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Assessment of 3PL Providers for Hazardous Materials

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Abstract: Hazardous materials (hazmat) production and transportation have been increasing continuously. Especially, as they could harm people and environment during hazmat transportation, the firms tend to give hazmat transportation and other logistic activities to third party logistics (3PL) providers. Although there are many studies on hazmat, to the best of our knowledge we have not met the studies on 3PL provider selection for hazmat. Therefore, the aim of this study is to propose an assessment multi criteria decision making (MCDM) model for the selection of 3PL provider for hazmat. In this model, fuzzy decision making trial and evaluation laboratory (DEMATEL) is used to weight of criteria. Fuzzy DEMATEL is a comprehensive technique to build and analyze a structural model involving causal relationships among complex criteria. Fuzzy TOPSIS is utilized to assess the alternatives. To show applicability and effectiveness of the proposed model, an illustrative example is presented in our study.

Keywords: Fuzzy DEMATEL, Fuzzy TOPSIS, Hazardous Materials, Multi Criteria Decision Making, Third Party Logistics.

1. Introduction

Hazardous materials (hazmat) can be produced from industrial and chemical plants, petroleum refineries, medical stations etc. Hazardous materials are solids, liquids or gases that could harm people, other living organisms, property or the environment (Leonelli et al., 2000; UNECE, 2013). Some possible accidents/incidents that impose risk to people, property and the environment could be an explosion in storage or processing facilities, leak of hazmat from their containers directly to the atmosphere, an explosion or leak due to a traffic accident involving hazmat-carrying vehicles. According to the European Agreement concerning the International Carriage of Dangerous Goods by Road (commonly known as ADR), there are nine main classes of hazmat; (1) Explosive and pyrotechnics, (2) Gasses, (3) Flammable and combustible liquids, (4) Flammable, combustible and dangerous-when-wet solids, (5) Oxidizers and organic peroxides, (6) Poisonous and infectious materials, (7) Radioactive materials, (8) Corrosive materials (acidic or basic), (9) Miscellaneous dangerous goods (hazardous wastes).

Hazmat transportation will continuously increase by all modes of transport, especially on the road. During hazmat transport, they could explode or leak and therefore they may spread to atmosphere or harm the environment. This situation leads to increase the risk arising from hazmat transportation. Moreover, it may cause some dangers such as explosions, release of toxic gas or fires. Because of harmful effects of hazmat transportation on people or environment, it has additional risk and should be considered meticulously. Therefore, its risk should be kept under control and reduced with huge attention (Leonelli et al., 2000).

Due to importance of hazmat transportation, many firms tend to give this activity to a 3PL provider. A 3PL provider is a firm that provides service to its customers of outsourced logistics activities. These activities are transportation, warehousing, inventory management, packaging and so on. Depending on globalization, owing to the fact that the importance of speed, flexibility, quality, cost and competition lead to corporations to transfer their logistics activities to 3PL providers. Therefore, 3PL provider selection is one of the most important problems for a firm. At the same time, selecting the most appropriate 3PL provider may become one of the most important decisions. Due to the fact that the selection process consists of decision makers, criteria and alternatives, 3PL provider selection is considered as a MCDM problem. Because of the nature of the decision-making process and subjectivity of qualitative criteria, MCDM shows uncertainty and vagueness.

In the literature on hazmat transportation, risk analysis, routing, scheduling or planning in the studies are met. However, one of the most important problems on this issue is to be given the transportation or other logistics activities to a 3PL provider. For this reason, this study aims to present a MCDM model which integrates fuzzy DEMATEL and fuzzy TOPSIS to assess 3PL providers for hazmat. The nature of 3PL provider selection is a complex MCDM problem including both quantitative and qualitative criteria which may be in conflict and may also be uncertain. Therefore, fuzzy DEMATEL technique is used in order to determine criteria weights. The main advantage of the fuzzy DEMATEL is that the method covers the accommodating indirect relationship with the cause-effect model. Fuzzy TOPSIS considering the closeness of the ideal solution is utilized to assess the alternative 3PL providers.

The rest of the paper is organized as follows: Literature review on hazmat transportation and 3PL provider selection is presented in Section 2. Fuzzy set theory is presented in Section 3. Section 4 gives definitions and steps of fuzzy DEMATEL and fuzzy TOPSIS. The model for selecting 3PL provider on hazmat is proposed in Section 5. A numerical example is presented for the application of the proposed model in Section 6. Finally, conclusions and future research topics are discussed in Section 7.

