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Facility Location Selection using PROMETHEE II Method

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Abstract

Selecting a location for a new organization or expansion of an existing facility is of vital importance to a decision maker. The cost associated with acquiring the land and facility construction makes the facility location a long-term investment decision. The best location is that which results in higher economic benefits through increased productivity and good distribution network. Selecting the proper facility location from a given set of alternatives is a difficult task, as many potential qualitative and quantitative criteria are to be considered. This paper solves a real time facility location selection problem using PROMETHEE II (preference ranking organization method for enrichment evaluation) method which is an effective multi-criteria decision-making (MCDM) tool often applied to deal with complex problems in the manufacturing environment.

Keywords
Facility location, Multi-criteria decision-making, PROMETHEE

1. Introduction
Facility location decisions are observed to be of immense importance in long-term planning for the manufacturing organizations. High costs related to property acquisition and facility construction make the facility location selection a long-term investment decision. The location selection decision may be required due to various reasons, like change in production capacity, addition or deletion of product line, change in distribution cost or change in customer demand. Wrong selection of location may result in inadequate qualified work force, unavailability of raw materials, insufficient transportation facility, increased operating expenses or even disastrous effect on the organization due to political and societal interference. Thus, the decision maker must select the location for a facility that will not only perform well, but also it will be flexible enough to accommodate the necessary future changes. 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. For these reasons, multi-criteria decision-making (MCDM) is found to be an effective approach to solve the location selection problems. In this paper, the preference ranking organization method for enrichment evaluation (PROMETHEE II) is employed to obtain the best choice from a finite set of alternative facility locations. While applying the PROMETHEE II method to solve a real time facility location selection problem [1], it is observed that this method proves its applicability and potentiality to solve such types of decision-making problems with multiple conflicting criteria and alternatives.

2. Literature Review
Past researchers have already applied different techniques to solve facility location selection problems. But most of those techniques use complex mathematical formulations, while ignoring qualitative information regarding criteria values. Randhawa and West [2] proposed a solution approach to facility location selection problems while integrating analytical and multi-criteria decision-making models. Houshyar and White [3] developed a mathematical model and heuristics approach that assigns N machines to N equal-sized locations on a given site such that the total adjacency flow between the machines is maximized. The proposed model is based on a 0-1 integer programming

formulation which may produce an optimal, but infeasible solution, followed by the heuristic which begins with the 0-1 integer solution and generates a feasible solution. Owen and Daskin [4] provided an overview of the methodologies that have been developed for solving facility location selection problems. Chu [5] presented a fuzzy TOPSIS (technique for order preference by similarity to ideal solution) method-based approach for the plant location selection problems. The ratings and weights assigned by the decision makers are first normalized into a comparable scale. The membership function of each normalized rating of each alternative location for each criterion is then developed. A closeness coefficient is proposed to determine the ranking order of the alternatives. Klose and Drexl [6] reviewed in details the contributions to the current state-of-the-art related to continuous location models, network location models, mixed-integer programming models and their applications to location selection decision. Yong [7] proposed a new fuzzy TOPSIS method which deals with the selection of plant location decision-making problems in linguistic environment, where the ratings of various alternative locations under different criteria and their relative weights are assessed in linguistic terms represented by fuzzy numbers. Farahani and Asgari [8] presented a TOPSIS methodology to find the supportive centers with the minimum number and maximum quality of locations in military logistic systems. Önüt and Soner [9] employed a fuzzy TOPSIS based methodology to solve the solid waste transshipment site selection problem, where the criteria weights are estimated using analytic hierarchy process (AHP). Amiri et al. [10] applied TOPSIS method along with heuristics based on fuzzy goal programming to select the best location. The facility location selection problem is solved in three stages, i.e. (a) finding the least number of distribution centers, (b) locating them in the best possible location, and (c) finding the minimum cost of locating the facilities. Although the facility location selection problems have already been solved using different MCDM techniques, this paper makes a maiden attempt to implement another appropriate MCDM approach, i.e. PROMETHEE II method to tackle this complex location selection decision-making problem.

3. PROMETHEE Method

Preference function based outranking method is a special type of MCDM tool that can provide a ranking ordering of the decision options. The PROMETHEE (preference ranking organization method for enrichment evaluation) method was developed by Brans and Vincke in 1985 [11]. The PROMETHEE I method can provide the partial ordering of the decision alternatives, whereas, PROMETHEE II method can derive the full ranking of the alternatives. In this paper, the PROMETHEE II method is employed to obtain the full ranking of the alternative locations for a given industrial application.

