang’s extent analysis are illustrated as the following, from Equations (2)–(9).

**Step 1:** The value of Fuzzy synthetic extent value ($S_i$) with respect to the $i$th criterion is defined as

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \odot \left[ \sum_{j=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} \quad (2)$$

To obtain equation $\sum_{j=1}^{m} M_{g_i}^j$, the Fuzzy addition operation of $m$ extent analysis values for a particular matrix is performed such as:

$$\sum_{j=1}^{m} M_{g_i}^j = \left( \sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \quad (3)$$

where $l$ is the lower limit value, $m$ is the most promising value, and $u$ is the upper limit value and to obtain $\left[ \sum_{j=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1}$. Perform the ‘Fuzzy addition operation’ of $M_{g_i}^j (j = 1, 2, 3, 4, 5, \ldots, m)$ values as given below $\sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j = (\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i)$. and then the inverse of the vector is computed, such as

$$\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1} = \left( \frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (4)$$

**Step 2:** As $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two TFNs, the degree of possibility of $M_2 \geq M_1 = (l_1, m_1, u_1)$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} [\min(\mu_{M_1}(x), \mu_{M_2}(y))] \quad (5)$$
\(x\) and \(y\) are the values on the axis of membership function of each criterion. This expression can be equivalently written as given in equation below:

\[
V(M_2 \geq M_1) = \begin{cases} 
1, & \text{if } m_2 \geq m_1, \\
0, & \text{if } l_1 \geq u_2, \\
\frac{l_1 - u_2}{m_2 - u_2 - (m_1 - l_1)}, & \text{otherwise}
\end{cases}
\] (6)

To compare \(M_1\) and \(M_2\), we need both the values of \(V(M_2 \geq M_1)\) and \(V(M_1 \geq M_2)\)

Step 3: The degree possibility for a convex Fuzzy number to be greater than \(k\) convex Fuzzy numbers \(M_i (i = 1, 2, 3, 4, 5, \ldots, k)\) can be defined by

\[
V(M \geq M_1, M_2, M_3, M_4, M_5, M_6, \ldots, M_k) = V[(M \geq M_1) \land (M \geq M_2) \land (M \geq M_3) \land (M \geq M_4) \land \ldots \land (M \geq M_k)] = \min_i V(M \geq M_i), i = 1, 2, 3, 4, 5, \ldots, k.
\] (7)

Assume that \(d'(C_i) = \min V(S_i \geq S_k)\) for \(k = 1, 2, 3, 4, 5, \ldots, n; k \neq i\), then the weight vector is given by

\[
W' = [d'(C_1), d'(C_2), d'(C_3), d'(C_4), d'(C_5), \ldots, d'(C_n)]^T
\] (8)

where \(C_i (i = 1, 2, 3, 4, 5, 6, \ldots, n)\) are \(n\) elements

Step 4: via normalization, the normalized weight vectors are given in Equation (9),

\[
W = [d(C_1), d(C_2), d(C_3), d(C_4), d(C_5), \ldots, d(C_n)]
\] (9)

where \(W\) is non-Fuzzy numbers and \(d\) is the coordinate of highest intersection point \(D\) between \(\mu_{M_1}\) and \(\mu_{M_2}\) (see Figure 2).

### 2.3. Fuzzy TOPSIS technique

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was first proposed by Hwang and Yoon (1981) and a Fuzzy TOPSIS method was later introduced by Chen and Hwang (1992). The basic idea for Fuzzy TOPSIS is to choose the alternative, which is as close to the positive ideal solution as possible and as far from the negative ideal solution as possible. The positive ideal solution is a solution with maximized

![Figure 2. The intersection between two TFNs (Chang, 1996)](image)
benefit criteria and minimized cost criteria. The negative ideal solution is a solution, where the cost criteria are maximized and benefit criteria are minimized. According to Chan and Kumar (2007), there are many real-life situations where human preference is uncertain and decision-makers might be reluctant or unable to assign crisp values to their judgments. The Fuzzy extended TOPSIS approach is capable of dealing with multi-criteria decision-making by translating the linguistic values into Fuzzy numbers and thereby allowing decision-makers to incorporate incomplete or unavailable information into the decision model (Kulak & Kahraman, 2005; Onut & Soner, 2007).

There are many applications of Fuzzy TOPSIS in the literature. Chen, Lin, and Huang (2006) developed a Fuzzy decision-making method to cope with the supplier selection problem in the supply chain system. Wang and Chang (2007) used TOPSIS for evaluating initial training aircraft. Abo-Sinna, Amer, and Ibrahim (2008) extended the TOPSIS for large-scale multi-objective non-linear programming problems. Torfi et al., (2010) used Fuzzy AHP and Fuzzy TOPSIS to evaluate the alternative options in respect to the user’s preference orders. Kara (2011) used Fuzzy TOPSIS and two-stage stochastic programming for supplier selection. In most of the real-life situations, the data are not so deterministic, it is imprecise or Fuzzy in nature. So, an extended TOPSIS for Fuzzy data as proposed by Chen (2000) and Chen et al. (2006) is discussed below.

The algorithm of the Fuzzy TOPSIS method can be described as follows:

**Step 1:** Form a committee of expert to evaluate the alternatives.

**Step 2:** Identify the evaluation criteria.

**Step 3:** Choose the appropriate linguistic variables for evaluating alternatives with respect to identified criteria.

**Step 4:** Determine the aggregated weight of alternatives with respect to each criterion. If the Fuzzy rating of all decision-makers are described as TFNs $\tilde{R}_k = (a_k, b_k, c_k)$, $k = 1, 2, 3, \ldots K$, then the aggregated Fuzzy rating can be determined as $R = (a, b, c)$, $k = 1, 2, 3, \ldots K$. Here, $a = \min_k (a_k)$, $b = \frac{1}{K} \sum_{k=1}^{K} b_k$, $c = \max_k (c_k)$.

