A Decision Support System for Warehouse Location Selection: A Case Study

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Abstract

The main aim of this research is to develop a decision support system for determining warehouse location. An anticipated model is constructed with fuzzy extension of the Analytic Hierarchy Process (FAHP) and fuzzy extension of the Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) methods. In this article 16sub-criteria divided in 5 main groups are taken for location decision model collected from literatures review and practical investigations in the distribution arena in Bangladesh.The weights of the sector and subsector are estimated by FAHP method and using FTOPSIS, eligible locations are ranked according to the results. Finally, an empirical study for warehouse location-allocation problem of the retail chain of Rahimafrooz Superstore Ltd. (RSL) named Agora in Bangladesh is presented to visualize the methodologies and effectiveness of the model proposed by this paper.

Keywords: Location Choice, Fuzzy Multi-Criteria Decision, Fuzzy AHP, Fuzzy TOPSIS, Retail Chain

Introduction

Warehouse as a component of logistics management system provides a place for receiving, storing and distributing surplus items to buyers as and when required and supports value adding operations. To sustain responsiveness in the competitive market, it plays a vital role in delivering right amount of products to the customer at right place in the right time. Ensuring product availability, it helps supply chain management to improve customer requirements which is the main driving force of any business. So, warehouse should be housed in appropriate location aiming product availability which will turn customer satisfaction and economic benefits. According to several researchers, warehouse location-allocation problem is considered as one of the most imperative strategic decisions in the optimisation of logistic systems (Anand, Kodali, & Dhanekula, 2012).

The main objective of a logistic system is to lower overall cost, hold right amount of inventory, ensure cycle service level (CSL), and obviously fulfill customers' needs. The role of a warehouse is very crucial as different value added operations such as consolidation, order assembly, cross docking, milk run etc. are performed within a warehouse with a view to reducing overall cost as well as cycle time. It provides numerous security measures against deterioration, theft, fire etc. and maintains proper environment for protecting the integrity of stored products until their final dispatch to the buyers. Warehouse assists the supply chain to achieve price stabilisation through the formation of time utility.

Location-allocation decision is a multi-criteria decision and needs a proper alignment with organisation's vision, mission, and core values. If not, it will incur huge cost which is irretrievable. An organisation should select a location that will lead to a certain way of supply chain surplus in terms of promoting distribution performance. Generally, in a single line diagram this selection steps can be shown in Fig. 1. The purpose of this study is to propose a fuzzy MCDM model for identifying the best warehouse location among available five alternatives. Different from other studies in the literature, FAHP and FTOPSIS methods have been used together in this study. In the assessment procedure, FAHP method has been applied to determine the weights of the criteria and to rank the locations, fuzzy TOPSIS approach has been used.

The rest of this study is arranged as follows: second section presents the literature review on warehouse allocation problem. Third section frameworks the developed methodology and provides a stepwise depiction of the anticipated fuzzy decision making approach. In fourth section, the application of the proposed framework for the selection of location has been given. And finally, in fifth section, results of the application are presented and suggestions for the future studies are clarified. This section wraps up this study.

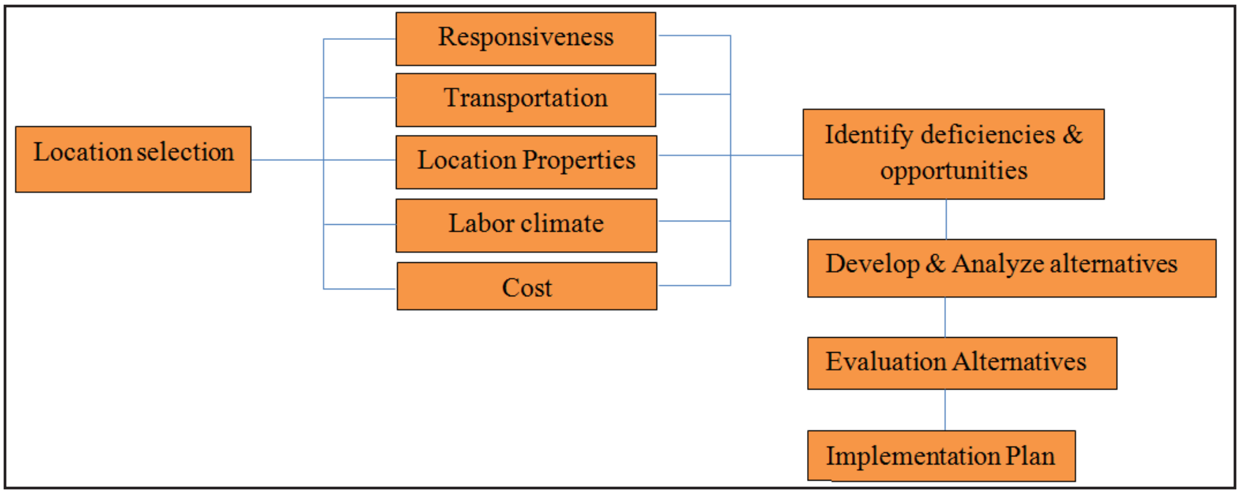

Fig. 1: Essential Element of Planning for Location Selection

Literature Review

There exists an enormous research works in the field of location selection process. A variety of quantitative and judgmental approaches have come to light in order to take right decision on location selection during the past years. However, this paper has tried to cover some of the insights from those contributions. Many papers on location selection problem are available in the literature to visualise the best one among several alternatives (Vlachopoulou, Silleos, & Manthou, 2001; Drezner, Scott, & Song, 2003; Colson & Dorigo, 2004; Michel & Hentenryck, 2004; Partovi, 2006; Sharma & Berry, 2007). A variety of techniques for location selection has been utilised by several researchers (Aikens, 1985; Aberbakh & Berman, 1995; Chen, 1996; Kuo, Chi, & Kao, 1999; Chen, 1999, 2001; Teng, 2000; Nicolau, 2002).

