The Application of Fuzzy Analytic Hierarchy Process Approach for the Selection of Warehouse Location: A Case Study

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Abstract

Warehouse location selection is a multi-criteria decision problem including both quantitative and qualitative criteria and has a strategic importance for many companies. The conventional methods for warehouse location selection are inadequate for dealing with the imprecise or vague nature of linguistic assessment. To overcome this difficulty, fuzzy multi-criteria decision-making methods are proposed. In this paper, we present a multi-criteria decision making approach for selecting warehouse location under partial or incomplete information (uncertainty). The proposed approach comprises of two steps. In step 1, we identify the criteria and sub-criteria for warehouse location selection to design the fuzzy analytical hierarchy process tree structure. In step 2, fuzzy analytic hierarchy process (FAHP) is used in determining of the weights of the main criteria, sub-criteria and alternatives by decision makers and then selection of the best alternative. This paper shows a successful application of fuzzy analytic hierarchy process to a real warehouse location selection problem of a big company in Iran.

Keywords: warehouse location; multi criteria decision making; fuzzy analytic hierarchy process (FAHP)

1. Introduction

Warehouses are a key aspect of modern supply chains and play a vital role in the success, or failure of businesses today [16]. A warehouse is a commercial building for buffering and storing goods. Warehouses are utilized by manufacturers, importers, exporters, retailers, transport businesses, etc. The location theory was first introduced by Weber (1989) who considered the problem of locating a single warehouse in order to minimize the total travel distance between the warehouse and a set of spatially distributed customers. Indeed, he proposed a material index for the selection of the location according to which, if this index is greater than one, the warehouse should be installed in the vicinity of the source of raw material; otherwise, it must be close to the market [5]. The decision process in question encompasses the identification, analysis, evaluation and selection among alternatives. Such a decision is among the most critical decisions of distribution network design. The selection of a warehouse location among alternative locations is a multi-criteria decision making problem including both quantitative and qualitative criteria. Such decisions are of great importance to companies because they are costly and difficult to reverse, and entail a long-term commitment. They also have an impact on operating costs and revenues. For instance, a poor choice of location might result in excessive transportation costs, a shortage of qualified labor, loss of competitive advantage or some similar condition that would be detrimental to operations [32]. The general procedure for making location decisions usually consists of the following steps:

- Decide on the criteria that will be used to evaluate location alternatives
- Identify criteria that are important
- Develop location alternatives
- Evaluate the alternatives and make a selection

The location of a warehouse is generally one of the most important and strategic decision in the optimization of logistic systems. It is a long-term decision and is influenced by many quantitative and qualitative criteria; however, some criteria are so important that they tend to dominate the decision dominate the decision in importance. Among the criteria taken into account in this paper are costs, labor characteristics, infrastructure and market. The conventional approaches to warehouse location selection problem tend to be less effective in dealing with the imprecise or vague nature of the linguistic assessment. In many situations, the values of the qualitative criteria are often imprecisely defined for decision-makers. In this paper, we present a multi criteria decision making approach to warehouse location selection under uncertain (fuzzy) circumstances.

The rest of the paper is organized as follows: the literature review on warehouse/facility location selection is given in Section 2. In Section 3 and 4, we present the preliminaries of fuzzy set theory and fuzzy analytic hierarchy process (FAHP). In Section 5, we present the multi criteria decision making approach for warehouse location selection based on fuzzy AHP. In Section 6, we present a case study and finally, in Section 7 we provide the conclusions and steps for future work.

2. Literature review

Among supply chain studies, many papers on warehouse/facility location problem have been published. Vlachopoulou et al. [35] aim at developing a geographic decision support system for the warehouse site selection process, enabling the manager to use quantitative and qualitative criteria in order to classify alternative warehouses or visualize the best one. Sharma and Berry [31] consider the single stage capacitated warehouse location problem (SSCWLP) where goods are shipped from plants to warehouses and from warehouses to markets. The problem is to choose a set of points where warehouses are located so that the sum of warehouse location costs and transportation costs are minimized. In their study they consider different formulation styles due to Geoffrion and Graves [17] and Sharma [29] for the multistage warehouse location problem; and cast them in the formulation style of Sharma and Sharma [30] to obtain a variety of formulations of the problem SSCWLP. A public warehouses selection support system (PWSS) software has been built by Colson and Dorigo [10] to give the opportunity to industrial users of exploiting a classical data base on public warehouses, where several items of information are given on each warehouse located in a given country.

