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SELECTION OF DISTRIBUTION CENTER LOCATION USING FUZZY TOPSIS APPROACH

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Abstract

Selection of distribution center location is one of the crucial activities for a company to reduce transportation costs and improve business performance. To select an appropriate location for the distribution center, decision-makers must consider many factors such as availability of labor, infrastructure, closeness to customers and suppliers, expansion capacity, etc. It is very difficult for the decision-makers to select an appropriate distribution center that satisfies all requirements of various criteria. In this paper, the fuzzy technique for order preference by similarity to the ideal solution (TOPSIS) approach is presented to evaluate and select an appropriate distribution center location from many alternative locations. The proposed approach involves identification of potential alternative locations, selection of evaluation criteria, use of fuzzy set theory and linguistic variables to evaluate the rating of alternatives to the criteria, and the fuzzy TOPSIS approach to generate aggregate scores for evaluation and selection of the best distribution location center from all alternatives. The best alternative for a distribution center location is the best alternative with the highest score. An illustrative example is presented to clarify the results and the applicability of the proposed approach. The result can suggest that managers in the company deal with multiple criteria and uncertainty in selecting distribution centers through linguistic parameters. The proposed approach can be practically applied in deciding upon the potential location of the distribution center when the data are vague, imprecise, and uncertain by nature.

Keywords: Distribution center, Multi-criteria decision-making, Fuzzy theory, Fuzzy TOPSIS.

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1. Introduction

Selection of distribution center location is one of the most important activities for a firm to improve business performance and enhance competitive advantage. Considering the increased road freight, traffic congestion, storage costs, growth of population, and transportation costs selection of distribution center location has become most vital and challenge for the decision-makers. The location of the distribution center is also considered to be a strategic and long-term decision due to a large amount of capital investment. The selection of appropriate locations will effectively assist in the economies of scale as well as archive higher customer satisfaction through more effective transportation (Ding 2013). To evaluate and select the best location for the distribution center, decision-makers must consider many factors such as availability of labor, infrastructure, closeness to customers and suppliers, expansion capacity, etc. It is very difficult for the decision-makers to select an appropriate distribution center location that satisfies all requirements of various criteria. Therefore, the selection of distribution centers is a multi-criteria decision-making (MCDM) problem in which decision-makers deal with several qualitative and quantitative factors with conflicting objectives. A group of decision-makers will evaluate and select distribution centers based on their knowledge and experience according to multiple criteria. The final decision is the aggregated values of all decision-makers' assessments.

Fuzzy Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is one of the most popular methods for solving MCDM problems. (Chen 2000, Chu 2002, Erkayman et al. 2011, Tan et al. 2010, Liao, 2011). The objective of this paper is to propose a fuzzy TOPSIS approach for distribution center location selection. Fuzzy set theory combined with TOPSIS has been recorded significant attention in the area of management, science, and engineering (Chen 2000, Chen and Hwang 1992, Triantaphyllou and Lin 1996, Chu 2002, Wang and Lee 2007, Li et al. 2011, Liao 2013, Chu and Lin 2003, Kutlu and Ekmekçioğlu 2012). Therefore, we have been motivated to propose the fuzzy TOPSIS approach for the evaluation and selection of distribution center locations.

The paper is organized as follows: Section 2 presents a brief literature review of existing fuzzy approaches. Section 3 describes the fuzzy theory and operations. Section 4 presents the proposed fuzzy TOPSIS method for distribution center selection. In Section 5, an illustrative example is proposed. Finally, the conclusion and future works are given in Section 6.

2. Literature Review

In literature, several multi-criteria decision-making approaches have been developed for distribution center selection based on qualitative and quantitative criteria such as the analytic hierarchy process (AHP), fuzzy set theory (FST), data envelopment analysis (DEA), and goal programming (GP). Fuzzy set theory was introduced by Zadeh (1965). Fuzzy set theory is widely used to deal with uncertainty and vagueness exits in the decision-making process. In recent years, many fuzzy TOPSIS methods have been developed for location evaluation and selection problems. Chen (2000) extended the TOPSIS method to fuzzy group decision-making using triangular fuzzy numbers to represent the numerical linguistic scales for rating and weighting. Bellman and Zahed

(1970) proposed some application of fuzzy theories to the various decision-making processes in a fuzzy environment. Ding (2013) proposed an integrated fuzzy MCDM method to select hub locations for global shipping carrier-based logistics service providers. Cheng et al. (2005) applied the analytic network process (ANP) approach to the selection of a shopping mall location. Liao and Kao (2011) proposed an intergraded fuzzy TOPSIS and multi-criteria goal programming (MCGP) approach to supplier selection in supply chain management.