**Step 5:** Construct the Fuzzy decision matrix.

**Step 6:** Normalized the Fuzzy decision matrix. For normalization, the linear-scale transformation can be used to transform the various criteria scales into a comparable scale. We can obtain normalized Fuzzy decision matrix $\tilde{R}$ (Chen, 2000).

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad i = 1, 2, 3, \ldots, m; \quad j = 1, 2, 3, \ldots, n$$

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

**Step 7:** Construct weighted normalized Fuzzy decision matrix.

Considering the different weight of each criterion, the weighted normalized decision matrix is computed by multiplying the important weight of evaluation criteria in the normalized Fuzzy decision matrix. The weighted normalized decision matrix $V$ is defined as

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad i = 1, 2, \ldots, m \quad \text{and} \quad j = 1, 2, \ldots, n$$

$\tilde{v}_{ij} = \tilde{r}_{ij} W$, where $W$ is the weighted vector of evaluating criteria.

**Step 8:** Determine the Fuzzy positive ideal solution (FPIS) and Fuzzy negative ideal solution (FNIS) as (Chen et al., 2006):
FPIS($P^*$) = ($\tilde{V}_1^*$, $\tilde{V}_2^*$, $\tilde{V}_3^*$, ..., $\tilde{V}_n^*$) and FNIS($P^-$) = ($\tilde{V}_1^-$, $\tilde{V}_2^-$, $\tilde{V}_3^-$, ..., $\tilde{V}_n^-$)

where $\tilde{V}_j^* = \max_i \{v_{ijk}\}$ and $\tilde{V}_j^- = \min_i \{v_{ijk}\}$; $i = 1, 2, ..., m; j = 1, 2, ..., n$.

Step 9: Calculate the distance of each alternative from FPIS and FNIS as

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, v_j^*); \quad i = 1, 2, 3, ..., m$$

and

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, v_j^-); \quad i = 1, 2, 3, ..., m$$

where $d_v$ is the distance measurement between two Fuzzy numbers.

Step 10: Calculate the closeness coefficient for each alternative Closeness Coefficient ($CC_i$) is defined as rank alternatives. The closeness coefficient represents the distance to the FPIS ($P^*$) and Fuzzy negative ideal solution ($P^-$). The closeness coefficient for each alternative is calculated as (Chen, 2000).

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*}, \quad i = 1, 2, 3, ..., m.$$  

Step 11: Rank the alternatives according to their closeness coefficient. According to the closeness coefficient, the ranking of the alternatives can be determined. According to equation, $CC_i = \frac{d_i^-}{d_i^- + d_i^*}$

A$_i$ would be closer to FPIS and farther from FNIS as $CC_i$ approaches to one.

3. Materials and methods

Supply chain coordination mechanisms manage the dependencies and uncertainties between supply chain members that may improve the performance of supply chain. A coordination mechanism is a set of methods used to manage interdependencies between organizations (Xu & Beamon, 2006). Coordination mechanisms provide tools for effectively managing interactions between people, processes, and entities that interact in order to execute common goals. Model proposed in the present work consists of integration of two methods one is Fuzzy AHP and another is Fuzzy TOPSIS. Fuzzy AHP is used to determine weights of decision criteria and Fuzzy TOPSIS in integration with Fuzzy AHP provides overall prioritization of alternatives.

3.1. Identification of decision-making criteria

In this paper, a questionnaire survey is used for data collection. Based on the review of literature and field visit of manufacturing organizations, coordination-related issues have been identified for survey and one of them is reported here. Twenty criteria are listed in the questionnaire for judging coordination level in the supply chain. Based on factor analysis and expert opinion, four coordination criteria namely joint decision-making (JDM), information sharing, use of information technology tools, and resource sharing are used for evaluating coordination in supply chain. The researchers performed factor analysis for supply chain coordination criteria. Factor analysis is often used in data reduction to identify a small number of factors that explain most of the variance that is observed in a much larger number of noticeable variables. Before starting factor analysis, communalities need to be checked for meeting minimum criteria. The factor solution should explain at least half of each original variable’s variance, so the communality value for each variable should be .50 or higher. The values of communalities are shown in Table 1.
Table 1. Communalities.

| Variable                                      | Initial | Extraction |
|-----------------------------------------------|---------|------------|
| Joint decision-making                        | 1.000   | .794       |
| Information sharing                          | 1.000   | .892       |
| Flexibility                                  | 1.000   | .603       |
| Effective communication                      | 1.000   | .823       |
| Standardization of rules                     | 1.000   | .689       |
| Flexible return policies                     | 1.000   | .685       |
| Risk and reward sharing                      | 1.000   | .838       |
| Resource sharing                             | 1.000   | .854       |
| Quantity discount                            | 1.000   | .863       |
| Plans and schedules                          | 1.000   | .646       |
| Incentive mechanisms                         | 1.000   | .817       |
| Credit scheme                                | 1.000   | .803       |
| Contracts                                    | 1.000   | .677       |
| Joint cost minimization                      | 1.000   | .709       |
| Collective learning                          | 1.000   | .723       |
| Knowledge sharing                            | 1.000   | .490       |
| Uses of information technology tools         | 1.000   | .689       |
| Order coordination                           | 1.000   | .815       |
| Performance monitoring                       | 1.000   | .733       |
| Scheduling of frequent meetings with stakeholders | 1.000 | .759       |

Note: Extraction method: Principal Component Analysis.