In 1989, Weber first familiarised the location theory. The author developed an idea for locating a warehouse that could reduce the total travel distance between the warehouse and end customers. In the selection process, he proposed a material index and based on the index the warehouse should be opened adjacent to the market having value of index less than one when the value of index becomes greater than one; otherwise, it must be near the source of raw material.

Partovi (2006) conducted a study to determine the best location for a facility using a hybrid model based on quality function deployment (QFD), analytic hierarchy process (AHP), and the analytic network process (ANP) concepts. Arostegui, Kadipasaoglu, & Khumawala (2006) proposed a framework for the selection of facilities location and compared the performance of some well-known general heuristic methods in order to facilitate the selection process for organisations. The anticipated methods were Tabu Search (TS), Simulated Annealing (SA), and Genetic Algorithms (GA).The contribution of this framework is that, by using it, the relevant authorities can assess the performance of three different methods before implementing any method for facility location. It could reduce unnecessary cost as well as effort.

Several researchers have conducted study on bank branch location process (Min, 1989; Miliotis, Dimopoulou, & Giannikos, 2002; Buyukozkan, 2004). Baumol and Wolfe (1958) used nonlinear programming for the location problem to minimise total delivery cost. Kuehn and Hamburger (1963) applied heuristic and search procedures for locating warehouses. Badri (1999) developed a framework with AHP and goal program modeling approaches to identify the most suitable international facility location. Tuzkaya, Önüt, Tuzkaya, & Gülsün (2008) proposed analytic network process (ANP) technique in the suitable facility location selection problem consisting qualitative and quantitative factors and tangible and intangible criteria.

To incorporate vagueness, uncertainty in the judgement of decision makers, several researchers have focused on the use of fuzzy multi-criteria decision making (MCDM) techniques for warehouse location selection process. Karmaker and Saha (2015) developed a framework to visualise the selection process under fuzzy environment. Relevant criteria were identified and the weights of main & sub-criteria were estimated by fuzzy AHP. The alternatives were ranked using TOPSIS & FTOPSIS. The value of this study is that organisations can evaluate the results under both fuzzy environment & non-fuzzy environment. Tzeng and Chen (1999) proposed a decision support model including fuzzy multi-objective programming and revised genetic algorithm approach. The value of the model is to help in identifying the optimal number and location of fire stations at an international airport. Kuo *et al*. (1999) presented a decision support system for the appropriate place of a new convenience store using the fuzzy sets theory integrated with analytic hierarchy process. Dey, Bairagi, Sarkar, and Sanyal (2012) suggested fuzzy extended multi-objective optimisation on the basis of ratio analysis (MOORA) for warehouse location selection.

Ertuğrul and Karakaşoğlu (2008) conducted a comparative analysis using fuzzy AHP and fuzzy TOPSIS methods for evaluating facility location of a textile company. In this research, a structured decision support system has been developed by fuzzy AHP and fuzzy TOPSIS methods. Here, to calculate the weights of warehouse location selection criteria, fuzzy AHP is used and alternative sites are ranked by fuzzy TOPSIS.

Problem Solving Methodology

The evaluation procedure in this paper consists of the following main steps:

Step 1: Identify the evaluation criteria considered as the most important performance measures for the allocation problem.

Step 2: Construct the hierarchy of the evaluation criteria and calculate the weights of these criteria using FAHP method.

Step 3: Conduct the FTOPSIS method to determine the final ranking results.

Methodology of FAHP

The fuzzy analytic hierarchy process (FAHP) is an extension of classical AHP method that allows decision makers to incorporate vagueness, uncertainty in their judgements. Traditional AHP approach provides satisfactory results in situations where crisp pair wise comparison of variable alternatives is sufficient to express the decision maker's opinion. Here, FAHP method is applied to estimate the weights of factors as the problem contains uncertainty & participants feel comfort to express their opinions by linguistics terms.