Awasthi et al. (2011) applied a multi-criteria decision-making approach for location planning for urban distribution centers under uncertainty. Asanaah et al. (2012) applied the AHP approach for supplier evaluation and selection in a pharmaceutical manufacturing company in Ghana. Chu (2002) proposed facility location selection using fuzzy TOPSIS under group decision. Chen (2001) proposed a fuzzy approach to select the location of the distribution center. Chu (2002) proposed facility location selection using fuzzy TOPSIS under group decision.Memari et al. (2019) used the multicriteria intuitionistic fuzzy TOPSIS method for the selection of sustainable suppliers.

Awasthi et al. (2011) proposed the application of fuzzy TOPSIS in the evaluation of sustainable transportation systems. Erkayman et al. (2011) proposed a fuzzy TOPSIS approach for logistic center location selection. Kutlu et al. (2012) used fuzzy failure models and effects analysis by using the fuzzy TOPSIS-based fuzzy AHP method. Kuo (2011) developed optimal location selection for an international distribution center by using a new hybrid method. Chen et al. (2002) proposed a selection model for logistics centers based on TOPSIS and MCGP methods. Lin and Chen (2004) proposed bid/ no-bid decision-making using a fuzzy linguistic approach. Liao and Kao (2011) developed an integrated fuzzy Topsis and MCGP approach to supplier selection in supply chain management. Lima et al. (2014) proposed a comparison between fuzzy AHP and fuzzy TOPSIS methods to supply selection. Rouyendegh and Saputro (2014) proposed supplier selection using integrated fuzzy TOPSIS and MCGP. Tuan and Hien (2017) proposed distribution center location selection using an extension of the fuzzy TOPSIS approach. Chatterjee and Stevic (2019) proposed a two-phase fuzzy AHP and fuzzy TOPSIS model for supplier evaluation in the manufacturing environment.

Tan et al. (2010) proposed construction project selection using the fuzzy TOPSIS approach. Okwu and Tartibu (2020) proposed TOPSIS and ANFIS based on evaluating a methodology for sustainable supplier selection in the retail industry. Triantaphyllou and Lin (1996) developed five fuzzy multi-attribute decision-making methods. Wang and Eihag (2006) proposed a fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment. Yang et al. (2007) proposed fuzzy theory for logistics distribution centers location problem under fuzzy environment. Li et al. (2011) developed an axiomatic fuzzy method for the selection of logistic center location. Chen

(2001) proposed a fuzzy approach to select the location distribution center. Wang and Lee (2007) proposed generalized TOPSIS for fuzzy multi-criteria group decision making. Chu and Lia (2005) proposed selecting distribution center locations using an improved fuzzy MCDM approach. Pati et al. (2020) proposed fuzzy TOPSIS and grey relation analysis integration for supplier selection in the fiber industry. Kumar and Barman (2021) proposed fuzzy TOPSIS and fuzzy VIKOR in selecting green suppliers for sponge iron and steel manufacturing.

3. Basic Fuzzy Set Theory

Fuzzy theory is widely used in decision-making processes where uncertainties and vagueness exist due to a lack of complete information. Fuzzy set theory was introduced by Zahed (1965). Fuzzy logic theory and techniques mainly constructed the concept of fuzzy sets, linguistic variables, membership function, and fuzzy arithmetic rules. Fuzzy sets and linguistic variables are the most commonly used in qualitative assessment. The concept of linguistic variables is very useful if the situations are imprecise or unclear to be described in common qualitative expression for the decision-making process. As Zadeh (1965) has said a realistic approach is the utilization of linguistic terms such that true, highly true, more true, less true, false, probable false, etc instead of a real number. Hence, the value can be expressed in linguistic terms which can be represented as a domain of the problem. The fuzzy set theory uses linguistics variables is translated into fuzzy numbers. The various shapes of fuzzy numbers commonly used are the triangular fuzzy number and the trapezoidal fuzzy number.