Table 2. Total variance explained by initial solution.

| Component | Initial Eigenvalues |
|-----------|---------------------|
| Component | Total               | % of variance | Cumulative % |
| 1         | 6.924               | 34.619       | 34.619       |
| 2         | 3.174               | 15.872       | 50.491       |
| 3         | 1.918               | 9.592        | 60.083       |
| 4         | 1.676               | 8.382        | 68.465       |
| 5         | 1.235               | 6.177        | 74.642       |
| 6         | .909                | 4.543        | 79.185       |
| 7         | .865                | 4.323        | 83.508       |
| 8         | .815                | 4.077        | 87.585       |
| 9         | .505                | 2.524        | 90.109       |
| 10        | .446                | 2.230        | 92.339       |
| 11        | .305                | 1.524        | 93.863       |
| 12        | .256                | 1.282        | 95.144       |
| 13        | .214                | 1.069        | 96.213       |
| 14        | .181                | .904         | 97.118       |
| 15        | .170                | .849         | 97.967       |
| 16        | .110                | .551         | 98.518       |
| 17        | .094                | .472         | 98.990       |
| 18        | .090                | .449         | 99.439       |
| 19        | .076                | .382         | 99.821       |
| 20        | .036                | .179         | 100.000      |

Note: Extraction method: Principal Component Analysis.
Here, principal component method with varimax rotation has been applied. It gives loading for each combination of variables and loading factors. Higher loadings mark a higher correlation between variable and factor. The variance explained by the initial solution, extracted solution, and rotated components solutions are displayed in Tables 2–4, respectively.

In the extracted sums of squared loadings, column shows cumulative percentage of variance of extracted components. Approximately, 75% of variability in the original 20 variables can be presented by these extracted five components; this considerably reduces the complexity of further data analysis.

The rotation maintains the cumulative percentage of variation explained by the extracted components, but that variation is now spread more evenly over the components. The large changes in the individual totals suggest that the rotated component matrix will be easier to interpret than the unrotated matrix. Rotation Sums of Squared Loadings are shown in the Table 4.

The Scree plot (shown in Figure 3) helps you to determine the optimal number of components. The eigenvalues of each component in the initial solution are plotted. Generally, the components on the steep slope need to be extracted. The components on the shallow slope contribute little to the solution. The last big drop occurs between the third and fourth components, so using the first five components is an easy choice.

In practice, interpretation of factors is difficult because they are correlated with several variables at a time, but with redistribution of variables, factors become interpretable. Rotation reduces the number of variables correlated with a given factor, but at the same time maximizes the size of correlation with a given factor. Here, we have used the Varimax rotation with Kaiser Normalization as a rotation method. Varimax rotation is an orthogonal rotation method that minimizes the number of variables that have high loadings on each factor. This method simplifies the interpretation of the factors and helps to

| Component | Initial Eigenvalues cumulative % | Extraction sums of squared loadings |
|-----------|-----------------------------------|-----------------------------------|
| 1         | 34.619                            | 6.924                             |
| 2         | 50.491                            | 3.174                             |
| 3         | 60.082                            | 1.918                             |
| 4         | 68.465                            | 1.676                             |
| 5         | 74.641                            | 1.235                             |

Note: Extraction method: Principal Component Analysis.

Table 3. Total variance explained by extracted solution.

| Component | Rotation sums of squared loadings |
|-----------|-----------------------------------|
| 1         | 3.990                             |
| 2         | 3.412                             |
| 3         | 3.241                             |
| 4         | 2.359                             |
| 5         | 1.927                             |

Note: Extraction method: Principal Component Analysis.

Table 4. Total variance explained by rotated component solution.
identify which variables are loaded on which component. The rotated component matrix (shown in Table 5) helps to determine what the components represent.

Table 5. Loading of components in rotated matrix.

| Rotated component matrix$^a$ | 1    | 2    | 3    | 4    | 5    |
|-------------------------------|------|------|------|------|------|
| Joint decision-making         | .101 | .853 | .176 | .057 | -.149|
| Information sharing           | .025 | .906 | .152 | .205 | .072 |
| Flexibility                   | .522 | .552 | .156 | .160 | -.062|
| Effective communication       | .861 | .199 | .159 | .104 | -.077|
| Standardization of rules      | .403 | .423 | .516 | -.227| .174 |
| Flexible return policies      | -.011| .327 | .410 | .410 | .492 |
| Risk and reward sharing       | .030 | .214 | .105 | .841 | .271 |
| Resource sharing              | .325 | .223 | .127 | .826 | .014 |
| Quantity discount             | .713 | -.248| .233 | .486 | .045 |
| Plans and schedules           | .762 | -.018| .130 | .186 | .112 |
| Incentive mechanisms          | .594 | .426 | -.247| .130 | .452 |
| Credit scheme                 | .680 | -.066| -.470| -.128| .316 |
| Contracts                     | .307 | -.060| .572 | .061 | .498 |
| Joint cost minimization       | .110 | .083 | .797 | .226 | .052 |
| Collective learning           | -.025| .220 | .644 | .450 | .238 |
| Knowledge sharing             | .392 | .231 | .532 | .010 | .007 |
| Uses of information technology tools | .143 | -.013| .066 | .201 | .790 |
| Order coordination            | .710 | .036 | .277 | -.132| .464 |
| Performance monitoring        | -.013| .460 | .722 | .019 | -.008|
| Scheduling of frequent meetings with stakeholders | -.083 | .751 | .246 | .221 | .280 |

Notes: Extraction method: Principal Component Analysis. Rotation method: Varimax with Kaiser Normalization. $^a$Rotation converged in 10 iterations.
Some coordination criteria in Table 5 are interdependent; so based on factor analysis, four coordination criteria namely JDM, information sharing, use of information technology tools, and resource sharing are used for evaluating coordination in supply chain.

3.2. Defining coordination criteria

As a result of factor analysis and discussion with experts, four important coordination mechanisms are identified and defined in the following section as our decision-making criteria. These are Joint Decision-Making (JDM), Information Sharing (IS), Use of Information Tools (UIT), and Resource Sharing (RS).

3.2.1. Joint decision making (JDM)

JDM is to involve supply chain members in decision-making and to delegate to the member with the best negotiating position to lead the relevant decision-making. JDM helps in resolving conflicts among supply chain members and handles exceptions in case of any future uncertainty. According to Chopra and Meindl (2004) member’s behavior like trust, cooperation, reliability, and commitments are the key parameters of successful JDM, which result in proper distribution of risk and rewards. Das, Narasimhan, and Talluri (2006) discussed the role of JDM to improve coordination. Joint considerations of cost, inventory holding costs, collaborative planning, costs of different processes, frequency of orders, coordinated-order quantity, and product development are some JDM activities to improve the performance of supply chain (Barron, 2007; Chen & Chen, 2005; Ganeshan, 1999; Haq & Kannan, 2006; Jain, Nagar, & Srivastava 2006; Kim & Oh, 2005). Some JDM initiatives can be taken to perform activities jointly to reduce uncertainties. These initiatives are efficient consumer response, vendor managed inventory, collaborative design and development, and joint ordering, which may help in JDM.