In this study, the extent FAHP is utilised, which was originally introduced by Chang (1992, 1996) for handling pair-wise comparison scale based on triangular fuzzy numbers (TFNs) followed by use of extent analysis method for synthetic extent value of the pair-wise comparison. Let be an object set, and be a goal set. As per Chang (1992, 1996) then each object is taken and extent analysis for each goal is performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^m, \text{ i= } 1, 2, \ldots, n,$$

where M_{gi}^j () are TFNs whose parameters are depicting least, most and largest possible values respectively and represented as (). The steps of Chang's extent analysis (Chang, 1992, 1996) can be detailed as follows (Bozbura & Beskese, 2007; Kahraman, Cebeci, & Ruan, 2004; Kabir & Hasin, 2011):

Step 1: The value of fuzzy synthetic extent with respect to the i^{th} object is defined as

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{1}$$

To obtain the fuzzy addition operation of *m* extent analysis values for a particular matrix is performed such as

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} a_j, \sum_{j=1}^{m} b_j, \sum_{j=1}^{m} c_j \right) \tag{2}$$

to obtain the fuzzy addition operation of *(j=1,2,…, m)* values is performed such as

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} a_j, \sum_{i=1}^{n} b_j, \sum_{i=1}^{n} c_j \right) \tag{3}$$

And then inverse of the vector above is computed, such as

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} c_i}, \frac{1}{\sum_{i=1}^{n} b_i}, \frac{1}{\sum_{i=1}^{n} a_i} \right) \tag{4}$$

Step 2: As $M_1 = (a_1, b_1, c_1)$ and $M_2 = (a_2, b_2, c_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (a_2, b_2, c_2) \geq M_1 = (a_1, b_1, c_1)$ is defined as

$$V(M_2 \geq M_1) = \sup\left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \quad (5)$$

And can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \quad (6)$$

$$= \begin{cases} 1 if b_2 \geq b_1 \\ 0 if a_1 \geq c_2 \\ \dfrac{a_1 - c_2}{(b_2 - c_2) - (b_1 - a_1)} otherwise \end{cases} \quad (7)$$

Fig. 2. (Chang, 1996) illustrates Eq. (6) where d is the ordinate of the highest intersection point D between and. To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

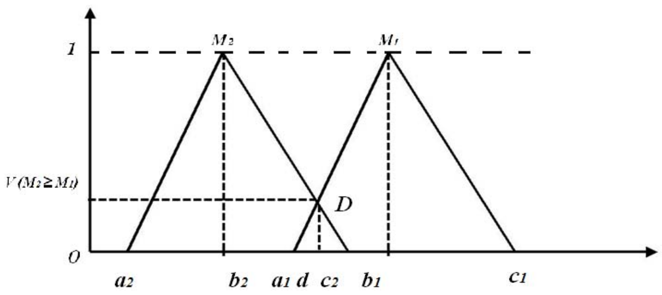

Fig. 2: The Intersection between M_1 and M_2

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy M_i (i = 1, 2, ..., k) numbers can be defined by

$$V(M \geq M_1, M_2 \ldots, M_k) \quad (8)$$
$$= V\left[(M \geq M_1) \text{and} (M \geq M_2) \text{and} \ldots (M \geq M_k)\right]$$

Assuming that $d(A_i) = \min V(S_i \geq S_k)$ for $k = 1, 2, ..., n; k \neq i$. Then the weight vector is given by

$$W' = \left(d'(A_1), d'(A_2), ..., d'(A_n)\right)^T \quad (9)$$

where $A_i\ (i = 1, 2, ..., n)$ are n elements.

Step 4: By normalisation, the normalised weight vectors are

$$W = \left(d(A_1), d(A_2), ..., d(A_n)\right)^T \quad (10)$$

where W is a non-fuzzy number.

Ranking Alternatives

For the assessment of warehouse locations, fuzzy TOPSIS method has been anticipated in this research. In this section, the procedural basics of fuzzy TOPSIS are explained.

The Methodology of FTOPSIS Method

The algorithm of the fuzzy TOPSIS method has mainly nine steps given in the following (Ashtiani, Haghighirad, Makui, & Montazer, 2009):

Step 1: Assignment of ratings to the criteria and the alternatives.

Let us assume there are J possible candidates called $A = \{A_1, A_2, A_3, ..., A_j\}$ which are to be evaluated against n criteria $C = \{C_1, C_2, C_3, ..., C_j\}$. The importance weights are denoted by $w_i\ \{i = 1, 2, ..., m\}$. The fuzzy ratings & importance weight of the k^{th} decision maker $D_k\ \{k = 1, 2, ..., K\}$ for each alternative $A_j\ \{j = 1, 2, ..., n\}$) with respect to criteria $C_i\ \{i = 1, 2, ..., m\}$ are denoted by $x_{ij}^k = \left(a_{ij}^k, b_{ij}^k, c_{ij}^k\right) and\ w_j^k = \left(w_{j1}^k, w_{j2}^k, w_{j3}^k\right)$ where $\{i = 1, 2, ..., m; j = 1, 2, ..., n; k = 1, 2, ..., K\}$ with membership function $x_{ij} = \left(a_{ij}, b_{ij}, c_{ij}\right)$.

Step 2: Compute aggregate fuzzy ratings for the alternatives.

The aggregated fuzzy ratings x_{ij} of alternatives (i) with respect to each criterion (j) are given by $x_{ij} = (a_{ij}, b_{ij}, c_{ij})$ such that:

$$a_{ij} = \min_k \left\{a_{ij}^k\right\}, b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ij}^k, c_{ij} = \max_k \left\{c_{ij}^k\right\} \quad (11)$$

The aggregated fuzzy weights (w_{ij}) of each criterion are calculated as $w_j^k\left(w_{j1}, w_{j2}, w_{j3}\right)$ where

$$w_{j1} = \min_k \left\{w_{jk1}\right\}, w_{j2} = \frac{1}{k}\sum_{k=1}^{K} w_{jk2}, w_{j3} = \max_k \left\{w_{jk3}\right\} \quad (12)$$

Step 3: Compute the fuzzy decision matrix.

