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ORIGINAL ARTICLE

Fuzzy-TISM: A Fuzzy Extension of TISM for Group Decision Making

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Abstract *This paper proposes Fuzzy-TISM, approach for group decision making process. The proposed approach is a fuzzy extension of TISM, which is a multi-criteria decision making technique. TISM is an effective technique and is applied widely to identify relationships among different criteria by creating a comprehensive systematic model of directly and indirectly related criteria. The proposed Fuzzy-TISM approach consolidates the process of group preference aggregation in the fuzzy environment, which can be easily applied to any real world group decision making problem. The proposed approach is a novel attempt to integrate TISM approach with the fuzzy sets. The integration of TISM with fuzzy sets provides flexibility to decision makers to further understand the level of influences of one criteria over another, which was earlier present only in the form of binary (0,1) numbers. 0 represents no influence and 1 represents influence. Due to this, the decision maker is left with only the option of saying 0 or 1 irrespective of the level of influence whether it is low, high, or very high. The proposed Fuzzy-TISM approach take care of this issue and gives a wider flexibility to express the level of influence using fuzzy numbers. The working methodology of proposed Fuzzy-TISM is demonstrated through an illustrative example based on vendor selection.*

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Introduction

The process of selecting the best alternative amidst a set of suitable alternatives is known as decision making. Multi-criteria decision-making (MCDM) problems are defined as decision making problems consisting of several criteria (Bellman and Zadeh 1970; Keeney and Raiffa 1976; Jain 1977; Ching-Lai and Yoon 1981; Nurmi 1981; Tanino 1984; Boender et al. 1989; Chen et al. 1992; Kacprzyk et al. 1992; Hsu and Chen 1996, 1997; Feng and Wang 2000; Chang and Yeh 2002; Lee 2002; Tsaur et al. 2002). MCDM problems can be divided into two categories. The first one is the classical MCDM problem, in which individual preferences are measured in crisp numbers (Keeney and Raiffa 1976; Chen et al. 1992; Feng and Wang 2000), and the second one is the Fuzzy MCDM (Bellman and Zadeh 1970; Jain 1977; Nurmi 1981; Tanino 1984; Chen et al. 1992; Kacprzyk et al. 1992; Hsu and Chen 1996, 1997; Chang and Yeh 2002; Lee 2002; Tsaur et al. 2002; Cebeci and Ruan 2007) problems, in which individual preferences are evaluated on vagueness, subjectivity and imprecision and expressed into linguistic terms, which are further mapped into fuzzy numbers (Zadeh 1965; Zimmermann 1987; Zimmerman 1991). ISM is one of the recognized methods for classical MCDM. It is a methodology that helps in discovering relationships among specific criteria that constitute problem related to the system (Jharkharia and Shankar 2005). The collective study of criteria helps us to develop understanding of direct and indirect relationships among them rather than studying individuals in isolation. The process begins with identifying criteria relevant to a problem and subsequently, a structural self-interaction matrix (SSIM) of criteria is developed using pairwise comparison approach. SSIM is then converted into reachability matrix and its transitivity is verified. Finally, elements are partitioned and structural model is extracted, which is known as ISM (Agarwal et al. 2007). Since ISM is well known classical MCDM approach, many researchers and practitioners have used it to solve MCDM problems. However, the inadequacy of crisp values to model real life situations in uncertain and fuzzy scenarios that are frequent in expert's judgments highlights the need to integrate fuzzy group decision making in ISM. Further, recent studies have also emphasized on uncertainty in linguistic terms under group decision environment (Xu 2004, 2006; Xu and Da 2008; Wei 2009; Fan and Liu 2010). In ISM, the reachability matrix is constructed by replacing relationship symbols of SSIM by 1 and 0. However, the true maximum and minimum values are far from these extreme values of 1 and 0. Therefore, the extreme values are not appropriate to represent relationship between elements. Previous studies have attempted to upgrade ISM to TISM in order to make elucidation of structural model fully interpretive. Further, the importance of implementing fuzzy TISM has been highlighted (Sushil 2012b) but it fails to deliver the procedural model for implementation in real world decision making. Moreover, there have been theoretical contributions in area of flexible systems management (Sushil 1997) and confluence of continuity and change management (Sushil 2012a), which inspired us to develop the fuzzy TISM model. Therefore, we propose a model for fuzzy TISM to analyze group preferences and interpret hierarchical relationship of elements in a complex system under fuzzy environment.

The rest of the paper is organized as follows. In "Preliminaries section, past relevant work on fuzzy theory and TISM methodology is reviewed. In "Literature Review" section, group decision making situation where application of ISM and TISM is involved is discussed. In "Fuzzy-TISM: A Fuzzy Extension of TISM" section, Fuzzy-TISM for group decision making is proposed and detailed description is provided. To demonstrate the application of Fuzzy-TISM an illustration based on vendor selection problem is given in "Illustrative Example" section followed by conclusions.

Preliminaries

Fuzzy theory plays significant role in dealing with vagueness and uncertainty in human language and thoughts in decision making. The assessment of decision makers depends upon their past knowledge and experiences and often their estimations are articulated in equivocal linguistic terms. However, in order to integrate various opinions, experiences, ideas and motivations of individual experts it becomes important to translate the linguistic judgments into fuzzy numbers. Thus, the problems discussed in group decision making environment highlights the need to implement fuzzy logic. Some of the essential definitions of fuzzy logic and its theory can be referred from (Zadeh 1965; Laarhoven and Pedrycz 1983; Zimmermann 1987; Kauffman and Gupta 1991; Zimmerman 1991; Li 1999).

In the fuzzy theory, the fuzzy set $\tilde{B}$ is the subset of universal set X, which can be characterized by membership function $\mu_{\tilde{B}}(x)$ representing a mapping $\mu_{\tilde{B}} : X \rightarrow [0, 1]$. The function value of $\mu_{\tilde{B}}(x)\tilde{B}$ is called the membership value representing degree of truth that x is an element of $\tilde{B}$. Assuming that $\mu_{\tilde{B}} \in [0, 1]$, where $\mu_{\tilde{B}}(x) = 0$ denotes that x belongs completely to fuzzy set $\tilde{B}$, while $\mu_{\tilde{B}}(x) = 1$ denotes that x does not belong to fuzzy set $\tilde{B}$. The membership function $\mu_{\tilde{B}}(x)$ of triangular fuzzy number can be defined as

$$\mu_{\tilde{B}}(x) = \begin{cases} 0, & x < l \\ \frac{x-l}{m-l} & l \le x \le m, \\ \frac{u-x}{u-m} & m \le x \le u, \\ 0, & otherwise \end{cases}$$

which can be represented by triplet (l, m, u) and $l \le m \le u$. See Fig. 1.

Following are the theorems which are used in this paper are briefly discussed.