3.2.2. Information sharing (IS)

Objective of information sharing is to provide relevant, timely, and accurate information to coordinate physical and financial flow that affect the organizational performance. Lee (2000) states that, to coordinate material, information, and financial flows, companies must have access to information reflecting their accurate supply chain picture all the times. Sharing of information across the various functional departments of an organization, supplier, and customer organizations also improve decision-making in supply chain. Information sharing should target on providing accurate and good-quality information for the decision-makers. Shared information provides the visibility of the operations in supply chain processes, such as customer demand, product-related data, cost-related data, process-related data, performance metrics, and so on (Soroor, Tarokh, & Shemshadi, 2009). The customer sharing the demand data with the supplier enables the supplier to schedule and utilize the resources more efficiently (Soroor et al., 2009). Information sharing between the supply chain members is essential for a responsive supply chain (Stanley, Cynthia, Chad, & Gregory, 2009). Information sharing is a challenging task that requires willingness and a high degree of trust among supply chain partners (Agarwal & Shankar, 2003). According to Lee (2000), coordination of information sharing is an attempt to make relevant, accurate, and timely information available to the decision-makers. Sharing of information between supply chain members helps to reduce lead time, reduces the supply chain costs, reduces the demand variability,
enhances responsiveness, and improves the service level (Arshinder, Kanda, & Deshmukh, 2007). Lack of information sharing leads to operational inefficiencies, increased operational costs, and additional coordination costs of supply chain, (Li & Wang, 2007). Information sharing helps to facilitate coordination between supply chain members. Information sharing in supply chain refers to the usage of information technology by a manufacturer with the purpose of enhancing communication with suppliers and customers in areas such as order tracking, knowledge management, and collaboration services. Hence, supply chain member may improve coordination by adopting superior information systems.

3.2.3. Use of information technology (UIT)

Information technology helps to link the point of production seamlessly with the point of delivery or purchase. Use of information technology makes company information systems compatible by accessing information pertaining to the supply chain activities like planning, monitoring, and estimating the lead times. Advances in information technology make possible for firms to quickly exchange products, information, and funds and utilize collaborative methods to optimize supply chain operations (Johnson & Whang, 2002; Koh, Gunasekaran, & Rajkumar, 2008; Liu, Zhang, & Hu, 2005; Machuca & Barajas, 2004). Liu et al. (2005) state that use of information technology enhance communication, which helps members of supply chain to review and monitor past and current performance, and estimate demand of certain products needed to be produced and to manage workflow system. Use of information technology also support sales, distribution and customer service processes, procurement, order fulfillment processes, and also strengthen the relationships along the supply chain for exchanging data and making joint decisions.

3.2.4. Resource sharing (RS)

Resource sharing is the cooperation among independent but related firms to share resources and capabilities to meet their customers’ most extraordinary needs. It is a particular degree of relationship among chain members as a means to share resources that result in higher business performance than would be achieved by the firms individually (Lambert, Emmelhainz, & Gardner, 1999).

3.3. Case application of proposed model

The effectiveness of the proposed methodology is discussed through a case study conducted in an Indian automotive part manufacturing company. The management of company has decided to incorporate coordination criteria into their trading partner prioritization process. To evaluate the performance of partners four coordination criteria are considered these are JDM, Information sharing (IS), UIT, and Resource Sharing (RS). A questionnaire is used for linguistic evaluations as each linguistic variable has its own numerical value in the preferred scale. In classical AHP, these numerical values are exact numbers, whereas in Fuzzy AHP method they are intervals between two numbers with most likely value. As the nature of the human being, linguistic values can change from person to person. In these circumstances, considering the fuzziness will provide less risky decisions. TFNs have been used for pairwise comparison of the criterion to know the importance of the criteria. Criteria are prioritized using Fuzzy AHP method.
After obtaining the weights for each criterion, they are normalized and are called the final importance degrees or weights for the hierarchy level. The final weights of criteria from Fuzzy AHP have been used in Fuzzy TOPSIS to get weighted normalized matrix.

3.3.1. Priority weights for decision criteria

The objective of using Fuzzy AHP is to determine important weight of the criteria that will be used in Fuzzy TOPSIS method. Pairwise comparison matrix that matches linguistic statement of data is formed in questionnaire and experts are asked to fill it. If the numbers of decision-makers are more than one, a group matrix will be obtained by calculating geometric average of Fuzzy numbers for all samples. Following steps explain the method of determining priority weights for decision criteria:

Step 1: A panel of three experts from the case company is selected as per their experience in the area of supply chain management and role in the company.

Step 2: Four criteria: JDM, Information Sharing (IS), Use of IT Tools (UIT), and Resource Sharing (RS) have been identified as the supply chain coordination mechanisms. These are shown in Figure 4.

Step 3: The experts were asked to give the relative weight to each criterion according to the linguistic variable as per Table 6, (Tolga, Demircan, & Kahraman, 2005).

After the criteria have been determined as given in Figure 3, a questionnaire has been prepared to determine the importance levels of these criteria. To evaluate the questions, experts only select the related linguistic variable according to Table 6; these are illustrated in Table 7.

Further, for calculations they are converted into the corresponding TFNs (refer Table 8).

Step 4: Fuzzy important weight of the criteria is calculated by taking geometric mean of the responses of the experts (Lee, 2009), this is shown in Table 9.

Step 5: Crisp relative important weight (priority vector) for identified criteria is calculated using the extent analysis method proposed by Chang (1996) as explained previously in this paper by equations number (2–9). The Fuzzy values of paired comparison are converted to crisp value via the Chang’s extent analysis (1996) as follows.

