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A Hybrid Fuzzy AHP and Fuzzy TOPSIS Approach for Warehouse Location Selection

Zahra Zare[1,*], Maysam Ashrafzadeh[2], Mumtaz Karatas[3]

[1] Department of Industrial and Human Factors Engineering Department, Wright State University, Dayton, USA, *zare.3@wright.edu*
[2] Department of Industrial Engineering Najafabad Branch, Islamic Azad University, Isfahan, Iran, *maysam.ashrefzadeh@gmail.com*
[3] Department of Industrial and Human Factors Engineering Department, Wright State University, Dayton, USA, *mumtaz.karatas@wright.edu*

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ABSTRACT

Determining warehouse locations is one of the most critical and strategic decisions in logistics systems and supply chains. In most cases, the process of warehouse location selection is posed as a multi-criteria decision-making (MCDM) problem where planners must choose the best site among several alternatives based on a set of qualitative and/or quantitative criteria. The aim of this study is to perform a comparative analysis of two well-known fuzzy MCDM methods, the Fuzzy Technique for Order Preference by Similarity to an Ideal Solution (FTOPSIS), the Fuzzy Analytic Hierarchy Process (FAHP), along with a hybrid approach that combines both methods to determine the most suitable warehouse location. Our analysis mainly focuses on evaluating the applicability of these methods in selecting the optimal warehouse location, using a case study of Entekhab Industrial Group, one of the largest home appliance manufacturers in Iran.

1. Introduction

Logistics and supply chain effectiveness is one of the main drivers of organizational competitiveness. Among the major decisions in this context, warehouse location selection is a strategic choice that significantly influences operational expenses, service quality, and customer satisfaction. The procedure for identifying the optimal site for a warehouse includes several (mostly) conflicting criteria. These criteria can be quantitative, such as fixed costs, variable costs, or other expenses, or qualitative, such as proximity to suppliers, transport reliability, and market access.

The complexity of this decision is further increased by the uncertainties in environmental factors and in some of the criteria. One way dealing with these uncertainties is to incorporate fuzzy decision making approaches to multi-criteria decision-making (MCDM) methods to allow decision makers

* *Corresponding author.*
E-mail address: zare.3@wright.edu

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handle imprecise and subjective information. Fuzzy logic has been widely studied for decades and has proven to be a valuable tool for handling uncertainty in support of effective decision-making.

In this study we propose a hybrid approach that utilizes the Fuzzy Analytic Hierarchy Process (FAHP) and the Fuzzy Technique for Order Preference by Similarity to an Ideal Solution (FTOPSIS) to determine the warehouse location selection decision with uncertainty. In particular, we employ FAHP to determine the relative weights of the assessment factors systematically by using expert pairwise comparisons. We then employ FTOPSIS to determine the ranking of the location alternatives.

We, then, demonstrate the applicability of the hybrid approach on a case study for the Entekhab Industrial Group, a large-scale home appliance manufacturer in Iran. The case study aims to identify the best location for a primary warehouse while considering the viability of closing down two existing locations of warehouses for optimal operational efficiency. We believe that, the case study demonstrates the use of our hybrid approach and offers insights into strategic facility location planning to real-life scenarios.

The remainder of this paper is organized as follows: Section 2 presents a literature review on warehouse location selection and the application of fuzzy MCDM techniques. Section 3 introduces the fundamental concepts of fuzzy sets and fuzzy numbers, describes the methodology of the FTOPSIS and FAHP approaches and proposed methodology. Section 4 illustrates the case study. Section 5 discusses our findings, compares the results of the applied approaches, and prioritizes the criteria and sub-criteria. Finally, Section 6 concludes the study with a discussion on future research directions.

2. Literature review

In this section we present an overview of the most relevant and current research on FAHP, FTOPSIS, and hybrid MCDM methods.

MCDM methods emerged as a set of approaches to tackle complex decision-making problems where multiple, and often conflicting criteria must be considered. Sahoo et al. [26] stated that MCDM techniques have been widely applied in different fields like renewable energy, healthcare, logistics, and supply chain management. MCDM techniques in fuzzy environments have enhanced decision support by minimizing uncertainty and vagueness in human judgment. Ceballos et al. [8] emphasized the importance of comparing various MCDM methods based on computational complexity, transparency, and practicality to recommend the most suitable method for specific problem domains.

FAHP improves the conventional AHP model by using fuzzy logic to manage ambiguity in pairwise comparisons. Jana et al. [17] applied FAHP in ranking financial indicators and verified their weights utilizing the extent analysis method as well as geometric mean approach. El-Hawy [15] proposed the Shadowed AHP model, enhancing decision robustness through aggregating various forms of fuzzy data and preserving uncertainty. El-Hawy [15] used the Shadowed AHP model to improve decision robustness through aggregating of various forms of fuzzy data and preserving uncertainty in making supplier choice decisions. Ashrafzadeh et al. [4] demonstrated a practical usage of FAHP for warehouse location choice, highlighting its effectiveness in structuring hierarchical criteria and sequencing them according to expert judgment.

FTOPSIS, on the other hand, compares alternatives based on their closeness to the ideal and anti-ideal solutions, gained unstoppable momentum for fuzzy decision-making environments. Ansari et al. [2] applied FTOPSIS to select the best security requirements engineering technique for healthcare software, emphasizing the usability of the technique in technical fields. Shamsuzzoha et al. [28] developed a FTOPSIS model for project selection and handled the complexity of projects appropriately using expert ratings. Sahoo et al. [27] proposed a computationally efficient min-max FTOPSIS for college site selection with improved speed and scalability. Palczewski and Sałabun (2019) reviewed a decade of FTOPSIS applications, confirming its flexibility across domains such as supply chain, energy, and business. In another study, Ashrafzadeh et al. [3] showed a real-world application in warehouse selection, reinforcing the method's practicality in logistics.

There also exist studies which implement hybrid approaches that integrate FAHP and FTOPSIS. Among those, Lima Junior et al. [22] compared these methods in a supplier selection problem and determined that FTOPSIS is versatile and easy to handle in more intricate decision issues, while FAHP is elaborate in the analysis of criteria. Sultana et al. [29] utilized a three-stage Fuzzy Delphi, FAHP, and FTOPSIS model and stated that the combination increases the reliability of clauses in multi-criteria decision-making, especially in supplier selection. Palczewski and Sałabun [25] noted heightened momentum towards the hybrid models in their overview, particularly in energy and supply chain domains.

Hybrid use of fuzzy techniques for warehouse and facility location issues has produced strong empirical outcomes. In their study, Ashrafzadeh et al. [4] applied FAHP to assess a few location options based on logistical and economic criteria and demonstrated the use of FTOPSIS in selecting warehouse locations under uncertainty, demonstrating its suitability in ranking under uncertainty. Boltürk et al. [6] applied hesitant FAHP for humanitarian logistics by including experts' hesitation while evaluating. On a broader level, Palczewski and Sałabun [25] and Sultana et al. [29] also discussed the problem types in which fuzzy hybrid models offer competitive results in MCDM frameworks for strategic facility planning.