The fuzzy decision matrix for the alternatives (D) and the criteria (W) is constructed as follows:

$$D = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix} \quad (13)$$

$$W = \left[w_1, w_{2,\ldots,} w_n \right] \quad (14)$$

where x_{ij} and w_j, $i = 1, 2, \ldots, m; j = 1, 2, \ldots, n$ are linguistic variables which can be described by triangular fuzzy numbers, $x_{ij} = (a_{ij}, b_{ij}, c_{ij})$ and $w_j\,(w_{j1}, w_{j2}, w_{j3})$.

Step 4: Normalise the fuzzy decision matrix.

The linear scale transformation is used to transform various criteria scales into a comparable scale. Thus, we have the normalised fuzzy decision matrix as:

$$\tilde{R} = \left[\tilde{r}_{ij} \right] m \times n, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \quad (15)$$

where

$$\tilde{r}_{ij} = \frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \text{ and } c_j^* = \max c_{ij} \,(\text{benefit criteria}) \quad (16)$$

$$\tilde{r}_{ij} = \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \text{ and } a_j^- = \min a_{ij} \,(\text{cost criteria}) \quad (17)$$

The above normalisation method preserves the property that the ranges of normalised triangular fuzzy numbers belong to [0, 1].

Step 5: Compute the weighted normalised matrix.

The weighted normalised fuzzy decision matrix $\tilde{V}$ is computed by multiplying the weights $\tilde{w}_j$ of evaluation criteria with the normalised fuzzy decision matrix $\tilde{r}_{ij}$ as:

$$\tilde{V} = \left[\tilde{v}_{ij} \right] m \times n, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n \quad \text{where } \tilde{v}_{ij} = \tilde{r}_{ij} (.) \tilde{w}_j \quad (18)$$

Step 6: Identify the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS). The FPIS and FNIS of the alternatives are computed as follows:

$$A^* = \{v_1^*, v_2^*, \ldots, v_n^* \text{ where } v_j^* = \{1, 1, 1\}, j = 1, 2, \ldots, n \quad (19)$$

$$A^- = \{v_1^-, v_2^-, \ldots, v_n^- \text{ where } v_j^- = \{0, 0, 0\}, j = 1, 2, \ldots, n \quad (20)$$

Step 7: Compute the distance of each alternative from FPIS and FNIS.

The distance (d_i^*, d_i^-) of each alternative $i = 1, 2, \ldots, m$ from the FPIS and the FNIS is computed as follows:

$$d_i^* = \sum_{j=1}^{n} d_v \left(\widetilde{v_{ij}}, \tilde{v}_j^* \right) i = 1, 2 \ldots, m; j = 1, 2, \ldots, n \quad (21)$$

$$d_i^- = \sum_{j=1}^{n} d_v \left(\widetilde{v_{ij}}, \tilde{v}_j^- \right), i = 1, 2 \ldots, m; j = 1, 2, \ldots, n \quad (22)$$

Step 8: The closeness coefficient (CC_i) of each alternative is calculated as follows:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad (23)$$

Step 9: By comparing CC_i values, the ranking of the alternatives are determined.

Proposed Framework with Example

Rahimafrooz Superstores Ltd (RSL) in Bangladesh has been used as a case study to demonstrate the practicality of the proposed methodology. Agora of Rahimafrooz Superstores Ltd (RSL) is the largest and first ever retail superstore in Bangladesh since 2001. Its objective is to provide quality and fresh products to the customers at minimum cost. Due to increasing number of demanded customer, it needs to to select a new warehouse location among suitable five alternatives to store items & supply products to different outlets. For ensuring product availability in stores, it desires to decide which location among the five alternatives a warehouse should be opened based on its vision and strategy. The five locations of this company are referenced as A_1, A_2, A_3, A_4, and A_5. First of all, the evaluation criteria for the selection decision were taken from the studies in the literature and the discussions with the company's managers. The hierarchical structure which contains five main criteria and 16 sub-criteria for the selection of the best warehouse location is constructed in Table 1.

Table 1: Hierarchical Representation of Criteria

Criteria		
Main Criteria		Responsiveness(C_1)
Transportation Conditions(C_2)		
Cost-related Factors(C_3)		
Location Properties (C_4)		
Favourable Labour Climate(C_5)		
Sub Criteria	Responsiveness(C_1)	Lead time & responsiveness (C_{11})
		Provide relevant information (C_{12})
	Transportation Conditions(C_2)	Quality of transportation (C_{21})
		Existence modes of transportation(C_{22})
		Telecommunication(C_{23})
	Cost-related Factors(C_3)	Land cost(C_{31})
		Handling cost(C_{32})
		Labour cost(C_{33})
		Transportation cost(C_{34})
	Location Properties (C_4)	Climate(C_{41})
		Land availability(C_{42})
		Quality and reliability of Utilities(C_{43})
		Proximity to producers(C_{44})
		Proximity to customers(C_{45})
	Favourable Labour Climate(C_5)	Skilled labour(C_{51})
		Availability of labour force(C_{52})

