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Application of Interval-valued Fuzzy Analytic Hierarchy Process Approach in Selection Cargo Terminals, a Case Study

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ABSTRACT

Cargo terminals are the gateways for entrance of commodities into the transportation network. Therefore, locating them in optimal locations could have a major impact on the cost effectiveness and efficiency of transport, traffic safety and reduction in environmental pollutions. Due to the presence of a large number of parameters involved and the existing uncertainties, decision making in this field is a complex task. If the decision makers cannot reach an agreement on the method of defining linguistic variables based on the fuzzy sets, favorable results and more accurate modeling can be achieved by using the interval-valued fuzzy sets (IVFSs) which provide an additional degree of freedom to represent the uncertainty and fuzziness in the real world. This study presents a group fuzzy analytic hierarchy process (AHP) based on IVFSs (IVF-AHP), and its application to find the optimal location for the Ghaen (Qayenat) cargo terminal in Ghaen City, Iran. The results show that the proposed method is a reliable method in selecting the optimal location for cargo terminals.

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1. INTRODUCTION

Existent suitable cargo terminal as the main gateway into the economic efficiency of the transportation network has an important role in economic efficiency of transportation, traffic safety and reducing environmental pollution. Selecting a suitable location for these terminals is important due to the high initial investment and operation costs of the future. There are several factors that should be considered simultaneously in locating the appropriate terminals. There are many stakeholders involved in this issue (government, private and public entities), some of which may not apply these criteria in their decision making, which may lead to wrong decisions. On the other hand, in the traditional approach to decision-making (without using engineering techniques) some criteria may not be considered or their uncertainties may not be applied correctly. Therefore, a framework is needed that is able to identify various decisions of individuals and stakeholders in the decision making process, evaluate the criteria based on their ideas and use them in decision making simultaneously.

Multi-criteria decision making (MCDM) is one of the branches of Operations Research that investigates the decision-making problems by considering relevant decision-making criteria [1, 2]. The decision makers rank the available alternatives based on the effective criteria using MCDM methods. Different MCDM methods have been presented for solving decision making problems, the most important of which are Elimination and Choice Translating Reality (ELECTRE), [3, 4]; Analytic Hierarchy Process (AHP), [5]; Technique for Order Preference by Simulation of Ideal Solution (TOPSIS) [6, 7]; Analytic Network Process (ANP), [8]; and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR), [9-11]. In this study, a fuzzy AHP method is presented based on

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the IVTFNs, which is named IVF-AHP. With the information uncertainty and inaccuracy considered, a new model for project evaluation and selection is proposed which it is combined with the fuzzy analytic hierarchy process (AHP). The proposed method is applied to select the optimal location for the Ghaen (Qayenat) cargo terminal in Ghaen City, Iran, as a case study. Section 2 presents literature review of the subject andSection 3 illustrates the IVFSs. Section 4 describes the IVF-AHP method for solving MCDM problems. In Sections 5 and 6, the application of IVF-AHP to a real case study is investigated. The conclusions are stated in Section 7. The proposed method provides a way to handle fuzzy multi-criteria group decision-making problems and to evaluate the qualities and weight of the attributes in complex situations.

2. LITERATURE REVIEW

The AHP, first introduced by [5], is a MCDM method for solving MCDM problems by setting their priorities. This method uses precise numbers in the rating of alternatives. The AHP uses objective mathematics to process the subjective and personal preferences of an individual or a group in decision-making [12]. The AHP works on a premise that decision making of complex problems can be handled by structuring it into a simple and comprehensible hierarchical structure. Solution of the AHP hierarchical structure is obtained by synthesizing local and global preference weights to obtain the overall priority [5]. The classical MCDM methods such as AHP cannot handle problems with imprecise information effectively. One of the tools which has been used for transmission of uncertainties in decision-making problems during recent decades is the type-1 fuzzy sets (FSs) introduced by [13]. To date, many researchers have extended the AHP based on fuzzy sets (fuzzy AHP methods). The most important and earliest fuzzy AHP methods are summarized below. Van Laarhoven and Pedrycz [14] proposed the first study that applied the fuzzy logic principle to AHP. Buckley [15] initiated trapezoidal fuzzy numbers to express the decision maker's evaluation on alternatives with respect to each criterion while Van Laarhoven and Pedrcyz [14] have used triangular fuzzy numbers. Chang [16] introduced a new approach for handling fuzzy AHP with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons. Cheng [17] proposed a new algorithm for evaluating naval tactical missile systems by the fuzzy analytical hierarchy process based on grade value of membership function. Deng [18] presented a fuzzy approach for tackling qualitative multi-criteria analysis problems in a simple and straightforward manner. Others research works are extensions of the available methods [19-22]. Fuzzy AHP methods have been used for a variety of specific applications in decision making problems by many researches, including hospital site selection [23], selection of optimum underground mining method [24], supplier selection in a washing machine company [25] and ranking suitable sites for irrigation with reclaimed water [26]. However, the application of the fuzzy AHP methods in locating the site for cargo terminal has not been reported in the literature. Lately, type-2 fuzzy sets (interval-valued fuzzy sets; IVFSs), introduced by [27, 28] have been utilized in transmission of uncertainties and fuzzy conceptions into MCDM methods. This is due to the fact that the IVFSs provide an additional degree of freedom to represent the uncertainty and fuzziness of the real world. The difference between FSs and IVFSs is that the membership function of the IVFSs is a fuzzy system within the interval of [0, 1], while that of the FSs is a numerical value in the interval of [0, 1]. Figure 1 illustrates the membership value at x' of the FS A. Thereby, the membership value of x' is $(\mu_A)_{x'}$. Figure 2 illustrates the membership value at x' of the IVFS A. Thereby, the membership value of x' is the interval of $[(\mu_{\tilde{A}})_1,(\mu_{\tilde{A}})_2]$.