3.1 Basic Concepts

Some basic definitions and notations of fuzzy set theory and fuzzy numbers reviewed from (Kaufmann and Gupta 1991, Ross 2004, Zaheh 1965, Zimmermann 2001) are presented as follows:

Definition 1: A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$ that maps each element x in X to a real number in the interval [0,1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$ (Kaufmann and Gupta 1991). The nearer the value of $\mu_{\tilde{A}}(x)$ to the unit, the higher the grade of membership of x in $\tilde{A}$.

Definition 2: If X is a collection of objects denoted generically by x, then a fuzzy set $\tilde{A}$ in X is a set of ordered pairs $\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \epsilon X\}$. $\mu_{\tilde{A}}$ is a value assigned to represent the membership of x in $\mu_{\tilde{A}}$. (Zimmermann 2001)

For example, if there are three fuzzy numbers in a fuzzy set $\tilde{A}$ namely x_1, x_2, x_3 and their membership values are defined, respectively, as 0.6, 0.8, 0.1 then, the fuzzy set $\tilde{A} = \{(x_1, 0.6), (x_2, 0.8), (x_3, 0.1)\}$

Definition 3: The triangular fuzzy number (Figure 1) is denoted as $\tilde{A} = (a_1, a_2, a_3)$, the membership function of the fuzzy number $\tilde{A}$ is defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & \mathrm{x} \leq \mathrm{a}_1 \\ \frac{x-a_1}{a_2-a_1} & \mathrm{a}_1 \leq \mathrm{x} \leq \mathrm{a}_2 \\ \frac{a_3-x}{a_3-a_2} & \mathrm{a}_2 \leq \mathrm{x} \leq \mathrm{a}_3 \\ 0 & \mathrm{x} > \mathrm{a}_3 \end{cases} \tag{1}$$

where (a_1, a_2, a_3) are real number and $a_1 < a_2 < a_3$. a_1, a_2, a_3 stands for the left bound value, mean value and right bound value respectively in the distribution of triangular fuzzy number. The membership function is presented in Eq. (1). The value of x at a_1 will give the smallest value of $\mu_{\tilde{A}}(x)$, i.e $\mu_{\tilde{A}}(x) = 0$. The value of x at a_2 gives the maximum value of $\mu_{\tilde{A}}(x)$, i.e $\mu_{\tilde{A}}(x) = 1$.

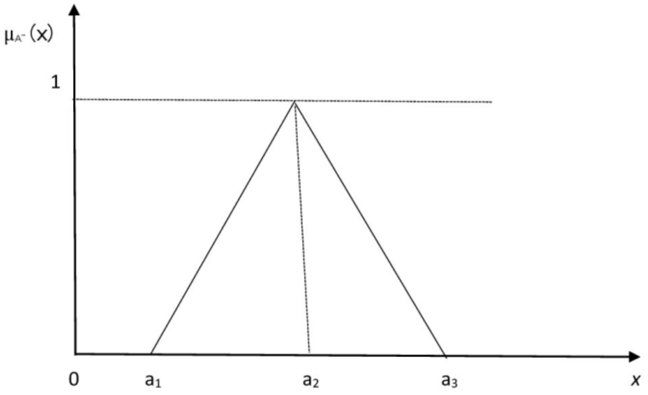

Figure 1: A triangular fuzzy number

Definition 4: A fuzzy set $\tilde{A}$ is convex if

$$\mu_{\tilde{A}}(\lambda x_1 + (1 - \lambda x_2) \geq min(\mu_{\tilde{A}} x_1, \mu_{\tilde{A}} x_2) \tag{2}$$

$x_1, x_2 \epsilon X, \lambda \epsilon (0,1)$ where $\mu_{\tilde{A}} x_1, \mu_{\tilde{A}} x_2$are the membership values of x_1, x_2 belonging to fuzzy set $\tilde{A}$ and λ is a real number $\lambda \epsilon (0,1)$ (Zimmermann 2001).

