FACILITY LOCATION SELECTION USING MAUT AND CCSD METHOD

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Abstract— **Facility location problems (FLP) are strategic decision making problems for new organizations and existing organizations planning for expansion. These are long term investment decision involving many factors that may be conflicting in nature. Best location provides better economical benefits and improved service to consumers.**

FLP is a multi-criteria decision making (MCDM) problem in which best location has to be selected from a set of alternatives considering many qualitative and quantitative criteria. In this article a multi attribute utility theory (MAUT) and correlation coefficient and standard deviation (CCSD) based methodology has been proposed to solve a real time facility location problem.

Index Terms— Facility location, Multi-criteria decision-making (MCDM), MAUT, correlation coefficient and standard deviation (CCSD)

I. Introduction

Plant location is the function of determining location for a plant for maximum operating economy and efficiency [1]. Facility location is a related to determination of geographical location to start, relocate or expand the operations of a firm in order to optimize at least one objective i.e. cost, profit, distances, service, or waiting time. It is not easy to change the location very often. Selecting the appropriate facility among a given set of alternatives is a difficult work requiring both qualitative and quantitative factors [2].

Facility location selection decisions affects several operational and logistical decisions of firms and have impact on operating costs and revenues of the firm. These decisions are costly and difficult to reverse, and they entail a long term commitment.

A good choice of location might result in optimum transportation costs, availability of qualified labor, adequate supplies of raw materials, or some similar condition that would give competitive edge to the company over competitors [3]. On the other hand, a bad facility location is a burden, and it may bankrupt the company. The location of a big plant cannot be changed due to changes in demands, transportation, and raw material price. Once a mistake is made for the location of facility, it becomes extremely difficult and costly to change it especially in large facilities [1]. Therefore, decision makers must select not only a well performing facility for the current situation, but also a probable performing facility for the lifetime of the company [4].

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Facility location decisions are observed to be of immense importance in long-term planning for the manufacturing organizations. Various important qualitative and quantitative criteria, such as availability of resources for production, investment cost, nearness of other facilities etc. are usually considered while selecting a facility location for a specific industrial application. The success or failure of a manufacturing organization largely depends on the consideration of those criteria as they directly influence the organizational performance. Selection of a proper location involves consideration of multiple feasible alternatives It is also observed that the selection procedure involves several objectives and it is often necessary to make compromise among the possible conflicting criteria [5]. For these reasons, multi-criteria decision making (MCDM) is found to be an effective approach to solve the facility location selection problems.

Randhawa and West [6] proposed a solution approach to facility location selection problems while integrating analytical and multi-criteria decision-making models. Sriniketha et. al [7] presented and an integrated decision-making methodology employing Analytical hierarchy process (AHP), and Preference ranking organization method for enrichment evaluations (PROMETHEE-II) in order to make the best use of information available, either implicitly or explicitly to solve the MCDM facility location problem. El-Santawy et al [8] proposed VIKOR based MCDM methodology for Ranking Facility Locations. Many researchers presented a number of MCDM approaches to solve the facility location problem [5-9]. However, in most of these methods the weights of criteria are determined subjectively. There is a gap in literature regarding the calculation of weights of the criteria objectively, addressing both qualitative and quantitative preferences of cost and benefit type.

In this paper, correlation coefficient and standard deviation (CCSD) is incorporated in multi attribute utility theory (MAUT) to obtain the best choice from a finite set of alternative facility locations. CCSD (SDV) is applied to allocate the weights of different criteria. The weight of the criterion reflects its importance in MCDM.

II. Problem environment.

The case of an automobile manufacturing factory has been considered here. The firm wanted to identify a geographical location from which it can start the operations of a new facility for some new car models. The location has to be selected in such a way that initial investment and transportation cost can be minimised while effectiveness of the operations can be improved.

In the literature a number of authors have addressed the plant location selection problem by cost based models. However, the facility location also depends upon many other factors like business culture of the place, infrastructure available, availability of manpower etc.

Due to this reason in this article a MCDM approach based on MAUT and Correlation coefficient and Standard deviation (CCSD) based methodology has been proposed to solve the problem.