Although both FAHP and FTOPSIS have been implemented in many fields including facility and logistics planning, successfully, there exist a few studies that employed a hybrid approach to warehouse location problems. Additionally, the concept of expert hesitation or multi-granular uncertainty, e.g., in Shadowed AHP or Hesitant FAHP models are not considered in detail. This paper aims to fill this gap with a hybrid decision model that uses FAHP to determine criteria weights and FTOPSIS to rank alternatives, applied to solve a real-world warehouse location selection problem.

3. Fuzzy Theory and Proposed Approach

To address the inherent imprecision of human thought, Zadeh [32] developed the fuzzy set theory, which provides a logical means to deal with uncertainties resulting from imprecision and ambiguity. Fuzzy set theory is among the strengths as it is able to model and represent vague or incomplete information effectively. It also supports the incorporation of mathematical functions and programming paradigms within the fuzzy system. A fuzzy set is a collection of elements, each with a degree of membership between 0 and 1, defined by its membership function.

In most daily decision-making situations, not considering fuzziness in human choices can lead to deceptive or unsound conclusions [31]. Fuzzy set theory, with its broader perspective than classical set theory, has enhanced significantly in modeling real-world complexity more accurately [16]. In particular, fuzzy sets and fuzzy logic have been essential tools for modeling uncertain systems in industrial processes, environmental science, and social sciences. They also enable reasoning in situations where uncertain information is not known, providing feasible approximations in such complex decision-making scenarios [5].

Symbols for fuzzy sets are typically denoted by a tilde (~). For instance, a triangular fuzzy number (TFN), denoted as $\widetilde{M}$, is graphically represented in Fig. 1. Such a number is characterized by three parameters: (l, m, u), which are the lower limit, the most likely value, and the upper limit of the fuzzy variable, respectively. The membership function of TFN is piecewise linear and increases from l to m and decreases from m to u. The function can be expressed as follows:

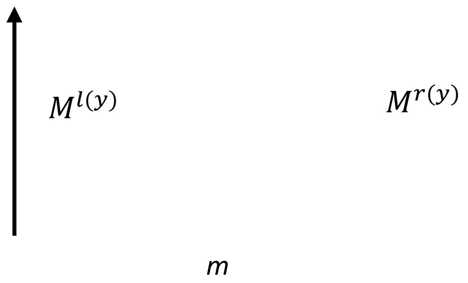

Fig 1. A triangular fuzzy number, $\widetilde{M}$

$$\mu(x/\widetilde{M}) = \begin{cases} 0 & if\ x < 1\ and\ x > u \\ (x-l)/(m-l) & if\ l \le x \le m \\ (u-x)/(u-m) & if\ m \le x \le u \end{cases} \tag{1}$$

Furthermore, any fuzzy number can be represented by its left and right functions across different membership levels, where $l(y)$ and $r(y)$ indicate the left and right-side values, respectively. Despite the development of numerous ranking procedures for fuzzy numbers in academic literature, most result in varying outputs and are usually complex mathematical operations and graphical complications. For an extensive discussion of fuzzy number algebraic operations, refer to Kahraman et al. [19].

$$\widetilde{M} = \left(M^{l(y)}, M^{r(y)}\right) = (l + (m-l)y, u + (m-u)y) \quad y \in [0,1] \tag{2}$$

3.1. Fuzzy TOPSIS Methodology

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is one of the first methods in the field of multi-criteria decision-making (MCDM). Formulated by Hwang and Yoon [18], TOPSIS relies on the idea that the most desirable alternative ought to be the closest to the positive-ideal solution (PIS), which concentrates on benefit maximization and cost minimization, and the farthest from the negative-ideal solution (NIS), where costs are maximized and benefits minimized. Traditionally, TOPSIS assumes that decision-makers possess precise information about both the criteria weights and performance ratings. However, in real-world scenarios, this precision is barely feasible due to the inherent imprecision of human judgments [27].

To better handle the uncertainties associated with subjective judgments, fuzzy set theory has been integrated into various MCDM methods, including TOPSIS. In fuzzy TOPSIS, the evaluation scores and criterion weight are typically characterized through linguistic variables, which are converted into fuzzy numbers. This extension allows decision-makers to express their preferences more realistically and in a more flexible manner. Chen and Hwang [12] were the early initiators who incorporated fuzzy numbers into TOPSIS and set up the basis for further development. Subsequent to them, Triantaphyllou and Lin [30] proposed a fuzzy version of TOPSIS, with a method calculating relative closeness based on alternatives under fuzzy arithmetic. Liang [21] propelled the domain forward one notch more by providing the concept for ideal and anti-ideal solution-based strategy within fuzzy context. Also, Chen [11] employed triangular fuzzy numbers and crisp Euclidean distances between fuzzy sets to extend TOPSIS for group decision-making cases. The steps in FTOPSIS are as follows:

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

Let us assume there are j possible candidates called $A = \{A_1, A_2, \ldots., A_j\}$ which are to evaluate against n criteria $C = \{C_1, C_2, \ldots., C_j\}$. The weights of criteria are denoted by W_i $(i = 1, \ldots, m)$. The performance ratings of each decision maker D_k $(k = 1, \ldots, K)$ for each alternative A_j $(j = 1, \ldots, n)$ with respect to criteria C_i $(i = 1, \ldots, m)$ are denoted by $\widetilde{\mathrm{R}}_k = \tilde{x}_{ijk}(i = 1, \ldots, m;\ j = 1, \ldots, n\ and\ k = 1, \ldots, K)$ with membership function $\mu_{\widetilde{R_k}}(x)$.

Step 2: Compute aggregate fuzzy ratings for the criteria and the alternatives.

If the fuzzy ratings of all the decision makers is given as triangular fuzzy number $\tilde{R}_k = (a_k, b_k, c_k)$, $(k = 1, \ldots, K)$ then the aggregated fuzzy rating is given by $\tilde{R} = (a, b, c), (k = 1, \ldots, K)$ where;

$$a = \min_k\{a_k\} \quad b = \frac{1}{K}\sum_{k=1}^{K} b_k \quad c = \min_k\{c_k\} \tag{3}$$

If fuzzy rating and importance weight of the k^{th} decision maker are $\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk})$ and $\widetilde{w}_{ijk} = (w_{jk1}, w_{jk2}, w_{jk3})$, $i = 1, \ldots, m;\ j = 1, \ldots, n$ respectively, then the aggregated fuzzy ratings $(\tilde{x}_{ij})$ of alternatives relative to each criteria are given as $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij})$ where:

$$a_{ij} = \min_k\{a_{ijk}\} \quad b_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk} \quad c_{ij} = \min_k\{c_{ijk}\} \tag{4}$$

The aggregated fuzzy weights $(\widetilde{w}_{ij})$ of each criterion are calculated as $\widetilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$ where:

$$w_{j1} = \min_k\{w_{jk1}\} \quad w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2} \quad w_{j3} = \max_k\{w_{jk1}\} \tag{5}$$

Step 3: Compute the fuzzy decision matrix.

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

$$\widetilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix},\ i = 1, \ldots, m;\quad j = 1, \ldots, n \tag{6}$$

$$\widetilde{W} = (\widetilde{w}_1, \widetilde{w}_2, \ldots., \widetilde{w}_n) \tag{7}$$

Step 4: Normalize the fuzzy decision matrix.