Definition 5: Let $\tilde{A}$= (a_1, a_2, a_3) and $\tilde{B}$ = (b_1, b_2, b_3) are two triangular fuzzy numbers the main operations of fuzzy number $\tilde{A}$ and $\tilde{B}$ can be expressed as follows:

(1) Additional of two triangular fuzzy numbers

$$\tilde{A} \oplus \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3), a_1 \geq 0, b_1 \geq 0 \tag{3}$$

(2) Subtraction of two triangular fuzzy numbers

$$\tilde{A} \ominus \tilde{B} = (a_1 - b_1, a_2 - b_2, a_3 - b_3), a_1 \geq 0, b_1 \geq 0 \tag{4}$$

(3) Multiplication of two triangular fuzzy numbers

$$\tilde{A} \otimes \tilde{B} = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3), a_1 \geq 0, b_1 \geq 0 \tag{5}$$

(4) Division of two triangular fuzzy numbers

$$\tilde{A} \oslash \tilde{B} = (\frac{a_1}{b_1}, \frac{a_2}{b_2}, \frac{a_3}{b_3}), a_1 \geq 0, b_1 \geq 0 \tag{6}$$

(5) Inverse of a triangular fuzzy number

$$\tilde{A}^{-1} = (\frac{1}{a_1}, \frac{1}{a_2}, \frac{1}{a_3}), a_1 \geq 0 \tag{7}$$

(6) Multiplication of a triangular fuzzy number by a constant

$$r \otimes \tilde{A} = (r \times a_1, r \times a_2, r \times a_3) a_1 \geq 0, r \geq 0 \tag{8}$$

(7) Division of a triangular fuzzy number by a constant

$$r \oslash \tilde{A} = (\frac{r}{a_1}, \frac{r}{a_2}, \frac{r}{a_3}), a_1 \geq 0, r \geq 0 \tag{9}$$

Definition 6: Let $\tilde{A}$= (a_1, a_2, a_3) and $\tilde{B}$ = (b_1, b_2, b_3) are two triangular fuzzy numbers, then the distance between $\tilde{A}$ and $\tilde{B}$ using the vertex method is defined as:

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3}[(a_1 - b_1)^2 + (a_2 - b_2)^2 + (a_3 - b_3)^2]} \tag{10}$$

3.2 Linguistic Variables

Linguistic variables are the words or sentences in the common language where each linguistic value can be the module by a fuzzy set (Kaufmann and Gupta 1985, Chen 2000, Lin and Chen 2004). The triangular fuzzy numbers are very commonly used for expressing linguistic terms (Yeh and Deng 2004). In this study, we have used a conversion scale of 1-9 to rate linguistic terms into triangular fuzzy numbers. The importance of weights of the five criteria are described by using the following linguistic terms: Very low (VL), Low (L), Medium (M), High (H), Very high (VH), which are defined in Table 1. The linguistic terms and the performance ratings of the alternatives for the criteria are described as: Very poor (VP), Poor (P), Fair (F), Good (G), Very good (VG), which is defined in Table 2.

Table 1. Linguistics variables for importance weight of criteria

Linguistic terms	Triangular Fuzzy numbers
Very Low (VL)	(0.1,0.1,0.3)
Low (L)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
High (H)	(0.5,0.7,0.9)
Very High (VH)	(0.7,0.9,0.9)

Table 2. Linguistics variables for alternative ratings

Linguistic terms	Triangular Fuzzy numbers
Very Poor (VP)	(1,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very Good (VG)	(7,9,9)

4. Fuzzy TOPSIS Method

The TOPSIS (Technique for Order Performance by Similarity to an Ideal Solution) method was developed by Hwang and Yoon (1981) to solve multiple attribute decision-making problems. In this approach, two alternatives are defined as the positive ideal solution (PIS) and the negative ideal solution (NIS). The TOPSIS method chooses an alternative that is the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. The positive ideal is a solution that maximizes the benefit criteria and minimizes the cost criteria whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang and Eihag 2006; Wang and Chang 2007). The positive ideal solution is computed of the best performance values from each criterion and the negative ideal solution consists of the worst performance values (Ertuğrul and Karakasoğlu 2008). The TOPSIS is used to find the rank of the attributes in real situations.

An extension of the basic TOPSIS method, several fuzzy TOPSIS methods have been developed to solve multi-criteria decision-making problems (Chen 2000, Chen and Hwang 1992, Triantaphyllou and Lin 1996, Chu 2002, Chu and Lin 2003, Kutlu and Ekmekçioğlu 2012). Therefore, the fuzzy TOPSIS method is applied in this study for evaluation and selection of distribution center location.