Figure 4. The hierarchy of the supply chain coordination criteria.
To determine Fuzzy combination expansion for each one of the criteria, first we calculate $P_{m_j}$ value for each row of the matrix.

$C_1 = (1 + 0.763 + 1.145 + 1.357, 1 + 1 + 1.587 + 1.817, 1 + 1.310 + 2.109 + 2.359) = (4.265, 5.404, 6.778)$

$C_2 = (0.763 + 1 + 1.357 + 1.5, 1 + 1 + 1.817 + 2.0, 1.310 + 1 + 2.359 + 2.5) = (4.620, 6.817, 7.169)$

| Statement               | TFN           | Reciprocal TFN |
|-------------------------|---------------|----------------|
| Absolute (A)            | (7/2, 4, 9/2) | (2/9, 1/4, 2/7) |
| Very strong (VS)        | (5/2, 3, 7/2) | (2/7, 1/3, 2/5) |
| Fairly strong (FS)      | (3/2, 2, 5/2) | (2/5, 1/2, 2/3) |
| Weak (W)                | (2/3, 1, 3/2) | (2/3, 1, 3/2)  |
| Equal (E)               | (1, 1, 1)     | (1, 1, 1)      |

Table 6. Values of triangular Fuzzy numbers (Tolga, Demircan, & Kahraman, 2005).

| Statement | C1 | C2 | C3 | C4 |
|-----------|----|----|----|----|
| C1        | E1 | E  | E  | W  | FS |
| E2        | E  | W  | FS | W  |    |
| E3        | E  | W  | FS | VS |    |
| C2        | E1 | E  | E  | W  | FS |
| E2        | E  | W  | FS | W  |    |
| E3        | E  | VS | FS |    |    |
| C3        | E1 | E  | E  | E  |    |
| E2        | E  | W  | W  |    |    |
| E3        | E  | W  | W  |    |    |
| C4        | E1 | E  | E  |    |    |
| E2        | E  | E  |    |    |    |
| E3        | E  | E  |    |    |    |

Table 7. Pairwise comparisons of criteria via linguistic variables.

|         | C1 |     |     |     |     |
|---------|----|-----|-----|-----|-----|
|         |    | C1  |     |     |     |
| C1      |    | E1  | (1, 1, 1) | (1, 1, 1) | (2/3, 1, 3/2) | (3/2, 2, 5/2) |
| E2      | (1, 1, 1) | (1, 1, 1) | (2/3, 1, 3/2) | (3/2, 2, 5/2) | (2/3, 1, 3/2) |
| E3      | (1, 1, 1) | (1, 1, 1) | (2/3, 1, 3/2) | (3/2, 2, 5/2) | (5/2, 3, 7/2) |
| C2      |    | (1, 1, 1) | (1, 1, 1) | (2/3, 1, 3/2) | (3/2, 2, 5/2) |
| E1      | (2/3, 1, 3/2) | (1, 1, 1) | (3/2, 2, 5/2) | (3/2, 2, 5/2) |    |
| E2      | (1, 1, 1) | (2/3, 1, 3/2) | (5/2, 3, 7/2) | (3/2, 2, 5/2) |    |
| E3      | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| C3      |    | (2/5, 1/2, 2/3) | (2/5, 1/2, 2/3) | (1, 1, 1) | (2/3, 1, 3/2) |
| E1      | (2/3, 1, 3/2) | (2/5, 1/2, 2/3) | (1, 1, 1) | (2/3, 1, 3/2) | (1, 1, 1) |
| E2      | (2/5, 1/2, 2/3) | (2/7, 1/3, 2/5) | (1, 1, 1) | (2/3, 1, 3/2) | (1, 1, 1) |
| E3      | (2/5, 1/2, 2/3) | (2/5, 1/2, 2/3) | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| C4      |    | (2/5, 1/2, 2/3) | (2/5, 1/2, 2/3) | (1, 1, 1) | (1, 1, 1) |
| E1      | (2/5, 1/2, 2/3) | (2/7, 1/3, 2/5) | (1, 1, 1) | (2/3, 1, 3/2) | (1, 1, 1) |
| E2      | (2/5, 1/2, 2/3) | (2/5, 1/2, 2/3) | (1, 1, 1) | (1, 1, 1) | (1, 1, 1) |
| E3      | (2/7, 1/3, 2/5) | (2/5, 1/2, 2/3) | (2/3, 1, 3/2) | (1, 1, 1) | (1, 1, 1) |

Table 8. Pairwise comparisons of selection criteria via TFNs.
Table 9. Fuzzy geometric mean of pairwise comparison.

|     | C1         | C2            | C3          | C4            |
|-----|------------|---------------|-------------|---------------|
| C1  | (1, 1, 1)  | (.763, 1, 1.310) | (1.145, 1.587, 2.109) | (1.357, 1.817, 2.359) |
| C2  | (.763, 1, 1.310) | (1, 1, 1) | (1.357, 1.817, 2.359) | (1.5, 2.0, 2.5) |
| C3  | (.474, .630, .873) | (.424, .550, .737) | (1, 1, 1) | (.763, 1, 1.310) |
| C4  | (.424, .550, .737) | (.400, .500, .667) | (.763, 1, 1.310) | (1, 1, 1) |

\[ C_3 = (0.474 + 0.424 + 1 + 0.763, 0.630 + 0.550 + 1 + 1, 0.873 + 0.737 + 1 + 1.310) \]
\[ = (2.661, 3.180, 3.920) \]

\[ C_4 = (0.424 + 0.400 + 0.763 + 1, 0.550 + 0.500 + 1 + 1, 0.737 + 0.667 + 1.310 + 1) \]
\[ = (2.587, 3.050, 3.714) \]

The \[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij}^l \] value is calculated as:
\[ (4.265, 5.404, 6.778) \otimes (4.620, 6.817, 7.169) \otimes (2.661, 3.180, 3.920) \]
\[ \otimes (2.587, 3.050, 3.714) \]
\[ = (14.133, 18.451, 21.581) \]