Their software public warehouses selection support has two purposes: to select public warehouses according to several criteria and to exploit a database when some data are missing. They use multiple-criteria selections and rankings with a mixture of classical true continuous criteria and Boolean ones from a methodological point of view. Michel and Hentenryck [26] present a very simple tabu-search algorithm which performs amazingly well on the uncapacitated warehouse location problem. The algorithm uses a linear neighborhood. Drezner et al. [13] concern themselves with the optimal location of a central warehouse, when the possible locations and the number of warehouses are known. They solve the problem sequentially. First, for any given central warehouse location, the problem is a pure inventory problem. They find the optimal policy for the inventory problem. They express the total inventory and transportation costs as a function of the central warehouse location. The next step is to optimize this total cost function over all possible central warehouse locations. Partovi [28] explains a new analytic model for facility location that takes into account both external and internal criteria that sustain competitive advantage. Partovi's model, which is based on quality function deployment (QFD), also includes the analytic hierarchy process (AHP) and the analytic network process (ANP) concepts to determine the best location for a facility.

The most well- known general heuristic methods for facility location problems are Tabu Search (TS), Simulated Annealing (SA), and Genetic Algorithms (GA). Arostegui et al. [2] compare the relative performance of TS, SA, and GA on various facilities location problems. Hidaka and Okano [18] propose a simulation-based approach to the large-scale incapacitated warehouse/facility location problems, including a heuristic algorithm named ''Balloon Search''. Tzeng and Chen [34] propose a location model based on a fuzzy multi objective approach. The model helps in determining the optimal number and sites of fire stations at an international airport, and also assists the relevant authorities in drawing up optimal locations for fire stations. Because of the combinatorial complexity of their model, a genetic algorithm is employed and compared with the enumeration method. Kuo et al. [21] develop a decision support system using the fuzzy sets theory integrated with analytic hierarchy process for locating a new convenience store. Chen [9] proposes a new multiple criteria decision-making method to solve the distribution center location selection problem under a fuzzy environment.

In the proposed method, the ratings of each alternative and the weight of criterion are described by linguistic variables that can be expressed in triangular fuzzy numbers. The final evaluation value of each distribution centre location is also expressed in a triangular fuzzy number.

3. Fuzzy sets and fuzzy number

To deal with vagueness of human thought, Zadeh [38] first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. With different daily decision making problems of diverse intensity, the results can be misleading if the fuzziness of human decision making is not taken into account [33]. Fuzzy sets theory providing a more widely frame than classic sets theory, has been contributing to capability of reflecting real world [14]. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling: uncertain systems in industry, nature and humanity; and facilitators for common-sense reasoning in decision making in the absence of complete and precise information. Their role is significant when applied to complex phenomena not easily described by traditional mathematical methods, especially when the goal is to find a good approximate solution [3].

A tilde '~' will be placed above a symbol if the symbol represents a fuzzy set. A triangular fuzzy number (TFN), $\tilde{M}$ is shown in Fig.1. A triangular fuzzy number is denoted simply as $(l/m, m/u)$ or (l, m, u). The parameters l, m and u, respectively, denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event. Each triangular fuzzy number has linear representations on its left and right side such that its membership function can be defined as:

$$\mu(x/\tilde{M}) = \begin{cases} 0 & x < l \\ (x-l)/(m\_l) & l \le x \le m \\ (u-x)/(u\_m) & m \le x \le u \\ 0 & x > u \end{cases} \qquad (1)$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

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

Where $l(y)$ and $r(y)$ denote the left side representation and the right side representation of a fuzzy number, respectively. Many ranking methods for fuzzy numbers have been developed in the literature. These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. The algebraic operations with fuzzy numbers can be found in Kahraman et al. [19]

4. Methodology of fuzzy AHP

A good decision-making model needs to tolerate vagueness or ambiguity because fuzziness and vagueness are common characteristics in many decision-making problems [37]. Since decision- makers often provide uncertain answers rather than precise values, the transformation of qualitative preferences to point estimates may not be sensible. Conventional AHP that requires the selection of arbitrary values in pair-wise comparison may not be sufficient and uncertainty should be considered in some or all pair-wise comparison values [37]. Since the fuzzy linguistic approach can take the optimism/pessimism rating attitude of decision-makers into account, linguistic values, whose membership functions are usually characterized by triangular fuzzy numbers, are recommended to assess preference ratings instead of conventional numerical equivalence method [24]. As a result, the fuzzy-AHP should be more appropriate and effective than conventional AHP in real practice where an uncertain pair-wise comparison environment exists [23]. In this study, Chang's [7, 8] extent analysis method is used to compare the performances of banks because of the computational easiness and efficiency of this method. Let $X = \{x_1, x_1, \ldots, x_n\}$ be an object set, and $U = \{u_1, u_1, \ldots, u_n\}$ be a goal set.