Determining the Weight of Criteria

The weights of the main criteria considering the decision makers' subjective judgments are estimated by using FAHP. To obtain better result through reducing the uncertainty and vagueness in the decision process, three decision maker's) pair wise comparisons were proposed in Fig. 3 for determining the weights of the main criteria and the sub-criteria by using Saaty's 1-9 scale (Chen, 2004). Saaty's 1-9 scale has been presented in Table 2. Then the aggregated fuzzy pair-wise comparison values of the three decision makers are transformed into triangular fuzzy numbers (TFNs) through Eq. (11) (Chen, Lin, & Huang, 2006). The aggregated fuzzy decision matrix as shown in Table 3 is constructed to measure the relative degree of importance for each criterion, based on the Chang's extent analysis.

$$D_1 = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{matrix} \begin{bmatrix} 1 & 1/3 & 5 & 3 & 7 \\ 3 & 1 & 7 & 5 & 9 \\ 1/5 & 1/7 & 1 & 1/7 & 5 \\ 1/3 & 1/5 & 7 & 1 & 7 \\ 1/7 & 1/9 & 1/5 & 1/7 & 1 \end{bmatrix} \qquad D_2 = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{matrix} \begin{bmatrix} 1 & 5 & 3 & 1/7 & 7 \\ 1/5 & 1 & 5 & 1/5 & 7 \\ 1/3 & 1/5 & 1 & 1/5 & 1/5 \\ 7 & 5 & 5 & 1 & 7 \\ 1/7 & 1/9 & 5 & 1/7 & 1 \end{bmatrix}$$

$$D_3 = \begin{matrix} C_1 \\ C_2 \\ C_3 \\ C_4 \\ C_5 \end{matrix} \begin{bmatrix} 1 & 1/7 & 5 & 1/5 & 9 \\ 7 & 1 & 1/5 & 7 & 1 \\ 1/5 & 5 & 1 & 7 & 5 \\ 5 & 1/7 & 1/7 & 1 & 5 \\ 1/9 & 1/5 & 1/5 & 1/5 & 1 \end{bmatrix}$$

Fig. 3: Pair-wise Comparison of Three Decision Makers

Table 2: Linguistic Variables for the Ratings of the Criteria

Level of importance	Linguistic variables
1	Equal important
3	Slightly more important
5	More important
7	Strongly more important
9	Extremely more important

Table 3: Aggregated Fuzzy Pair-wise Comparison Matrix

	C_1	C_2	C_3	C_4	C_5
C_1	(1,1,1)	(0.143,1.83,5)	(3,4.33,5)	(0.14,1.11,3)	(7,7.67,9)
C_2	(0.2,3.4,7)	(1,1,1)	(0.2,4.07,7)	(0.2,4.07,7)	(1,5.67,9)
C_3	(0.2,0.24,0.33)	(0.14,1.78,5)	(1,1,1)	(0.14,2.45,7)	(0.2,3.4,5)
C_4	(0.33,4.11,7)	(0.14,1.78,5)	0.14,4.05,7	(1,1,1)	(5,6.33,7)
C_5	(0.11,0.13,0.14)	(0.11,0.42,1)	(0.20,2.6,5)	(0.14,0.14,0.2)	(1,1,1)

The values of fuzzy synthetic extent are calculated using Eq. (1) which is shown in Table 4. The degree of possibility of supremacy of each criterion over another denoting by ≥). The obtained synthetic values are compared by using Eq. (7) and the following results are obtained:

$V(S_{C_1} \geq S_{C_2}) = 0.96$ $V(S_{C_1} \geq S_{C_3}) = 1.00$ $V(S_{C_1} \geq S_{C_4}) = 0.978$ $V(S_{C_1} \geq S_{C_5}) = 1.00$
$V(S_{C_2} \geq S_{C_1}) = 1.00$ $V(S_{C_2} \geq S_{C_3}) = 1.00$ $V(S_{C_2} \geq S_{C_4}) = 1.00$ $V(S_{C_2} \geq S_{C_5}) = 1.00$
$V(S_{C_3} \geq S_{C_1}) = 0.86$ $V(S_{C_3} \geq S_{C_2}) = 0.84$ $V(S_{C_3} \geq S_{C_4}) = 0.85$ $V(S_{C_3} \geq S_{C_5}) = 1.00$
$V(S_{C_4} \geq S_{C_1}) = 1.00$ $V(S_{C_4} \geq S_{C_2}) = 0.99$ $V(S_{C_4} \geq S_{C_3}) = 1.00$ $V(S_{C_4} \geq S_{C_5}) = 1.00$
$V(S_{C_5} \geq S_{C_1}) = 0.53$ $V(S_{C_5} \geq S_{C_2}) = 0.57$ $V(S_{C_5} \geq S_{C_3}) = 0.81$ $V(S_{C_5} \geq S_{C_4}) = 0.53$

Table 4: Analysis of Fuzzy Synthetic Extent

$S_{c_1} = (11.29, 15.94, 23) \otimes (1/106.86, 1/64.58, 1/23.76) = (0.11, 0.25, 0.97)$

$S_{c_2} = (2.60, 18.20, 31) \otimes (1/106.86, 1/64.58, 1/23.76) = (0.02, 0.28, 1.30)$

$S_{c_3} = (1.69, 8.87, 18.33) \otimes (1/106.86, 1/64.58, 1/23.76) = (0.02, 0.14, 0.77)$