2. Literature Review

The studies related to hazmat transportation are increasing in the literature. Bubbico et al. (2004) presented a risk analysis model for hazmat on road and rail utilizing geographic information systems (GIS). Zografos and Androutsopoulos (2004) developed a new heuristic algorithm to solve the vehicle routing and scheduling problems while aiming to minimize risk and cost. Alumur and Kara (2007) proposed a multi-objective location-routing model for the collection, transportation, treatment and disposal of hazardous wastes in order to minimize the transportation risk and the total cost. Glickman and Erkut (2007) presented a quantitative risk assessment approach for hazardous materials in a rail yard where tank cars are received and stored. Berman et al. (2007) proposed a method for determination of the optimal design of a specialized team network which can be represented via a maximal arc-covering model in order to maximize its ability to respond to such incidents in a region. Zografos and Androutsopoulos (2008) proposed a decision support system to assess alternative distribution routes considering risk, travel time and evacuation implications while correlating the emergency response deployment decisions. Bonvicini and Spadoni (2008) introduced a new model named OPTIPATH which was integrated with TRAT4-GIS (geographic information system) software to select less risky routes of the alternatives. Bianco et al. (2009) presented a bi-level flow model for hazmat network design problem for total risk minimization and risk equity. They used a heuristic algorithm for the bi-level model solution and applied the model on real scenarios of an Italian regional network. Trépanier et al. (2009) studied integration of databases on hazmat accidents, road accidents and work accidents which were cross-analyzed to analyze hazmat accidents in the province of Quebec, Canada. Ghatee et al. (2009) developed preemptive priority-based algorithms for the minimal cost flow problem with fuzzy link costs to understand the effect of uncertain factors in applied shipment problems. They applied these algorithms for hazmat transportation. Yang et al. (2010) studied on a survey on hazmat accidents during road transport in China between years 2000 - 2008. Xie et al. (2012) developed a mixed integer linear model for multimodal hazmat location and routing problem. This model aims to optimize transfer yard locations and routing plans simultaneously; also performed to two case studies. Zhao et al. (2012) used Bayesian networks based on expert knowledge using Dempster–Shafer evidence theory to prioritize the factors that influence hazmat accidents. Reilly et al. (2012) developed a three-player game of the interactions among a terrorist, a carrier and a government agency under terrorist threat for hazmat transportation; and also developed a solution approach for this game. Liu et al. (2013) introduced an integrated model that considers the combination of broken rail prevention and tank car safety design enhancement for risk reduction. They used pareto-optimality technique to maximize risk reduction at a given level of investment. Toumazis and Kwon (2013) developed a solution method based on the conditional value-at-risk measure for mitigating risk in routing hazmat. Gumus (2009) introduced a two-step approach to select the right and most appropriate transportation firm for hazardous waste generators. The author used fuzzy Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methods to evaluate alternative firms.

Many studies on 3PL provider selection are met in the literature. MCDM methods and the other techniques have been used to select the most suitable 3PL provider. Wadhwa and Ravidran (2007) used the weighted objective, goal programming and compromise programming for vendor selection in outsourcing. The results were compared by using value path approach. Liu and Wang (2009) proposed a MCDM method for evaluating and selecting of 3PL providers which consist of three different approaches. Fuzzy Delphi Method was used for identifying the criteria; fuzzy inference method was used for eliminating the unsuitable 3PL providers and fuzzy linear assignment approach was used for the final selection. Jharkharia and Shankar (2007) used ANP to select a logistics service provider. Li et al. (2012) used fuzzy sets to select distribution agent for an air conditioner firm among five alternative 3PL firms. Yücel and Güneri (2011) developed a weighted additive fuzzy programming approach in supplier selection problem. Ho et. al. (2012) developed an integrated approach, combining quality function deployment (QFD) and AHP to evaluate and select the optimal third-party logistics service provider in a company based on hard disk component manufacture. Li and Wan (2014) combined Linear Programming Technique for Multidimensional Analysis of Preference (LINMAP) and TOPSIS to select IT outsourcing providers. Çakır et al. (2009) and Vijayvargiya and Dey (2010) utilized Fuzzy AHP for the selection of 3PL company. Bottani and Rizzi (2006) used Fuzzy TOPSIS for selection of 3PL company. Qureshi et al. (2008) used TOPSIS by triangular fuzzy numbers. Araz et al. (2007) developed a 3PL selection model which integrates fuzzy AHP and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) methods. Teixeira de Almeida (2007) used Electre Method for outsourcing contracts selection. Liou and Chuang (2010) developed a hybrid multi criteria model including Dematel, ANP and Vikor for selection of 3PL service provider company. By using Dematel method; dependent and independent criteria were found and by using ANP the weights of criteria were determined. Dulmin and Mininno (2003) proposed a supplier selection model using Promethee and GAIA methods. Their method was used by an Italian firm which operated rail roads. Montazer et al. (2009) designed an expert decision aiding system by using Fuzzy Electre III method for vendor selection.

When we examine the literature on hazmat transportation, the studies related to 3PL provider selection are not seen. However, one of the most important problems on this issue is to be given the transportation and some other logistics activities to a 3PL provider. For this reason, in this study we aim to propose an assessment model for 3PL providers in hazmat.

3. Fuzzy Set Theory

Here, we give some definitions on fuzzy set theory (Zadeh, 1965).

Definition 1: If *X* is a collection of objects denoted generically by *x* then a fuzzy set *A* in *X* is a set of ordered pairs:

$$A = \{(x, \mu_A(x)) \mid x \in X\}$$

$\mu_A(x)$ is called the membership function or grade of membership of *x* in *A* which maps *X* to [0,1]. A fuzzy set *A* on the domain *X* is defined a map

$$A : X \to [0,1]$$

Definition 2: A fuzzy number *A* is a convex and normal fuzzy subset of *X*. Here, the convex set implies that,

$\forall x_1, x_2 \in X,\ \forall \lambda \in [0,1],\ \mu_A(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_A(x_1), \mu_A(x_2))$ (1)

Definition 3: A triangular fuzzy number (TFN) *A* can be defined by a triplet (*a*,*b*,*c*). The membership function is defined as

$$\mu_A(x) = \begin{cases} \dfrac{x-a}{b-a}, & a \leq x \leq b \\ \dfrac{c-x}{c-b}, & b \leq x \leq c \\ 0, & otherwise \end{cases} \quad (2)$$

Basic arithmetic operations on TFNs $A_1=(a_1,b_1,c_1)$, where $a_1 \leq b_1 \leq c_1$ and $A_2=(a_2,b_2,c_2)$, where $a_2 \leq b_2 \leq c_2$ can be shown as follows;

Fuzzy number addition ⊕ defined as,
$(a_1,b_1,c_1) \oplus (a_2,b_2,c_2) = (a_1+a_2, b_1+b_2, c_1+c_2)$ (3)

Fuzzy Number subtraction defined as,
$(a_1,b_1,c_1)\,\Theta\,(a_2,b_2,c_2) = (a_1-a_2, b_1-b_2, c_1-c_2)$ (4)

Fuzzy number multiplication ⊗ defined as,
$(a_1,b_1,c_1) \otimes (a_2,b_2,c_2) = (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2)$ (5)

4. Methods

In this section, fuzzy DEMATEL and fuzzy TOPSIS used to weight criteria and to assess and rank alternatives are explained, respectively.