According to the method of Chang [8] 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:

$$M_{gi}^{1}, M_{gi}^{2}, \ldots, M_{gi}^{m}, \quad i = 1, 2, \ldots, n \tag{3}$$

Where all the $M_{gi}^{j}\ (j = 1, 2, \ldots, m)$ 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:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} \tag{4}$$

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

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{5}$$

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

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_j, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \tag{6}$$

And then compute the inverse of the vector in Eq. (6) such that:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} l_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} u_i} \right) \tag{7}$$

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:

$$V(M_2 \geq M_1) = \sup\left[\min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \tag{8}$$

And can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{9}$$

Where d is the ordinate of the highest intersection point D between μ_{M1} and μ_{M2} (see Fig. 2). To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

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:

$$V(M \geq M_1, M_2, ..M_k) = V(M \geq M_1)\ and\ V(M \geq M_2)\ and \ldots and\ V(M \geq M_k) = \min V(M \geq M_i) \quad (10)$$

Assume that:

$$d'(A_i) = \min V(S_i \geq S_k) \quad (11)$$

For $k = 1,2,\ldots,K;\ k \neq i$ then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (12)$$

Where $A_i\ (i = 1,2,\ldots,n)$ are n elements

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

$$W' = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad (13)$$

Many of the FAHP applications on various cases can be found in literature based on Chang's extent analysis. Kwong and Bai [22] applied this method to prioritize customer requirements in the QFD. On the other hand, Bozdag et al. [4] utilized this approach in the evaluation of CIM alternatives. Kahraman et al. [20] developed an analytical selection tool to measure the customer satisfaction in catering firms in Turkey. A methodology to improve the quality of decision-making in software development project under uncertain conditions was proposed by Buyukozkan et al. [6]. The relationship between competitiveness and technology management was established by Erensal et al. [15] using FAHP based on Chang's extent analysis. Wu and Kreng [36] submitted a paper, including a FAHP approach, to evaluate alternatives of knowledge portal development tools by considering judgments of five experts.

5. *Warehouses location selection under uncertainty*

The proposed framework for warehouses location selection under uncertainty consists of two steps:

Step 1: Define the main criteria and sub-criteria for the selection of warehouse location to design the fuzzy analytical hierarchy process tree structure.

Step 2: Calculate the weights of the main criteria and sub-criteria and alternatives and then Compute the overall score of each warehouse location and choose the best location.
These steps are presented in detail as follows.

5.1. Define the main criteria and sub-criteria

The first step involves selection of criteria and sub-criteria for warehouse location selection to design the fuzzy analytical hierarchy process tree structure. In this study, 7 criteria and 20 sub-criteria were used for the selection of warehouse location. These criteria and sub-criteria were selected from the studies of Min and Melachrinoudis [27], Alberto [1] and MacCarthy and Atthrirawong [25], Demirel et al. [11] and Dogan [12]. The definitions of the criteria are summarized as follows:

1) Costs

Costs are one of the factors highly affected by the facility location. Under the cost criterion, four sub-criteria are defined: labor costs, transportation costs, handling costs and land cost. Labor costs are the criterion that changes in respect to the living conditions at alternative locations. Transportation costs vary according to the economic structure of the alternative regions, transportation facilities and alternative transportation types as air, land, railroad, and marine. Handling costs, which are caused by the storage of the goods, are composed of capital, work power, equipment and risk costs and vary from a region to another. Land cost is considered as a criterion that differs from one region to another. The cost of land for a warehouse is one of the major costly elements in this investment.

2) Labor characteristics

This main criterion defines the state of qualified labor at a location and the degree of the availability of such labor.

Skilled labor defines the ideal personnel required for a work, such as those who obtain qualifications and have sufficient training. This is one of the requirements in order to perform on time and in a qualified manner meeting a high level of standard. The skilled labor may not be at the desired level at each location. Availability of labor force is a criterion that changes based on the level of development in the region, training levels, and population structure.

3) Geographical location

This main criterion includes the land availability and climate. Land availability is a criterion that changes according to the structure of the alternative regions. Climate is a criterion that varies from a region to another. Significant climate fluctuations and severe weather conditions disrupt the business as well as affecting human efficiency.

4) Infrastructure

It is a main criterion defining the basic structure of transportation, and communication systems, based on the location of a warehouse. This criterion is composed of four sub-criteria: the existence of modes of transportation, telecommunication, quality and reliability of modes of transportation and quality and reliability of utilities. Existence of modes of transportation has an importance based on the availability of different transportation types in the location. Telecommunication systems are a criterion that defines the communication facilities and communication technologies of the warehouse with the customer nodes, the producers or the suppliers. Quality and reliability of modes of transportation defines the transportation service between the customer nodes, suppliers, and the warehouse, to be performed in a reliable and qualified way based on the different transportation modes. Reliable and quality service means timely delivery, delivery to the correct location and delivery of undamaged goods. Quality and reliability of utilities are considered as a criterion that differs from one region to another.