$S_{c_4} = (6.62, 17.27, 27) \otimes (1/106.86, 1/64.58, 1/23.76) = (0.06, 0.27, 1.14)$

$S_{c_5} = (1.57, 4.29, 7.34) \otimes (1/106.86, 1/64.58, 1/23.76) = (0.01, 0.07, 0.31)$

Then the priority weights are calculated by using Eq. (8):

$d'(C_1)$=min(0.96,1.00,0.978,1.00)=0.96
$d'(C_2)$=min(1.00,1.00,1.00,1.00)=1.00
$d'(C_3)$=min(0.86,0.84,0.85,1.00)=0.84
$d'(C_4)$=min(1.00,0.99,1.00,1.00)=0.99
$d'(C_5)$=min(0.53,0.57,0.81,0.53)=0.53

Finally, the weight vector forms W′ = (0.96, 1.00, 0.84, 0.99, 0.53). After the normalisation, normalised weight vector with respect to the main-criteria forms as *W* = (0.2232, 0.2315, 0.1940, 0.2286, 0.1227). The normalised weight vector respect to main goal is portrayed in Fig. 4. According to Fig. 4, the most important criteria having priority of 0.2315 is "Transportation Condition" in the decision makers' subjective judgments which are followed by the others. The weights of the sub-criteria $(\widetilde{w_j})$ are calculated by the same computational ways which are presented in Table 5.

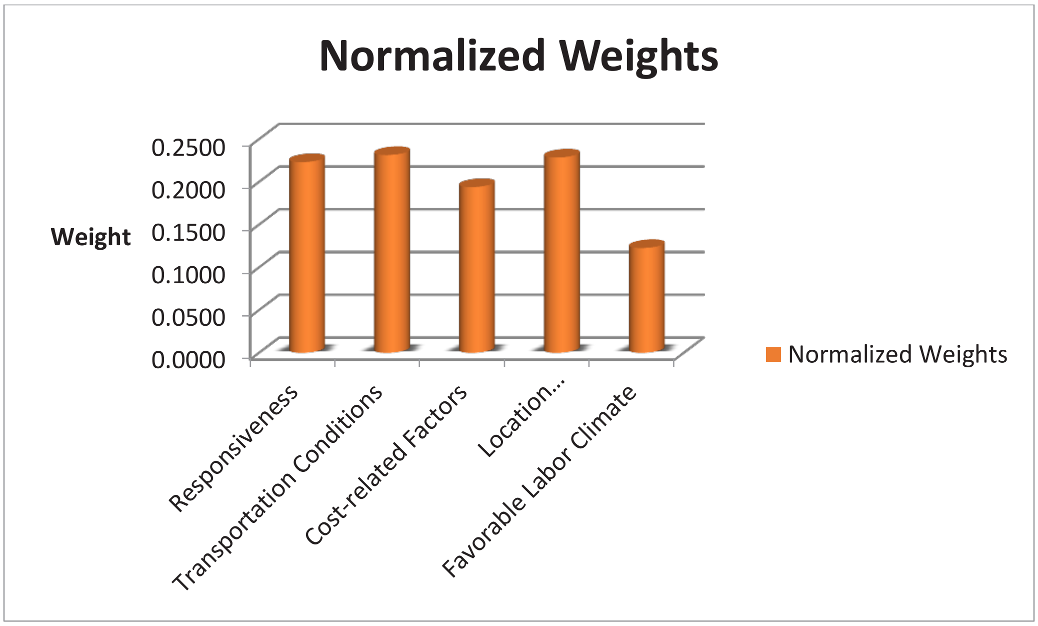

Fig. 4: Comparison of Weights of Main Criteria

Table 5: Weights of Sub-Criteria

Sub-criteria	Weight	Sub-criteria	Weight
C_{11}	0.5278	C_{34}	0.2770
C_{12}	0.4722	C_{41}	0.1361
C_{21}	0.4505	C_{42}	0.1005
C_{22}	0.3019	C_{43}	0.1688
C_{23}	0.2477	C_{44}	0.3035
C_{31}	0.2122	C_{45}	0.2910
C_{32}	0.2658	C_{51}	0.5278
C_{33}	0.2450	C_{52}	0.4722

Assessment of the Alternatives

As indicated before, one of the well-known MCDM approaches named fuzzy TOPSIS method is used to rank the potential alternatives considering the weights of all criteria which are obtained by fuzzy AHP. In the first step of the algorithms, a fuzzy decision matrix is developed by transforming fuzzy linguistics variables into triangular fuzzy numbers in fuzzy TOPSIS method. Linguistics assessment of five alternatives using linguistics variables and decision matrix are shown in Table 6. Then, the aggregated values of each sub-criterion are calculated by using Eq. (11) for fuzzy TOPSIS method as shown in Table 7. After calculating the aggregated values of the sub-criteria, eligible locations are ranked by using fuzzy TOPSIS method. These aggregated values are the main input. Normalisation of these values is made through Eqs. (15), (16) & (17). Lately, fuzzy weighted normalised decision matrix is formed by multiplying each of the normalised fuzzy decision matrix elements with their weights. The positive and negative ideal solution is calculated by using Eqs. (19) & (20). Then the distance of each warehouse location from PIS and NIS with respect to each criterion are calculated like in Eqs. (21) & (22). Afterwards the closeness coefficients (CC_i) of five alternatives are calculated with Eq. (23) and the ranking is done in a decreasing order. Calculation steps of the fuzzy TOPSIS method are given Table 8. In Table 9, locations of the warehouse are ranked with respect to fuzzy TOPSIS method. Based on the results shown in Table 9, the order of ranking of five warehouse location using fuzzy TOPSIS method is $A_2 > A_1 > A_5 > A_4 > A_3$. So, depending on the values of closeness coefficients (CC_i) of five warehouse location, alternative A_2 becomes the most dominating location having highest CC_i of 0.2439 which is followed by the others. So, A_2 should be selected as best warehouse location among five alternatives.