3. INTERVAL-VALUED FUZZY SETS

The type-2 fuzzy sets concept, also known as IVFSs, was proposed by [27, 28]. IVFSs are useful in situations where it is not possible for a membership function of the type, $\mu:X\rightarrow[0,1]$, to assign an exact value from the interval [0,1] to each element, $x \in X$, without losing some information [27, 28]. In these situations the membership degree is defined as a continuum of values ranging over the interval of [0,1] rather than an exact value selected from the interval [0,1]. The mathematical description of the type-2 fuzzy concept is as follows [28]:

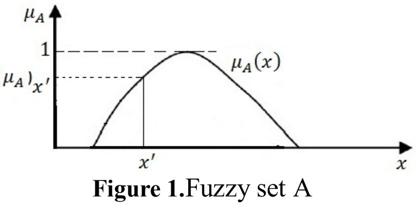


Figure 1. Fuzzy set A

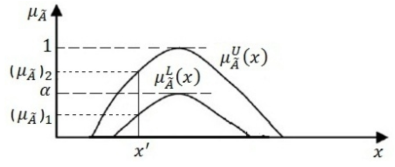


Figure 2. Interval-valued fuzzy set A

$$\begin{aligned} &A=\{x,[\mu_A^L(x),\mu_A^U(x)]\},\ x\in X\\ &\mu_A^L,\mu_A^U:X\rightarrow[0,1]\ \ \forall x\in X,\ \mu_A^L\le\mu_A^U\\ &\bar{\mu}_A(x)=[\mu_A^L(x),\mu_A^U(x)]\\ &A=\{(x,\bar{\mu}_A(x))\},\ x\in(-\infty,+\infty)\end{aligned} \tag{1}$$

where $\mu_A^L(x)$ is the lower limit of the degree of membership and $\mu_A^U(x)$ its upper limit. Given two interval-valued fuzzy numbers, $N_x=[N_x^-;N_x^+]$ and $M_x=[M_x^-;M_x^+]$, according to [28], we have:

Definition 1 If $.\in(+,-,\times,\div)$, then $N.M(x.y)=[N_x^-.M_y^-;N_x^+.N_y^+]$, for a positive non-fuzzy number (*v*), $v.M(x.y)=[v.M_y^-;v.M_y^+]$.

Definition 2 Let $\tilde{N}$ and $\tilde{M}$ be two IVTFNs (Figure 4). $\tilde{N}$ and $\tilde{M}$ can then be represented as [29]:

$$\tilde{N}=[(N_1',N_1);N_2;(N_3,N_3')] \tag{2}$$

$$\tilde{M}=[(M_1',M_1);M_2;(M_3,M_3')] \tag{3}$$

Definition 2.1. The addition, subtraction, multiplication and division operations between $\tilde{N}$ and $\tilde{M}$ are defined as follows:

$$\tilde{N}+\tilde{M}=[(N_1'+M_1',N_1+M_1);N_2+M_2;(N_3+M_3,N_3'+M_3')] \tag{4}$$

$$\tilde{N}-\tilde{M}=[(N_1'-M_1',N_1-M_1);N_2-M_2;(N_3-M_3,N_3'-M_3')] \tag{5}$$

$$\tilde{N}\times\tilde{M}=[(N_1'\times M_1',N_1\times M_1);N_2\times M_2;(N_3\times M_3,N_3'\times M_3')] \tag{6}$$

$$\tilde{N}/\tilde{M}=[(N_1'/M_3',N_1/M_3);N_2/M_2;(N_3/M_1,N_3'/M_1')] \tag{7}$$