Theorem 1 Let $\tilde{B}_1 = (l_1, m_1, u_1)$ and $\tilde{B}_2 = (l_2, m_2, u_2)$ be two triangular fuzzy numbers. The addition operation of $\tilde{B}_1$ and $\tilde{B}_2$ is denoted by $\tilde{B}_1 \oplus \tilde{B}_2$ which results into another triangular fuzzy number and that can be represented by

$$\tilde{B}_1 \oplus \tilde{B}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (1)$$

Theorem 2 CFCS (Converting Fuzzy data into Crisp Scores) defuzzification method (Opricovic and Tzeng, 2003). Let $\tilde{B}_k = (l_k, m_k, u_k); k = 1, 2, \ldots..n$ be the positive triangular fuzzy number and $\tilde{B}_k^{crisp}$ denotes the crisp value.

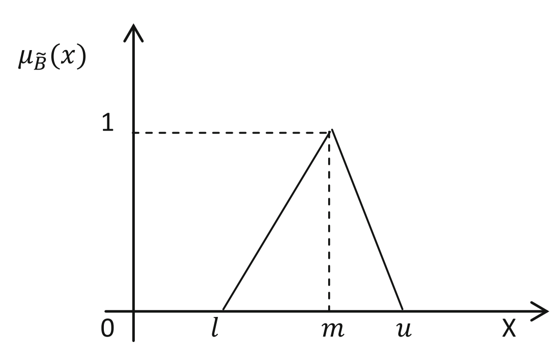


Fig. 1 A triangular fuzzy number $\tilde{B}$

The crisp value of i-th criteria can be determined by following four steps

Step 1: Computing $\mathrm{L} = \min(l_k)$; $\mathrm{R} = \max(u_k)$; $k = 1, 2, \ldots..n$ and $\Delta = R - L$, then Compute for each alternatives using Eq. (5).

$$x_{lk} = (l_k - L)/\Delta,\ x_{mk} = (m_k - L)/\Delta,\ x_{uk} = (u_k - L)/\Delta \quad (2)$$

Step 2: Compute left score (ls) and right score (rs) normalized values using Eq. (3).

$$x_k^{ls} = x_{mk}/(1 + x_{mk} - x_{lk}) \text{ and } x_k^{rs} = x_{uk}/(1 + x_{uk} - x_{mk}) \quad (3)$$

Step 3: Compute total normalized crisp value using Eq. (4).

$$x_k^{crisp} = \left[x_k^{ls} \times \left(1 - x_k^{ls}\right) + x_k^{rs} \times x_k^{rs}\right]/\left[1 - x_k^{ls} + x_k^{rs}\right] \quad (4)$$

Step 4: Compute crisp value for $\tilde{B}_k$ using Eq. (5).

$$\tilde{B}_k^{crisp} = L + x_k^{crisp} \times \Delta \quad (5)$$

Literature review

The theoretical foundation of TISM proposed by Sushil (Sushil 2012b) is built on ISM methodology developed by Warfield (1973, 1974). Much details on ISM and its various applications can be referred from (Harary et al. 1965), Warfield and Hill (1973), Malone (1975), Hawthorne and Sage (1975), Warfield (1976, 1994, 1999), Jedlicka and Meyer (1980), Waller (1980), Mandal and Deshmukh (1994), (Sushil 1994), Sharma et al. (1995), Warfield (2003), Saxena et al. (2006), Agarwal et al. (2007), Lee (2007), Mohammed (2008), (Haleem and Sushil 2012), Sagar et al. (2013), Mangala et al. (2014), and Srivastava and Sushil (2014).

TISM (Sushil 2012b) is derived from ISM facilitates the graphical representation of complex systems. ISM assists individuals in developing complex relationships among multiple elements in complex system. ISM is an interpretive method that helps the group to decide structural relationship between multiple elements and extract structure, which is portrayed in digraph model. ISM permits identification of system structure, which contain elements related to other in some fashion (Farris and Sage 1975). Previous studies adopted the enhanced version of ISM which is called TISM (Nasim 2011; Sushil 2012b; Dubey and Ali 2014). TISM is the method that demonstrates direct as well as transitive relationship in order to make structural model fully interpretive. Nasim (2011) has shown the applicability of TISM in modelling continuity and change in e-government, and similarly Prasad and Suri (2011) has shown the applicability of TISM in the private higher technical education. TISM has also been used to study relationship amongst various strategic performance criteria for effective strategy execution (Srivastava 2013; Srivastava and Sushil 2014). Following are the main steps involved in the ISM methodology.

TISM (similar to ISM) begins with defining the elements and determining contextual relationships within elements. Further, we develop SSIM, reachability matrix, Transitivity matrix, lower triangular format of reachability matrix, digraph for TISM and the interpretive structural based on contextual relationships (Saxena et al. 2006).

Developing SSIM

The relation between any two elements (i and j) is judged by experts keeping in view of contextual relationship within each element. Four types of symbols are used namely V, A, X, and O to demonstrate the relation between any two elements under consideration. The SSIM can be prepared by filling responses of group of experts on pairwise interaction matrix.

Developing Reachability Matrix

The reachability matrix is constructed by transforming information within SSIM into 1′s and 0′s.

Transitivity Check on Reachability Matrix

A transitivity check has to be performed on reachability matrix. The transitivity matrix is checked for the transitivity rule and updated till full transitivity is established.

Reachability Matrix Partition

After creating reachability matrix and performing transitivity check, the next step is to create digraph and extract structural model. The partition of reachability matrix process can be carried by using relation partition and level partition on sets and subsets of elements (Warfield 1974).

Creating Digraph for TISM

After identifying the levels of elements the relationship between elements are constructed using serial numbers of elements and directed arrows. The constructed digraph is complex and has to be examined interactively to eliminate transitivity. After elimination of transitivity we finalize the digraph for total interpretive structural model. The digraph portrays information related to hierarchy of elements.

Final TISM Model

Final TISM model is created after the initial digraph of ISM where all transitive links along with the direct influencing links are shown. In addition, information is also mentioned along with all links (direct and transitive links) to give a proper justification behind the influence of one criterion to other.

Fuzzy-TISM: A Fuzzy Extension of TISM

The detailed procedure for the proposed model of Fuzzy-TISM is discussed here. The linguistic terms and its linguistic values are shown in Table 1. The linguistic values are assumed based on the triangular fuzzy numbers for linguistic variables shown in Fig. 2. Fuzzy interrelationship between two factors are shown using symbols which are given in Fig. 3. Stepwise description of Fuzzy-TISM is as follows.