Six selection criteria are considered here to affect the location selection decision which is as follows:

i. Closeness of market (C1)- closeness to both finished goods and raw material market directly effects the transportation time and cost.
ii. Infrastructure (C2) – Availability of power supply, water and transportation related infrastructure.
iii. Availability of work force (C3)- availability of skilled work force in the region.
iv. Cost of labor (C4) (in rupees/worker) – Wage rates in Rupees per day
v. Cost of land (C5) – Cost of land in Rupees per square feet.
vi. Business environment (C6) – political environment, work culture, government policies and tax rates.

Among these criteria C1, C2, C3 & C6 are qualitative attributes and C4& C5 are quantitative attributes. Some attributes (C1, C2, C3 & C6) are benefit attributes and some other (C4&C5) are cost attributes.

The company has Identified Eight different geographical locations as alternatives from which the best location has to be selected.

III. Theoretical Background

III A. Multi Attribute Utility Functions

The multi attribute utility theory plays a vital role in solving the multiple criteria decision-making problems. It provides a freedom of judgment to the Decision Maker, thus making it more realistic in nature. MAUF facilitates a high quality interactive analysis of the decision problem and presents a comprehensive structure for their evaluation.
Utility Function U(CVj)=U(cv1, cv2,,…,cvI) for any combination of 'I' attributes/criterions (cv1, cv2,...,cvI) for 'J' alternatives(CV1, CV2,..,CVJ) can be expressed as either (1) an additive model or (2) a multiplicative function of the Individual Attribute Utility Functions U1(cv1), U2(cv2),...,UI(cvI) [10]. Here, we have used the additive model, where each of the criterions is independent in nature. The Utility U(CVj) of jth alternative for I criterions (cv1, cv2,..., cvI) can be expressed as :

$$U(CV_j) = \sum_{i=1}^{n} w_i \times U_i(cv_{ij}) \quad \ldots(1)$$

where w_i is weight (scaling factors) for the ith attribute and Ui(cvij) is Utility of the outcome cvij for the ith attribute of jth alternative. Ui(cvij) is generally the preference of the decision maker regarding the importance of ith attribute of jth alternative. The set of the utility value of all of the criterions of an alternative are known as criterion vector. Similarly the weight vector assimilates all of the weights.
The formulation of MAUF and its parameters (weights) is difficult task. Determination of the importance of the various criterions in a multiple objective scenario is a critical step in the formulation of the MAUF. It is referred as 'weight' and denoted as 'w'.

III B. Correlation coefficient and standard deviation (CCSD) method

Wang and Luoo [11] proposed CCSD method for determining the weights of criteria in MCDM. Singh and Benyoucef [12] incorporated CCSD method in fuzy TOPSIS for resolving supply chain coordination problems. CCSD method determines the weights of criteria by considering the standard deviation of each criterion and their correlation coefficients with the overall assessment of decision alternatives. The correlation coefficients are determined by removing each criterion from the overall assessment of decision alternatives. If the correlation coefficient for a criterion turns out to be very high and close to one, then the removal of this criterion will have little effect on decision making; otherwise, the criterion should be given an important weight. The CCSD method is formulated as a system of nonlinear equations that are transformed into a nonlinear optimization model for solution.

Suppose there are m decision alternatives A1, . . . , Am to be evaluated in terms of n selection criteria C1, . . . , Cn, which forms a crisp decision matrix denoted by X = (xij)n×m, where xij is the performance value of Ai with respect to Cj . Due to the incommensurability among different criteria, the decision matrix X = (xij)n×m needs to be normalized to eliminate its dimensional units and bring them in range of [0-1]. The crisp criteria are normalised into the range of [0-1] using equation (1) and (2).

i)Benefit criterion (larger the better type):

$$r_{ij} = \frac{[x_{ij} - min\{x_{ij}\}]}{[max\{x_{ij}\} - min\{x_{ij}\}]} \quad (2)$$

ii) Cost criterion (smaller the better type)

$$r_{ij} = \frac{[min\{x_{ij}\} - x_{ij}]}{[max\{x_{ij}\} - min\{x_{ij}\}]} \quad (3)$$

Where, x_{ij} is performance rating of the i_{th} alternative A_i with respect to j_{th} attribute C_j.

Let the normalised decision matrix $Z = (z_{ij})_{m\times n}$ =

	C_1	C_2	...	C_n
A_1	z_{11}	z_{12}	…	z_{1n}
A_2	z_{21}	z_{22}	…	z_{2n}
...	…	…	…	…
A_m	z_{m1}	z_{m2}	…	z_{mn}

(4)

where $W = (w_1, . . . ,w_n)$ is the weight vector of criteria, which satisfies $W \geq 0$ and $\left[\sum_{j=1}^{n} w_j = 1\right]$

The overall assessment value 'ρ_i' of each A_i is a linear function of criteria weights.