5) Market

It is a main criterion that defines the distance of the location of the warehouse to the customers, suppliers and producers. Moreover, this criterion contains the supply periods and the ability to respond to an order. Proximity to customers defines the distance of the warehouse location to the customer nodes. Proximity to suppliers or producers defines the distance of the warehouse location to the suppliers and the producers. Lead times and responsiveness defines the ability and the period to fulfill meets an order requirement.

6) Macro environment

This main criterion includes the government policies, industrial arrangements and laws, and the development plans of the region at macro level. Policies of government are considered as a criterion that differs from one region to another. Being parallel to the development level of the region, it includes the factors such as various incentives, tax exemptions, and investment facilities. Industrial regulations laws, which are parallel to the policies and implementations of the local administrations, are criterion principles that define various laws and arrangements. Zoning and construction plan is a criterion that defines the different development plans, implementations and arrangements of local administrations at alternative locations.

7) Economic factors

This main criterion includes the tax incentives and tax structures and financial incentives. Tax incentives and tax structures vary based on the regions that have priority in development. The credit incentives by the state or private banks, which can be called financial incentives, are realized in various regions.

Fig. 3 shows the structuring of the warehouse location selection hierarchy of four levels. The top level of the hierarchy represents the ultimate goal of the problem which is selection of the best warehouse location. The second level of the hierarchy is grouped under seven main criteria. At the third level, these main criteria are decomposed into various sub-criteria that may affect the warehouse's choice. Finally, the bottom level of the hierarchy represents the alternative.

5.2. Calculate the weights of the main criteria and sub-criteria and alternatives

After the construction of the hierarchy, the different priority weights of each main criterion, sub-criterion and alternatives were calculated using the fuzzy AHP approach. First the expert compared the main criteria with respect to the main goal; then the expert compared the sub-criteria with respect to the main criteria. At the end, the expert compared the alternatives with respect to each sub-criterion. The expert used the linguistic variables to make the pair-wise comparisons. Then the linguistic variables were converted to triangular fuzzy numbers.

Table 1 shows the linguistic variables and their corresponding triangular fuzzy numbers. Then the priority weights of each main criterion, sub-criterion and alternative were calculated using FAHP method. In the last step, the priority weights of the main criteria, sub-criteria and alternatives were combined to select the best alternative for warehouse location.

6. Case Study

Entekhab industrial group, a big company in Iran, wants to decide on where it will locate its new warehouse. The alternative locations have been determined by the six experts of the company (D_1, D_2, …, D_6). The committee used linguistic variables (Tables 1) to rate the three alternatives (Tabriz (A_1), Arak (A_2) and Isfahan (A_3)). Fuzzy evaluation matrix of the main criteria is constructed by the pair-wise comparison of the different criterion relevant to the main criterion using triangular fuzzy numbers, which is shown in Table 2. The value of fuzzy synthetic extent with respect to each main criterion is calculated by using Eq. (4) and the formula for algebraic operations of the fuzzy set. The different values of fuzzy synthetic extent with respect to the seven different criteria are denoted by S_1, S_2, S_3, S_4, S_5, S_6 and S_7, respectively. For example:

$S_1 = (7, 9.667, 12.5)\ (0.0136, 0.018, 0.024) = (0.095, 0.174, 0.301)$

The degree of possibility of S_i over S_j ($i \neq j$) can be determined by Eq. (9). For example:

$V(S_1 \geq S_2) = 1$, $V(S_1 \geq S_3) = 1$, $V(S_1 \geq S_4) = 1$, $V(S_1 \geq S_5) = 0.73$, $V(S_1 \geq S_6) = 1$, $V(S_1 \geq S_7) = 1$.
With the help of Eq. (10), the minimum degree of possibility can be stated. For example:

$\text{Min } V(S1 \geq S_2, S_3, S_4, S_5, S_6, S_7) = \min(1, 1, 1, 0.73, 1, 1) = 0.73$

Therefore the weight vector is given as $W_G = (0.73, 0.1, 0.16, 0.75, 1, 0.43, 0.46)^T$ and after the normalization process, the weight vector with respect to decision criteria C_1, C_2, C_3, C_4, C_5, C_6 and C_7 can be presented as follows:

$W_G = (0.202, 0.027, 0.044, 0.205, 0.275, 0.119, 0.128)^T$.

The complete result is shown in Table 2.