Raw data are normalized via linear scale transformation to bring the various criteria scales into a comparable scale. The normalized fuzzy decision matrix $\tilde{R}$ is given by:

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \dots & \tilde{r}_{1j} & \dots & \tilde{r}_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{r}_{i1} & \dots & \tilde{r}_{ij} & \dots & \tilde{r}_{in} \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{r}_{mi} & \dots & \tilde{r}_{mj} & \dots & \tilde{r}_{mn} \end{bmatrix}, \; i = 1, \dots, m; \quad j = 1, \dots, n \tag{8}$$

where:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad and \; c_j^* = \max_i \{c_{ij}\} \tag{9}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \quad and \quad a_j^- = \min_i \{a_{ij}\} \tag{10}$$

Step 5: Compute the weighted normalized matrix.

The weighted normalized matrix $\tilde{V}$ for criteria is computed by multiplying the weights ($\widetilde{w}_j$) of evaluation criteria with the normalized fuzzy decision matrix $\tilde{r}_{ij}$:

$$\tilde{V} = \begin{bmatrix} \tilde{v}_{11} & \dots & \tilde{v}_{1j} & \dots & \tilde{v}_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{v}_{i1} & \dots & \tilde{v}_{ij} & \dots & \tilde{v}_{in} \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{v}_{mi} & \dots & \tilde{v}_{mj} & \dots & \tilde{v}_{mn} \end{bmatrix}, \; i = 1, \dots, m; \quad j = 1, \dots, n \quad where \; \tilde{v}_{ij} = \tilde{r}_{ij}.\widetilde{w}_j \tag{11}$$

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

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*), \quad where \quad \tilde{v}_j^* = \max_i \{v_{ij3}\}, \; i = 1, \dots, m; \quad j = 1, \dots, n \tag{12}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-), \quad where \quad \tilde{v}_j^- = \min_i \{v_{ij1}\}, \; i = 1, \dots, m; \quad j = 1, \dots, n \tag{13}$$

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

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

$$d_i^* = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^*\right), \; i = 1, \dots, m \tag{14}$$

$$d_i^- = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}, \tilde{v}_j^-\right), \; i = 1, \dots, m \tag{15}$$

where $d_v(\tilde{a}, \tilde{b})$ is the distance measurement between two fuzzy numbers $\tilde{a}$ and $\tilde{b}$.

Step 8: Compute the closeness coefficient (CC_i) of each alternative.

The closeness coefficient CC_i represents the distances to the fuzzy positive ideal solution (A^*) and the fuzzy negative ideal solution (A^-) simultaneously. The closeness coefficient of each alternative is calculated as:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*}, i = 1, \dots, m \tag{16}$$

Step 9: Rank the alternatives.

In step 9, the different alternatives are ranked according to the closeness coefficient CC_i in decreasing order. The best alternative is closest to the FPIS and farthest from the FNIS.

3.2. Fuzzy AHP Methodology

Fuzzy-AHP will be more appropriate and effective than classical AHP in real life where there is an uncertain pair-wise comparison environment [20]. This is because, in the majority of decision-making scenarios, human judgments are likely to be imprecise, vague, or subjective. Classical AHP requires precise numerical comparisons, which may not be realistic enough to represent the vagueness of human preferences. With the incorporation of fuzzy set theory, fuzzy-AHP allows decision-makers to express their preferences quantitatively in linguistic terms, which are then converted into fuzzy numbers. This improves the robustness of the decision-making process under uncertainty. In this study, Chang's [9, 10] extent analysis method is used to compare the performances of banks because of the computational easiness and efficiency of this method. Let $X = \{x_1, x_2, \dots, x_n\}$ be an object set, and $U = \{\mu_1, \mu_2, \dots, \mu_n\}$ be a goal set. According to the method of Chang [10] extent analysis, each object is taken and extent analysis for each goal, g_i, is performed, respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m \qquad i = 1,2, \dots . n \tag{17}$$

where all the M_{gi}^j $(j = 1,2, \dots, m)$ are TFNs.

The steps of Chang's extent analysis can be given as in the following:

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

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]^{-1} \tag{18}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$ perform the fuzzy addition operation of M_{gi}^j $(j = 1,2, \dots, m)$ extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{19}$$

And to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j\right]$ perform the fuzzy addition operation of M_{gi}^j $(j = 1,2, \dots, m)$ values such that:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_j, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{20}$$

And then compute the inverse of the vector in Eq. 21 such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i}\right) \tag{21}$$

Step 2: The degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$, is defined as:

$$V(M_2 \geq M_1) = \sup\left[Min(\mu_{M1}(X), \mu_{M2}(y))\right] \tag{22}$$

and can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & if m_2 \geq m_1 \\ 0 & if l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{23}$$

where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2} (Fig. 2). Both values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ are required for comparison between M_1 and M_2.

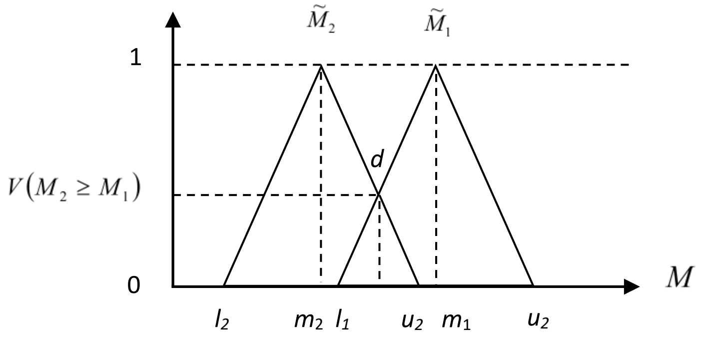

Fig 2. The intersection between M_1 and M_2

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

$$V(M \geq M_1, M_2, \ldots M_k) = V(M \geq M_1) \; and \; V(M \geq M_2) \; and \ldots and \; V(M \geq M_k) = min\, V(M \geq M_i) \tag{24}$$

Assume that:

$$d'(A_i) = min\, V(S_i \geq S_k) \quad k = 1,2, \ldots, n; k \neq i \tag{25}$$

$$W' = \left(d'(A_1), d'(A_2), \ldots, d'(A_n)\right)^T \quad A_i(i = 1,2, \ldots, n) \tag{26}$$

Step 4: Via normalization, the normalized weight vectors are:

$$W' = \left(d(A_1), d(A_2), \ldots, d(A_n)\right)^T \quad A_i(i = 1,2, \ldots, n) \tag{27}$$

3.3. Hybrid Fuzzy AHP and TOPSIS Methodology

In the FTOPSIS method, two key concepts are used: the "ideal solution" and the "similarity to the ideal solution". In contrast, the FAHP is based on the premise of pairwise comparisons. The hybrid approach calls on the advantages of both methods simultaneously. In this integrated method, the weights of criteria and sub-criteria are first determined using the FAHP based on pairwise comparisons. Then, using the FTOPSIS method, the best alternative was selected, and the remaining alternatives were ranked accordingly. The steps of this combined method follow the general procedure of the FTOPSIS approach, with the distinction that the weights of the criteria and sub-criteria are derived from the FAHP method [7].