4.1. Fuzzy Dematel

The DEMATEL method is developed between 1972 and 1976 by the researchers of Geneva Research Centre of the Battelle Memorial Institute (Aksakal and Dağdeviren, 2010). This method identifies the importance of criteria and the relations among the criteria. It is based on digraphs, which can divide factors into cause group and effect group (Wei-Wen and Lee, 2007; Shieh et al. 2010). The main advantageous of this technique is to reveal the relationships among factors and prioritize factors based on the type of relationships and severity of their effects on other factors. The number of studies on fuzzy DEMATEL is increasing in recent years. This technique has been applied to various areas such as evaluation of the green supply chain management practices (Lin, 2013), evaluation of the interactive trade (Wang, 2012), location selection (Kuo, 2011), truck selection (Baykasoğlu et al., 2013), identifying critical success factors in emergency management (Zhou et al., 2011), evaluation of human resource for science and technology (Choua et al., 2012).

The procedure of fuzzy DEMATEL method is summarized as follows:

Determine fuzzy initial direct relation matrix

The decision makers are asked to express their opinion about the direct influence between any two factors by an integer score ranging from 0, 1, 2, 3 and 4 by TFNs shown as in Table 1.

Table 1. Fuzzy Evaluation Scale

Linguistic Terms	Influence Score	TFNs
No influence	0	(0,0,0.25)
Very Low influence	1	(0,0.25,0.50)
Low influence	2	(0.25,0.50,0.75)
High influence	3	(0.50,0.75,1)
Very high influence	4	(0.75,1,1)

The initial direct relation matrix Z is a $(n \times n)$ matrix obtained by pair-wise comparisons in terms of influences and directions between criteria, in which z_{ij} is denoted as the degree to which the criterion i affects the criterion j, i.e., $Z = [z_{ij}]_{n\times n}$ (Wei-Wen and Lee, 2007). According to Table 1, the linguistic variables are implied by TFNs. The initial direct relation matrix (*Z*) is transformed into fuzzy initial direct relation matrix ($\tilde{Z} = [\tilde{z}_{ij}]_{n\times n}$) by using TFNs.

Obtain normalized fuzzy direct relation matrix

Normalized fuzzy direct relation matrix $\tilde{X} = [\tilde{x}_{ij}]_{n\times n}$ is produced by Eq. (6) and (7), in which diagonal elements are equal to zero.

$$\tilde{x}_{ij} = \frac{\tilde{Z}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \quad (6)$$

$$r = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} l_{ij}\right) \quad r = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} m_{ij}\right)$$

$$r = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} u_{ij}\right) \tag{7}$$

Find total relation fuzzy matrix

Normalized fuzzy direct relation matrix can be separated into three matrices i.e. (X_l, X_m, X_u). Therefore, the total relation matrix $\tilde{T}$ can be acquired by using Eq. (8), in which the I is denoted as the identity matrix.

$$\tilde{T} = \tilde{X} + \tilde{X}^2 + \tilde{X}^3 + \ldots = \sum_{i=1}^{\infty} \tilde{X}^i = \tilde{X}(I - \tilde{X})^{-1} \tag{8}$$

$\tilde{T} = [t_{ij}]_{n \times n}$ and $\tilde{t}_{ij} = (t_{ij,l}, t_{ij,m}, t_{ij,u})$ is the overall influence rating of decision maker for each criterion i against j.

Find causer and receiver groups

Let $\tilde{D}_i$ and $\tilde{R}_i$ be the sum of i-th row $\left(\tilde{D} = \sum_{j=1}^{n} t_{ij}\right)$ and the sum of i-th column $\left(\tilde{R} = \sum_{i=1}^{n} t_{ij}\right)$ in matrix $\tilde{T}$, respectively. D_i shows the total effects, both direct and indirect, given by factor i to the other factors; R_i shows the total effects, both direct and indirect, received by factor i from the other factors.

The sum $(\tilde{D}_i + \tilde{R}_i)$ gives us an index representing the total effects both given and received by factor i. In other words, $(\tilde{D}_i + \tilde{R}_i)$ shows the degree of importance (total sum of effects given and received) that factor i plays in the system. In addition, the difference $(\tilde{D}_i - \tilde{R}_i)$ shows the net effect that factor i contributes to the system. When $(\tilde{D}_i - \tilde{R}_i)$ is positive, factor i is a net causer, and when $(\tilde{D}_i - \tilde{R}_i)$ is negative, factor i is a net receiver.

Defuzzification

The Converting Fuzzy data into Crisp Scores (CFCS) method can be used for defuzzification. This method is developed by Opricovic and Tzeng (2003). This defuzzification method is four step algorithm and calculated by the maximum average value of right and left fuzzy values. $(\tilde{D}_i + \tilde{R}_i)$ and $(\tilde{D}_i - \tilde{R}_i)$ can be defuzzified by Eq. (9) to (16).