The different sub-criteria are compared under each of the criterion separately by following the same procedure as discussed above. Whenever the value of $(l_1-u_2)>0$, the elements of the matrix must be normalized and then do the same process to find the weight vector of each sub-criterion. The fuzzy evaluation matrices of the sub-criteria and the weight vectors of each sub-criterion with respect to the criterion C_1-C_7 are shown in Tables 3-9.

Similarly the fuzzy evaluation matrices of decision alternatives and corresponding weight vector of each alternative with respect to corresponding sub-criteria can be determined. Owing to the limited space, the pair-wise comparison matrix of alternatives with respect to sub-criteria labor Costs (C_{11}), transportation Costs (C_{12}), handling Costs (C_{13}), land Cost (C_{14}) will be presented here in Tables 11.-13.

The complete result of weight vectors of each alternative with respect to the sub-criteria are shown in Tables 14.

Finally the priority weights of the main criterion, sub-criteria and alternatives were combined to select the best alternative for warehouse location, as shown in Table 14. By comparing the final weights of the three alternatives (Table 14) we find that $A_3 > A_2 > A_1$ .Therefore, alternative Isfahan (A_3) is recommended as the best warehouse location.

7. Conclusion

A warehouse location selection is a multi-criteria decision-making problem including both quantitative and qualitative. In this paper, we presented a multi-criteria decision making approach for warehouse location selection under fuzzy environment. The proposed approach comprises of two steps. In step 1, the main criteria and sub-criteria for the selection of warehouse location were identified. After the main criteria and sub-criteria were determined, the hierarchy of the warehouse location selection was structured. The top level of the hierarchy represented the ultimate goal of the problem which is selection of the best warehouse location. The second level of the hierarchy was grouped under seven main criteria. These criteria were Costs, labor characteristics, geographical location, infrastructure, market, macro environment, economic factors. At the third level, these main criteria were decomposed into various sub-criteria that may affect the warehouse's choice.

These sub-criteria were labor costs, transportation costs, handling costs, land cost, skilled labor, availability of labor force, land availability, climate, existence of modes of transportation, telecommunication systems, quality and reliability of modes of transportation, quality and reliability of utilities, proximity to customers, proximity to suppliers or producer, lead times and responsiveness, policies of government, industrial regulations laws, zoning and construction plan, tax incentives and tax structures, financial incentives. Finally, the bottom level of the hierarchy represented the alternative. In step 2, fuzzy analytic hierarchy process (FAHP) was used in determining of the weights of the criteria, sub-criteria and alternatives by decision makers and then the priority weights of the main criteria, sub-criteria and alternatives were combined to select the best alternative for warehouse location. The warehouse location selection problem in this paper can be solved by fuzzy TOPSIS and the obtained results can be compared for further research.