4. Case Study

Entekhab industrial group, a big company in Iran, wanted to select the best warehouse location and eliminate two of the existing warehouses. The alternative locations were determined by the six experts of the company ($D_1, D_2, \ldots, D_6$) to rate the six alternatives (Isfahan (A_1), Arak (A_2), Gilan (A_3), Ardabil (A_4), East Azarbaijan (A_5) and West Azarbaijan (A_6)). In this section, the warehouses of Entekhab Industrial Group were ranked using three approaches: the FTOPSIS method, the FAHP, and the integrated approach that combines the FTOPSIS and FAHP methods.

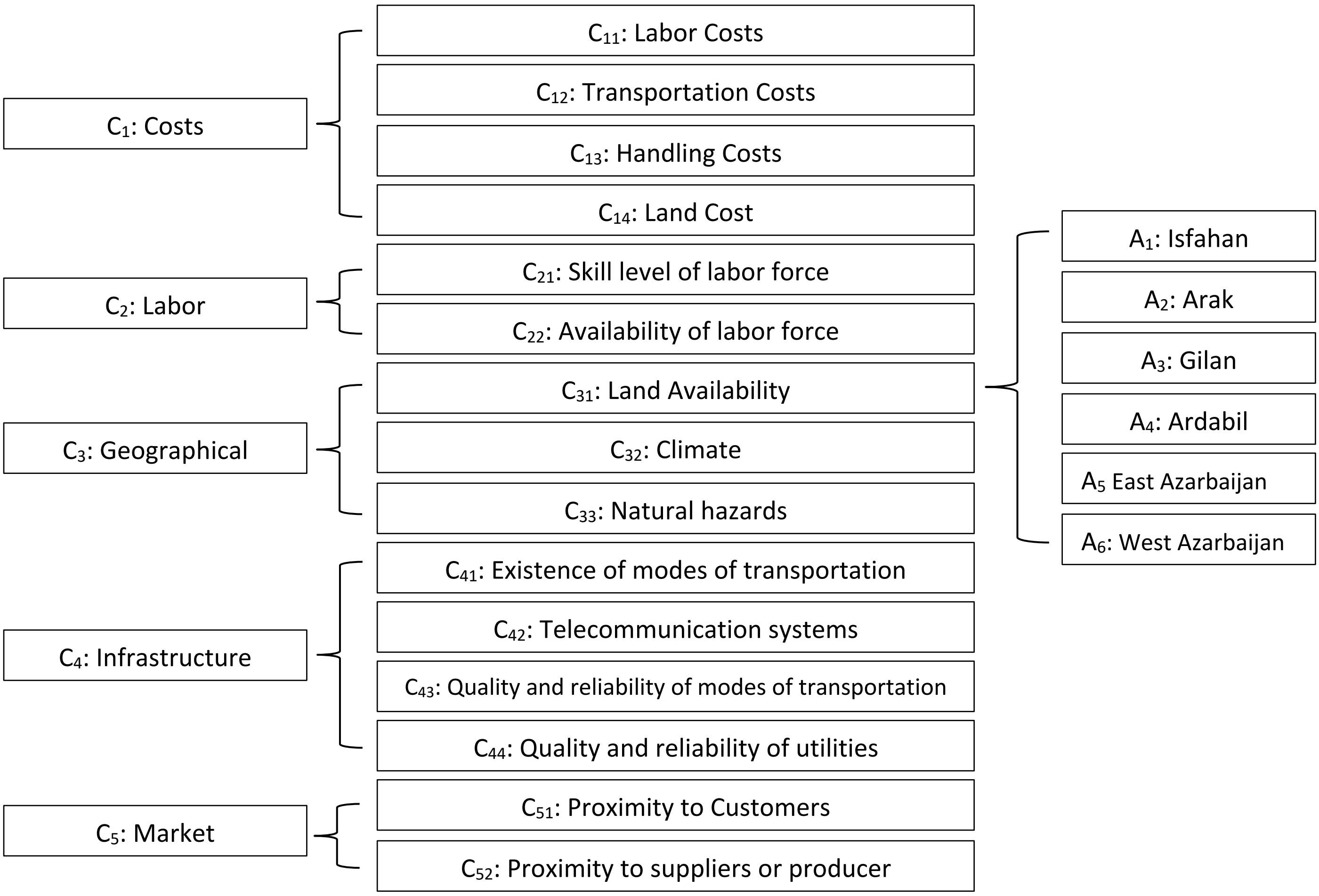

Fig 3. Criteria and sub-criteria for warehouse location selection

4.1. Selection of criteria and sub-criteria for warehouse location selection

In the initial stage, the criteria and sub-criteria for warehouse location selection are identified to construct the hierarchical structure of FAHP. In this research, a total of five main criteria and fifteen sub-criteria were considered for determining the optimal warehouse location. These factors were derived from previous works, including those of Ashrafzadeh et al. [3,4], Min and Melachrinoudis [24], Alberto [1], MacCarthy and Atthirawong [23], as well as Demirel et al. [13] and Dogan [14]. A summary of the criteria definitions is provided in Figure 3.

4.2. Ranking using the FTOPSIS method

15 criteria were used for the selection of the warehouse location. These criteria are reported in Table 1.

Table 1
Warehouse selection criteria

Definition	Criteria
Labor Costs	C_1
Transportation costs	C_2
Handling costs	C_3
Land costs	C_4
Skill level of labor force	C_5
Availability of labor force	C_6
Land availability	C_7
Climate	C_8
Natural hazards	C_9
Existence of modes of transportation	C_{10}
Telecommunication systems	C_{11}
Quality and reliability of modes of transportation	C_{12}
Quality and reliability of utilities	C_{13}
Proximity to customers	C_{14}
Proximity to suppliers or producer	C_{15}

To evaluate the six location alternatives based on 15 criteria, the committee applied linguistic scales as shown in Tables 2 and 3.

Table 2
Linguistic terms for alternative ratings

Linguistic term	Membership function
Very Low (VL)	**(0,0,0.2)**
Low (L)	**(0.1,0.2,0.3)**
Medium Low (ML)	**(0.2,0.35,0.5)**
Medium (M)	**(0.4,0.5,0.6)**
Medium High (MH)	**(0.5,0.65,0.8)**
High (H)	**(0.7,0.8,0.9)**
Very High (VH)	**(0.8,1,1)**

Table 3
Linguistic terms for criteria ratings

Linguistic term	Membership function
Very Poor (VP)	**(0,0,2)**
(P) Poor	**(1,2,3)**
Medium Poor (MP)	**(2,3.5,5)**
Fair (F)	**(4,5,6)**
Medium Good (MG)	**(5,6.5,8)**
Good (G)	**(7,8,9)**
Very good (VG)	**(8,10,10)**

The evaluation results were provided in Tables 4 and 5, respectively.