Table 1 Linguistic scales for the influence

Linguistic terms	Linguistic values
Very high influence (VH)	(0.75,1.0,1.0)
High influence (H)	(0.5,0.75,1.0)
Low influence (L)	(0.25,0.5,0.75)
Very low influence (VL)	(0,0.25,0.5)
No influence (No)	(0,0,0.25)

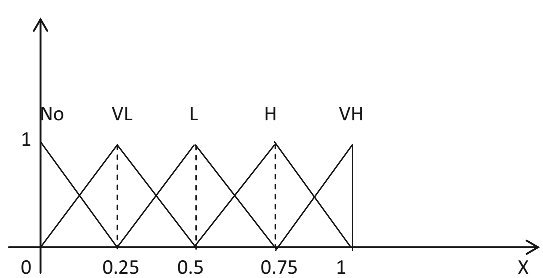


Fig. 2 Triangular fuzzy numbers for linguistic variables

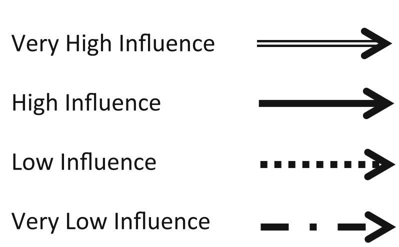


Fig. 3 Symbols for representation of fuzzy relationship between criteria

Step 1: Start of Decision Making Process

The decision making process begins with defining decision goals, gathering significant information and identifying possible range of alternatives. Further alternatives are evaluated, selected and monitored to ensure decision goals are achieved (Hess and Siciliano 1996; Opricovic and Tzeng 2003). Thus, after setting decision goal a committee is formed for gathering group knowledge, which assists in problem solving.

Step 2: Selection of Criteria

In this step, a set of criteria has to be established. The criteria have relationships through which either they influence/impact the other criteria or influenced/impacted by other criteria and may be both. To deal with the uncertainty in linguistic judgments of experts, we renounce crisp method of decision making in TISM and incorporate fuzzy linguistic scale for group decision making (Li 1999). The varied degree of influence/impact can be expressed in five linguistic terms as {Very high, High, Low, Very low, No}. The corresponding positive fuzzy triangular numbers are demonstrated in Table 1 and Fig. 2.

Step 3: Gathering Responses and Creating SSIM Matrix

The relationship between the criteria $C = \{ C_i | i = 1, 2...n\}$ is gathered from group of s experts and filled in SSIM matrix. The respondents can use the combination of symbols V, A, X and O and linguistic terms (mentioned in Table 1) to demonstrate the relationship between the criteria. The respondents will have following four options.

i. V: To demonstrate the relationship from element i to element j but not vice versa; the relationship can be represented as V followed by {Very high (VH), High (H), Low (L), Very low (VL)}. For example V (VH) or V(H) or V(L) or V(VL).
ii. A: To demonstrate the relationship from element j to element i but not vice versa; the relationship can be represented as A followed by {Very high (VH), High(H), Low (L), Very low (VL)}.
iii. X: To demonstrate the relationship from element i to j and j to i; the relationship can be represented as X followed by {Very high (VH), High (H), Low (L), Very low (VL)}.
iv. O: To demonstrate no existence of relationship; the relationship can be represented as O followed by {No influence (No)}. For example O(No)

In addition to above responses in fuzzy, the respondents are also informed to justify in few words their assessment at all levels of influence, i.e. VH, H, L, VL, and No of one criterion to other.

Step 4: Calculation of Aggregated SSIM and Final Fuzzy Reachability Matrix

Here, mode has been used to aggregate responses of individual experts, i.e. the preferences of individual experts with highest frequencies are pooled together in aggregated SSIM matrix. Further, aggregated SSIM matrix is transformed into fuzzy reachability matrix. The linguistic terms in aggregated SSIM matrix are replaced by corresponding fuzzy triangular linguistic values. The following situations occur during creation of final fuzzy reachability matrix.

i. If the entry (i,j) is V(VH) : The entry (i,j) can be denoted by (0.75,1.0,1.0) and entry (j,i) will be 0{No} which will be denoted by (0,0,0.25)
ii. If the entry (i,j) is V(H) : The entry (i,j) can be denoted by (0.5,0.75,1.0) and entry (j,i) will be 0{No} which will be denoted by (0,0,0.25)
iii. If the entry (i,j) is V(L): The entry (i,j) can be denoted by (0.25,0.5,0.75) and entry (j,i) will be 0{No} which will be denoted by (0,0,0.25)
iv. If the entry (i,j) is V(VL): The entry (i,j) can be denoted by (0,0.25,0.5) and entry (j,i) will be 0{No} which will be denoted by (0,0,0.25)
v. If the entry (i,j) is A(VH): The entry (i,j) will be 0{No} which will be denoted by (0,0,0.25) and entry (j,i) can be denoted by (0.75,1.0,1.0)
vi. If the entry (i,j) is A(H): The entry (i,j) will be 0{No} which will be denoted by (0,0,0.25) and entry (j,i) can be denoted by (0.5,0.75,1.0)
vii. If the entry (i,j) is A(L): The entry (i,j) will be 0{No} which will be denoted by (0,0,0.25) and entry (j,i) can be denoted by (0.25,0.5,0.75)
viii. If the entry (i,j) is A(VL): The entry (i,j) will be 0{No} which will be denoted by (0,0,0.25) and entry (j,i) can be denoted by (0,0.25,0.5)
ix. If the entry (i,j) is X(VH): The entry (i,j) can be denoted by (0.75,1.0,1.0) and entry (j,i) can be denoted by (0.75,1.0,1.0)
x. If the entry (i,j) is X(H): The entry (i,j) can be denoted by (0.5,0.75,1.0) and entry (j,i) can be denoted by (0.5,0.75,1.0)
xi. If the entry (i,j) is X(L): The entry (i,j) can be denoted by (0.25,0.5,0.75) and entry (j,i) can be denoted by (0.25,0.5,0.75)
xii. If the entry (i,j) is X(VL): The entry (i,j) can be denoted by (0,0.25,0.5) and entry (j,i) can be denoted by (0,0.25,0.5)
xiii. If the entry (I,j) is X(VH,H): The entry (i,j) can be denoted by (0.75,1,1) and entry (j,i) can be denoted by (0.5,0.75,1). Similar other possible scenarios are– X(VH,L), X(VH,VL), X(H,VH), X(H,L), X(H,VL), X(L,VH), X(L,H),X(L,VL), X(VL,VH), X(VL,H), X(VL,L)
xiv. If the entry (i,j) is 0(No): The entry (i,j) and entry (j,i) is denoted by (0,0,0.25)

The final fuzzy reachability is denoted as $\tilde{Z}$

$$\tilde{Z} = \begin{bmatrix} \tilde{z}_{11} & \tilde{z}_{12} & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & \tilde{z}_{22} & \cdots & \tilde{z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \tilde{z}_{nn} \end{bmatrix}$$

where $\tilde{Z}_{ij} = (l_{ij}, m_{ij}, u_{ij})$

Step 5: Calculation of Driving Power and Dependence for MICMAC Analysis

Fuzzy reachability matrix is generated from aggregated fuzzy SSIM matrix in step 4 above. The driving power and dependence are calculated by summing rows and columns of fuzzy reachability matrix using Eq. (1). To carry out MICMAC analysis based on fuzzy reachability matrix, Eq. (5) is applied for defuzzification.