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Figures and Tables

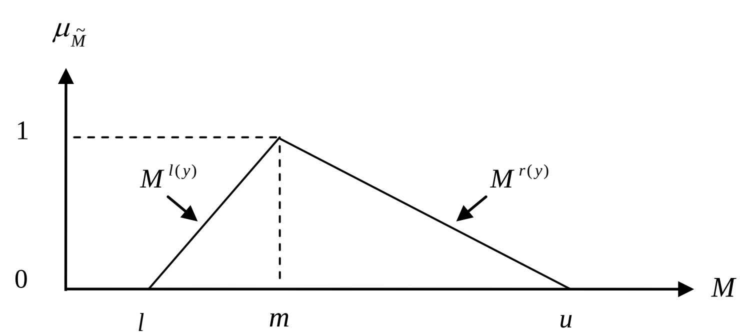

Figure 1. A triangular fuzzy number, $\tilde{M}$

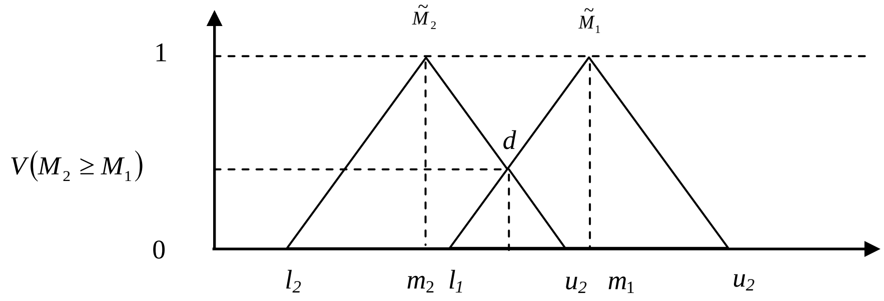

Figure 2. The intersection between M_1 and M_2

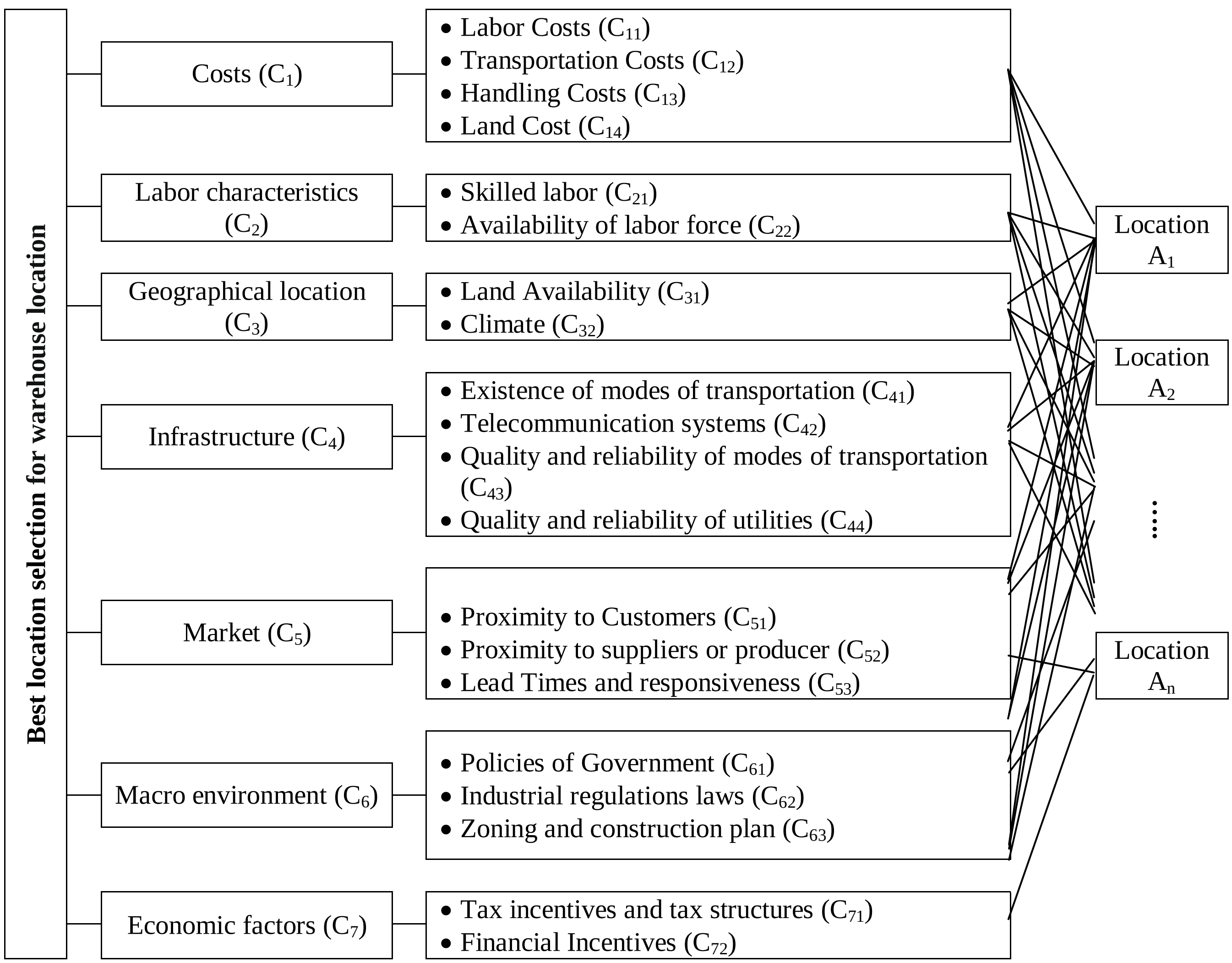

Figure 3. The hierarchy of the warehouse location selection problem

Table 2. The fuzzy evaluation matrix with respect to the goal.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7		S_1	S_2	S_3	S_4	S_5	S_6	S_7	W_G
C_1	(1,1,1)	(1.5,2,2.5)	(1.5,2,2.5)	(0.5,1,1.5)	(0.5,0.667,1)	(1,1.5,2)	(1,1.5,2)	$V(S_1>S_i)$	-	1	1	1	0.73	1	1	0.202
C_2	(0.4,0.5,0.67)	(1,1,1)	(0.5,1,1.5)	(0.4,0.5,0.67)	(0.33,0.4,0.5)	(0.5,0.667,1)	(0.5,0.667,1)	$V(S_2>S_i)$	0.39	-	1	0.38	0.1	0.69	0.69	0.027
C_3	(0.4,0.5,0. 67)	(0.667,1,2)	(1,1,1)	(0.4,0.5,0.67)	(0.33,0.4,0.5)	(0.5,0.667,1)	(0.5,0.667,1)	$V(S_3>S_i)$	0.44	1	-	0.43	0.16	0.72	0.72	0.044
C_4	(0.667,1,2)	(1.5,2,2.5)	(1.5,2,2.5)	(1,1,1)	(0.5,0.667,1)	(1,1.5,2)	(1,1.5,2)	$V(S_4>S_i)$	1	1	1	-	0.75	1	1	0.205
C_5	(1,1.5,2)	(2,2.5,3)	(2,2.5,3)	(1,1.5,2)	(1,1,1)	(1.5,2,2.5)	(1.5,2,2.5)	$V(S_5>S_i)$	1	1	1	1	-	1	1	0.275
C_6	(0.5,0.667,1)	(1,1.5,2)	(1,1.5,2)	(0.5,0.667,1)	(0.4,0.5,0. 67)	(1,1,1)	(0.5,1,1.5)	$V(S_6>S_i)$	0.71	1	1	0.71	0.43	-	1	0.119
C_7	(0.5,0.667,1)	(1,1.5,2)	(1,1.5,2)	(0.5,0.667,1)	(0.4,0.5,0.67)	(0.667,1,2)	(1,1,1)	$V(S_7>S_i)$	0.73	1	1	0.73	0.46	1	-	0.128

S_1= (0.095,0.174,0.301), S_2= (0.049,0.085,0.152), S_3= (0.052,0.085,0.164), S_4= (0.098,0.174,0.313), S_5= (0.136,0.234,0.385), S_6= (0.067,0.123,0.221), S_7= (0.069,0.123,0.233).

Table 1.The linguistic variables and their corresponding fuzzy numbers

Linguistic variables	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(111)	(111)