Definition 2. 2. Let:

$$h(\tilde{N})=\frac{(N_1'+N_1+2N_2+N_3+N_3')}{6} \tag{8}$$

$$h(\tilde{M})=\frac{(M_1'+M_1+2M_2+M_3+M_3')}{6} \tag{9}$$

We say:

$$\tilde{N}>\tilde{M}\ \text{if}\ h(\tilde{N})>h(\tilde{M}) \tag{10}$$

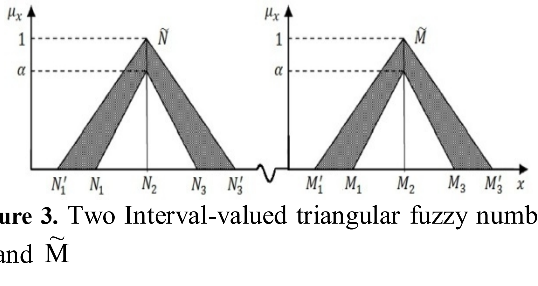


Figure 3. Two Interval-valued triangular fuzzy numbers $\tilde{N}$ and $\tilde{M}$

4. THE PROPOSED METHOD

The proposed method in this study is a group IVF-AHP method to solve MCDM problems. While determining precisely the degree of membership case by case is most difficult, it can be expressed as an interval of real numbers instead. Taking this into consideration, in this paper the importance of the weight of attributes and the rating of the decision alternatives with respect to attributes are pooled as linguistic variables, a concept very useful in dealing with situations that are too complex or ill-defined. Linguistic variables are then considered as IVTFNs by using some mathematical equations. Here, a questionnaire is used to pool the opinions of the experts. In order to receive their realistic opinions, an iterative technique of questioning with a consistency analysis is implemented. Decision making by using this method involves several essential steps as follows:

Step 1: Forming a committee for decision making, this committee involves experts and decision makers.

Step 2: The effective criteria in the decision-making problems are determined by using a comprehensive literature review and the opinions of experts. The potential alternatives are then proposed based on the determined criteria by experts.

Step 3: The hierarchy diagram is a graphic representation of the decision problem in which the objective is in the highest level, criteria in intermediate, and alternatives in the lowest level.

Step 4: The experts' opinions regarding the importance or rating of decision element are pooled by using a questionnaire.

Step 5: According to the questionnaires, a comparison matrix is established based on each expert opinion for each decision element using the scale of Table 1. Let El$_1$, El$_2$,….El$_n$ denote a set of decision elements. Their comparison matrix is defined as follows:

$$N=(\beta_{ij})_{n\times n}=\begin{array}{c} \\ El_1\\ El_2\\ \vdots\\ El_n\end{array}\begin{array}{c}\begin{array}{cccc} El_1 & El_2 & \cdots & El_n\end{array}\\ \begin{bmatrix}1 & \beta_{12} & \cdots & \beta_{1n}\\ 1/\beta_{12} & 1 & \cdots & \beta_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/\beta_{1n} & 1/\beta_{2n} & \cdots & 1\end{bmatrix}\end{array} \tag{11}$$

$$\beta_{ij}=1,\ (i,j=1,2,...,n.,\ i=j) \tag{12}$$

$$\beta_{ij}=\frac{\lambda_i}{\lambda_j},\ (i,j=1,2,...,n.,\ i\neq j) \tag{13}$$

where β_{ij} is a precise number that expresses the relative importance (or the relative rating) of element i (λ_i), over the relative importance (or the relative rating) of element j (λ_j).The λ_i and λ_j are obtained from the linguistic judgments inserted in the questionnaires by the experts.

TABLE 1. Linguistic variables for the importance weight of attribute and the ratings

Definition		Precise number
For the importance of criteria	**For the ratings**	
Very bad (VB)	Very low (VL)	1
Bad (B)	low (L)	3
Medium (M)	Medium (M)	5
Good (G)	High (H)	7
Very Good (VG)	Very High (VH)	9

TABLE 2. Consistency index, RI. of random matrices [5]

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Step 6: Following the above outlines, an interval valued fuzzy matrix, $\tilde{A}$ can be calculated, based on all of the opinions of experts, as:

$$\tilde{A}=(\tilde{x}_{ij})_{n\times n}=\begin{bmatrix}1 & \tilde{x}_{12} & \cdots & \tilde{x}_{1n}\\ \tilde{x}_{12}^{-1} & 1 & \cdots & \tilde{x}_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \tilde{x}_{1n}^{-1} & \tilde{x}_{2n}^{-1} & \cdots & 1\end{bmatrix} \tag{14}$$