$Z_{ij}^k = (l_{ij}^k, m_{ij}^k, u_{ij}^k)$ Triangular fuzzy set.

Normalization:

$$xl_{ij}^k = (l_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max}, \tag{9}$$

$$xm_{ij}^k = (m_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max}, \tag{10}$$

$$xr_{ij}^k = (u_{ij}^k - \min l_{ij}^k) / \Delta_{\min}^{\max}; \tag{11}$$

$$\Delta_{\min}^{\max} = \max u_{ij}^k - \min l_{ij}^k \tag{12}$$

Calculating left (ls) and right (us) normalized values:

$$xls_{ij}^k = xm_{ij}^k / (1 + xm_{ij}^k - xl_{ij}^k) \tag{13}$$

$$xus_{ij}^k = xu_{ij}^k / (1 + xu_{ij}^k - xm_{ij}^k) \tag{14}$$

Calculating total normalized value:

$$x_{ij}^k = [xls_{ij}^k (1 - xls_{ij}^k) + xus_{ij}^k * xus_{ij}^k] / [1 - xls_{ij}^k + xus_{ij}^k] \tag{15}$$

Finding crisp value:

$$z_{ij}^k = \min l_{ij}^k + x_{ij}^k \Delta_{\min}^{\max}. \tag{16}$$

We can also defuzzificate total relation fuzzy matrix by using Eq. (9) to (16). Finding the defuzzificated matrix give us a chance for setting threshold value. The causal diagram and analysis are able to obtain with $(\tilde{D}_i + \tilde{R}_i)^{Def}$ and $(\tilde{D}_i - \tilde{R}_i)^{Def}$.

Calculating weight of criteria

The weights of criteria can be calculated by using Eq. (17) and (18). They must be between 0 and 1 and the sum of the weights must be equal to 1.

$$w_i = \sqrt{\left[(\tilde{D}_i + \tilde{R}_i)^{Def}\right]^2 + \left[(\tilde{D}_i - \tilde{R}_i)^{Def}\right]^2} \tag{17}$$

$$w_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{18}$$

4.2. Fuzzy Topsis

TOPSIS method was firstly introduced by Hwang and Yoon (1981). In this technique, the best alternative is assumed that is the shortest distance from positive ideal solution (PIS) and is the farthest distance from negative ideal solution (NIS) (Ertuğrul and Karakaşoğlu, 2009). PIS is a solution maximizing benefit criteria and minimizing cost criteria; on the other hand, NIS provides a solution maximizing cost criteria and minimizing benefit criteria (Wang and Elhag, 2006). This method has been applied to many MCDM problems in the literature (Chu, 2002; Chu and Lin, 2003; Lai et al., 1994; Wang et al., 2005). Although the evaluation is done based on crisp data in traditional TOPSIS method, many real world situations consist of uncertainty and vagueness. For this reason, fuzzy set theory which was proposed by Zadeh (1965) was used to develop fuzzy TOPSIS method (Chen, 2000; Kulak et al., 2005). Therefore, fuzzy TOPSIS technique and its application in MCDM problems is encountered for ranking of alternatives in many studies (Kahraman et al., 2007; Önüt and Soner, 2008; Yang and Hung, 2007).

In this study, fuzzy TOPSIS method presented by Chen (2000) is utilized to assess and rank the alternatives. Chen's (2000) fuzzy TOPSIS method and related definitions are presented in the below:

Assumed that p decision makers, m alternatives and n criteria are considered in a MCDM problem. Decision makers assess the alternatives for each criterion.

$$\tilde{x}_{ij} = \frac{1}{p}\left[\tilde{x}^1_{ij}(+)\tilde{x}_{ij}^2(+)\cdots(+)\tilde{x}_{ij}^p\right] \tag{19}$$

$$\tilde{w}_j = \frac{1}{p}\left[\tilde{w}_j^1(+)\tilde{w}_j^2(+)\cdots(+)\tilde{w}_j^p\right] \tag{20}$$

where $\tilde{x}_{ij}^p$ and $\tilde{w}_j^p$ represent importance degree that is given by p^{th} decision maker. Therefore, fuzzy MCDM group decision making method can be shown as a decision matrix:

$$R = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \qquad \tilde{W} = [\tilde{w}_1,\ \tilde{w}_2,\ \ldots,\ \tilde{w}_n]$$

where $\tilde{x}_{ij}$ and $\tilde{w}_j$ i=1, 2,…, m j=1, 2,…, n are linguistic variables. These variables are shown by TFNs represented in [0,1], $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$. Then, fuzzy decision matrix (R) is normalized and is entitled as normalized fuzzy decision matrix ($\tilde{R}$).

$$\tilde{R} = [\tilde{r}_{ij}]_{\mathrm{m\,x\,n}} \tag{21}$$

Assumed that B and C show benefit and cost criteria, respectively;

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \quad c_j^* = \max_i c_{ij} \quad \text{if } j \in B; \tag{22}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad a_j^- = \min_i a_{ij} \quad \text{if } j \in C \tag{23}$$

where $\tilde{r}_{ij}$ is used by normalized TFNs. The weighted normalized fuzzy decision matrix ($\tilde{V}$) is obtained with consideration criteria weights:

$$\tilde{V} = [\tilde{v}_{ij}]_{\mathrm{m\,x\,n}}, \quad i = 1, 2, \ldots, m, \quad j = 1, 2, \ldots, n \tag{24}$$

where $\tilde{v}_{ij}$ is calculated by $\tilde{r}_{ij}(.)\tilde{w}_j$. In the next step, fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FPIS, A^-) can be defined as $\tilde{v}_j^* = (1,1,1)$ ve $\tilde{v}_j^- = (0,0,0)$ $j = 1, 2, \ldots, n$. Here, positive ideal solution is $A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*)$ and negative ideal solution is $A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-)$. Thus, positive and negative distance measure for alternatives are calculated by using Eq. 25 and 26, respectively.

$$d_i^* = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^*\right) \quad i = 1, 2, \ldots, m \tag{25}$$

$$d_i^- = \sum_{j=1}^{n} d\left(\tilde{v}_{ij}, \tilde{v}_j^-\right) \quad i = 1, 2, \ldots, m \tag{26}$$

In the last step, closeness coefficients of the alternatives are determined as in Eq. (27).