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$$\rho_i = \sum_{j=1}^{n} z_{ij} w_{j,} \qquad i = 1,2,..., m. \tag{5}$$

The best decision alternative is the one with the highest ρ_i value.

Remove criterion C_j from the set of criteria and consider its impact on decision making. When C_j is dropped out, the overall assessment value of each decision alternative can be redefined as:

$$\rho_{ij} = \sum_{k=1,k\neq j}^{n} z_{ik} w_{ik}, \quad i = 1,..., m. \tag{6}$$

The correlation coefficient (ξ) between the values of C_j and the above overall assessment values can be expressed as:

$$\xi_j = \frac{\sum_{i=1}^{m}\left(z_{ij} - \bar{z}_j\right)\left(\rho_{ij} - \bar{\rho}_j\right)}{\sqrt{\sum_{i=1}^{m}\left(z_{ij} - \bar{z}_j\right)^2 . \sum_{i=1}^{m}\left(\rho_{ij} - \bar{\rho}_{j\,j}\right)^2}}, \quad j = 1,..., n \tag{7}$$

Where,

$$\bar{z}_j = \frac{1}{\mathrm{m}} \sum_{i=1}^{m} z_{ij}, \quad j = 1,..., n \tag{8}$$

$$\bar{\rho}_j = \frac{1}{\mathrm{m}} \sum_{i=1}^{m} \rho_{ij} = \sum_{k=1,k\neq j}^{n} \bar{z}_k w_k, \quad j = 1,..., n \tag{9}$$

- If ξ_j is high enough and close to 1, then C_j and the overall assessment without the inclusion of C_j will have nearly the same numerical distributions and rankings. In this case, the removal of C_j has little effect on decision making and it can therefore be assigned a very small weight.
- If ξ_j is very low, say close to -1, then C_j and the overall assessment without the inclusion of C_j will have almost opposite numerical distributions and rankings and it should be given a very important weight.

Moreover, criteria with big standard deviations should be given more important weights than those with small standard deviations. In another word, if a criterion has equal utilities on all the alternatives considered, then it can be removed from the set of criteria without any impact on decision making. Based upon the above analyses, weights of criteria are defined as:

$$w_j = \frac{\sigma_j \sqrt{1-\xi_j}}{\sum_{k=1}^{m} \sigma_k \sqrt{1-\xi_k}}, \quad j=1,\ldots, n. \tag{10}$$

where σ_j is standard deviation of the value of C_j determined by:

$$\sigma_j = \sqrt{\frac{1}{n} \sum_{i=1}^{m} \left(z_{ij} - \bar{z}_j\right)^2}, \quad j = 1,...n \tag{11}$$

In order to shorten the difference between the largest and the smallest weights 1 – ξ_j is root squared. Equation (10) is a system of nonlinear equations. It contains *n* equations, which can uniquely determine *n* weight variables. To solve the equation, we convert it into the following nonlinear optimization model for solution:

$$\text{Minimize } J = \sum_{j=1}^{m} \left(w_j - \frac{\sigma_j \sqrt{1-\xi_j}}{\sum_{k=1}^{m} \sigma_k \sqrt{1-\xi_k}} \right)^2 \tag{12}$$

Subject to $\sum_{j=1}^{n} w_j = 1 \quad w_j \geq 0, \quad j = 1,..., n,$

The resultant weights of criteria are referred to as CCSD weights.

IV. Solution Methodology

Step 1: Collect the actual data for quantitative criteria for each alternative

Step 2: Collect the opinion of decision makers for qualitative criteria for each alternative on scale of 1 to 10. Whereas, 1 is lowest score and 10 is highest score.

Step 3: Normalise the values in order to bring values of all the criteria on the same scale. Use equation (2) for benefit attributes and equation (3) for cost attributes and prepare the normalised decision matrix $Z = (z_{ij})_{m\times n}$ using equation (4).

Step 4: Enumerate the weight of each criteria using correlation coefficient method (eq(5) to eq(12).

Step 5: Enumerate the overall assessment value U(CVj) of each alternative A_i using equation (1).