Step 6: Reachability Matrix Level Partition

Here, reachability matrix is portioned using relation and level partition. Before the start of level partitioning, the transitivity of reachability matrix is also checked to identify the presence of any transitive links.

Step 7: Creating Fuzzy-TISM Digraphs and Defuzzified TISM Digraphs

Following symbols are proposed in Fig. 3 to establish the fuzzy relationship among criteria.

The Fuzzy-TISM digraphs and defuzzified TISM are represented by simple directed arrows in order to visualize the level of influence. TISM digraph is constructed after defuzzification of fuzzy reachability matrix obtained at step 4 above. For an instance, fuzzy reachability matrix can be defuzzified by considering H and VH fuzzy linguistics terms as 1 and rest VL, L, No as 0.

Illustrative Example

To demonstrate the application of Fuzzy-TISM approach, an illustrative example related to vendor selection problem is considered here. Finally, in the "Discussion and Interpretation" section, detailed discussion on the proposed Fuzzy-TISM digraphs and defuzzified TISM digraph are provided.

Developing Inter-relationship of Vendor Selection Problem Using Fuzzy-TISM

Step 1: Start of Decision Making Process

In this study, the responses of 5 experts are collected for evaluation of interrelationship among criteria. These experts are well experienced with the vendor selection process.

Step 2: Selection of Criteria

The following criteria have been selected that are critical for selecting vendor or supplier:

1. *Quality (C1)*: The quality of the material/goods supplied by the vendor.
2. *Delivery (C2)*: Time taken to deliver the materials to the manufacturer.
3. *Production facilities (C3)*: Production facilities owned by the vendor.
4. *Price(C4)*: the price charged by the vendor for the supplied goods or materials.
5. *Financial Position (C5)*: The financial status of the vendor firm.
6. *Technological flexibility (C6)*: the type of technology utilized by the vendors to produce their materials or goods and also having flexibility in upgrading it as per need of advancement.
7. *Top level commitment (C7)*: The commitment levels at the top positions of the vendor firms.
8. *Transport and communication (C8)*: Transportation and communication facilities.
9. *Service (C9)*: After sales services provided by the vendor.
10. *Attitude and willingness (C10)*: Willingness to keep long-term relation with the firm.

Step 3: Gathering Responses and Creating SSIM Matrix

In this study, responses of five experts are taken and are aware about the underlying problem and have good amount of work experience dealing such problem. After collecting responses from all five experts on the degree of relationship between the criteria, the initial SSIM matrices obtained from five different experts are provided from the Tables 3, 4, 5, 6, 7 for each expert and are provided in the Appendix.

Step 4: Calculation of Aggregated SSIM and Fuzzy Reachability Matrix

Table 2 shows the aggregated values of SSIM matrix of five experts shown from Tables 3, 4, 5, 6, 7 (refer to Appendix). The responses are aggregated using mode (linguistic terms with highest frequency of occurrence).

Further, aggregated SSIM matrix is transformed into final fuzzy reachability matrix. Table 8 indicates fuzzy reachability matrix $\tilde{Z}$ of five experts and is given in Appendix.

Step 5: Calculation of Driving Power and Dependence for MICMAC Analysis

The fuzzy values of driving power and dependence for criteria are shown in the Table 9, which is given in Appendix. Table 9, also presents the crisp values of driving power and dependence. Further, the calculation of crisp values of driving power and dependence for performing MICMAC analysis is done using Eq. (5). Below the crisp value of criteria Quality (C1) is shown using Eq. (5). Similarly, the crisp value is calculated for all other criteria. Based on the crisp values, the driving power and dependence matrix (MICMAC analysis) is represented in Table 10.

Table 2 Aggregated SSIM matrix

	C10	C9	C8	C7	C6	C5	C4	C3	C2
C1	O(No)	O(No)	O(No)	A(H)	A(VH)	A(H)	X(H)	A(VH)	O(No)
C2	A(VH)	O(No)	A(H)	A(VH)	A(H)	A(H)	X(H)	O(No)	
C3	O(No)	O(No)	O(No)	A(H)	A(VH)	A(H)	V(L)		
C4	O(No)	X(H)	A(H)	O(No)	A(VH)	A(H)			
C5	O(No)	O(No)	V(H)	A(VH)	V(H)				
C6	O(No)	V(L)	O(No)	O(No)					
C7	V(VH)	V(H)	O(No)						
C8	A(L)	V(L)							
C9	A(H)								

Driving power fuzzy value of C1 = (1.5,1.75,4)

$L = \min(l_k) = 1.5$, $R = \max(u_k) = 7.75$, $\Delta = 6.25$, $l_1 = 1.5, m_1 = 1.75\, and\, u_1 = 4$. $\min(l_k)$ and $\max(u_k)$ are calculated considering driving power fuzzy values of all criterion

$x_{l1} = 0.0000$, $x_{m1} = 0.0400$, $x_{u1} = 0.0400 x_1^{ls} = 0.0385$ and $x_1^{rs} = 0.2941$

$x_1^{crisp} = 0.0983$

$\tilde{B}_1^{crisp} = 2.1147$

Hence, the driving power crisp value of C1 = 2.1147.

Dependence fuzzy value of C1 = (4,5.25,7)

$L = \min(l_k) = 1$, $R = \max(u_k) = 8.25$, $\Delta = 7.25$, $l_1 = 4, m_1 = 5.25\, and\, u_1 = 7$. $\min(l_k)$ and $\max(u_k)$ are calculated considering dependence fuzzy values of all criterion

$x_{l1} = 0.4138$, $x_{m1} = 0.5862$, $x_{u1} = 0.8276 x_1^{ls} = 0.5000$ and $x_1^{rs} = 0.6667$

$x_1^{crisp} = 0.5952$

$\tilde{B}_1^{crisp} = 5.3155$

Hence, the dependence crisp value of C1 = 5.3155.

Step 6: Reachability Matrix Partition Using Relation and Level Partition

Here, the defuzzified reachability matrix is generated based on the aggregated fuzzy reachability matrix shown in Table 8 of the Appendix. To generate the defuzzified reachability matrix, the paper considers the fuzzy linguistic term consisting of Very High Influence (VH) and High Influence (H) as 1 and rests others 0. (*It is to be noted that at this step decision maker can choose only VH as 1 and others 0*). Table 11 of Appendix provides the defuzizfied reachability matrix. Table 11 also contains the transitive links after checking the transitivity among all criteria. Based on Table 11, the defuzzified MICMAC analysis is done and shown in Table 12 of the Appendix. Also, the level partitioning is conducted based on Table 11 and level partitions are shown from Tables 13, 14, 15, 16 of the Appendix. Table 13 shows the first iteration where in Quality (C1), Delivery (C2), Price (C4) and Service (C9) are found to be at level 1. For representation purpose, the listing of criteria from C1 to C10 is shown as 1 to 10 from Tables 13, 14, 15, 16 (refer Appendix), which are the various level partitioning matrices. Table 14 shows the second iteration where in Production facility (C3) and Transport and Communication (C8) are found at level 2. Similarly, in Table 15, Technological flexibility (C6), and Attitude and Willingness (C10) are found to be at level 4. Finally, in Table 16, financial position (C5) and Top level commitment (C7) are found to be at level 4 and level 5, respectively.

