Plant Location Selection by Using a Three-Step Methodology: Delphi-AHP-VIKOR

B. Vahdani, S. M. Mousavi, and R. Tavakkoli-Moghaddam

Abstract**—**Nowadays, the plant location selection has a critical impact on the performance of numerous companies. In this paper, a methodology is presented to solve this problem. The three decision making methods, namely Delphi, AHP and improved VIKOR, are hybridized in order to make the best use of information available based on the decision makers or experts. In this respect, the aim of using Delphi is to select the most influential criteria by a few decision makers. The AHP is utilized to give weights of the selected criteria. Finally, the improved VIKOR method is applied to rank alternatives. At the end of paper, an application example demonstrates the applicability of the proposed methodology.

Keywords**—**Decision making, Plant location selection, Delphi, AHP, Improved VIKOR.

I. INTRODUCTION

THE plant location problem is an important issue and has significant impacts on the efficiency of manufacturing companies [1]. Many potential criteria, such as investment cost, human resources, availability of acquirement material, climate etc., must be considered in selecting a particular plant location [2, 3]. Therefore, plant selection can be viewed as multiple criteria decision making (MCDM) problem. Many precision-based plant location methods have been investigated [4-6]. In real life, the evaluation data of plant location suitability for various subjective criteria and the weights of the criteria are usually expressed in linguistic terms [2]. Previous studies have applied MCDM approaches to generate and solve facility location selection problems. Liang and Wang [3] developed an algorithm for facility site selection based on hierarchical structure analysis, where the ratings of various alternative locations under various subjective criteria and the weights of all criteria are assessed in linguistic terms represented by fuzzy numbers. Kuo et al. [7] proposed a decision support system (DSS) by integrating fuzzy set theory and the AHP in selecting a site for a new convenience store (CVS). Additionally, Kuo et al. [8] developed a DSS for locating new CVSs by integrating the fuzzy AHP and an artificial neural network (ANN). Chen [9] developed a new MADM approach for resolving the DC location selection problem under fuzzy environments based on a stepwise ranking procedure. Liang and Wang [3] proposed a fuzzy MCDM method for the facility site selection, where the ratings of various alternative locations under various subjective criteria and the weights of all criteria are assessed in linguistic terms represented by fuzzy numbers. Chou et al. [10] presented a new fuzzy simple additive weighting system (SAWS), for solving plant location selection problems by using objective/subjective attributes under decision-making (GDM) conditions.

Recently, some researchers have focused on the technique for order preference by similarity to an ideal solution (TOPSIS) method to solve the plant location selection problem [1, 6, 9, 11]. The basic principle of the TOPSIS method is that the chosen alternative should have the ‘‘shortest distance’’ from the ideal solution and the ‘‘farthest distance’’ from the ‘‘negative-ideal’’ solution. The TOPSIS method introduces two ‘‘reference’’ points, but it does not consider the relative importance of the distances from these points. In contrast, the proposed methodology based on the improved VIKOR method introduces the ranking index based on the particular measure of ‘‘closeness’’ to the ideal solution without the need to ask the experts. Moreover, the normalized values by vector normalization in the TOPSIS method may depend on the evaluation unit the normalized value, whereas in the VIKOR method does not depend on the evaluation unit of a criterion function [12, 13].

In DM problems, a decision maker has to choose the best alternative that satisfies all criteria. Generally, it is hard to achieve this goal, so a good compromise solution needs to be found. This problem maybe become complex when multiple DMs are involved [14, 15, 18]. On the other hand, over the years many researchers focused on using different MCDM techniques, but to this date, to the best of our knowledge, the improved VIKOR method has not been in use for plant location problems. To solve these problems in multi-criteria decision making, a new methodology based on Delphi-AHP-VIKOR is proposed. In this methodology, three decision making methods, namely Delphi, AHP and VIKOR, are integrated in order to make the best use of information available, either implicitly or explicitly. In this respect, the aim of using Delphi is selecting most influential criteria via expertise of experts. AHP is utilized to give the weights of just-selected criteria. And finally, improved VIKOR method is taken into account to rank alternative. The improved VIKOR

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method provides the maximum group utility for the majority and minimum of an individual regret for the opponent. It introduces the multi criteria ranking index based on the particular measure of closeness to the ideal solution.

This paper is arranged into five sections. In Section II, the proposed methodology is concisely provided. An application example of location selection in the multi criteria decision making environment is used to illustrate the feasibility of the proposed methodology in Section III. Finally, conclusions are offered in Section IV.

II. Proposed Methodology

During four last decades many researches devoted their times and efforts to best design methodologies for decision making purposes under different and, in most cases, conflict criteria. The proposed methodology is designed in such a way that makes use of MCDM techniques as efficient as possible. Three different techniques namely Delphi, AHP and VIKOR are combined in order to rank alternatives with respect to criteria. The reason of using Delphi method is to select the criteria among set of possible criteria defining all aspect of the under-consideration problem and also to provide alternatives values with respect to each criterion in order to form the decision matrix. Moreover, one important characteristic of every decision problem is the relative importance of each criterion. To resolve this issue, the well known AHP (Analytic Hierarchical Process) is incorporated in the decision process. To rank the alternative one of the most efficient problem that received enormous attention since it first introduction in 1998 [12, 13].