Step 6: Rank the alternatives according to the total weighted score obtained and select the highest rank alternative as best location.

V. Illustrative example

The facility location has to be selected by taking into account closeness of market (C1), Infrastructure (C2), Availability of work force (C3), cost of labour (C4) (in rupees/worker), cost of land (C5), Business environment (C6). Among these criteria C4 and C5 are cost type quantitative criteria and the remaining are the benefit type qualitative attributes.

Eight different geographical locations are considered as alternatives from which the best alternative has to be selected by evaluating them against the criteria C1, C2, C3, C4, C5 & C6.

Step 1: Quantitative score of criteria C4 (cost of labour) in terms of Rs/day and C5 (cost of land) in terms of Rs/sqft for all the alternative location is collected. Same is depicted in Table 1.

Step 2: Score of all the qualitative criteria on scale of 1 to 10 for each alternative (A_i) has been collected from decision makers. The preferences of decision makers are shown in Table 1.

Table 1: Crisp decision matrix of 6 attributes and 8 alternatives.

	C1	C2	C3	C4	C5	C6
A1	2	4	4	350	5	4
A2	6	4	6	300	4	7
A3	6	8	6	300	5	2
A4	8	2	8	350	3	5
A5	4	6	8	300	4	3
A6	4	8	2	295	6	8
A7	8	4	5	250	2	3
A8	2	4	7	250	2	4

Step 3: In order to bring values of all the criteria on the same scale all the criteria are normalised. The benefit Criteria C1,C2, C3 & C6 are normalised using equation (2) and the cost criteria are normalised by using equation 3. The normalised decision matrix is shown in Table 2.

Table 2: Normalised decision matrix

	C1	C2	C3	C4	C5	C6
A1	0.00	0.33	0.33	0.00	0.24	0.33
A2	0.67	0.33	0.67	0.50	0.45	0.83
A3	0.67	1.00	0.67	0.50	0.26	0.00
A4	1.00	0.00	1.00	0.00	0.71	0.50
A5	0.33	0.67	1.00	0.50	0.38	0.17
A6	0.33	1.00	0.00	0.55	0.00	1.00
A7	1.00	0.33	0.50	1.00	0.88	0.17
A8	0.17	0.33	0.83	1.00	1.00	0.33

Using equation 4 to equation 12 the weights of all six criteria has been enumerated as w1=0.156, w2=0.2018, w3=0.1672, w4=0.13602, w5= 0.1446, w6= 0.1944. The normalised score of all the criteria and weights of the criteria are placed in equation (1) for all the alternatives. In other words the normalised score of the criteria 'z_i' in normalised decision matrix are multiplied with the weight 'w_i'. The weighted normalized decision matrix is shown in Table 3.

Table 3. Weighted normalize decision matrix

	C1	C2	C3	C4	C5	C6	overall assessment U(CVj)
A1	0.0000	0.0673	0.0557	0.0000	0.0344	0.0648	0.2222
A2	0.1040	0.0673	0.1115	0.0680	0.0654	0.1620	0.5781
A3	0.1040	0.2018	0.1115	0.0680	0.0379	0.0000	0.5232
A4	0.1560	0.0000	0.1672	0.0000	0.1033	0.0972	0.5236
A5	0.0520	0.1346	0.1672	0.0680	0.0551	0.0324	0.5092
A6	0.0520	0.2018	0.0000	0.0748	0.0000	0.1944	0.5230
A7	0.1560	0.0673	0.0836	0.1360	0.1274	0.0324	0.6026
A8	0.0260	0.0673	0.1393	0.1360	0.1446	0.0648	0.5780

Alternative 7 is identified as best alternative. On the basis of overall assessment the alternatives are ranked in order of their importance as follows:

Rank	1	2	3	4	5	6	7	8
Alternative	A7	A2	A8	A4	A3	A6	A5	A1
Score	0.6026	0.5781	0.5780	0.5236	0.5231	0.5230	0.5092	0.2222

VI. Conclusion

The problem of facility location selection is a strategic issue and has significant impact on the performance of the manufacturing organizations. These decisions have long-term implications, it is therefore important to select the most appropriate location for a given industrial application which will minimize the cost over an extended time period. The present study explores the use of MAUT in solving a location selection problem and CCSD method is incorporated to explore the weights of the criteria in MAUT. A real time industrial example is also demonstrated to show the efficacy of the proposed methodology.

VII. References

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