The TIVFNs $\tilde{x}_{ij}$ and $\tilde{x}_{ij}^{-1}$ are used to represent the opinions of experts about each decision element. These TIVFNs are obtained as:

$$\tilde{x}_{ij}=(a'_{ij},a_{ij});m_{ij};(b'_{ij},b_{ij}),\ (i,j=1,2,...,n.,\ i\neq j) \tag{15}$$

$$\tilde{x}_{ij}^{-1}=(\frac{1}{b_{ij}},\frac{1}{b'_{ij}});\frac{1}{m_{ij}};(\frac{1}{a_{ij}},\frac{1}{a'_{ij}}),\ (i,j=1,2,...,n.,\ i\neq j) \tag{16}$$

$$a'_{ij}=\underset{k}{\mathrm{Min}}(x_{ijk}),\ k=1,...,K \tag{17}$$

$$a_{ij}=\underset{k}{\mathrm{Min}}(\beta_{ijk})+\frac{(\prod_{k=1}^{K}\beta_{ijk})^{\frac{1}{k}}-\underset{k}{\mathrm{Min}}(\beta_{ijk})}{2},\ k=1,...,K \tag{18}$$

$$m_{ij}=(\prod_{k=1}^{K}\beta_{ijk})^{\frac{1}{k}},\ k=1,...,K \tag{19}$$

$$b_{ij}=\underset{k}{\mathrm{Max}}(\beta_{ijk})-\frac{\underset{k}{\mathrm{Max}}(\beta_{ijk})-(\prod_{k=1}^{K}\beta_{ijk})^{\frac{1}{k}}}{2},\ k=1,...,K \tag{20}$$

$$b'_{ij}=\underset{k}{\mathrm{Max}}(\beta_{ijk}),\ k=1,...,K \tag{21}$$

where, $a'_{ij}\leq a_{ij}\leq m_{ij}\leq b_{ij}\leq b'_{ij}$; β_{ijk} indicates the relative importance (or the relative rating) of element i (λ_i), over the relative importance (or the relative rating) of element j (λ_j) based on opinion of expert k (calculated by Equations (11), (12) and (13)), and K is the number of experts involved in the decision making.

Step 7: Convert the fuzzy comparison matrices (Equation(14)) into crisp comparison as follows:

$$A=(x_{ij})_{n\times n}=\begin{bmatrix}1 & x_{12} & \cdots & x_{1n}\\ x_{12}^{-1} & 1 & \cdots & x_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ x_{1n}^{-1} & x_{2n}^{-1} & \cdots & 1\end{bmatrix} \tag{22}$$

where:

$$x_{ij}=\frac{a'_{ij}+a_{ij}+2m_{ij}+b'_{ij}+b_{ij}}{6} \tag{23}$$

$$x_{ij}^{-1}=\frac{\frac{1}{b_{12}}+\frac{1}{b'_{12}}+2\frac{1}{m_{12}}+\frac{1}{a_{12}}+\frac{1}{a'_{12}}}{6} \tag{24}$$

Step 8: Analyze the consistency of each comparison matrix (Equation(22)) by calculating the consistency index (CI) and the consistency ratio (CR) (Calabrese et al. 2013):

$$CI=\frac{\lambda_{max}-n}{1-n} \tag{25}$$

$$CR=(CI-RI(n))\times 100\% \tag{26}$$

where λ_{max} is the largest value of the comparison matrix, n the dimension of the matrix and RI(n) a random index depending on n as shown in Table 2.

The consistency of the matrix is acceptable only if CR is less than 10%. If a matrix results are inconsistent, it is then necessary to obtain new comparison judgments and new fuzzy comparison matrix. The matrix review must be continued until the consistency is satisfied.

Step 9: After the consistency is satisfied, the relative interval-valued fuzzy weights of decisions elements $(\tilde{W}_i)$ are calculated based on interval valued fuzzy matrix (see Equation(12)) as follows:

$$\tilde{Z}_i=\left[\tilde{x}_{ij}\otimes\cdots\otimes\tilde{x}_{in}\right]^{\frac{1}{n}}=(z'_{1i},z_{1i});z_{2i};(z_{3i},z'_{3i}) \tag{27}$$

$$\tilde{W}_i=\tilde{Z}_i\otimes(\tilde{Z}_i\oplus\cdots\oplus\tilde{Z}_n)^{-1}=(w'_{1i},w_{1i});w_{2i};(w_{3i},w'_{3i}) \tag{28}$$

Step 10: The relative weights (local weights) of the decision elements (W_i) which are non-fuzzy numbers are obtained as:

$$W_i = \frac{w'_{1i} + w_{1i} + 2w_{2i} + w_{3i} + w'_{3i}}{6} \quad (29)$$

Step 11: The relative weights of the decision elements (calculated in previous step) are aggregated according to Saaty's AHP, [8] to obtain the total weight and an overall rating for the alternatives. Each alternative with the higher weight has the higher priority.