Table 4 Linguistic assessments for the six alternatives

		D_1	D_2	D_3	D_4	D_5	D_6
C_1	A_1	G	MG	MG	G	G	G
	A_2	F	MG	F	MG	MG	F
	A_3	F	MG	F	MG	MG	F
	A_4	F	F	F	MG	MG	F
	A_5	MG	F	MG	MG	G	F
	A_6	MG	F	F	MG	MG	F
C_2	A_1	G	MG	MG	MG	G	G
	A_2	F	F	MG	F	MG	MG
	A_3	F	MG	F	F	MG	F
	A_4	F	F	MG	MG	MG	F
	A_5	MG	F	MG	MG	MG	F
	A_6	MG	F	F	MG	MG	F
C_3	A_1	G	MG	MG	MG	G	G
	A_2	MG	F	F	F	MG	MG
	A_3	MG	F	F	F	MG	MG
	A_4	MG	F	MG	F	MG	MG
	A_5	MG	F	MG	F	MG	MG
	A_6	MG	F	F	F	MG	MG
C_4	A_1	MP	F	F	MP	MP	P
	A_2	F	MP	F	MP	F	F
	A_3	MP	MP	MP	F	F	F
	A_4	MP	MP	MP	F	F	F
	A_5	MP	MP	F	F	F	F
	A_6	MP	MP	MP	F	F	F
C_5	A_1	G	MG	G	MG	G	VG
	A_2	MG	MG	MG	F	MG	G
	A_3	MG	MG	F	F	MG	MG
	A_4	MG	MG	F	F	MG	F
	A_5	MG	F	MG	F	MG	MG
	A_6	MG	MG	F	F	MG	F
C_6	A_1	G	MG	G	MG	G	MG
	A_2	MG	MG	MG	MG	MG	MG
	A_3	F	MG	F	F	MG	MG
	A_4	F	F	MG	MG	MG	MG
	A_5	MG	MG	MG	MG	MG	MG
	A_6	MG	MG	MG	MG	MG	MG
C_7	A_1	G	MG	G	G	MG	MG
	A_2	F	MG	F	F	MG	F
	A_3	F	MG	MG	MG	MG	F
	A_4	MG	F	F	MG	MG	F
	A_5	MG	F	MG	MG	MG	F
	A_6	F	MG	MG	MG	F	F
C_8	A_1	G	MG	MG	G	G	MG
	A_2	MG	MG	MG	G	G	MG
	A_3	MG	MG	MG	MG	MG	F
	A_4	F	F	MG	F	MG	F
	A_5	MG	F	MG	MG	MG	F
	A_6	F	F	F	MG	F	F
C_9	A_1	VG	G	VG	G	G	G
	A_2	VG	G	G	G	G	G
	A_3	MG	MG	F	F	MG	F
	A_4	MG	F	F	F	MG	F
	A_5	F	F	F	MP	F	MP
	A_6	G	F	MG	G	G	MG
C_{10}	A_1	G	G	VG	G	G	VG
	A_2	MG	MG	MG	MG	MG	G
	A_3	MG	MG	F	MG	F	MG
	A_4	MG	F	F	MG	MG	F
	A_5	MG	MG	G	MG	MG	MG
	A_6	F	F	MG	MG	MG	F
C_{11}	A_1	MG	F	F	MG	MG	MG
	A_2	F	F	F	MG	MG	F
	A_3	F	F	F	F	F	F
	A_4	F	F	F	F	MG	F
	A_5	F	F	F	F	MG	F
	A_6	F	F	F	F	MG	F
C_{12}	A_1	MG	MG	G	G	G	G
	A_2	MG	MG	MG	MG	MG	G
	A_3	MG	MG	F	MG	F	MG
	A_4	MG	F	F	MG	MG	F
	A_5	MG	MG	MG	MG	MG	MG
	A_6	F	F	MG	MG	MG	F
C_{13}	A_1	G	MG	MG	MG	G	G
	A_2	MG	MG	MG	MG	MG	MG
	A_3	F	MG	F	MG	MG	F
	A_4	MG	F	MG	F	F	F
	A_5	MG	F	MG	F	MG	MG
	A_6	MG	F	F	F	F	F
C_{14}	A_1	G	MG	MG	G	G	G
	A_2	MG	MG	MG	MG	MG	F
	A_3	MG	MG	F	MG	G	F
	A_4	MG	F	F	G	MG	F
	A_5	G	G	G	MG	G	MG
	A_6	G	MG	MG	G	MG	F
C_{15}	A_1	VG	G	VG	G	VG	G
	A_2	G	MG	MG	MG	G	MG
	A_3	MG	MG	F	MG	MG	F
	A_4	MG	F	F	F	F	F
	A_5	MG	F	F	F	F	F
	A_6	MG	F	F	F	F	F

Table 5
Linguistic assessments for the 15 criteria

	D_1	D_2	D_3	D_4	D_5	D_6
C_1	M	M	ML	MH	MH	ML
C_2	H	H	H	VH	VH	H
C_3	MH	H	H	H	MH	H
C_4	M	MH	MH	MH	H	MH
C_5	MH	M	M	MH	MH	MH
C_6	ML	ML	ML	M	M	ML
C_7	MH	MH	MH	MH	H	MH
C_8	ML	ML	M	ML	ML	ML
C_9	M	M	ML	ML	MH	ML
C_{10}	MH	H	MH	MH	H	MH
C_{11}	H	H	H	M	H	M
C_{12}	VH	VH	VH	VH	VH	VH
C_{13}	ML	MH	M	M	MH	ML
C_{14}	VH	H	H	VH	H	H
C_{15}	H	H	H	H	VH	VH

Subsequently, the aggregated fuzzy weights for the alternatives were determined through Eq. 4 and the aggregated fuzzy weights for each criterion were calculated using Eq. 5 as presented in Tables 6 and 7.

Table 6
Aggregate fuzzy criteria weight

Criteria	Weight
C_1	(0.2,0.5,0.8)
C_2	(0.7,0.867,1)
C_3	(0.5,0.75,0.9)
C_4	(0.4,0.65,0.9)
C_5	(0.4,0.6,0.8)
C_6	(0.2,0.4,0.6)
C_7	(0.5,0.675,0.9)
C_8	(0.2,0.375,0.6)
C_9	(0.2,0.45,0.8)
C_{10}	(0.5,0.7,0.9)
C_{11}	(0.4,0.7,0.9)
C_{12}	(0.8,1,1)
C_{13}	(0.2,0.5,0.8)
C_{14}	(0.7,0.867,1)
C_{15}	(0.7,0.867,1)

Table 7
Aggregate fuzzy decision matrix

Criteria	Alternative					
	A_1	A_2	A_3	A_4	A_5	A_6
C_1	(5,7.5,9)	(4,5.75,8)	(4,5.75,8)	(4,5.5,8)	(4,6.25,9)	(4,5.75,8)
C_2	(5,7.25,9)	(4,5.75,8)	(4,5.5,8)	(4,5.75,8)	(4,6,8)	(4,5.75,8)
C_3	(5,7.25,9)	(4,5.75,8)	(4,5.75,8)	(4,6,8)	(4,6,8)	(4,5.75,8)
C_4	(2,4,6)	(2,4.5,6)	(2,4.25,6)	(2,4.25,6)	(2,4.5,6)	(2,4.25,6)