The steps of the fuzzy TOPSIS method are presented as follows:

Step 1: Consider multi-criteria decision-making problem, suppose there are m alternatives to be evaluated, $A_i, (i = 1,2 \ldots m)$, with respect to n evaluation criterion $C_j, (j = 1,2 \ldots n)$ and K decision-makers.

Step 2: Choose the linguistic variable $(\tilde{X}_{ij}, i = 1,2 \ldots m, j = 1,2..n)$ for alternatives with respect to criteria and the fuzzy linguistic ratings $\tilde{X}_{ij}$ as triangular fuzzy numbers: $\tilde{X}_{ij} = (a_{ij}, b_{ij}, c_{ij})$.

Step 3: Aggregate the weight W_j of the criterion C_j to get the aggregate fuzzy ratings $\tilde{X}_{ij}$ of the alternative of alternative A_i under the criteria C_j can be calculated as:

$$\tilde{X}_{ij} = \frac{1}{K}[\tilde{x}_{ij}^1(+)\tilde{x}_{ij}^2(+)\ldots.(+)\tilde{x}_{ij}^k], \quad i = 1,2..m; j = 1,2..n \tag{11}$$

$$\widetilde{W}_j = \frac{1}{K}[\widetilde{w}_j^1(+)\widetilde{w}_j^2(+)\ldots.(+)\widetilde{w}_j^k], \quad j = 1,2,..n \tag{12}$$

where $\tilde{x}_{ij}$ is the rating of the kth decision-maker for ith alternative with respect to jth criterion (Chen 2000).

Step 4: The fuzzy decision matrix for the alternatives $(\widetilde{D})$ and the criteria $(\widetilde{W})$ is constructed as follows:

$$\widetilde{D} = \begin{pmatrix} \tilde{X}_{11} & \tilde{X}_{12}\ldots & \tilde{X}_{1n} \\ \tilde{X}_{21} & \tilde{X}_{22}\ldots & \tilde{X}_{2n} \\ : & : & : \\ \tilde{X}_{m1} & \tilde{X}_{m2}\ldots & \tilde{X}_{mn} \end{pmatrix} i = 1,2\ldots m; j = 1,2\ldots n \tag{13}$$

where $\tilde{X}_{ij}$ is the rating of the alternative A_i with respect to criterion j (i.e. C_j) and W_j denotes the importance weight of C_i

$$\widetilde{W} = [\widetilde{w}_1, \widetilde{w}_2, \ldots \widetilde{w}_{n1}] \tag{14}$$

Step 5: Normalized the fuzzy decision matrix denoted as $\tilde{R}$

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn}, i = 1,2..m; j = 1,2..n \tag{15}$$

$$\tilde{r}_{ij} = (\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}), j\epsilon B; \tag{16}$$

$$\tilde{r}_{ij} = (\frac{a_j^-}{c_{ij}}, \frac{b_j^-}{b_{ij}}, \frac{c_j^-}{a_{ij}}), j\epsilon C; \tag{17}$$

$$c_j^* = \max_i c_{ij} \text{if} \quad j\epsilon B; \tag{18}$$

$$a_j^- = \min_i a_{ij} \text{if} \quad j\epsilon C; \tag{19}$$

where B and C are the set of benefit criteria and cost criteria respectively.

Step 6: Construct the fuzzy weighted normalized matrix. The fuzzy weighted normalized matrix $\tilde{V}$ for criteria is calculated by multiplying the weight $(\widetilde{w}_j)$ of evaluation criteria with the normalized fuzzy decision matrix $(\tilde{r}_{ij})$.

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn}, \quad i = 1,2\ldots m; j = 1,2\ldots n, \tag{20}$$

where

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \widetilde{w}_j \tag{21}$$

Step 7: Determine the fuzzy positive ideal solution (FPIS), A^* and fuzzy negative ideal solution (FNIS), A^-. The FPIS and FNIS calculation can be obtained as follows:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) \quad (22)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \quad (23)$$

Where $\tilde{v}_j^* = \max_i(v_{ij3})$ and $\tilde{v}_j^- = \min_i(v_{ij1})$ since $\tilde{v}_j$ is weighted normalized TFNs. $i = 1,2\ldots m$; $j = 1,2\ldots n$.

Step 8: Compute the distance of each alternative from FPIS and FNIS. The distance of each alternative from A^* and A^- can be calculated as follows:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i = 1,2\ldots m \quad (24)$$

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

where d(.,.) represents the distance between two triangular fuzzy numbers.