5. CASE STUDY

One of the aims of this study is selecting an optimal site for a cargo terminal in Ghaen (Qayenat), located 110 km north of Birjand (the capital of South Khorasan province) in Iran. In order to decide on the optimal location for the cargo terminal, as the first step, the most effective attributes (criteria and sub-criteria) in the cargo terminal site selection were determined by conducting a comprehensive review of the literature and experts' opinions. Table 3 lists the selected attributes and a brief explanation about them is presented here.

Local area (C_1): Includes: Non-adjacent to the city limits and urban development (S_1). Non-adjacent to the public centers (such as recreation centers, cultural heritage and tourism) (S_2). Adjacent to main road (S_3). Adjacent to convection networks, water distribution and gas station (S_4).

Land Topography (C_2): Topography is very important due to heavy traffic and avoiding the risk of flooding and landslides, and it should be smooth, especially for cars traffic.

Cost (C_3): Includes cost of land, energy and water supply and all costs associated with construction. **The predominant direction of wind (C_4):** This is important in transmission of noise and health in the city.

Environmental impact (C_5): The environmental impact should be considered, especially in relation to cutting of trees.

Expansion possibility in the future (C_6): Cargo terminal should be in a place to allow future development in terms of land costs, environmental damage, etc.

Distance from the cargo center (C_7): It is preferred that the distance from the main centers of cargo production is low. Considering the effective criteria chosen, by using the experts' opinions and the collected data, four potential cargo terminal sites (site 'A', 'B', 'C' and 'D') in the surrounding areas of Ghaen city were proposed. To determine the importance of the weight of the attributes and to rate the alternatives using the proposed method, a questionnaire was designed. Then,the four experts (E_1, E_2, E_3 and E_4) involved in this project were asked to express the importance of the weight of each attribute and the rating of alternatives with respect to each attribute using linguistic variables inserted in the questionnaires (Table 1). Then, a consistency check was carried out. Where they were not satisfactory, the opinions were sent back to the experts. This process was repeated until the consistency check became acceptable. Table 4 shows the opinions of the experts on the importance weight of the attributes and the rating of the alternatives with respect to each attribute in the final repetition.The proposed method was then applied to select the optimal location. First, the hierarchical structure of the cargo terminal site selection problem was built. Figure 4 shows this structure with four levels: one objective (cargo terminal site selection), seven criteria (C_1-C_7), four sub-criteria (S_1-S_4) and four alternatives (A, B, C and D).

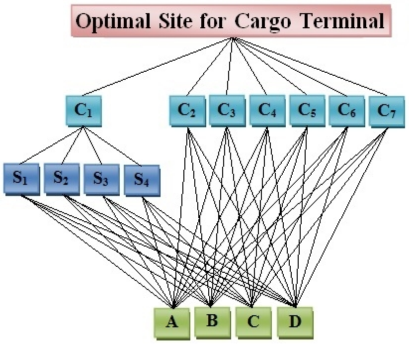


Figure 4. The hierarchical structure of the cargo terminal location of Gaen City problem

TABLE 3. The most important attributes for locating the cargo terminal

Criteria	Definition	Sub-criteria	Definition
C_1	Local area	S_1	Non-adjacent to the city limits and urban development
		S_2	Non-adjacent to the public centers (such as recreation centers, cultural heritage and tourism)
		S_3	Adjacent to main road
		S_4	Adjacent to convection networks, water distribution and gas station
C_2	Land Topography		
C_3	Cost		
C_4	The predominant direction of wind		
C_5	Environmental destruction		
C_6	Expansion possibility in the future		
C_7	Distance from the cargo center		

TABLE 4. Experts' opinions about the importance weight of attributes and the rating of alternatives