C_5	**(5,7.833,10)**	**(4,6.5,9)**	**(4,6,8)**	**(4,5.75,8)**	**(4,6,8)**	**(4,5.75,8)**
C_6	**(5,7.25,9)**	**(5,6.5,8)**	**(4,5.75,8)**	**(4,6,8)**	**(5,6.5,8)**	**(5,6.5,8)**
C_7	**(5,7.25,9)**	**(4,5.5,8)**	**(4,6,8)**	**(4,5.75,8)**	**(4,6,8)**	**(4,5.75,8)**
C_8	**(5,7.25,9)**	**(5,7,9)**	**(4,6,25,8)**	**(4,5.5,8)**	**(4,6,8)**	**(4,5,25,8)**
C_9	**(7,8.667,10)**	**(7,8.333,10)**	**(4,5.75,8)**	**(4,5.5,8)**	**(2,4.5,6)**	**(4,7,9)**
C_{10}	**(7,8.667,10)**	**(5,6.75,9)**	**(4,6,8)**	**(4,5.75,8)**	**(5,6.75,9)**	**(4,5.75,8)**
C_{11}	**(4,6,8)**	**(4,5.5,8)**	**(4,5,6)**	**(4,5,25,8)**	**(4,5,25,8)**	**(4,5,25,8)**
C_{12}	**(5,7.5,9)**	**(5,6.75,9)**	**(4,6,8)**	**(4,5.75,8)**	**(5,6.5,8)**	**(4,5.75,8)**
C_{13}	**(5,7.25,9)**	**(5,6.5,8)**	**(4,5.75,8)**	**(4,5.5,8)**	**(4,6,8)**	**(4,5,25,8)**
C_{14}	**(5,7.5,9)**	**(4,6,25,8)**	**(4,6.25,9)**	**(4,6,9)**	**(5,7.5,9)**	**(4,6.75,9)**
C_{15}	**(7,9,10)**	**(5,7,9)**	**(4,6,8)**	**(4,5.25,8)**	**(4,5.25,8)**	**(4,5.25,8)**

In the following phase, the fuzzy decision matrix of the alternatives was normalized using Eq. 8,9 and 10. Afterwards, the fuzzy weighted decision matrix for the six alternatives was constructed by applying Eq. 11. The fuzzy positive ideal solution (A^*) and the fuzzy negative ideal solution (A^-) were then computed using Eq. 12 and 13. Next, the distance of each weighted alternative from both the positive ideal (A^*) and negative ideal (A^-) solutions were calculated according to Eq 14 and 15, with the results summarized in Table 8.

Table 8
Distance $d_v(A_1, A^*)$ and $d_v(A_1, A^-)$ for alternatives

	d^*						d^-					
	A_1	A_2	A_3	A_4	A_5	A_6	A_1	A_2	A_3	A_4	A_5	A_6
C_1	**0.455**	**0.498**	**0.498**	**0.503**	**0.487**	**0.498**	**0.452**	**0.383**	**0.383**	**0.380**	**0.437**	**0.383**
C_2	**0.394**	**0.478**	**0.486**	**0.478**	**0.471**	**0.478**	**0.458**	**0.362**	**0.357**	**0.362**	**0.367**	**0.362**
C_3	**0.398**	**0.464**	**0.464**	**0.046**	**0.046**	**0.464**	**0.450**	**0.365**	**0.365**	**0.370**	**0.370**	**0.365**
C_4	**0.518**	**0.503**	**0.510**	**0.510**	**0.503**	**0.510**	**0.475**	**0.488**	**0.481**	**0.481**	**0.488**	**0.481**
C_5	**0.395**	**0.441**	**0.458**	**0.463**	**0.458**	**0.463**	**0.411**	**0.350**	**0.300**	**0.297**	**0.300**	**0.030**
C_6	**0.325**	**0.337**	**0.358**	**0.354**	**0.337**	**0.337**	**0.325**	**0.282**	**0.274**	**0.276**	**0.282**	**0.282**
C_7	**0.041**	**0.486**	**0.473**	**0.479**	**0.473**	**0.479**	**0.434**	**0.351**	**0.359**	**0.355**	**0.359**	**0.355**
C_8	**0.331**	**0.334**	**0.356**	**0.367**	**0.360**	**0.370**	**0.320**	**0.318**	**0.028**	**0.269**	**0.273**	**0.267**
C_9	**0.449**	**0.453**	**0.528**	**0.532**	**0.588**	**0.503**	**0.487**	**0.048**	**0.369**	**0.367**	**0.271**	**0.424**
C_{10}	**0.360**	**0.452**	**0.501**	**0.507**	**0.452**	**0.507**	**0.475**	**0.387**	**0.033**	**0.322**	**0.387**	**0.322**
C_{11}	**0.459**	**0.471**	**0.502**	**0.478**	**0.478**	**0.478**	**0.446**	**0.436**	**0.307**	**0.431**	**0.431**	**0.431**
C_{12}	**0.335**	**0.352**	**0.424**	**0.431**	**0.364**	**0.431**	**0.047**	**0.439**	**0.357**	**0.348**	**0.377**	**0.349**
C_{13}	**0.459**	**0.474**	**0.498**	**0.503**	**0.494**	**0.507**	**0.045**	**0.392**	**0.383**	**0.380**	**0.039**	**0.378**
C_{14}	**0.388**	**0.464**	**0.459**	**0.467**	**0.388**	**0.446**	**0.465**	**0.373**	**0.432**	**0.427**	**0.465**	**0.443**
C_{15}	**0.321**	**0.442**	**0.513**	**0.534**	**0.534**	**0.534**	**0.520**	**0.407**	**0.331**	**0.317**	**0.317**	**0.317**

Based on these distances, the closeness coefficient CC_i for each alternative was derived using Eq. 16. The final ranking based on FTOPSIS, presented in Table 9, indicated that A_1 ranks highest, followed by A_2, A_5 , A_6 , A_4 , and A_3 . Consequently, Isfahan (A_1) is identified as the most suitable location for establishing the warehouse. Based on the results alternatives A_4 and A_3 are the least preferred warehouse locations and are recommended for elimination.

Table 9
Closeness coefficient CC_i of the three alternatives

	A_1	A_2	A_3	A_4	A_5	A_6
d_i^*	5.9983	6.6491	7.0285	7.0628	6.8432	7.0059
d_i^-	6.6346	5.8146	5.2979	5.3835	5.5092	5.4558
CC_i	0.5252	0.4665	0.4298	0.4325	0.446	0.4378

4.3. Ranking using the FAHP method

in this method, the committee utilized linguistic variables (Table 10) to evaluate the six alternatives.

Table 10
The linguistic variables

Linguistic variables	Triangular fuzzy scale
Just equal	(1,1,1)
Equally important	(1,1,1)
Weakly important	(0.5714,1,1.75)
Strongly more important	(1.25,2,2.75)
Very strongly more important	(2.25,3,3.75)
Absolutely more important	(3.25,4,4.75)

The fuzzy evaluation matrix for the main criteria was constructed through pairwise comparisons among the criteria associated with the main objective, employing triangular fuzzy numbers, as shown in Table 11.

Table 11
The fuzzy evaluation matrix with respect to the goal

	C_1	C_2	C_3	C_4	C_5
C_1	(1,1,1)	(1.25,2.4,3.75)	(1.25,2.4,3.75)	(0.57,1,1.57)	(0.36,0.6,1.75)
C_2	(0.27,0.43,0.8)	(1,1,1)	(0.57,1,1.57)	(0.27,0.43,0.8)	(0.21,0.3,0.44)
C_3	(0.27,0.43,0.8)	(0.57,1,1.57)	(1,1,1)	(0.27,0.77,1.75)	(0.21,0.32,0.44)
C_4	(0.57,1,1.57)	(1.25,2.4,3.75)	(0.57,1.6,3.75)	(1,1,1)	(0.36,0.8,1.75)
C_5	(0.57,1.8,2.75)	(2.25,3.2,4.75)	(2.25,3.2,4.75)	(0.57,1.4,2.75)	(1,1,1)

Subsequently, the fuzzy synthetic extent for each main criterion was calculated using Eq. 18 and the fuzzy set algebraic operations. These synthetic extent values corresponding to the five criteria are denoted as S_1, S_2, S_3, S_4 and S_5 respectively. The degree of possibility of S_i over S_j (i≠j) can be determined by Eq. 23. With the help of Eq. 24, the minimum degree of possibility can be stated. Therefore, the weight vector and after the normalization process, the weight vector with respect to decision criteria C_1, C_2, C_3, C_4 and C_5 can be shown in Table 12.