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \tag{27}$$

Alternatives are ranked according to their closeness coefficients and the alternative with the highest closeness coefficient is selected as the most appropriate one.

5. The Proposed Model

In this section, we propose a fuzzy MCDM model to assess the alternative 3PL providers for hazmat. The steps of the proposed model are shown in Fig. 1.

Step 1: Establish a decision making group and determine criteria

Firm charges a decision making group consisting of expert, experienced and qualified persons for evaluating of criteria. Decision makers are shown by ($k = 1, 2, ..., p$).The required criteria represented by ($c_i \; i = 1, 2, ..., n$) for 3PL provider selection for hazmat in accordance with the structure of problem are determined from the studies on this issue in the literature or the needs of firm. Moreover, fuzzy evaluation scale which consists of linguistic variables, influence score and TFNs are designed.

Step 2: Assess the criteria by decision makers

All the decision makers assess the criteria using influence score or linguistic variables which are shown in Table 1.

Step 3: Form the initial direct relation/average matrix

The initial direct relation matrix is formed by the average values of fuzzy numbers which are existing in decision makers' evaluation matrix.

Step 4: Normalize the fuzzy initial direct relation matrix

Normalized fuzzy initial direct relation matrix is formed by using Eq. (6) and Eq. (7). The first, second and third values are found by dividing the values by r which can be found by Eq. (2)

Step 5: Find total relation fuzzy matrix

Total relation matrix can be found by using Eq. (8). To simplify the calculations we should separate the normalized fuzzy initial direct relation matrix into three matrices. The first matrix must be the first value of fuzzy number which are in the normalized fuzzy initial direct relation matrix, the second must be the medium values and the third must be last value of fuzzy numbers. Cause and effecting criteria are determined by the sums of the columns and rows. D values are the sums of the rows and R values are the sums of the columns. Then, we found D+R values and D-R values.

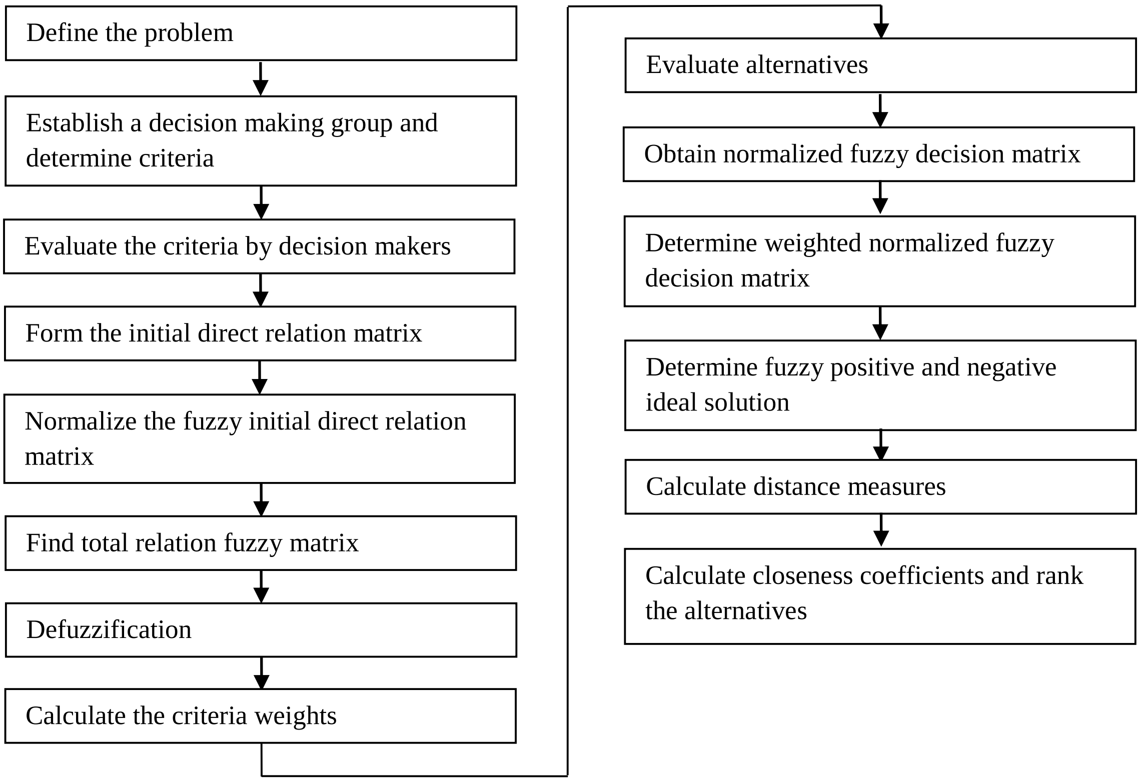

Fig. 1. The steps of the assessment model

Step 6: Defuzzification

$(\tilde{D}_i + \tilde{R}_i)$ values and $(\tilde{D}_i - \tilde{R}_i)$ values are defuzzificated by Eq. (9) to (16) respectively. Or we can find threshold value by defuzzificating the total relation fuzzy matrix. After defuzzificating total relation fuzzy matrix, we can also calculate *D*+*R* and *D*-*R* values. We can defuzzificate the total relation fuzzy matrix by using Eq. (9) to (16). Threshold value can be found by the average value of defuzzificated total relation matrix or can be determined by the decision makers. Threshold value reduces the cause and effecting criteria. So we don't use the number which are smaller than the threshold value.