Step 9: Determine the closeness coefficient (CC_i), $i = 1,2\ldots m$ of each alternative:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \quad i = 1,2\ldots m \quad (26)$$

where CC_i range belongs to the interval [0,1] and $i = 1,2\ldots m$.

Step 10: Determine the ranking order of all alternatives according to their relative closeness values. The best alternative is closer to the (FPIS, A^*) and farther from, (FNIS, A^-). The alternative with the highest closeness coefficient is the best one among a set of feasible alternatives.

5. An illustrative example

Let us assume that XYZ automobile manufacturing company is planning to establish a new distribution center. A decision-making committee of three members D1, D2, and D3 is formed to assess and select the most suitable distribution center location for the company. It is assumed that the degree of importance of the three decision-makers is equal. The potential location alternatives A1, A2, and A3 are available for evaluation of the distribution center.There are seven criteria C(i), i=1,2...7 are selected for evaluation of distribution center.The proposed fuzzy TOPSIS method is applied to select the most suitable distribution center location for the company. The steps are presented as follows:

Step 1: Selection of evaluation criteria for distribution center location.

In this step, the criteria used for the evaluation of distribution center location are presented. Based on the literature survey, the criteria are identified and discussed with decision-makers. Seven criteria are finally selected to evaluate the most suitable location for the distribution center. The seven criteria are resource availability (C1), transport services and infrastructure (C2), expansion capability (C3), investment of cost (C4), closeness to demand market (C5), proximity to customer bases (C6), and suppliers networks (C7). They are shown in Table 3. In Table 3, the criteria investment of cost (C4) belong to the cost category, i.e. the less the better, and all other remaining criteria are benefited type criteria i.e. the more the better.

Table 3. Criteria for selection of distribution center location

Criteria	Criteria category
Resource availability (C1)	Benefit (the more the better)
Transport services and infrastructure(C2)	Benefit (the more the better)
Expansion capability (C3)	Benefit (the more the better)
Investment of cost (C4)	Cost (the less is better)
Closeness to demand market (C5)	Benefit (the more the better)
Proximity to customer bases (C6)	Benefit (the more the better)
Suppliers networks (C7)	Benefit (the more the better)

Step 2: Evaluation and selection of best alternative location using fuzzy TOPSIS

In this step, the allocation of linguistic rating to the subjective criteria and the alternatives for each criterion are presented by the decision-makers. The decision-making group includes three members D1, D2, and D3. They have good experience in manufacturing and distribution centers management. Table 4 and Table 5 are the decision-makers' assessments of the importance of the criteria using linguistic rating and alternatives. The weight of the seven criteria obtained from decision-makers according to the linguistic terms are transformed to fuzzy triangular numbers.

The ratings of the three distribution center location alternatives are aggregated by Eq. (11) and given in Table 6. Using Chen’s (2000) fuzzy arithmetic calculation, the aggregate ratings for the three distribution center locations A1, A2, and A3 for seven criteria are evaluated by Eq. (12) in Table 7. The normalized fuzzy decision matrix is formulated using Eq. (15), (16), and (17) as shown in Table 8. The weighted normalized fuzzy decision matrix for the three alternative distribution centers is constructed using Eq. (20)-(21) in Table 9. The fuzzy positive ideal solution (A^{*}) and fuzzy negative ideal solution (A^{-}) for three distribution center locations are calculated using Eq. (22)-(23) in Table 10.

The distance d(.) of each distribution center location from the fuzzy positive ideal solution (A^{*}) and fuzzy negative ideal solution (A^{-}) are computed according to the Eq. (24)-(25). The distance d(.) results are shown in Table 11. Using the distances (d_i^{*}), (d_i^{-}), the closeness coefficients of distribution center locations are calculated by Eq. (26) as shown in Table 12. According to the closeness coefficient (CC_i) values, the ranking order of three distribution center locations is $A1 > A3 > A2$. Therefore, location A1 is selected as the best distribution center location for the manufacturing company.