Importance weight										**Rating**															
										A				**B**				**C**				**D**			
Criterion	**E_1**	**E_2**	**E_3**	**E_4**	**Sub-Criterion**	**E_1**	**E_2**	**E_3**	**E_4**	**E_1**	**E_2**	**E_3**	**E_4**	**E_1**	**E_2**	**E_3**	**E_4**	**E_1**	**E_2**	**E_3**	**E_4**	**E_1**	**E_2**	**E_3**	**E_4**
C_1	H	H	VH	H	S_1	H	VH	H	VH	G	M	M	G	G	M	M	G	G	M	M	G	G	M	M	**G**
					S_2	M	M	M	M	G	B	B	G	G	G	M	G	VG	G	G	VG	G	G	M	**M**
					S_3	M	H	H	H	G	M	G	G	G	M	G	G	M	G	M	M	VG	VG	VG	**G**
					S_4	M	L	L	M	G	G	VG	G	M	G	M	M	M	M	M	M	G	G	VG	**VG**
C_2	M	L	M	M						G	M	B	G	G	G	M	G	VG	G	G	VG	G	G	M	**B**
C_3	VH	VH	VH	H						G	M	G	G	VG	G	M	G	G	M	VG	G	G	M	B	**B**
C_4	M	M	L	L						G	M	G	G	G	G	G	G	VG	G	G	VG	G	G	M	**B**
C_5	L	L	L	L						VG	VG	VG	VG	B	B	M	M	B	B	B	M	G	G	VG	**VG**
C_6	H	L	M	M						M	M	M	M	G	VG	M	G	B	M	G	M	G	G	M	**B**
C_7	M	M	L	H						VG	VG	VG	VG	B	B	M	M	B	B	B	M	G	G	VG	**VG**

TABLE 6. Interval valued fuzzy positive reciprocal matrix of alternatives with respect to C_2

	A	**B**	**C**	**D**
A	(1.000,1.000);1.000;(1.000,1.000)	(0.600,0.705);0.809;(0.905,1.000)	(0.429,0.542);0.656;(0.717,0.778)	(0.600,0.800);1.000;(1.667,2.333)
B	(1.000,1.118);1.236;(1.451,1.667)	(1.000,1.000);1.000;(1.000,1.000)	(0.714,0.763);0.811;(0.905,1.000)	(1.000,1.118);1.236;(1.785,2.333)
C	(1.286,1.405);1.524;(1.929,2.333)	(1.000,1.117);1.233;(1.317,1.400)	(1.000,1.000);1.000;(1.000,1.000)	(1.000,1.262);1.524;(2.262,3.000)
D	(0.429,0.714);1.000;(1.333,1.667)	(0.429,0.619);0.809;(0.905,1.000)	(0.333,0.495);0.656;(0.828,1.000)	(1.000,1.000);1.000;(1.000,1.000)

TABLE 5. Comparison of the alternatives with respect to C_2

a)based on opinion of E_1

	A	**B**	**C**	**D**
A	1.00	1.00	0.78	1.00
B	1.00	1.00	0.78	1.00
C	1.29	1.29	1.00	1.29
D	1.00	1.00	0.78	1.00

b) based on opinion of E_2

	A	**B**	**C**	**D**
A	1.00	0.71	0.71	0.71
B	1.40	1.00	1.00	1.00
C	1.40	1.00	1.00	1.00
D	1.40	1.00	1.00	1.00

c) based on opinion of E_3

	A	**B**	**C**	**D**
A	1.00	0.60	0.43	0.60
B	1.67	1.00	0.71	1.00
C	2.33	1.40	1.00	1.40
D	1.67	1.00	0.71	1.00

d) based on opinion of E_4

	A	**B**	**C**	**D**
A	1.00	1.00	0.78	2.33
B	1.00	1.00	0.78	2.33
C	1.29	1.29	1.00	3.00
D	0.43	0.43	0.33	1.00

For example, the calculations for the alternatives with respect to C_2 are as follows:

The opinions of experts to determine the rating of the alternatives with respect to C_2in the final repetition are collected according to row 4 and columns 11 to 26 in Table 4.By using the scale of Table 1 and Equations (11), (12) and (13), the comparison matrices of the alternatives with respect to C_2, based on each expert's opinion, are established according to Table 5.

The interval-valued fuzzy matrix of alternatives with respect to $C_2$is calculated as presented in Table 6 (see Equations(14) to (21)). The crisp comparison matrix of alternatives with respect to C_2 is calculated by Equations(22), (23) and (24) and the results are presented in Table 7. The CR for this matrix is calculated using Equation(26) and the result is presented at the bottom of Table 6. As can be observed, the value of the CRis less than 0.1.Thus, this matrixis consistent, and the judgments about the alternatives with respect to C_2 are acceptable.