Step 7: Calculate criteria weights

W_i is calculated by using the Eq. (17) and criteria weights are obtained by Eq. (18).

Step 8: Assess alternatives

Decision makers assess alternative for the criteria by using fuzzy linguistic variables. Decision makers' evaluations with linguistic variables are converted to TFNs and fuzzy decision matrices are obtained.

Step 9: Determine weighted normalized fuzzy decision matrix

The weighted normalized fuzzy decision matrix $\tilde{v}$ is founded as in Eq. (24).

Step 10: Determine fuzzy positive and negative ideal solution

(FPIS, A^*) and (FPIS, A^-) are determined considering benefit and cost criteria.

Step 11: Calculate distance measures

Distance measures are calculated using Eq. (25) and (26).

Step 12: Calculate closeness coefficients and rank the alternatives

The closeness coefficients of the alternatives are calculated by Eq. (27) and alternatives are ranked according to their closeness coefficients.

Finally, the alternative which has the highest closeness coefficient should be selected.

6. Illustrative Example

In this section, a numerical example is presented to show the applicability and efficiency of the proposed model for assessment of 3PL providers for hazmat. A firm which produces chemical materials wants to select a 3PL provider to transfer its some logistics activities and transportation. The firm has determined five alternative 3PL providers and eight criteria to assess alternatives.

Step 1: Establish a decision making group and determine criteria

The firm charges of a decision making group consist of three decision makers. They are expert, experienced and qualified. The required criteria ($c_i \; i = 1,2,...,8$) for 3PL provider selection in hazmat in accordance with the structure of problem are determined from the studies on this issue in the literature or the needs of firm. These are managerial success, technological capabilities, vehicles and equipment, operational performance, service quality, costs, risk management, communication and information systems and appropriateness on regulations.

Step 2: Assess the criteria by decision makers

All the decision makers have assessed the criteria using influence score and the evaluation matrices for each decision maker (x_1, x_2, x_3) are shown below.

$$x_1 = \begin{bmatrix} 0 & 1 & 1 & 2 & 0 & 2 & 1 & 2 \\ 2 & 0 & 3 & 2 & 4 & 3 & 3 & 3 \\ 1 & 2 & 0 & 1 & 2 & 1 & 1 & 1 \\ 1 & 2 & 2 & 0 & 3 & 0 & 0 & 2 \\ 1 & 4 & 1 & 3 & 0 & 3 & 4 & 3 \\ 2 & 1 & 1 & 0 & 2 & 0 & 3 & 1 \\ 1 & 4 & 2 & 2 & 4 & 2 & 0 & 4 \\ 2 & 3 & 2 & 1 & 4 & 2 & 3 & 0 \end{bmatrix}$$

$$x_2 = \begin{bmatrix} 0 & 2 & 2 & 3 & 3 & 2 & 2 & 2 \\ 2 & 0 & 4 & 4 & 4 & 3 & 2 & 2 \\ 1 & 2 & 0 & 2 & 3 & 2 & 1 & 2 \\ 2 & 4 & 3 & 0 & 4 & 2 & 2 & 2 \\ 2 & 3 & 4 & 3 & 0 & 2 & 2 & 2 \\ 2 & 1 & 3 & 2 & 3 & 0 & 1 & 2 \\ 1 & 1 & 2 & 3 & 2 & 1 & 0 & 1 \\ 3 & 2 & 2 & 3 & 2 & 2 & 1 & 0 \end{bmatrix}$$

$$x_3 = \begin{bmatrix} 0 & 1 & 3 & 4 & 2 & 3 & 2 & 1 \\ 2 & 0 & 4 & 4 & 4 & 1 & 4 & 1 \\ 2 & 2 & 0 & 4 & 3 & 0 & 2 & 0 \\ 3 & 2 & 3 & 0 & 3 & 1 & 4 & 0 \\ 3 & 1 & 3 & 3 & 0 & 0 & 2 & 0 \\ 2 & 1 & 0 & 1 & 2 & 0 & 0 & 2 \\ 1 & 3 & 3 & 2 & 2 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 2 & 4 & 1 & 0 \end{bmatrix}$$

Step 3: Form the initial direct relation/average matrix

The initial direct relation matrix is formed by the average values of fuzzy numbers and presented in Table 2.

Step 4: Normalize the fuzzy initial direct relation matrix

Normalized fuzzy initial direct relation matrix is formed by using Eq. (6) and Eq. (7). Table 3 gives normalized fuzzy initial direct relation matrix.

Step 5: Find total relation fuzzy matrix

Total relation matrix can be found by using Eq. (8). To simplify the calculations we should separate the normalized fuzzy initial direct relation matrix into three matrices. The first matrix must be the first value of fuzzy number which are in the normalized fuzzy initial direct relation matrix, the second must be the medium values and the third must be last value of fuzzy numbers. D values are the sums of the rows and R values are the sums of the columns. Than we found D+R values and D-R values.