Table 4. Linguistic rating for the seven criteria

Criteria	Decision-makers		
	D1	**D2**	**D3**
Resource availability (C1)	H	H	M
Transport services and infrastructure(C2)	VH	VH	H
Expansion capability (C3)	H	M	H
Investment of cost (C4)	VH	H	VH
Closeness to demand market (C5)	VH	VH	VH
Quality of life (C6)	M	H	H
Suppliers networks (C7)	H	H	H

Table 5. Linguistic rating for the three alternatives

Criteria	Alternatives	Decision-makers		
		D1	**D2**	**D3**
C1	A1	P	F	F
	A2	F	G	G
	A3	G	G	G
C2	A1	G	F	G
	A2	G	G	G
	A3	G	G	G
C3	A1	VG	G	VG
	A2	VG	VG	VG
	A3	G	G	G
C4	A1	F	G	G
	A2	G	G	F
	A3	G	G	G
C5	A1	VG	G	G
	A2	G	F	F
	A3	G	G	F
C6	A1	G	VG	G
	A2	VG	G	VG
	A3	G	G	VG
C7	A1	F	G	F
	A2	P	F	P
	A3	G	F	F

Table 6. Aggregate fuzzy weights for the criteria

Criteria	Decision-makers			Aggregated fuzzy weights
	D1	D2	D3	
C1	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.63,0.9)
C2	(0.7,0.9,0.9)	(0.7,0.9,0.9)	(0.5,0.7,0.9)	(0.5,0.83,0.9)
C3	(0.5,0.7,0.9)	(0.7,0.9,0.9)	(0.5,0.7,0.9)	(0.5,0.76,0.9)
C4	(0.7,0.9,0.9)	(0.5,0.7,0.9)	(0.7,0.9,0.9)	(0.5,0.83,0.9)
C5	(0.7,0.9,0.9)	(0.7,0.9,0.9)	(0.7,0.9,0.9)	(0.7,0.9,0.9)
C6	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.63,0.9)
C7	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.5,0.7,0.9)

Table 7. Aggregate fuzzy ratings for the alternatives

Criteria	Alternatives	Decision-makers			Aggregated fuzzy ratings
		D1	D2	D3	
C1	A1	(1,3,7)	(3,5,7)	(3,5,7)	(1,4.33,7)
	A2	(3,5,7)	(5,7,9)	(5,7,9)	(3,6.33,9)
	A3	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
C2	A1	(5,7,9)	(3,5,7)	(5,7,9)	(3,6.33,9)
	A2	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
	A3	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
C3	A1	(7,9,7)	(5,7,9)	(7,9,9)	(5,8.33,9)
	A2	(7,9,9)	(7,9,9)	(7,9,9)	(7,9,9)
	A3	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
C4	A1	(3,5,7)	(5,7,9)	(5,7,9)	(3,6.33,9)
	A2	(5,7,9)	(5,7,9)	(3,5,7)	(3,6.33,9)
	A3	(5,7,9)	(5,7,9)	(5,7,9)	(5,7,9)
C5	A1	(7,9,9)	(5,7,9)	(5,7,9)	(5,7.66,9)
	A2	(5,7,9)	(3,5,7)	(3,5,7)	(3,5.66,9)
	A3	(5,7,9)	(5,7,9)	(3,5,7)	(3,6.33,9)
C6	A1	(5,7,9)	(7,9,9)	(5,7,9)	(5,7.66,9)
	A2	(7,9,9)	(5,7,9)	(7,9,9)	(5,8.33,9)
	A3	(5,7,9)	(5,7,9)	(7,9,9)	(5,7.66,9)
C7	A1	(3,5,7)	(5,7,9)	(3,5,7)	(3,5.66,9)
	A2	(1,3,5)	(3,5,7)	(1,3,5)	(1,3.66,7)
	A3	(5,7,9)	(3,5,7)	(3,5,7)	(3,5.66,9)

Table 8. Normalized fuzzy decision matrix for the three alternatives

Criteria	**Alternatives**		
	A1	**A2**	**A3**
C1	(0.11,0.481,0.78)	(0.33,0.703,1)	(0.55,0.78,1)
C2	(0.33,0.703,1)	(0.55,0.78,1)	(0.55,0.78,1)
C3	(0.55,0.925,1)	(0.78,1,1)	(0.55,0.78,1)
C4	(0.33,0.473,1)	(0.33,0.473,1)	(0.33,0.428,0.6)
C5	(0.55,0.851,1)	(0.33,0.628,1)	(0.55,0.703,1)
C6	(0.55,0.851,1)	(0.55,0.925,1)	(0.55,0.851,1)
C7	(0.55,0.628,1)	(0.11,0.406,0.78)	(0.33,0.628,1)