Step 7: Creating Fuzzy-TISM Digraphs and Defuzzified TISM Digraph

Here, the fuzzy interrelationships among all criteria are shown using proposed Fuzzy-TISM approach. Hence, all Fuzzy-TISM digraphs are shown in Fig. 4. In Fuzzy-TISM digraphs, the influence of one criterion over all other criteria at all levels (i.e. VH, H, L, VL, No) are shown. Figure 4a–j together constitutes Fuzzy-TISM and it represents individual fuzzy relationship of criteria 1–10 with other criteria. Based on the defuzzified reachability matrix (refer Table 11), the defuzzified TISM digraph is constructed and shown in the Fig. 5. Figure 5 represents digraph of TISM considering only fuzzy linguistic terms VH and H as 1 and rests other 0. Symbols as shown in the Fig. 3 are used to establish the fuzzy relationships between criteria.

Discussion and Interpretation

As it can be seen that Fig. 4a–j individually show the level of influence of one criterion over others. At the end, Fig. 5 only represents interrelationship based on TISM among all criteria having very high influence (VH) and high influence (H). However, in order to establish interrelationship among criteria in the presence of all levels of influence then Figs. 4 and 5 can be considered simultaneously, which is obtained using Fuzzy-TISM approach. *For an instance,* considering level 5, If the decision maker would like to know the strength of the relationship of criteria present at level 5 i.e. C7 (Top level commitment) with respect to other criteria then the decision maker would refer Fig. 5g. Criteria C7 (Top level commitment) has very high influence over C2 (Delivery), C5 (Financial Position) and C10 (Attitude and willingness) and high influence over C1 (Quality), C3 (Production facilities) and C9 (Service). Similarly, considering level 3, if the decision maker likes to know the strength of the relationship of criteria present at level 3, i.e. C6 and C10 with other criteria then he/she can refer Fig. 4f, j, respectively. Criteria C10 (Attitude and willingness) has very high influence over criterion C2 (Delivery), high influence over C9 (Service) and low influence over C8 (Transport and telecommunication). Another criterion C6 (Technological flexibility) at level 3 has very high influence C1 (Quality), C3 (Production facilities) and C4 (Price), high influence over C2 (Delivery) and low influence over C9 (Service). In a similar way, other interpretations can also be done easily using digraphs provided by the Fuzzy-TISM approach. From Fig. 5, it can be seen that the criteria that influence vendor selection

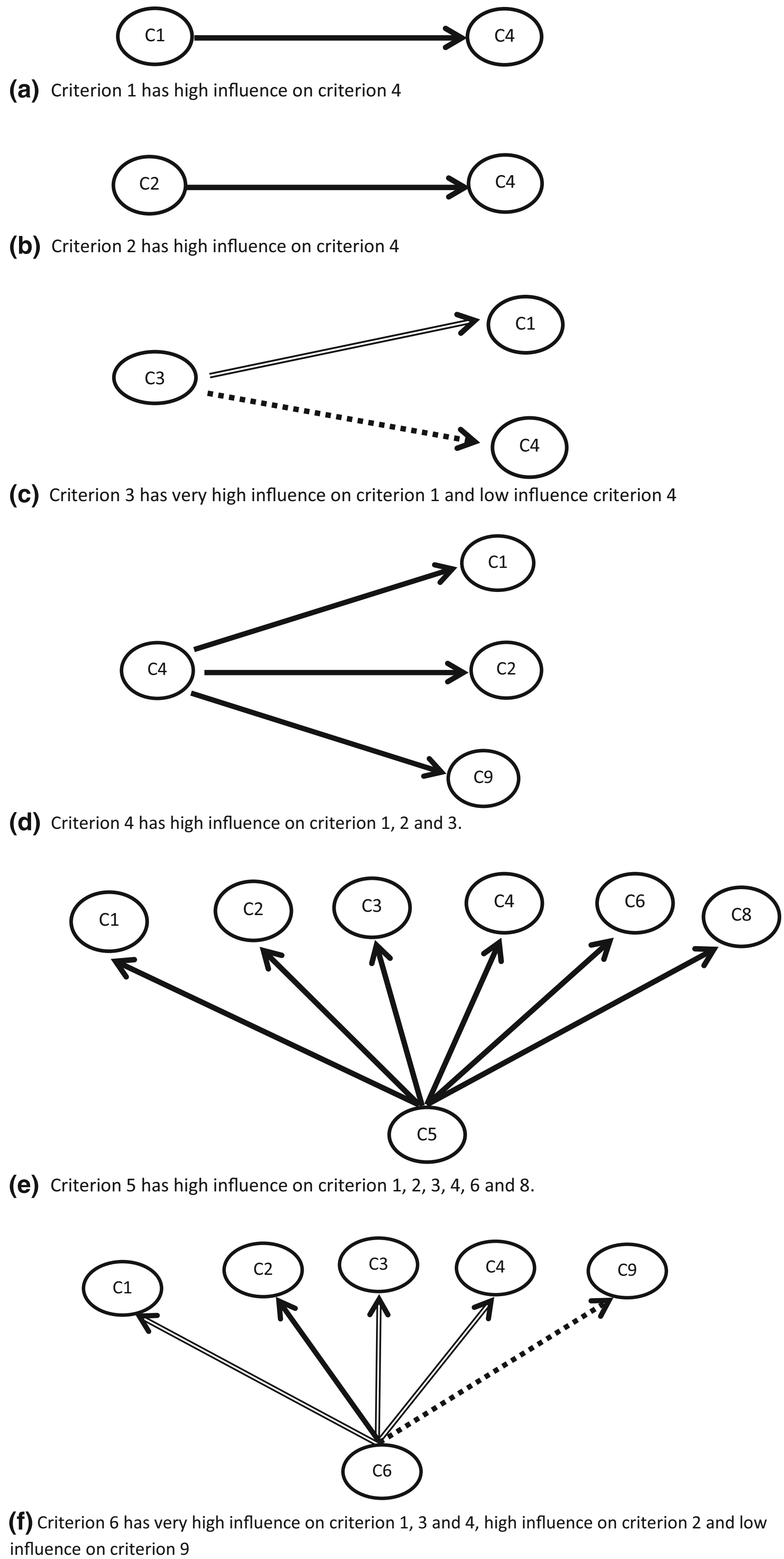
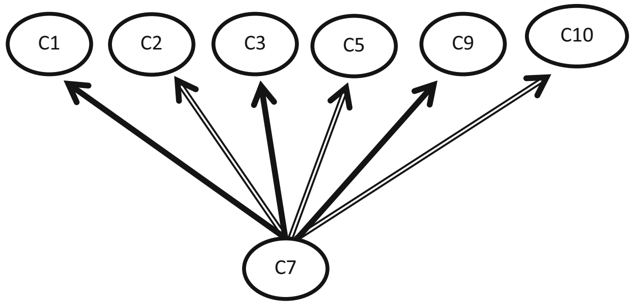
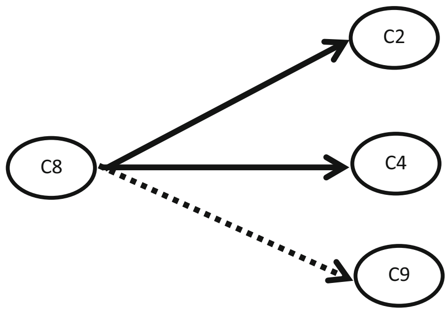