Table 12
The values of S_i and the degree of possibility of S_i for each row of the pairwise comparison matrix of criteria with respect to the goal.

S_i		S_1	S_2	S_3	S_4	S_5	MinV(S_i>S_k)	WG
(0.088,0.234,0.616)	V(S_1>S_i)	-	1	1	1	0.8188	0.8188	0.2444
(0.046,0.1,0.246)	V(S_2>S_i)	0.5427	-	0.9478	0.6	0.3229	0.3229	0.0963
(0.046,0.111,0.295)	V(S_3>S_i)	0.6285	1	-	0.6806	0.4159	0.4159	0.1241
(0.074,0.215,0.616)	V(S_4>S_i)	0.9654	1	1	-	0.7935	0.7935	0.2368
(0.131,0.341,0.822)	V(S_5>S_i)	1	1	1	1	-	1	0.2984

Subsequently, sub-criteria under each main criterion were evaluated individually following the same procedure. In the next step, the fuzzy evaluation matrices for decision alternatives and their corresponding weight vectors concerning each sub-criterion were derived. The complete set of weight vectors for alternatives with respect to the sub-criteria is summarized in Table 13.

Finally, the priority weights of the main criteria, sub-criteria, and alternatives were integrated to identify the optimal warehouse location. The final ranking based on FAHP, shown in Table 13, indicate that alternative A_1 outperforms the others, with the ranking as A_1 >A_2 >A_3 >A_5 >A_6 >A_4 . Therefore, Isfahan (A_1) is recommended as the most suitable warehouse location. Based on the results alternatives A_6 and A_4 are the least preferred warehouse locations and are recommended for elimination.

Table 13
Computed weights

C_i	W_i	C_{ij}	W_{ij}	A_1	A_2	A_3	A_4	A_5	A_6
C_1	0.2444	C_{11}	0.2038	0.1889	0.1599	0.1599	0.1599	0.1657	0.1657
		C_{12}	0.2855	0.1817	0.1641	0.0163	0.0163	0.1641	0.1641
		C_{13}	0.2689	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
		C_{14}	0.2418	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
C_2	0.0963	C_{21}	0.5466	0.1856	0.1715	0.1662	0.1586	0.1631	0.0155
		C_{22}	0.4534	0.1756	0.0165	0.1641	0.1655	0.0165	0.0165
C_3	0.1241	C_{31}	0.3864	0.1798	0.1621	0.1643	0.1643	0.1654	0.1643
		C_{32}	0.2924	0.1756	0.1714	0.1645	0.0162	0.1645	0.0162
		C_{33}	0.3212	0.2004	0.1934	0.1468	0.1468	0.1341	0.1785
C_4	0.2368	C_{41}	0.2386	0.1903	0.1685	0.1577	0.1574	0.1685	0.1577
		C_{42}	0.2517	0.1667	0.1667	0.1667	0.1667	0.1667	0.1667
		C_{43}	0.3131	0.1768	0.1709	0.1628	0.1617	0.0165	0.1628
		C_{44}	0.1966	0.0018	0.1653	0.1631	0.1631	0.1653	0.1631
C_5	0.2984	C_{51}	0.5	0.1747	0.1642	0.1631	0.1631	0.1708	0.1642
		C_{52}	0.5	0.2448	0.1871	0.1614	0.1356	0.1356	0.1356
Final weights				0.188068	0.170377	0.162678	0.158293	0.160617	0.159966

4.4. Ranking using the Combined Fuzzy AHP and Fuzzy TOPSIS

In this method, the weights of the criteria and sub-criteria are obtained based on the pairwise comparison approach of the FAHP. Then, by applying the FTOPSIS, and utilizing the concepts of the "ideal solution" and "closeness to the ideal solution," the best alternative is determined, and the remaining options are ranked accordingly. In this approach, it is no longer necessary to form the pairwise comparison matrix of alternatives with respect to the sub-criteria, nor to calculate the

S_i values and the degree of possibility of S_i for each row of the pairwise comparison matrix of alternatives relative to the sub-criteria. The calculated weights of the criteria are presented in Table 14, along with the final weight assigned to each criterion.

Table 14
Weights of the criteria

C_i	W_i	C_{ij}	W_{ij}	Final weights
C_1	0.2444	C_{11}	0.2038	0.0498
		C_{12}	0.2855	0.0698
		C_{13}	0.2689	0.0657
		C_{14}	0.2418	0.0591
C_2	0.0963	C_{21}	0.5466	0.0527
		C_{22}	0.4534	0.0437
C_3	0.1241	C_{31}	0.3864	0.048
		C_{32}	0.2924	0.0363
		C_{33}	0.3212	0.0399
C_4	0.2368	C_{41}	0.2386	0.0565
		C_{42}	0.2517	0.0596
		C_{43}	0.3131	0.0741
		C_{44}	0.1966	0.0466
C_5	0.2984	C_{51}	0.5	0.1492
		C_{52}	0.5	0.1492

Next, the distances of each weighted alternative from both the positive ideal (A^*) and negative ideal (A^-) solutions were calculated, with the results summarized in Table 15.

Table 15
Distance $d_v(A_1, A^*)$ and $d_v(A_1, A^-)$ for alternatives

	d^*						d^-					
	A_1	A_2	A_3	A_4	A_5	A_6	A_1	A_2	A_3	A_4	A_5	A_6
C_1	0.014	0.019	0.019	0.020	0.018	0.019	0.020	0.014	0.014	0.014	0.018	0.014
C_2	0.020	0.027	0.028	0.027	0.027	0.027	0.027	0.020	0.019	0.020	0.020	0.020
C_3	0.018	0.026	0.026	0.025	0.025	0.026	0.026	0.018	0.018	0.019	0.019	0.018
C_4	0.025	0.024	0.025	0.025	0.024	0.025	0.025	0.027	0.026	0.026	0.027	0.026
C_5	0.017	0.021	0.023	0.023	0.023	0.023	0.022	0.017	0.014	0.013	0.014	0.013
C_6	0.012	0.014	0.017	0.017	0.014	0.014	0.017	0.014	0.012	0.013	0.014	0.014
C_7	0.013	0.002	0.018	0.019	0.018	0.019	0.019	0.013	0.014	0.013	0.014	0.013
C_8	0.010	0.010	0.014	0.014	0.014	0.015	0.014	0.014	0.011	0.099	0.010	0.098
C_9	0.076	0.079	0.018	0.018	0.024	0.016	0.027	0.026	0.017	0.017	0.011	0.020
C_{10}	0.011	0.020	0.024	0.025	0.020	0.025	0.027	0.019	0.015	0.014	0.019	0.014
C_{11}	0.019	0.020	0.023	0.021	0.021	0.021	0.019	0.018	0.096	0.018	0.018	0.018
C_{12}	0.020	0.022	0.028	0.029	0.023	0.029	0.029	0.028	0.021	0.021	0.023	0.021
C_{13}	0.013	0.014	0.018	0.019	0.018	0.019	0.018	0.014	0.013	0.013	0.013	0.013
C_{14}	0.041	0.056	0.055	0.056	0.041	0.053	0.059	0.044	0.053	0.052	0.059	0.055
C_{15}	0.027	0.051	0.065	0.068	0.068	0.068	0.072	0.051	0.039	0.036	0.036	0.036

Based on these distances, the closeness coefficient CC_i for each alternative was derived. The final ranking, presented in Table 16, indicates that A_1 ranks highest, followed by A_2, A_5 , A_6 , A_3 , and A_4 . Consequently, Isfahan (A_1) is identified as the most suitable location for establishing the warehouse.