Table 9. Weighted normalized fuzzy decision matrix for the three alternatives

Criteria	**Alternatives**		
	A1	**A2**	**A3**
C1	(0.033,0.303,0.702)	(0.099,0.442,0.9)	(0.165,0.49,0.9)
C2	(0.165,0.583,0.9)	(0.275,0.647,0.9)	(0.275,0.674,0.9)
C3	(0.275,0.703,0.9)	(0.39,0.76,0.9)	(0.275,0.592,0.9)
C4	(0.165,0.392,0.9)	(0.165,0.392,0.9)	(0.165,0.355,0.54)
C5	(0.385,0.765,0.9)	(0.231,0.565,0.9)	(0.385,0.632,0.9)
C6	(0.165,0.536,0.9)	(0.165,0.582,0.9)	(0.165,0.536,0.9)
C7	(0.275,0.439,0.9)	(0.055,0.284,0.702)	(0.165,0.439,0.9)

Table 10. FPIS (A^*) and FNIS (A^-)

Criteria	**FPIS (A^*)**	**FNIS (A^-)**
C1	(0.9,0.9,0.9)	(0.033,0.033,0.033)
C2	(0.9,0.9,0.9)	(0.165,0.165,0.165)
C3	(0.9,0.9,0.9)	(0.275,0.275,0.275)
C4	(0.9,0.9,0.9)	(0.165,0.165,0.165)
C5	(0.9,0.9,0.9)	(0.231,0.231,0.231)
C6	(0.9,0.9,0.9)	(0.165,0.165,0.165)
C7	(0.9,0.9,0.9)	(0.055,0.055,0.055)

Table 11. Distance d(A_1,A^*) and d(A_1,A^-) for the three alternatives

Criteria	d(A_1,A^*)	d(A_2,A^*)	d(A_3,A^*)	d(A_1,A^-)	d(A_2,A^-)	d(A_3,A^-)
C1	0.6184	0.5327	0.4859	0.4165	0.5547	0.5709
C2	0.4621	0.3892	0.3837	0.4881	0.5114	0.5200
C3	0.3783	0.3053	0.4022	0.4373	0.4615	0.4046
C4	0.5158	0.5158	0.5677	0.4441	0.4441	0.2427
C5	0.3073	0.4319	0.3351	0.5021	0.4317	0.4590
C6	0.4735	0.4623	0.4735	0.4753	0.4878	0.4753
C7	0.4483	0.6144	0.5009	0.5507	0.3962	0.5396

Table 12. Closeness coefficients (CC_i) of the three alternatives

	A1	A2	A3	Ranking
d_i^+	3.2040	3.2519	3.1492	$A1 > A3 > A2$
d_i^-	3.3143	3.2877	3.2123	
CC_i	0.5084	0.5027	0.5049	

6. Conclusions

The selection of a distribution center is one of the most critical decision-making activities for firms to improve business performance and obtain a competitive advantage. Multiple quantitative and qualitative criteria are considered in the decision process to select the appropriate location for the distribution center. Therefore, the location planning of a distribution center is a multi-criteria decision-making (MCDM) problem. The fuzzy set theory approach helps decision-makers deal with uncertainty and vagueness in the decision-making process. This paper uses the fuzzy TOPSIS approach to evaluate and select an appropriate distribution center by considering multiple subjective criteria under a fuzzy environment. In this approach, the rating values of alternatives for the relative importance of criteria are expressed on linguistic terms, which are represented by fuzzy triangular numbers. The fuzzy TOPSIS approach determines aggregate scores and generates an overall performance rating from all potential alternatives. The alternatives with the highest score are finally selected as the best distribution center location for implementation. An illustrative example is presented for the approach. The result of fuzzy TOPSIS analysis is summarized in Table 12. Based on closeness coefficient (CCi) values, the ranking of the distribution centers is A1> A3> A2. The proposed model results indicate that A1 is the best alternative with a CCi value of 0.5084.

The main contribution of this approach is the ability to deal with multiple subjective criteria and the selection of distribution centers through the use of linguistic variables and fuzzy set theory. The proposed approach can be practically applied for deciding upon other areas of management, engineering when data are vague, imprecise, and uncertain by nature. The fuzzy set theory approach integrated with hybrid methods can be considered for future research.

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