Fig. 4 Fuzzy-TISM digraphs of all criteria influencing others containing all fuzzy linguistic terms (i.e. *VH*, *H*, *L*, *VL*, *No*)

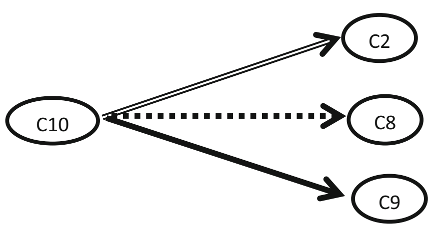


(g) Criterion 7 has very high influence on criterion 2, 5 and 10 and high influence on criterion 1, 3 and 9



(h) Criterion 8 has high influence on criterion 2 and 4 and low influence on criterion 9

(i) Criterion 9 has high influence on criterion 4.



(j) Criterion 10 has very high influence on criterion 2, high influence on criterion 9 and low influence on criterion 8.

Fig. 4 continued

problem at very high influence (VH) and high influence (H) are C7 (top level commitment), C5 (financial position), C6 (technological flexibility), and C10 (attitude and willingness).

Conclusions

The paper proposes a Fuzzy-TISM, a fuzzy extension of TISM, approach for group decision making problems. Due to the presence of fuzziness through fuzzy approach the decision makers have the flexibility in terms of assigning the level of influence one criteria can have on other directly. Earlier in the pure ISM or TISM approaches this was not possible due to the presence of binary numbers for influence (1) or not influences (0). The proposed Fuzzy-TISM approach takes care of this issue and provide wider flexibility while assessing interrelationship among various criteria. In addition to this, the proposed approach is also user friendly due to the simplified way of introducing the fuzzy

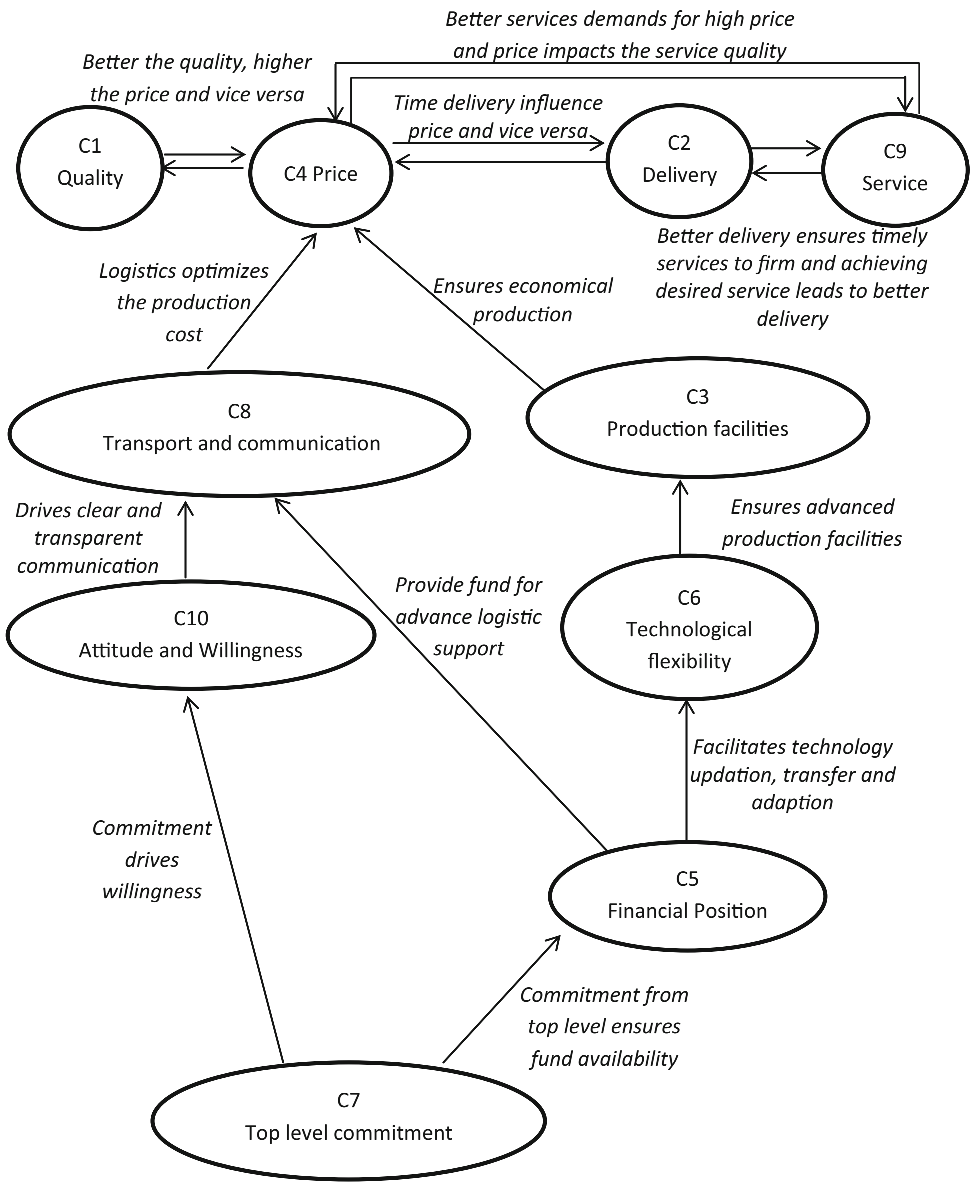


Fig. 5 TISM digraph of vendor selection considering fuzzy linguistic term very high influence (*VH*) and high influence (*H*) as 1 and rest as 0

triangular values in TISM for better decision making under fuzzy environment. In the proposed Fuzzy-TISM approach, mode has been used as the method for aggregation of group preferences under fuzzy environment, which makes it easily implementable for any group decision making process of real business application. Furthermore, this aggregation method also helps in preserving the fuzzy linguistic values, which can be subsequently used in establishing fuzzy relationship of each criterion.