According to the final rankings, A_4 and A_3 are the least preferred warehouse locations and are recommended for elimination.

Table 16
Closeness coefficient CC_i of the three alternatives

	A_1	A_2	A_3	A_4	A_5	A_6
d_i^*	0.2684	0.351	0.3991	0.4041	0.3766	0.3967
d_i^-	0.4204	0.3364	0.2943	0.2974	0.3138	0.3045
CC_i	0.6104	0.4894	0.4244	0.4239	0.4546	0.4345

5. Discussion

After ranking the proposed warehouse locations based on the techniques used, the results of the techniques used were compared to identifying the optimal location. As shown in Table 17, Isfahan ranked first in all three techniques. Therefore, Isfahan was selected as the final warehouse location for Entekhab Industrial Group. It is worth noting that it ranks three to six varied rankings for each of the three techniques. Due to this gap, the hybrid approach of FAHP and FTOPSIS was selected as the final ranking technique. It utilizes pairwise comparisons to obtain weights of criteria and sub-criteria and calculates the distance of each alternative from the fuzzy ideal and anti-ideal solutions to derive the final ranking.

Table 17
Comparison of the Results of the Applied Approaches

FTOPSIS Method	FAHP Method	Combined Approach
Isfahan	Isfahan	Isfahan
Arak	Arak	Arak
East Azarbaijan	Gilan	East Azarbaijan
West Azarbaijan	East Azarbaijan	West Azarbaijan
Ardabil	West Azarbaijan	Gilan
Gilan	Ardabil	Ardabil

5.1. Criteria and Sub-Criteria Prioritization

In this study, besides ranking alternatives, the order of priority of criteria and sub-criteria was also determined in the FTOPSIS method, the FAHP method, and the hybrid method of these two methods, following the determination of weights of the criteria and sub-criteria. The results of this priority are presented in Table 18 and Table 19. Table 18 shows the prioritization of the criteria using the FAHP method and the combined method. As can be seen, the market criterion has the highest influence, while that of labor characteristics have the lowest on the choice of warehouse location for Entekhab Industrial Group. The prioritization of the sub-criteria using their respective criteria is also demonstrated in this table.

Table 19 shows the ranking of criteria and sub-criteria via the FTOPSIS method and the FAHP method. Here, it is clear that in the FTOPSIS method, the most influential criterion is " quality and reliability of modes of transportation " and the least influencing criterion is "climate " on choosing the location for the warehouse of Entekhab Industrial Group. In the FAHP approach, sub-criteria " proximity to customers " and " proximity to suppliers or producer" exert the greatest influence, while "climate " remains the least influential factor.

Table 18
Prioritization of Factors Influencing Warehouse Location Selection

Rank	Criteria	Rank	Sub-Criteria
1	Market	1	Proximity to customers
		1	Proximity to suppliers or producer
2	Costs	1	Transportation costs
		2	Handling costs
		3	Land costs
		4	Labor costs
3	Infrastructure	1	Quality and reliability of modes of transportation
		2	Telecommunication systems
		3	Existence of modes of transportation
		4	Quality and reliability of utilities
4	Geographical location	1	Land availability
		2	Natural hazards
		3	Climate
5	Labor characteristics	1	Skill level of labor force
		2	Availability of labor force

Table 19
Prioritization of Factors Influencing Warehouse Location Selection

Rank	Criteria (FTOPSIS Method)	Rank	Sub-Criteria (FAHP Method)
1	Quality and reliability of modes of transportation	1	Proximity to customers
2	Proximity to customers	1	Proximity to suppliers or producer
2	Proximity to suppliers or producer	2	Quality and reliability of modes of transportation
2	Transportation costs	3	Transportation costs
3	Handling costs	4	Handling costs
4	Existence of modes of transportation	5	Telecommunication systems
5	Land availability	6	Land costs
6	Telecommunication systems	7	Existence of modes of transportation
7	Land costs	8	Skill level of labor force
8	Skill level of labor force	9	Labor costs
9	Labor costs	10	Land availability
9	Quality and reliability of utilities	11	Quality and reliability of utilities
10	Natural hazards	12	Availability of labor force
11	Availability of labor force	13	Natural hazards
12	Climate	14	Climate

5.2. Analysis of the Impact of Criteria and Sub-Criteria on the Ranking of Proposed Locations

Each of the criteria and sub-criteria used in the comparison of the proposed warehouse locations influences the final ranking of the locations.

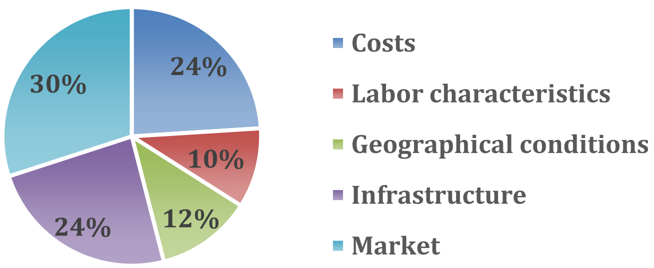

Fig. 4. The Impact of Criteria on the Ranking of Proposed Locations

The application of the FAHP enables the researcher to take into account how this influences the results of the ranking. Figure 4 depicts the impact of the main criteria on ranking the proposed locations for Entekhab Industrial Group warehouses.

6. Conclusion

The study addressed the problem of warehouse location selection in a fuzzy environment through a hybrid FAHP and FTOPSIS approach. By integrating the strengths of both methods, the study provided an applicable methodology for measuring multiple criteria and handling the inherent vagueness of expert judgment. The proposed methodology is applied to Entekhab Industrial Group, one of Iran's top home appliance manufacturers, and identified Isfahan as the most suitable place for the company's main warehouse, while also proposing that two lower priority locations be excluded.

The findings of all three methods equally ranked Isfahan as the top alternative, which confirms the accuracy of ranking by the hybrid method. Also, the criteria and sub-criteria ranking demonstrated that market proximity, transportation costs, and the reliability of transportation modes were among the most influential criteria in decision-making. This reinforces the importance of both logistical efficiency and market access in warehouse site selection.

As a future direction for research, the proposed approach can be compared with other fuzzy MCDM techniques for representing interdependencies between criteria. Furthermore, employing a broader set of criteria and alternative fuzzy numbers can enhance evaluation precision and reliability.

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