The VIKOR (VlseKriterijumska Optimizacija l Kompromisno Resenje that means Multi-Criteria Optimization and Compromise Solution) method is based on the compromise programming of multi criteria decision making. The basic concept of VIKOR lies in defining the positive and negative ideal solution. Hereafter, the step of the proposed methodology will be detailed.

Step 1. Construct a committee of experts with K members.

Step 2. Ask each expert to suggest some criteria upon which the decision model will be constructed and best alternative will be ranked accordingly.

Step 3. Delphi method [14] is used until a decision concerning agreed-upon criteria is reached.

Step 4. Construct a hierarchical model for the just-selected criteria, and using AHP technique aggregated weights of criteria will be calculated. As in business, management and science, the knowledge, experience and expertise of some experts are often preferred among others in a group of experts. This can be expressed by assigning unequal weights λ to the experts, which lead us to the weighted AHP method.

Step 4.1. Use pair-wise comparison to get the degree of importance of each criterion.

Step 4.2. By the geometric average, all experts' opinion will be integrated to obtain a weight for every aggregative criterion. For this purpose, since each expert has a weight, we must use the weighted geometric average as follows:

$$w_{ij} = \left(\prod_k w_{ijk}^{\lambda_k} \right)^{\frac{1}{\sum_k \lambda_k}} \tag{1}$$

Step 4.3. Using a heuristic method, arithmetic average, each criterion weight is calculated. In so doing, first, sum arrays in each column. Then, each array in each column is divided by its respective column sum to get a normalized matrix. Last, average each row to get every criterion weight.

Step 4.4. Check the consistency index. The consistency index of comparison matrix is $(\lambda_{\max}-n)/(n\text{-}1)$, where $\lambda_{\max}$ denotes the largest Eigen value of comparison matrix, say matrix X. In AHP, a comparison matrix is reciprocal, each array in this matrix represents the importance alternative i over alternative j, and in our case alternatives are replaced by criteria.

Step 5. At this stage, the aggregated rating of alternative under criterion is determined by using the Delphi method. Like AHP, here it is assumed that each expert has its own weights. Therefore, the weighted Delphi method is used and summarize as follows [14]:

Step 5.1. K experts are asked to provide their evaluation and rating. In this method, each of the experts has a weight λ_k according to their degree of experience.

Step 5.2. First, the weighted average f_{ij} of all f_{ijk} is computed as follows:

$$f_{ij} = \frac{\left(\lambda_1 \times f_{ij1}\right) + \ldots + \left(\lambda_k \times f_{ijk}\right)}{\lambda_1 + \ldots + \lambda_k} \tag{2}$$

Then for each expert, the deviation between the weighted average f_{ij} and f_{ijk} is computed.

Step 5.3. To reach at a decision about group decision matrix a threshold value is defined [14]. If the distance between the weighted average and expert's data is greater than this value, then the relevant expert is notified and the process will begin and repeat from step 5 until there is no distance value exceeding the threshold value. This process is repeated until two successive averages are reasonably close to each other. It is assumed that the distance being less than or equal to 0.2 corresponds to two reasonably close estimates [16].

Step 6. Using the compromise ranking, or VIKOR, rank alternative from which the most appropriate one can easily be selected. The steps of the VIKOR method are as follows:

Step 6.1. Determine the best and worst values, also known as positive ideal and negative ideal solutions:

$$f_j^* = \max_i f_{ij} \quad \text{and} \quad f_j^- = \min_i f_{ij}. \tag{3}$$

Step 6.2. Calculate the values $w_j\left(f_j^* - f_{ij}\right)/\left(f_j^* - f_j^-\right)$, S_i and R_i:

$$S_i = \sum_{j=1}^{k} w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right), \quad (4)$$

$$R_i = \max_j \left[w_j \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_j^-\right) \right] \quad (5)$$

where, S_i is A_i with respect to all criteria calculated by the sum of the distance for best value, and R_i is A_i with respect to the *j*-th criterion, calculated by the maximum distance from the worst value.

Step 6.3. Calculate the following values [18]:

$$S^* = \min_i S_i$$

$$S^- = \max_i S_i$$

$$R^* = \min_i R_i$$

$$R^- = \max_i R_i$$

$$Q_i = v\left(S_i - S^*\right) / \left(S^- - S^*\right) + \left(1 - v\right)\left(R_i - R^*\right) / \left(R^- - R^*\right)$$

$$Q_i = \frac{S_i + R_i}{2} \frac{(S_i - S^*)}{(S^- - S^*)} + \frac{2 - (S_i + R_i)}{2} \frac{(R_i - R^*)}{(R^- - R^*)} \quad (6)$$

According to [17], S^* is the minimum value of S_i, which is the maximum majority rule or maximum group utility, and R^* is the minimum value of R_i, which is the minimum individual regret of the opponent. Thus, the index Q_i is obtained and is based on the consideration of both the group utility and the individual regret of the opponent. In addition, here means the weight of the strategy of the maximum group utility.