The proposed method is a novel attempt in this direction. The incorporation of fuzzy in TISM allows the respondent to judge degree of relationship between criteria. Here, in this paper, the respondent can select influence levels namely {Very high, High, Low, Very low, No} of one criterion over others. The final Fuzzy-TISM model consists of individual fuzzy relationships between each criterion with other. Finally, fuzzy TISM model can fully interpret the structural model, which can help managers in considering the relationships of significant strength and discounting of weak strength.

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Appendix

See Appendix Tables 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16

Table 3 SSIM matrix of expert # 1

	C10	C9	C8	C7	C6	C5	C4	C3	C2
C1	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	V(VH)	O(No)	O(No)
C2	O(No)	O(No)	A(H)	A(VH)	O(No)	O(No)	X(H,VH)	O(No)	
C3	O(No)	O(No)	O(No)	A(H)	A(VH)	A(VH)	O(No)		
C4	O(No)	A(H)	A(L)	O(No)	A(VH)	O(No)			
C5	O(No)	O(No)	V(H)	A(H)	V(H)				
C6	O(No)	V(H)	O(No)	O(No)					
C7	V(VH)	V(H)	O(No)						
C8	A(H)	V(L)							
C9	A(H)								

Table 4 SSIM matrix of expert # 2

	C10	C9	C8	C7	C6	C5	C4	C3	C2
C1	O(No)	O(No)	O(No)	A(H)	A(VH)	A(H)	A(H)	A(L)	O(No)
C2	A(VH)	O(No)	A(VH)	O(No)	O(No)	A(H)	X(H)	O(No)	
C3	O(No)	O(No)	O(No)	A(L)	A(H)	A(L)	V(H)		
C4	O(No)	X(H)	O(No)	O(No)	A(VH)	A(H)			
C5	O(No)	O(No)	O(No)	A(L)	V(H)				
C6	O(No)	V(L)	O(No)	O(No)					
C7	V(VH)	V(H)	O(No)						
C8	A(L)	O(No)							
C9	A(H)								

Table 5 SSIM matrix of expert # 3

	C10	C9	C8	C7	C6	C5	C4	C3	C2
C1	O(No)	O(No)	O(No)	A(H)	A(VH)	A(L)	X(H)	O(No)	O(No)
C2	A(H)	O(No)	A(VH)	A(VH)	A(H)	A(H)	V(L)	O(No)	
C3	O(No)	O(No)	O(No)	A(H)	O(No)	A(H)	O(No)		
C4	O(No)	O(No)	A(H)	O(No)	A(H)	A(H)			
C5	O(No)	O(No)	V(L)	A(VH)	V(H)				
C6	O(No)	V(L)	O(No)	O(No)					
C7	V(H)	V(VH)	O(No)						
C8	A(L)	V(VH)							
C9	A(H)								

Table 6 SSIM matrix of expert # 4

	C10	C9	C8	C7	C6	C5	C4	C3	C2
C1	O(No)	O(No)	O(No)	A(H)	A(H)	A(H)	V(H)	A(VH)	O(No)
C2	O(No)	O(No)	A(H)	A(L)	A(H)	A(H)	V(L)	O(No)	
C3	O(No)	O(No)	O(No)	A(H)	A(L)	A(H)	V(L)		
C4	O(No)	X(L)	A(H)	O(No)	O(No)	O(No)			
C5	O(No)	O(No)	V(H)	O(No)	V(H)				
C6	O(No)	O(No)	O(No)	O(No)					
C7	V(VH)	V(L)	O(No)						
C8	O(No)	O(No)							
C9	A(H)								

Table 7 SSIM matrix of expert # 5

	C10	C9	C8	C7	C6	C5	C4	C3	C2
C1	O(No)	O(No)	O(No)	O(No)	A(VH)	O(No)	X(H)	A(VH)	O(No)
C2	A(VH)	O(No)	A(H)	A(VH)	A(H)	O(No)	X(H)	O(No)	
C3	O(No)	O(No)	O(No)	O(No)	A(VH)	A(H)	V(L)		
C4	O(No)	X(H)	O(No)	O(No)	A(VH)	A(H)			
C5	O(No)	O(No)	V(VH)	A(VH)	O(No)				
C6	O(No)	O(No)	O(No)	O(No)					
C7	V(L)	V(H)	O(No)						
C8	O(No)	V(L)							
C9	O(No)								

Table 8 Fuzzy reachability matrix based on Aggregated fuzzy SSIM matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1		No	No	H	No	No	No	No	No	No
C2	No		No	H	No	No	No	No	No	No
C3	VH	No		L	No	No	No	No	No	No
C4	H	H	No		No	No	No	No	H	No
C5	H	H	H	H		H	No	H	No	No
C6	VH	H	VH	VH	No		No	No	L	No
C7	H	VH	H	No	VH	No		No	H	VH
C8	No	H	No	H	No	No	No		L	No
C9	No	No	No	H	No	No	No	No		No
C10	No	VH	No	No	No	No	No	L	H	

Table 9 Final fuzzy reachability matrix $\tilde{Z}$ of 5 experts with fuzzy and crisp values of driving power and dependence of criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	**	#
C1	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1.5,1.75,4)	2.1147
C2	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1.5,1.75,4)	2.1147
C3	(0.75,1,1)	(0,0,0.25)	(1,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(2,2.5,4.5)	2.8288
C4	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(2.5,3.25,5.5)	3.5940
C5	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(1,1,1)	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(4,5.5,7.75)	5.5519
C6	(0.75,1,1)	(0.5,0.75,1)	(0.75,1,1)	(0.75,1,1)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0,0,0.25)	(4,5.25,6.75)	5.2630
C7	(0.5,0.75,1)	(0.75,1,1)	(0.5,0.75,1)	(0,0,0.25)	(0.75,1,1)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(0.5,0.75,1)	(0.75,1,1)	(4.75,6.25,7.75)	6.1480
C8	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1,1,1)	(0.25,0.5,0.75)	(0,0,0.25)	(2.25,3,5.25)	3.3492
C9	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.5,0.75,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(1,1,1)	(0,0,0.25)	(1.5,1.75,4)	2.1147
C10	(0,0,0.25)	(0.75,1,1)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	(0.5,0.75,1)	(1,1,1)	(2.5,3.25,5.25)	3.5449
*	(4,5.25,7)	(4.5,6,7.75)	(2.75,3.5,5.5)	(4.5,6.25,8.25)	(1.75,2,4)	(1.5,1.75,4)	(1,1,3.25)	(1.75,2.25,4.5)	(3,4.25,6.5)	(1.75,2,4)		
#	5.3155	5.9667	3.7883	6.1780	2.3437	2.1314	1.3288	2.6277	4.4617	2.3437		