Equally important	(1/2,1,3/2)	(2/3,1,2)
Weakly important	(1,3/2,2)	(1/2,2/3,1)
Strongly more important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	(5/2,3,7/2)	(2/7,1/3,2/5)

Table 3. Evaluation of the sub-criteria with respect to criterion C_1

	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	(1,1,1)	(0.4,0.5,0.667)	(0.4,0.5,0.667)	(1,1.5,2)
C_{12}	(1.5,2,2.5)	(1,1,1)	(0.5,1,1.5)	(1.5,2,2.5)
C_{13}	(1.5,2,2.5)	(0.667,1,2)	(1,1,1)	(1.5,2,2.5)
C_{14}	(0.5,0.667,1)	(0.4,0.5,0.667)	(0.4,0.5,0.667)	(1,1,1)

The weight vector from Table III is calculated $W_{C1}=(0.166,0.388,0.388,0.058)^T$.

Table 4. Evaluation of the sub-criteria with respect to criterion C_2

	C_{21}	C_{22}
C_{21}	(1,1,1)	(1,1.5,2)
C_{22}	(0.5,0.667,1)	(1,1,1)

The weight vector from Table IV is calculated $W_{C2}=(0.684,0.316)^T$.

Table 5. Evaluation of the sub-criteria with respect to criterion C_3

	C_{31}	C_{32}
C_{31}	(1,1,1)	(1,1.5,2)
C_{32}	(0.5,0.667,1)	(1,1,1)

The weight vector from Table V is calculated $W_{C3}=(0.684,0.316)^T$.

Table 6. Evaluation of the sub-criteria with respect to criterion C_4

	C_{41}	C_{42}	C_{43}	C_{44}
C_{41}	(1,1,1)	(0.5,1,1.5)	(0.5,0.667,1)	(1,1.5,2)
C_{42}	(0.667,1,2)	(1,1,1)	(0.5,0.667,1)	(1,1.5,2)
C_{43}	(1,1.5,2)	(1,1.5,2)	(1,1,1)	(1.5,2,2.5)
C_{44}	(0.5,0.667,1)	(0.5,0.667,1)	(0.4,0.5,0.667)	(1,1,1)

The weight vector from Table VI is calculated $W_{C4}=(0.251,0.263,0.371,0.114)^T$.

Table 7. Evaluation of the sub-criteria with respect to criterion C_5

	C_{51}	C_{52}	C_{53}
C_{51}	(1,1,1)	(0.5,1,1.5)	(0.5,0.667,1)
C_{52}	(0.667,1,2)	(1,1,1)	(0.5,0.667,1)
C_{53}	(1,1.5,2)	(1,1.5,2)	(1,1,1)

The weight vector from Table VII is calculated W_{C5}= $(0.273,0.297,0.43)^T$.