Table 6: Decision Matrix for Fuzzy TOPSIS Method using Fuzzy Linguistics Variables

	A_1			A_2			A_3			A_4			A_5		
	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3	D_1	D_2	D_3
C_{11}	VG	VG	G	G	MG	MG	MG	F	MG	MG	F	MG	G	G	MG
C_{12}	G	G	MG	F	MG	F	MG	F	G	F	G	G	VG	G	F
C_{21}	MG	G	G	MG	MG	MG	MG	F	MG	MG	F	MG	MG	MG	F
C_{22}	G	VG	G	MG	MG	MG	MG	F	MG	MG	F	MG	MG	G	MG
C_{23}	MG	F	MG	F	F	MG	F	F	F	F	F	F	F	F	MG
C_{31}	MP	F	MP	F	F	MP	MP	MP	F	MP	MP	F	MP	F	F
C_{32}	G	MG	MG	MG	F	F	MG	F	F	MG	MG	F	MG	MG	F
C_{33}	G	MG	G	F	F	MG	F	F	MG	F	F	MG	MG	MG	MG
C_{34}	G	MG	MG	F	MG	F	F	F	F	F	MG	F	MG	MG	MG
C_{41}	G	MG	G	MG	MG	G	MG	MG	MG	F	MG	MG	MG	MG	MG
C_{42}	G	G	G	F	F	F	F	MG	MG	MG	F	MG	MG	MG	MG
C_{43}	G	MG	MG	MG	MG	MG	F	F	MG	MG	MG	MG	MG	MG	MG
C_{44}	VG	VG	G	G	MG	MG	MG	F	MG	MG	F	MG	MG	F	MG
C_{45}	G	MG	G	MG	MG	MG	MG	F	MG	MG	F	MG	G	G	F
C_{51}	G	G	MG	MG	MG	F	MG	F	F	MG	F	F	MG	MG	F
C_{52}	G	G	MG	MG	MG	MG	F	F	F	F	MG	F	MG	MG	MG

Table 7: Aggregated Decision Matrix of FTOPSIS Method

	FTOPSIS				
	A_1	A_2	A_3	A_4	A_5
C_{11}	(5,7.67,9)	(5,6.33,7)	(3,5.67,7)	(3,5.67,7)	(5,5.67,7)
C_{12}	(5,5.67,7)	(3,4.33,7)	(3,5,7)	(3,4.33,5)	(3,5.67,9)
C_{21}	(5,5.67,7)	(7,7,7)	(3,5.67,7)	(3,5.67,7)	(3,5.67,7)
C_{22}	(5,7.67,9)	(7,7,7)	(3,5.67,7)	(3,5.67,7)	(5,6.33,7)
C_{23}	(3,5.67,7)	(3,4.33,7)	(3,3,3)	(3,3,3)	(3,4.33,7)
C_{31}	(1,1.67,3)	(1,2.33,3)	(1,1.67,3)	(1,1.67,3)	(1,2.33,3)
C_{32}	(5,6.33,7)	(3,4.33,7)	(3,4.33,7)	(3,5.67,7)	(3,5.67,7)
C_{33}	(5,5.67,7)	(3,4.33,7)	(3,4.33,7)	(3,4.33,7)	(7,7,7)
C_{34}	(5,6.33,7)	(3,4.33,7)	(3,3,3)	(3,4.33,7)	(7,7,7)
C_{41}	(5,5.67,7)	(5,6.33,7)	(7,7,7)	(3,5.67,7)	(7,7,7)
C_{42}	(5,5,5)	(3,3,3)	(3,5.67,7)	(3,5.67,7)	(7,7,7)
C_{43}	(5,6.33,7)	(7,7,7)	(3,4.33,7)	(7,7,7)	(7,7,7)
C_{44}	(5,7.67,9)	(5,6.33,7)	(3,5.67,7)	(3,5.67,7)	(3,5,7)
C_{45}	(5,5.67,7)	(7,7,7)	(3,5.67,7)	(3,5.67,7)	(3,4.33,5)
C_{51}	(5,5.67,7)	(3,5.67,7)	(3,4.33,7)	(3,4.33,7)	(3,5.67,7)
C_{52}	(5,5.67,7)	(7,7,7)	(3,3,3)	(3,4.33,7)	(7,7,7)