* Dependence; ** Driving power; # Crisp value

Table 10 Driving power and Dependence Matrix (MICMAC) based on fuzzy reachability matrix of Table 9

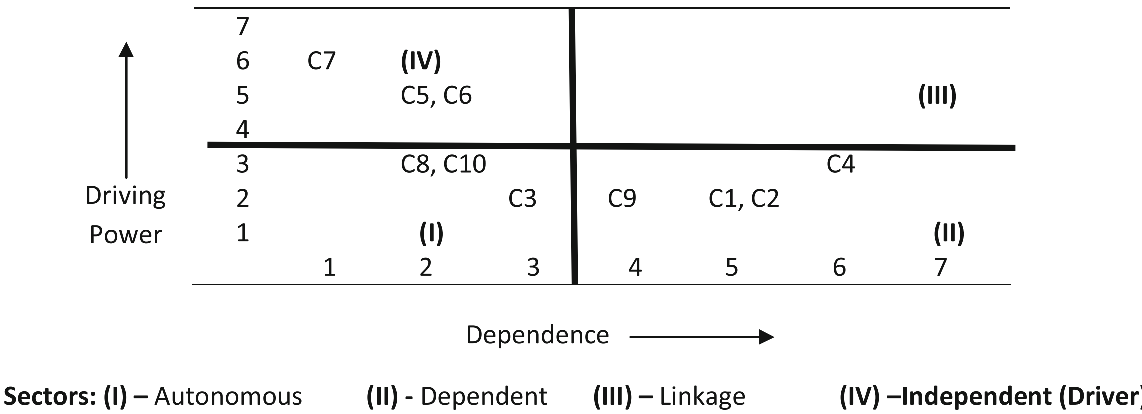

Table 11 Defuzzified reachability matrix with fuzzy linguistic terms Very High Influence (VH) and High Influence (H) as 1 and rest as 0. Shaded region indicates transitive links

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	1	0	1	0	0	0	0	1	0
C2	1	1	0	1	0	0	0	0	1	0
C3	1	1	1	1	0	0	0	0	1	**0**
C4	1	1	0	1	0	0	0	0	1	0
C5	1	1	1	1	1	1	0	1	1	0
C6	1	1	1	1	0	1	0	0	1	0
C7	1	1	1	1	1	1	1	1	1	1
C8	1	1	0	1	0	0	0	1	1	0
C9	1	1	0	1	0	0	0	0	1	0
C10	1	1	0	1	0	0	0	0	1	1

Table 12 Driving power- Dependence Matrix (MICMAC) based on defuzzified reachability matrix based on Table 11

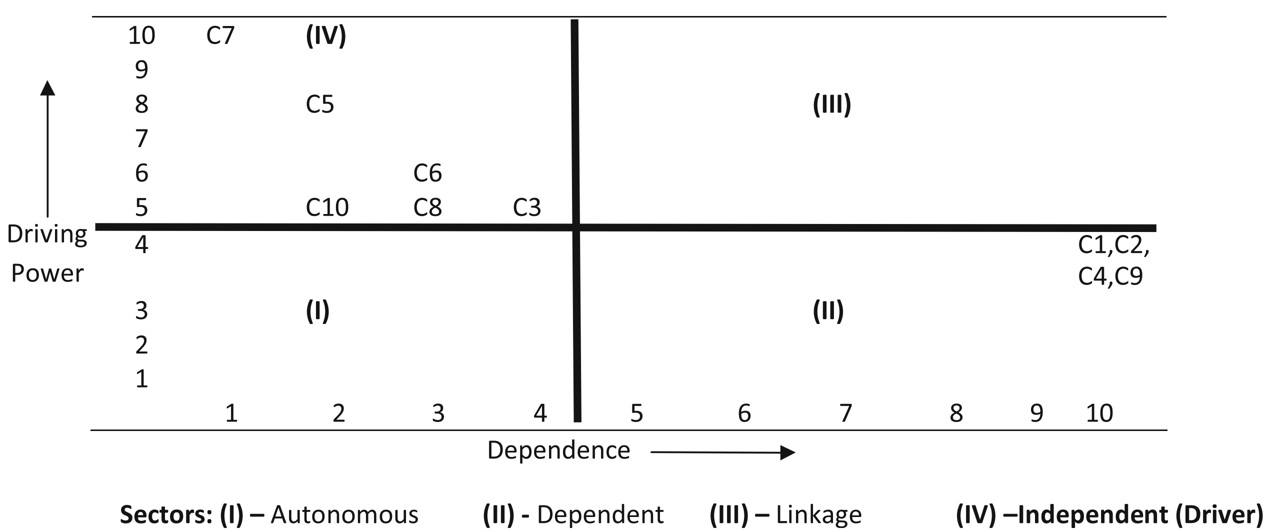

Table 13 First Iteration of final fuzzy reachability matrix partition

Variables	Reachability	Antecedent	Intersection	Level
1	1,2,4,9	1,2,3,4,5,6,7,8,9,10	1,2,4,9	1
2	1,2,4,9	1,2,4,5,6,7,8,9,10	1,2,4,9	1
3	1,2,3,4,9	3,5,6,7	3	
4	1,2,4,9	1,2,3,4,5,6,8,9,10	1,2,4,9	1
5	1,2,3,4,5,6,8,9	5,7	5	
6	1,2,3,4,6,9	5,6	6	
7	1,2,3,4,5,7,8,9,10	7	7	
8	1,2,4,8,9	5,8	8	
9	1,2,4,9	1,2,3,4,5,6,7,8,9,10	1,2,4,9	1
10	1,2,4,9,10	7,10	10	

Table 14 Second Iteration of final fuzzy reachability matrix partition

Variables	Reachability	Antecedent	Intersection	Level
3	3	3,5,6,7	3	2
5	3,5,6,8	3,5,6,7	3,5,6	
6	3,6	5,6,7	6	
7	3,5,6,7,8,10	6,7	6,7	
8	8	5,7,8	8	2
10	8,10	7,10	10	

Table 15 Third Iteration of final fuzzy reachability matrix partition

Variables	Reachability	Antecedent	Intersection	Level
5	5,6	5,7	5	
6	6	5,6,7	6	3
7	5,6,7,10	6,7	6,7	
10	10	7,10	10	3

Table 16 Fourth Iteration of final fuzzy reachability matrix partition

Variables	Reachability	Antecedent	Intersection	Level
5	5	5,7	5	4
7	5,7	7	7	5

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Key Questions

1. What is the flexibility in the Fuzzy-TISM approach?
2. How the Fuzzy-TISM approach has improved the group decision making process?
3. How the Fuzzy-TISM approach can be compared with the Fuzzy-ISM approach?

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