Then, calculate the \[ [\sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij}^l]^{-1} \] value
\[ \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{ij}^l \right]^{-1} = (1/21.581, 1/18.451, 1/14.133) = (0.046, 0.054, 0.071) \]

The value of Fuzzy synthetic extent (s_i) with respect to i-th criteria (i = 1, 2, 3, 4) is calculated as:
\[ s_1 = (4.265, 5.404, 6.778) \otimes (0.046, 0.054, 0.071) = (0.196, 0.292, 0.481) \]
\[ s_2 = (4.620, 6.817, 7.169) \otimes (0.046, 0.054, 0.071) = (0.213, 0.368, 0.509) \]
\[ s_3 = (2.661, 3.180, 3.920) \otimes (0.046, 0.054, 0.071) = (0.122, 0.172, 0.278) \]
\[ s_4 = (2.587, 3.050, 3.714) \otimes (0.046, 0.054, 0.071) = (0.119, 0.162, 0.264) \]

Now, the \( V \) values (preference order) are calculated using these vectors.
\[ V(s_1 \geq s_2) = \frac{0.213 - 0.481}{(0.292 - 0.481) - (0.368 - 0.213)} = 0.779; \]
\[ V(s_1 \geq s_3) = 1; \quad V(s_1 \geq s_4) = 1 \]
\[ V(s_2 \geq s_1) = 1; \quad V(s_2 \geq s_3) = 1; \quad V(s_2 \geq s_4) = 1; \]
\[ V(s_3 \geq s_1) = \frac{0.196 - 0.278}{(0.172 - 0.278) - (0.292 - 0.196)} = 0.406; \]
\[ V(s_3 \geq s_2) = \frac{0.213 - 0.278}{(0.172 - 0.278) - (0.368 - 0.213)} = 0.249; \quad V(s_3 \geq s_4) = 1 \]
The priorities of weights are calculated using

\[ d'(C_1) = \min(0.779, 1, 1) = 0.779 \]
\[ d'(C_2) = \min(1, 1, 1) = 1 \]
\[ d'(C_3) = \min(0.406, 0.249, 1) = 0.249 \]
\[ d'(C_4) = \min(0.782, 0.198, 0.934) = 0.198 \]

After normalization, priority weight with respect to main goal for all four criteria are determined, which is given as, \( W = (0.350, 0.449, 0.112, 0.089) \)

\[
\begin{bmatrix}
    C_1 \\
    C_2 \\
    C_3 \\
    C_4 \\
\end{bmatrix} =
\begin{bmatrix}
    0.350 \\
    0.449 \\
    0.112 \\
    0.089 \\
\end{bmatrix}
\]

### 3.3.2. Prioritizing alternatives using Fuzzy TOPSIS technique

The objective of using Fuzzy TOPSIS technique is to prioritize trading partners based on identified coordination criteria for improving supply chain performance. After finding the important weights of the criteria, we will now use the Fuzzy TOPSIS technique to rank the supply chain partners. To validate the proposed model, case study has been conducted in an automobile parts manufacturing company to prioritize trading partner. Here, we have considered three most significant partners of the case company \( P_1, P_2, \) and \( P_3 \) to prioritize them. The evaluation criteria are JDM, Information Sharing (IS), UIT, and Resource Sharing (RS). The hierarchical structure for selection of best suitable supply chain partner is shown in Figure 5.

In the present case, a committee of three experts \( E_1, E_2, \) and \( E_3 \) is constituted to make their judgments for trading partners based on four coordination criteria JDM, Information Sharing (IS), UIT, and Resource Sharing (RS). Three most significant partners of the case company \( P_1, P_2, \) and \( P_3 \) are selected after discussion with the company senior officials. Then, the proposed methodology, which is integration of Fuzzy AHP and Fuzzy TOPSIS, is used to prioritize identified trading partners (\( P_1, P_2, \) and \( P_3 \)) based on four coordination criteria, which are JDM (\( C_1 \)), Information sharing (\( C_2 \)), Use of Information Tools (\( C_3 \)), and Resource sharing (\( C_4 \)) as used in Fuzzy AHP method.
Objective
Partner Selection for Coordination in Supply Chain

Criteria
Joint Decision Making (C1)
Information Sharing (C2)
Use of IT Tools (C3)
Resource Sharing (C4)

Alternatives
Trading Partner 1 (P1)
Trading Partner 2 (P2)
Trading Partner 3 (P3)

Figure 5. Hierarchical structure for selecting trading partners.

Table 10. Linguistic variables for rating.

| Linguistic variables       | Triangular Fuzzy numbers |
|----------------------------|--------------------------|
| Very poor (VP)             | (0, 0, 2)                |
| Poor (P)                   | (1, 2, 3)                |
| Medium poor (MP)           | (2, 3.5, 5)              |
| Fair (F)                   | (4, 5, 6)                |
| Medium good (MG)           | (5, 6.5, 8)              |
| Good (G)                   | (7, 8, 9)                |
| Very good (VG)             | (8, 10, 10)              |

Table 11. Rating of the supply chain partners in linguistic terms.

| Criterion | Partner | E₁  | E₂  | E₃  |
|-----------|---------|-----|-----|-----|
| C₁        | P₁      | VG  | VG  | MG  |
|           | P₂      | G   | G   | VG  |
|           | P₃      | MG  | MG  | MG  |
| C₂        | P₁      | G   | VG  | VG  |
|           | P₂      | VG  | VG  | MG  |
|           | P₃      | G   | G   | G   |
| C₃        | P₁      | G   | VG  | G   |
|           | P₂      | MG  | G   | G   |
|           | P₃      | G   | VG  | G   |
| C₄        | P₁      | G   | F   | G   |
|           | P₂      | G   | G   | G   |
|           | P₃      | F   | G   | VG  |
Table 10 shows linguistic variables, to rate the alternatives with respect to each criterion.

The performance rating of three experts on supply chain partners for each criterion, in linguistic variables are obtained and shown in Table 11.