Table 8. Evaluation of the sub-criteria with respect to criterion C_6

	C_{61}	C_{62}	C_{63}
C_{61}	(1,1,1)	(1,1.5,2)	(1,1.5,2)
C_{62}	(0.5,0.667,1)	(1,1,1)	(0.5,1,1.5)
C_{63}	(0.5,0.667,1)	(0.667,1,2)	(1,1,1)

The weight vector from Table VIII is calculated W_{C6}= $(0.43,0.273,0.297)^T$.

Table 9. Evaluation of the sub-criteria with respect to criterion C_7

	C_{71}	C_{72}
C_{71}	(1,1,1)	(0.5,1,1.5)
C_{72}	(0.667,1,2)	(1,1,1)

The weight vector from Table IX is calculated W_{C7}= $(0.5, 0.5)^T$.

Table 10. Evaluation of alternatives with respect C_{11}

	A_1	A_2	A_3
A_1	(1,1,1)	(0.5,0.667,1)	(0.4,0.5, 0.667)
A_2	(1,1.5,2)	(1,1,1)	(0.5,0.667,1)
A_3	(1.5,2,2.5)	(1,1.5,2)	(1,1,1)

The weight vector from Table X is calculated W_{C11}= $(0.097,0.345,0.558)^T$.

Table 11 Evaluation of alternatives with respect C_{12}

	A_1	A_2	A_3
A_1	(1,1,1)	(0.5,1,1.5)	(0.5,0.667,1)
A_2	(0.667,1,2)	(1,1,1)	(0.5,0.667,1)
A_3	(1,1.5,2)	(1,1.5,2)	(1,1,1)

The weight vector from Table XI is calculated W_{C12}= $(0.273,0.297,0.43)^T$.

Table 12. Evaluation of alternatives with respect C_{13}

	A_1	A_2	A_3
A_1	(1,1,1)	(0.5,0.667,1)	(0.4,0.5, 0.667)
A_2	(1,1.5,2)	(1,1,1)	(0.5,0.667,1)
A_3	(1.5,2,2.5)	(1,1.5,2)	(1,1,1)

The weight vector from Table XII is calculated W_{C13}= $(0.097,0.345,0.558)^T$.

Table 13. Evaluation of alternatives with respect C_{14}

	A_1	A_2	A_3
A_1	(1,1,1)	(0.5,0.667,1)	(0.4,0.5, 0.667)
A_2	(1,1.5,2)	(1,1,1)	(0.5,0.667,1)
A_3	(1.5,2,2.5)	(1,1.5,2)	(1,1,1)

The weight vector from Table XIII is calculated W_{C14}= $(0.097,0.345,0.558)^T$.

Table 14. Computed global weights

Main criteria and local weights		sub-criteria and local weights		Alternatives		
				A_1	A_2	A_3
Costs (C_1)	0.202	Labor Costs (C_{11})	0.166	0.097	0.345	0.558
		Transportation Costs (C_{12})	0.388	0.273	0.297	0.43
		Handling Costs (C_{13})	0.388	0.097	0.345	0.558
		Land Cost (C_{14})	0.058	0.097	0.345	0.558
Labor characteristics (C_2)	0.027	Skilled labor (C_{21})	0.684	0.558	0.345	0.097
		Availability of labor force (C_{22})	0.316	0.558	0.345	0.097
Geographical location (C_3)	0.044	Land Availability (C_{31})	0.684	0.273	0.297	0.43
		Climate (C_{32})	0.316	0.558	0.345	0.097
Infrastructure (C_4)	0.205	Existence of modes of transportation (C_{41})	0.251	0.558	0.345	0.097
		Telecommunication systems (C_{42})	0.263	0.381	0.381	0.237
		Quality and reliability of modes of transportation (C_{43})	0.371	0.558	0.345	0.097
		Quality and reliability of utilities (C_{44})	0.114	0.333	0.333	0.333
Market (C_5)	0.275	Proximity to Customers (C_{51})	0.273	0.273	0.43	0.297
		Proximity to suppliers or producer (C_{52})	0.297	0.558	0.345	0.097
		Lead Times and responsiveness (C_{53})	0.43	0.273	0.43	0.297
Macro environment (C_6)	0.119	Policies of Government (C_{61})	0.43	0.097	0.345	0.558
		Industrial regulations laws (C_{62})	0.273	0.273	0.297	0.43
		Zoning and construction plan (C_{63})	0.297	0.097	0.345	0.558
Economic factors (C_7)	0.128	Tax incentives and tax structures (C_{71})	0.5	0.097	0.345	0.558
		Financial Incentives (C_{72})	0.5	0.273	0.297	0.43
Final weights				0.213	0.248	0.258