Table 2. Initial Direct Relation Matrix ($\tilde{Z}$)

	c_1			c_2			c_3			c_4			c_5			c_6			c_7			c_8		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
c_1	0.000	0.000	0.000	0.083	0.333	0.583	0.250	0.500	0.750	0.500	0.750	0.917	0.250	0.417	0.667	0.333	0.583	0.833	0.167	0.417	0.667	0.167	0.417	0.667
c_2	0.250	0.500	0.750	0.000	0.000	0.000	0.667	0.917	1.000	0.583	0.833	0.917	0.750	1.000	1.000	0.333	0.583	0.833	0.500	0.750	0.917	0.250	0.500	0.750
c_3	0.083	0.333	0.583	0.250	0.500	0.750	0.000	0.000	0.000	0.333	0.583	0.750	0.417	0.667	0.917	0.083	0.250	0.500	0.083	0.333	0.583	0.083	0.250	0.500
c_4	0.250	0.500	0.750	0.417	0.667	0.833	0.417	0.667	0.917	0.000	0.000	0.000	0.583	0.833	1.000	0.083	0.250	0.500	0.333	0.500	0.667	0.167	0.333	0.583
c_5	0.250	0.500	0.750	0.417	0.667	0.833	0.417	0.667	0.833	0.500	0.750	1.000	0.000	0.000	0.000	0.250	0.417	0.667	0.417	0.667	0.833	0.250	0.417	0.667
c_6	0.250	0.500	0.750	0.000	0.250	0.500	0.167	0.333	0.583	0.083	0.250	0.500	0.333	0.583	0.833	0.000	0.000	0.000	0.167	0.333	0.583	0.167	0.417	0.667
c_7	0.000	0.250	0.500	0.417	0.667	0.833	0.333	0.583	0.833	0.333	0.583	0.833	0.417	0.667	0.833	0.083	0.250	0.500	0.000	0.000	0.000	0.250	0.500	0.667
c_8	0.250	0.500	0.750	0.250	0.417	0.667	0.167	0.333	0.583	0.167	0.417	0.667	0.417	0.667	0.833	0.417	0.667	0.833	0.167	0.417	0.667	0.000	0.000	0.000

Table 3. Normalized Fuzzy Direct Relation Matrix ($\tilde{X}$)

	c_1			c_2			c_3			c_4			c_5			c_6			c_7			c_8		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
c_1	0.000	0.000	0.000	0.026	0.069	0.096	0.079	0.103	0.123	0.158	0.155	0.151	0.079	0.086	0.110	0.105	0.121	0.137	0.053	0.086	0.110	0.053	0.086	0.110
c_2	0.079	0.103	0.123	0.000	0.000	0.000	0.211	0.190	0.164	0.184	0.172	0.151	0.237	0.207	0.164	0.105	0.121	0.137	0.158	0.155	0.151	0.079	0.103	0.123
c_3	0.026	0.069	0.096	0.079	0.103	0.123	0.000	0.000	0.000	0.105	0.121	0.123	0.132	0.138	0.151	0.026	0.052	0.082	0.026	0.069	0.096	0.026	0.052	0.082
c_4	0.079	0.103	0.123	0.132	0.138	0.137	0.132	0.138	0.151	0.000	0.000	0.000	0.184	0.172	0.164	0.026	0.052	0.082	0.105	0.103	0.110	0.053	0.069	0.096
c_5	0.079	0.103	0.123	0.132	0.138	0.137	0.132	0.138	0.137	0.158	0.155	0.164	0.000	0.000	0.000	0.079	0.086	0.110	0.132	0.138	0.137	0.079	0.086	0.110
c_6	0.079	0.103	0.123	0.000	0.041	0.082	0.053	0.069	0.096	0.026	0.052	0.082	0.105	0.121	0.172	0.000	0.000	0.000	0.053	0.069	0.096	0.053	0.086	0.110
c_7	0.000	0.052	0.082	0.132	0.138	0.137	0.105	0.121	0.137	0.105	0.121	0.137	0.132	0.138	0.172	0.026	0.052	0.082	0.000	0.000	0.000	0.079	0.103	0.110
c_8	0.079	0.103	0.123	0.079	0.086	0.110	0.053	0.069	0.096	0.053	0.086	0.110	0.132	0.138	0.172	0.132	0.138	0.137	0.053	0.086	0.110	0.000	0.000	0.000

Step 6: Defuzzification

In step 6, we have defuzzificated the values in step 5 by using Eq. (9) and (16). It is shown in Table 4 as $(\tilde{D}+\tilde{R})^{Def}$ and $(\tilde{D}-\tilde{R})^{Def}$.

Table 4. *D* and *R* Values and criteria weights

	$(\tilde{D}+\tilde{R})^{Def}$	$(\tilde{D}-\tilde{R})^{Def}$	weight
c_1	6.200	0.246	0.113
c_2	7.713	1.072	0.142
c_3	6.723	-0.823	0.124
c_4	7.444	-0.284	0.136
c_5	8.237	-0.684	0.151
c_6	5.563	-0.167	0.102
c_7	6.694	0.132	0.122
c_8	6.056	0.508	0.111

Step 7: Calculate criteria weights

In this step, we calculate the criteria weights by using Eq. (17) and (18) as shown in the Table 4.

Step 8: Assess alternatives

Decision makers have assessed alternatives for eight criteria as in Table 6 by using fuzzy linguistic variables presented in Table 5.