Linguistic variables shown in Table 11 are converted into their corresponding TFNs, according to Table 10. This rating of the supply chain partners in TFNs is presented in Table 12.

To form Fuzzy decision matrix, aggregated rating for the supply chain partners is calculated according to the steps suggested in algorithms of Fuzzy TOPSIS method. Table 13 report the Fuzzy rating of partners for each criterion.

Table 12. Rating of partners in triangular Fuzzy numbers.

| Criterion | Partner | E_1     | E_2     | E_3     |
|-----------|---------|---------|---------|---------|
| C_1       | P_1     | (8, 10, 10) | (8, 10, 10) | (8, 10, 10) |
|           | P_2     | (7, 8, 9)   | (7, 8, 9)   | (8, 10, 10) |
|           | P_3     | (5, 6.5, 8) | (5, 6.5, 8) | (5, 6.5, 8) |
| C_2       | P_1     | (7, 8, 9)   | (8, 10, 10) | (8, 10, 10) |
|           | P_2     | (8, 10, 10) | (8, 10, 10) | (5, 6.5, 8) |
|           | P_3     | (7, 8, 9)   | (7, 8, 9)   | (7, 8, 9)   |
| C_3       | P_1     | (7, 8, 9)   | (4, 5, 6)   | (7, 8, 9)   |
|           | P_2     | (7, 8, 9)   | (7, 8, 9)   | (7, 8, 9)   |
|           | P_3     | (4, 5, 6)   | (7, 8, 9)   | (8, 10, 10) |

Table 13. Fuzzy rating of criteria (Fuzzy decision matrix).

| Criterion | Partners |
|-----------|---------|
|           | P_1     | P_2     | P_3     |
| C_1       | (8, 10, 10) | (7, 8.667, 10) | (5, 6.5, 8) |
| C_2       | (7, 9.333, 10) | (5, 8.833, 10) | (7, 8, 9)   |
| C_3       | (7, 8.667, 10) | (5, 7.5, 9)   | (7, 8.667, 10) |
| C_4       | (4, 7, 9)   | (7, 8, 9)   | (4, 7.667, 10) |

Table 14. Normalized Fuzzy decision matrix.

| Criteria | Partners |
|----------|---------|
|          | P_1     | P_2     | P_3     |
| C_1      | (.8, 1.0, 1.0) | (.7, .867, 1.0) | (.5, .65, .8) |
| C_2      | (.7, .933, 1.0) | (.5, .883, 1.0) | (.7, .8, .9)   |
| C_3      | (.7, .867, 1.0) | (.5, .75, .9)   | (.7, .867, 1.0) |
| C_4      | (.4, .7, .9)   | (.7, .8, .9)   | (.4, .767, 1.0) |
Fuzzy decision matrix is normalized according to method suggested by Chen (2000) and shown in Table 14. Normalized Fuzzy decision matrix, with corresponding weight for each criterion is presented in Table 15.

After normalization, a weighted normalized Fuzzy decision matrix is formed by multiplying the corresponding weight of each criterion as shown in Table 15 and weighted normalized Fuzzy decision matrix is shown in Table 16.

Now, FPIS and Fuzzy negative ideal solution (FNIS) are calculated as in the following:

\[ P^* = [(0.350, 0.350, 0.350, 0.350), (0.449, 0.449, 0.449, 0.449), (0.112, 0.112, 0.112, 0.112), (0.089, 0.089, 0.089, 0.089)] \]

\[ P^- = [(0.175, 0.175, 0.175, 0.175), (0.225, 0.225, 0.225, 0.225), (0.056, 0.056, 0.056, 0.056), (0.036, 0.036, 0.036, 0.036)] \]

After determining FPIS and FNIS, the distances of each alternative from FPIS and FNIS with respect to each criterion are calculated using Vertex method (Chen, 2000) as

\[ d_1^* = d(P_1, P^*) = \sqrt{\frac{1}{3}[(0.350 - 0.280)^2 + (0.350 - 0.350)^2 + (0.350 - 0.350)^2]} = 0.0404 \]

\[ d_1^- = d(P_1, P^-) = \sqrt{\frac{1}{3}[(0.175 - 0.280)^2 + (0.175 - 0.350)^2 + (0.175 - 0.350)^2]} = 0.1552 \]

Table 15. Normalized Fuzzy decision matrix with criteria weight.

|     | C1       | C2       | C3       | C4       |
|-----|----------|----------|----------|----------|
| P1  | (.8, 1.0, 1.0) | (.7, .933, 1.0) | (.7, .867, 1.0) | (.4, .7, .9) |
| P2  | (.7, .867, 1.0) | (.5, .883, 1.0) | (.5, .75, .9) | (.7, .8, .9) |
| P3  | (.5, .65, .8) | (.7, .8, .9) | (.7, .867, 1.0) | (.4, .767, 1.0) |
| Criterion weight | .350 | .449 | .112 | .089 |

Table 16. Weighted normalized Fuzzy decision matrix.

|     | C1       | C2       | C3       | C4       |
|-----|----------|----------|----------|----------|
| P1  | (.280, .350, .350) | (.314, .419, .449) | (.078, .097, .112) | (.036, .062, .080) |
| P2  | (.245, .303, .350) | (.225, .374, .449) | (.056, .084, .101) | (.062, .071, .080) |
| P3  | (.175, .228, .280) | (.314, .359, .404) | (.078, .097, .112) | (.036, .068, .089) |

Table 17. Distance between P_i (i = 1, 2, 3) and P^* with respect to each criterion (C1, C2, C3, C4).

|     | C1   | C2   | C3   | C4   | Sum   |
|-----|------|------|------|------|-------|
| d1^* = d(P1, P^*) | .0404 | .0798 | .0218 | .0346 | .1766 |
| d2^* = d(P2, P^*) | .0663 | .1364 | .0365 | .0191 | .2583 |
| d3^* = d(P3, P^*) | .1296 | .0972 | .0218 | .0327 | .2813 |
Similarly, other values of $d_i^*$ for three alternatives with respect to each criterion have been calculated. These values are shown in Table 17. Further, values of $d_i^−$ for three alternatives with respect to each criterion have been calculated. These values are shown in Table 18.