TABLE 7. Crisp comparison matrix of alternatives with respect to C_2

	A	**B**	**C**	**D**
A	1.000	0.805	0.630	1.233
B	1.285	1.000	0.834	1.451
C	1.667	1.217	1.000	1.762
D	1.024	0.762	0.661	1.000

CR=4%

TABLE 8. Calculations of The relative fuzzy weights of alternatives with respect to C_2

$\widetilde{W}_i$	$\widetilde{Z}_i$	**Alternative (i)**
(0.115,0.155);0.210; (0.283,0.373)	(0.627,0.744);0.854; (1.020,1.161)	A
(0.168,0.206);0.260; (0.344,0.452)	(0.919,0.988);1.055; (1.237,1.404)	B
(0.195,0.247);0.320; (0.430,0.569)	(1.065,1.186);1.301; (1.548,1.769)	C
(0.091,0.142);0.210; (0.278,0.366)	(0.497,0.684);0.854; (1.000,1.136)	D

TABLE 9. The total weight of the alternatives

Alternatives				**Sub-criterion**	**Criterion**
D	**C**	**B**	**A**		
0.250	0.250	0.250	0.250	S_1 (0.349)	C_1 (0.223)
0.247	0.328	0.275	0.195	S_2 (0.222)	
0.326	0.220	0.240	0.240	S_3 (0.281)	
0.311	0.192	0.221	0.292	S_4 (0.176)	
0.216	0.347	0.281	0.224		C_2 (0.122)
0.182	0.310	0.293	0.277		C_3 (0.257)
0.204	0.313	0.279	0.252		C_4 (0.108)
0.334	0.145	0.166	0.374		C_5 (0.083)
0.259	0.247	0.345	0.254		C_6 (0.137)
0.334	0.145	0.166	0.374		C_7 (0.147)
0.272	0.280	0.282	0.302		Total Weight

Similar calculations are made to obtain the crisp comparison matrices of criteria (using opinions inserted in columns 1 to 10 of Table 4), the crisp comparison matrices of sub-criteria (using opinions inserted in columns 1 to 10 of Table 4), the crisp comparison matrices of the alternatives with respect to the other criteria and sub-criteria (using opinions inserted in columns 11 to 26 of Table 4) and their CR values.The relative fuzzy weights of alternatives with respect to C_2 are calculated using Equations(27) and (28).The results are presented in Table 8.

Using Equation (29), the relative weights of alternative iwith respect to $C_2\,(W^*_{iC_2})$, which are non-fuzzy numbers, are obtained as follows:

$$W_{AC_2}=\frac{0.115+0.155+(2\times 0.210)+0.283+0.373}{6}=0.224$$

$$W_{BC_2}=\frac{0.168+0.206+(2\times 0.260)+0.344+0.452}{6}=0.281$$

$$W_{CC_2}=\frac{0.195+0.247+(2\times 0.320)+0.430+0.569}{6}=0.347$$

$$W_{DC_2}=\frac{0.091+0.142+(2\times 0.210)+0.278+0.366}{6}=0.216$$

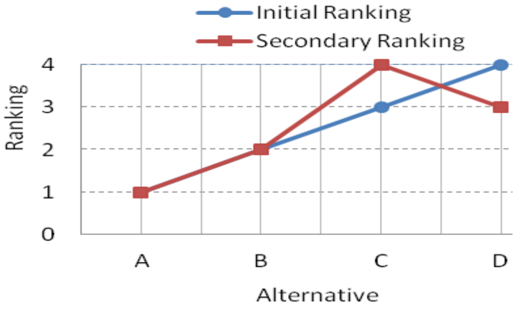
As can be observed, the relative weight of alternative C with respect to $C_2\,(W^*_{iC2})$ is higher than the other alternatives. Therefore, alternative C is the optimal alternative based on criterion C_2. Similar calculations are made based on the opinions of the experts in the final repetition (inserted in Table4)to obtain the relative weight of the attributes and the rating alternatives with respect to the attributes. Table 9 shows the relative weights of criteria (see column 2), the relative weight of sub-criteria (see column 2) and the relative weight of alternatives with respect to each attribute (see columns 3, 4, 5 and 6). The total weight of each alternative resulted from the combination of the relative weights of the decision elements according to AHP is shown in the last row of this table. As can be seen, also in the last row, the four proposed sites were ranked “A”, “B”, “C” and “B”, respectively. Therefore, alternative “A” is the optimal site for the cargo terminal of the Ghaen City, Iran. For example, the total weight of the alternative “A” is calculated according to AHP as follows:

$$\begin{aligned}W^t_A &== (0.223\times 0.349\times 0.250)+(0.223\times 0.222\times 0.195)\\&+(0.223\times 0.281\times 0.240)+(0.223\times 0.176\times 0.292)+\\&(0.122\times 0.224)+(0.257\times 0.277)+(0.108\times 0.252)\\&+(0.083\times 0.374)+(0.137\times 0.254)+(0.147\times 0.374)=0.302\end{aligned}$$