Table 8: Calculation Steps of the Fuzzy TOPSIS Method for the Location Selection

	Weighted normalized values					FPIS	FNIS
	A_1	A_2	A_3	A_4	A_5	(A^+)	(A^-)
C_{11}	(0.29,0.45,0.53)	(0.29,0.37,0.41)	(0.18,0.33,0.41)	(0.18,0.33,0.41)	(0.29,0.33,0.41)	(1,1,1)	(0,0,0)
C_{12}	(0.26,0.30,0.37)	(0.33,0.48,0.78)	(0.33,0.56,0.78)	(0.16,0.30,0.47)	(0.16,0.30,0.47)	(1,1,1)	(0,0,0)
C_{21}	(0.32,0.36,0.45)	(0.45,0.45,0.45)	(0.19,0.36,0.45)	(0.19,0.36,0.45)	(0.19,0.36,0.45)	(1,1,1)	(0,0,0)
C_{22}	(0.17,0.26,0.30)	(0.23,0.23,0.23)	(0.10,0.19,0.23)	(0.10,0.19,0.23)	(0.17,0.21,0.23)	(1,1,1)	(0,0,0)
C_{23}	(0.11,0.20,0.25)	(0.11,0.15,0.25)	(0.11,0.11,0.11)	(0.11,0.11,0.11)	(0.11,0.15,0.25)	(1,1,1)	(0,0,0)
C_{31}	(0.07,0.23,0.21)	(0.07,0.09,0.21)	(0.07,0.13,0.21)	(0.07,0.13,0.21)	(0.07,0.09,0.21)	(1,1,1)	(0,0,0)
C_{32}	(0.11,0.13,0.16)	(0.11,0.18,0.27)	(0.11,0.18,0.27)	(0.11,0.14,0.27)	(0.11,0.14,0.27)	(1,1,1)	(0,0,0)
C_{33}	(0.10,0.13,0.15)	(0.10,0.17,0.24)	(0.10,0.17,0.24)	(0.10,0.17,0.24)	(0.10,0.10,0.10)	(1,1,1)	(0,0,0)
C_{34}	(0.12,0.13,0.17)	(0.12,0.19,0.28)	(0.28,0.28,0.28)	(0.12,0.19,0.28)	(0.12,0.12,0.12)	(1,1,1)	(0,0,0)
C_{41}	(0.10,0.11,0.14)	(0.10,0.12,0.14)	(0.14,0.14,0.14)	(0.06,0.11,0.14)	(0.14,0.14,0.14)	(1,1,1)	(0,0,0)
C_{42}	(0.07,0.07,0.07)	(0.04,0.04,0.04)	(0.04,0.08,0.10)	(0.04,0.08,0.10)	(0.10,0.10,0.10)	(1,1,1)	(0,0,0)
C_{43}	(0.12,0.15,0.17)	(0.17,0.17,0.17)	(0.07,0.10,0.17)	(0.17,0.17,0.17)	(0.17,0.17,0.17)	(1,1,1)	(0,0,0)
C_{44}	(0.17,0.26,0.30)	(0.17,0.21,0.24)	(0.10,0.19,0.24)	(0.10,0.19,0.24)	(0.10,0.17,0.24)	(1,1,1)	(0,0,0)
C_{45}	(0.21,0.24,0.29)	(0.29,0.29,0.29)	(0.12,0.24,0.29)	(0.12,0.24,0.29)	(0.12,0.18,0.21)	(1,1,1)	(0,0,0)
C_{51}	(0.38,0.43,0.53)	(0.23,0.43,0.53)	(0.23,0.33,0.53)	(0.23,0.33,0.53)	(0.23,0.43,0.53)	(1,1,1)	(0,0,0)
C_{52}	(0.34,0.38,0.47)	(0.47,0.47,0.47)	(0.20,0.20,0.20)	(0.20,0.29,0.47)	(0.47,0.47,0.47)	(1,1,1)	(0,0,0)
d+	12.2904	12.1929	12.8039	12.8152	12.5479		
d-	3.8065	3.9336	3.3792	3.3965	3.6135		
CC_i	0.2365	0.2439	0.2088	0.2095	0.2236		

Table 9: Ranking of the Warehouse Location

Alternatives	Fuzzy TOPSIS	
	CC_i	Ranking
A_1	0.2365	2
A_2	0.2439	1
A_3	0.2088	5
A_4	0.2095	4
A_5	0.2236	3

RESULTS AND DISCUSSIONS

Depending on the values of closeness coefficients of five alternatives, 'location A_2'is the highest ranking alternative. So, the company should select 'location A_2' for their new warehouse which will provide better results and improve customer satisfaction.

Conclusions

To stay competitive in global business arena, warehouse plays a vital role delivering products in right time at right place which in turn increases market profitability as well as customer satisfaction. In business, customer satisfaction paves the way of ultimate profit & growth. To ensure product availability in market in right quantity, warehouse must be established in proper location by the organisation. In this research, a hybrid fuzzy model with FAHP & FTOPSIS for location evaluation is proposed and using historical data of a company the closeness coefficients of five alternatives are obtained by which the best location is selected. Here, 21 input variables having 5 main criteria & 16 sub-criteria for five sites have been considered to determine the result. Comparing to other variable approaches such as analytical hierarchy process, weighted average method etc. it could help the managers because it incorporates vagueness, ambiguity in the pair-wise comparison process. Thus, this fuzzy model would become an effective tool for the assessment of warehouse location problem.

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