The closeness coefficient of three alternatives $CC_i (i = 1, 2, 3)$ are calculated by using $CC_i = \frac{d_i^+}{d_i^+ + d_i^−}$ and results are presented in Table 19.

Then, the closeness coefficient of three alternatives $CC_i (i = 1, 2, 3)$ are calculated by using $CC_i = \frac{d_i^+}{d_i^+ + d_i^−}$, and results are presented in Table 19.

The closeness coefficient represents the distance to the FPIS ($P^*$) and Fuzzy negative ideal solution ($P^−$). Table 19 provides the values of closeness coefficients for all partners. The value of closeness coefficient for first partner is .6967, for second .5777, and for third partner is .5061. This indicates that first partner is closest to FPIS and should be given first priorities. Based on closeness coefficients given in the Table 19, the ranking order of partners have been determined, the priorities of the partner are $P_1 > P_2 > P_3$.

The first partner is determined as most appropriate partner for the auto parts manufacturing company under consideration, because the first partner is closer to the FPIS and farther from the FNIS. Similarly, third partner for which closeness coefficient value is lowest, identified as the least preferred because it farther to FPIS and close to FNIS.

### 4. Results and discussions

The conventional methods of partner selection hardly analyze the supply chain of the trading partner. These methods have limitation in dealing with the imprecise or vague nature of linguistic assessment. Decision-makers face uncertainties from subjective perceptions and experiences in the decision-making process. To overcome this limitation, Fuzzy multi-criteria decision-making method has been adopted in this research work.

Here, an integrated approach of the Fuzzy AHP and Fuzzy TOPSIS is used to prioritize the trading partners based on supply chain coordination criteria. Fuzzy AHP is applied to calculate the relative weights of each criterion and then Fuzzy TOPSIS is applied to prioritize the supply chain partner based on these selection criteria. The suggested methodology has been applied with the help of real-life case study.

The case study deals with ranking of three partners by the decision-makers based on four coordination criteria in a leading automobile parts manufacturing company. As a result, Fuzzy AHP Information sharing between the trading partners is determined as the most important criterion for coordination, because this criterion has highest weight.

| $d_i^− = d(P_i, P^−)$ | $d_i^+$ | $d_i^− + d_i^+$ | $CC_i = \frac{d_i^+}{d_i^+ + d_i^−}$ | Rank |
|------------------------|--------|-----------------|----------------|------|
| $d_1^−$ = d(P1, P^−)   | .1552  | .1786           | .0296          | .4056|
| $d_2^−$ = d(P2, P^−)   | .1316  | .1553           | .0307          | .3534|
| $d_3^−$ = d(P3, P^−)   | .0678  | .1390           | .0458          | .3534|

| $d_i^*$ | $d_i^−$ | $d_i^− + d_i^*$ | $CC_i = \frac{d_i^∗}{d_i^∗ + d_i^−}$ | Rank |
|---------|---------|-----------------|----------------|------|
| $P_1$   | .1766   | .4056           | .6967          | 1    |
| $P_2$   | .2583   | .3534           | .5777          | 2    |
| $P_3$   | .2813   | .2882           | .5061          | 3    |

Similarly, other values of $d_i^*$ for three alternatives with respect to each criterion have been calculated. These values are shown in Table 17. Further, values of $d_i^−$ for three alternatives with respect to each criterion have been calculated. These values are shown in Table 18.
priority. JDM ranked second important criterion followed by information sharing. Then, the partners are ranked based on closeness coefficient, which is calculated for each partner using Fuzzy TOPSIS. The ranking order of three partner based on their supply chain coordination has been determined as P₁ > P₂ > P₃. The partner ‘P₁’ is the best suited partner for the case study problem.

5. Limitations and future scope of the research work
To prioritize different vendor based on their supply chain coordination criteria, an integrated approach of Fuzzy AHP and Fuzzy TOPSIS is applied in this paper. Results of Fuzzy AHP and Fuzzy TOPSIS are based on the criteria identified through literature survey and case studies. Testing and validation of the models are limited to the experiences from the case company. The values for pairwise comparisons in Fuzzy AHP and Fuzzy TOPSIS depend on the knowledge of the decision-makers. The scores stating the relationship among criteria were obtained in an interview with experts. The effectiveness of the result depends on the opinion of experts. In order to improve the result, more number of experts can be interviewed. The proposed method can be applied to other multi-criteria decision-making problems like personnel selection, software selection, machine selection, and project selection.

6. Conclusions
In this paper, a multi-criteria decision-making model has been developed and presented in a Fuzzy environment for trading partner prioritization. The Fuzzy approach capable of capturing vagueness associated with subjective perception of decision-makers has been applied. The supply chain partner prioritization is a crucial strategic decision for long-term survival of the firm, because the profitability of a firm and customer satisfaction is directly proportional to the effectiveness of selection process. It has been observed from the literature that decision-makers face the uncertainties from subjective perceptions and experiences in the decision-making process. Using Fuzzy AHP and Fuzzy TOPSIS, uncertainty and vagueness can be effectively handled and reached to a more effective decision. As a result, Fuzzy AHP Information sharing between the trading partners is determined as the most important criterion for coordination, because this criterion has highest weight priority. JDM ranked second important criterion followed by information sharing. Then, the partners are ranked based on closeness coefficient, which is calculated for each partner using Fuzzy TOPSIS. The partner ‘P₁’ is the best suited partner for the case study problem. The first partner is determined as most appropriate partner for the auto parts manufacturing company under consideration, because the first partner is closer to the FPIS and farther from the FNIS. Similarly, third partner for which closeness coefficient value is lowest identified as the least preferred, because it is farther to FPIS and close to FNIS. The model is useful in solving the practical problem, because vagueness and imprecision can be effectively handled in this model. If the criteria and alternatives are clearly defined, the present model can be adopted in any industry.

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