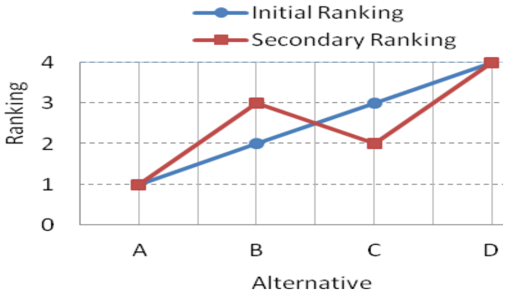
Similarly: $W^t_B = 0.282,\ W^t_C = 0.280,\ W^t_D = 0.272$

6. SENSITIVITY ANALYSIS

To test the sensitivity of the final ranks of the alternatives, a comprehensive sensitivity analysis is carried out on the importance of criteria and sub-criteria. The effect of each criterion is tested by reducing separately, the weight of each criterion by one levels (i.e., from H to M).If the importance of C_1, C_2, C_4, C_5 and $C_7$is reduced by two levels, the priorities of the alternatives remain unchanged.If the importance of criterion$C_3$is reduced by one level, D takes C’s position in overall ranking and the priorities of other alternatives remain unchanged (see Figure 5a).If the importance of criterion C_6 is reduced by one level, C takes B’s position in overall ranking and the priorities of other alternatives remain unchanged (see Figure 5b).It is noted that the effect of reducing the importance of each criterion has been reviewed separately.Sensitivity of the final ranks of the alternatives based on the sub-criteria weights is analyzed by systematically changing the proposed importance weights. If the importance of the sub-criteria (S_1, S_2, S_3 and S_4) is reduced by one level, the priorities of the alternatives remain unchanged.



(a) criterion C_3



(b) criterion C_6

Figure 5. Sensitivity analysis on the importance of criteria C_3 and C_6

7. CONCLUSION

Selecting a suitable terminal site location is among those decisions that significantly affect city limits and urban development. In addition, the terminal construction is a hugely costly project and it must be constructed in a location that has more potential to offset the associated costs. Hence, extensive studies from various aspects must be carried out to select the best site. Given the dependence of this matter to different quantitative and qualitative parameters, decision making regarding the site selection is a complex task. In this paper, a method is proposed, based on interval-valued fuzzy sets (IVF-AHP method) that can provide a way to handle fuzzy multi-criteria group decision-making problems and evaluate the qualities and weights of the attributes in complex situations. Considering the underlying fuzziness, the IVF-AHP method provides favorable results in a more flexible and intelligent manner than traditional fuzzy sets. Therefore, this method is a suitable decision-making tool for solving MCDM problems. The method was applied to select the optimal site for a cargo terminal for Ghaen City, Iran, as a case study. After applying the proposed method, alternative "A" was identified as the optimal site. Although in this study the proposed method is illustrated by application to a cargo terminal site selection problem, it should be noted that the method is generic and can be applied also to rating problems in other areas.

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Application of Interval-valued Fuzzy Analytic Hierarchy Process Approach in Selection Cargo Terminals, a Case Study

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چکیده

پایانه‌ها دروازه‌ی ورود کالاها به شبکه‌ی حمل و نقل هستند. بنابراین، موقعیت آنها در محل مناسب، می‌تواند تأثیر عمده‌ای بر اثر بخشی هزینه و بهره‌وری از شبکه حمل و نقل، ایمنی ترافیک و کاهش آلودگی‌های زیست محیطی داشته باشند. با توجه به تاثیر عوامل متعدد، و عدم قطعیت‌های موجود، تصمیم‌گیری در این زمینه یک کار پیچیده است. اگر تصمیم‌گیرندگان نمی‌تواند به توافق در مورد روش تعریف متغیرهای موثر بر اساس مجموعه‌های فازی برسند، نتایج مطلوب و مدل‌سازی دقیق‌تر، می‌تواند با استفاده از مجموعه‌ی فازی با ارزش بازه (IVFSs)، که یک درجه آزادی اضافی از عدم اطمینان و فازی در جهان واقعی ارائه می‌دهنده، به دست آید. این مطالعه یک فرآیند گروه تحلیلی فازی سلسله مراتبی (AHP) براساس IVFSs (IVF-AHP) است و کاربرد آن را برای پیدا کردن محل بهینه‌ی پایانه‌ی حمل و نقل در شهر قائن، ایران را ارائه می کند. نتایج نشان می‌دهد که روش پیشنهادی یک روش قابل اعتماد در انتخاب محل مناسب برای حمل و نقل پایانه می‌باشد.

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