Table 5. Linguistic variables and TFNs

Linguistic variables	TFNs
Very Bad (VB)	(0.0, 0.0, 0.1)
Bad (B)	(0.0, 0.1, 0.3)
Medium Bad (MB)	(0.1, 0.3, 0.5)
Medium (M)	(0.3, 0.5, 0.7)
Medium Good (MG)	(0.5, 0.7, 0.9)
Good (G)	(0.7, 0.9, 1.0)
Very Good (VG)	(0.9, 1.0, 1.0)

Table 6. Evaluation of alternatives

Criteria	Alternative	DM1	DM2	DM3	$\tilde{V}$
c_1	x_1	M	MG	VG	(0.567,0.733,0.867)
	x_2	M	G	G	(0.567,0.767,0.9)
	x_3	G	MG	M	(0.5,0.7,0.867)
	x_4	MG	M	MB	(0.3,0.5,0.7)
	x_5	M	G	M	(0.433,0.633,0.8)
c_2	x_1	M	M	MG	(0.367,0.567,0.767)
	x_2	M	MG	MG	(0.433,0.633,0.833)
	x_3	G	MG	M	(0.5,0.7,0.867)
	x_4	G	M	MB	(0.367,0.567,0.733)
	x_5	G	MG	MG	(0.567,0.767,0.933)
c_3	x_1	M	MG	MB	(0.3,0.5,0.7)
	x_2	B	MB	MB	(0.067,0.233,0.433)
	x_3	MB	MB	MB	(0.1,0.3,0.5)
	x_4	MB	M	MG	(0.3,0.5,0.7)
	x_5	M	MB	MG	(0.3,0.5,0.7)
c_4	x_1	MB	M	MG	(0.3,0.5,0.7)
	x_2	VG	VG	MG	(0.767,0.9,0.967)
	x_3	VG	G	VG	(0.833,0.967,1)
	x_4	G	MG	MB	(0.433,0.633,0.8)
	x_5	G	G	G	(0.7,0.9,1)
c_5	x_1	B	MB	B	(0.033,0.167,0.367)
	x_2	MB	B	MB	(0.067,0.233,0.433)
	x_3	MB	B	MB	(0.067,0.233,0.433)
	x_4	M	M	M	(0.3,0.5,0.7)
	x_5	M	MB	MG	(0.3,0.5,0.7)
c_6	x_1	MG	MG	G	(0.567,0.767,0.933)
	x_2	VG	VG	G	(0.833,0.967,1)
	x_3	G	MG	M	(0.5,0.7,0.867)
	x_4	B	M	B	(0.1,0.233,0.433)
	x_5	M	G	MG	(0.5,0.7,0.867)
c_7	x_1	M	M	MG	(0.367,0.567,0.767)
	x_2	G	G	VG	(0.767,0.933,1)
	x_3	G	MG	MG	(0.567,0.767,0.933)
	x_4	M	B	M	(0.2,0.367,0.567)
	x_5	G	G	G	(0.7,0.9,1)
c_8	x_1	MG	M	MG	(0.433,0.633,0.833)
	x_2	G	G	MG	(0.633,0.833,0.967)
	x_3	VG	MG	MG	(0.633,0.8,0.933)
	x_4	M	MG	M	(0.367,0.567,0.767)
	x_5	VG	G	G	(0.767,0.933,1)

Step 9: Determine weighted normalized fuzzy decision matrix

Decision makers' linguistic evaluations have been converted to TFNs and the fuzzy decision matrices have been obtained. After that, the weighted normalized fuzzy decision matrix $\tilde{V}$ has been found as in Eq. (24) and can be seen in Table 6.

Step 10: Determine fuzzy positive and negative ideal solution

We assumed that the criterion costs and the other criteria are cost and benefit criteria respectively in this example. According to this, fuzzy positive ideal solution and fuzzy negative ideal solution are determined as below:

$$A^* = \begin{bmatrix} (1,1,1),(1,1,1),(1,1,1),(1,1,1),(0,0,0),(1,1,1), \\ (1,1,1),(1,1,1) \end{bmatrix}$$
$$A^- = \begin{bmatrix} (0,0,0),(0,0,0),(0,0,0),(0,0,0),(1,1,1),(0,0,0), \\ (0,0,0),(0,0,0) \end{bmatrix}$$

Step 11: Calculate distance measures

Distance measures for alternatives have been calculated by using Eq. (25) and (26). Moreover, the closeness coefficients of alternatives have been calculated by Eq. (27). The results for distance measures and closeness coefficients are shown in Table 7.

Table 7. Distance measures and closeness coefficients

Alternative	d^*	d^-	CC_i
x_1	3.203	5.211	0.619
x_2	2.368	6.014	0.718
x_3	2.671	5.732	0.682
x_4	4.313	4.080	0.486
x_5	2.596	5.824	0.692

Step 12: Calculate closeness coefficients and rank the alternatives

According to Table 7, the alternatives are ranked as $x_2 \succ x_5 \succ x_3 \succ x_1 \succ x_4$. Consequently, the second one should be selected as the most appropriate alternative.

7. CONCLUSION

Owing to the fact that hazmat production and transportation are increasing and they have harmful effects for human and environment, hazmat transportation and other logistics activities should be given huge importance. Especially, hazmat transportation has a big potential risk for accidents or incidents. Hence, firms want to transfer these logistics activities to a 3PL provider which is expert and professional for hazmat. Although there are many studies on hazmat transportation, the studies related to 3PL provider selection for hazmat have not been met in the literature. In this study, we focus on a MCDM assessment model to select the most suitable 3PL provider using fuzzy DEMATEL and fuzzy TOPSIS. Fuzzy DEMATEL has been used to weight the criteria and fuzzy TOPSIS has been utilized to assess the alternative 3PL providers. The proposed assessment model has been applied to an illustrative example in order to show the applicability of it. In future studies, some other MCDM techniques can be performed to select 3PL provider for hazmat.

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