Step 7. Select the best alternative. Choose $Q(a')$ as the best solution with the minimum of Q_i.

III. Numerical Example

In this section, a hypothetical plant location selection problem is designed to demonstrate the efficiency of the proposed methodology. Assume that a company is looking to select a location to build a new plant. After preliminary screening, three locations *A*1, *A*2, and *A*3 are chosen for further evaluation. A committee of three decision makers, *D*1, *D*2, and *D*3, has been formed to conduct the assessment and to select the most appropriated candidate by the Delphi method. Three benefit criteria and two cost criteria are considered: (1) Skilled workers (*C*1); (2) Expansion possibility (*C2)*; (3) Availability of acquired material (*C*3); (4) Investment cost (*C*4); and (5) Risks imposed on site (*C*5).

The proposed methodology is then applied to solve this problem. The computational procedure is summarized as follows:

Before taking any action, suffice it to say that in order to rate alternative with respect to criteria in Delphi method, a 9 point-scale system, as in AHP, is applied [19] (Table I). Based on Step 4 and according to the AHP, a hierarchy is constructed and using pair-wise comparison criteria weights are calculated. First, paired-wise comparison matrices for each DM should be filled in (see Table II). Then, these matrices using Eq. (1) are integrated to form a group matrix. Finally, as the last step in AHP, the weight of each criterion is calculated and tabulated (see Table III). After obtaining the criteria weights, now it is time to ask each expert for rating alternatives with respect to each criterion. This is done using 9-point scale system is Table II. The gathered data are shown in Table IV.

Using (2), the integrated decision matrix will be as what appeared in Table V. In fact, the resulting table is retained after several interview, since the deviation between each array and average exceed threshold set equal to 0.2 at the beginning of empirical study. For ranking alternatives, according to Step 6 of the proposed methodology, the calculated data along with the final values of Q_i is given in Table VI. Therefore, we can use Q_i to determine A_3 as most acceptable alternative or single optimal solution.

TABLE I
9-Point Scale System

Judgment	Explanation	Score
Equally	Equally preferred	1
		2
Moderately	Moderately preferred	3
		4
Strongly	Strongly preferred	5
		6
Very Strongly	Very strongly preferred	7
		8
Extremely	Extremely preferred	9

TABLE II
Inter-Criteria Comparions Matrix

Cri. No.	C1			C2			C3			C4			C5		
	E 1	E 2	E 3	E 1	E 2	E 3	E 1	E 2	E 3	E 1	E 2	E 3	E 1	E 2	E 3
C_1	1	1	1	5	7	0.3	2	3	1	4	1	9	7	4	2
C_2	0.2	0.14	3	1	1	1	0.3	3	0.2	0.5	8	3	2	9	7
C_3	0.5	0.3	1	3	0.3	5	1	1	1	6	2	5	5	5	8
C_4	0.25	1	0.11	2	0.12	0.3	0.16	0.5	0.2	1	1	1	3	4	2
C_5	0.14	0.25	0.5	0.5	0.11	0.1	0.2	0.2	0.12	0.3	0.25	0.5	1	1	1

TABLE III
Normalized Integrated Matrix

Criteria	C_1	C_2	C_3	C_4	C_5
C_1	0.418	0.476	0.489	0.295	0.239
C_2	0.136	0.155	0.154	0.184	0.238
C_3	0.213	0.251	0.249	0.391	0.303
C_4	0.138	0.083	0.062	0.098	0.165
C_5	0.095	0.036	0.045	0.032	0.055
Weights	0.384	0.173	0.281	0.109	0.052

TABLE IV
Alternatives Evaluation With Respect To The Criteria

Cri. No.	C1			C2			C3			C4			C5		
	E 1	E 2	E 3	E 1	E 2	E 3	E 1	E 2	E 3	E 1	E 2	E 3	E 1	E 2	E 3
A_1	2	5	1	7	4	4	7	6	7	3	2	2	5	6	9
A_2	3	3	5	2	7	3	1	4	7	1	2	3	1	1	5
A_3	4	8	8	6	1	7	3	8	9	2	1	1	8	3	4

TABLE V
INTEGRATED EVALUATION MATRIX

Alter.	C_1	C_2	C_3	C_4	C_5
A_1	2.272	4.364	4.727	2.273	5.818
A_2	2.818	3.182	2.727	1.455	1.545
A_3	5.090	3.727	6.727	1.182	2.636

TABLE VI
VIKOR METHOD RESULTS

	Q	Rank
A_1	0.652	2
A_2	0.816	3
A_3	0.299	1

IV. CONCLUSION

This paper presents a multi-criteria decision model for evaluating alternatives in the plant location problem. For this purpose, a three-step methodology is introduced, in which the Delphi selects the most influential criteria via expertise of experts or decision makers. Then, the improved VIKOR method applies AHP' weights as input weights. Finally, an application example is provided to show applicability and performance of the proposed methodology.

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