The procedural steps as involved in PROMETHEE II method are enlisted as below [11, 12]:

Step 1: Normalize the decision matrix using the following equation:

$$R_{ij} = \left[X_{ij} - \min(X_{ij}) \right] \Big/ \left[\max(X_{ij}) - \min(X_{ij}) \right] \; (i=1,2,...,n : j=1,2,...,m) \tag{1}$$

where X_{ij} is the performance measure of i^{th} alternative with respect to j^{th} criterion.

For non-beneficial criteria, Eqn. (1) can be rewritten as follows:

$$R_{ij} = \left[\max(X_{ij}) - X_{ij} \right] \Big/ \left[\max(X_{ij}) - \min(X_{ij}) \right] \tag{2}$$

Step 2: Calculate the evaluative differences of i^{th} alternative with respect to other alternatives. This step involves the calculation of differences in criteria values between different alternatives pair-wise.

Step 3: Calculate the preference function, $P_j(i, i')$.

There are mainly six types of generalized preference functions as proposed by Brans and Mareschal [12, 13]. But these preference functions require the definition of some preferential parameters, such as the preference and indifference thresholds. However, in real time applications, it may be difficult for the decision maker to specify which specific form of preference function is suitable for each criterion and also to determine the parameters involved. To avoid this problem, the following simplified preference function is adopted here:

$$P_j(i, i') = 0 \text{ if } R_{ij} \le R_{i'j} \tag{3}$$

$$P_j(i, i') = (R_{ij} - R_{i'j}) \text{ if } R_{ij} > R_{i'j} \tag{4}$$

Step 4: Calculate the aggregated preference function taking into account the criteria weights.

Aggregated preference function, $$\pi(i, i') = \left[\sum_{j=1}^{m} w_j \, x \, P_j(i, i') \right] \Big/ \sum_{j=1}^{m} w_j \tag{5}$$

where w_j is the relative importance (weight) of j^{th} criterion.

Step 5: Determine the leaving and entering outranking flows as follows:

Leaving (or positive) flow for i^{th} alternative, $\varphi^{+}(i) = \frac{1}{n-1}\sum_{i'=1}^{n}\pi(i,i') \qquad (i \neq i')$ (6)

Entering (or negative) flow for i^{th} alternative, $\varphi^{-}(i) = \frac{1}{n-1}\sum_{i'=1}^{n}\pi(i',i) \qquad (i \neq i')$ (7)

where n is the number of alternatives.

Here, each alternative faces (n – 1) number of other alternatives. The leaving flow expresses how much an alternative dominates the other alternatives, while the entering flow denotes how much an alternative is dominated by the other alternatives. Based on these outranking flows, the PROMETHEE I method can provide a partial preorder of the alternatives, whereas, the PROMETHEE II method can give the complete preorder by using a net flow, though it loses much information of preference relations.
Step 6: Calculate the net outranking flow for each alternative.

$$\varphi(i) = \varphi^{+}(i) - \varphi^{-}(i) \tag{8}$$

Step 7: Determine the ranking of all the considered alternatives depending on the values of $\varphi(i)$. The higher value of $\varphi(i)$, the better is the alternative. Thus, the best alternative is the one having the highest $\varphi(i)$ value.

The PROMETHEE method is an interactive multi-criteria decision-making approach designed to handle quantitative as well as qualitative criteria with discrete alternatives. In this method, pair-wise comparison of the alternatives is performed to compute a preference function for each criterion. Based on this preference function, a preference index for alternative i over i' is determined. This preference index is the measure to support the hypothesis that alternative i is preferred to i'. The PROMETHEE method has significant advantages over the other MCDM approaches, e.g. multi-attribute utility theory (MAUT) and AHP. The PROMETHEE method can classify the alternatives which are difficult to be compared because of a trade-off relation of evaluation standards as non-comparable alternatives. It is quite different from AHP in that there is no need to perform a pair-wise comparison again when comparative alternatives are added or deleted.

4. Illustrative Example

Rao [1] employed the graph theory and matrix approach (GTMA) for selection of the best facility location for a given industrial application. The same example is considered here to demonstrate the applicability and effectiveness of PROMETHEE II method as a MCDM tool. This example takes into account eight facility location selection criteria and three alternative facility locations. The objective and subjective information regarding different location selection criteria are given in Table 1. All these criteria, except the cost of labor, are expressed subjectively in linguistic terms. The objective values for these criteria are assigned from an 11-point scale, as given in Table 2. The fuzzy judgments average (A), above average (AA), high (H) and very high (VH), shown in Table 1, are considered equivalent to good, very good etc. with respect to different criteria. The eight selection criteria as considered here to affect the location selection decision are closeness of market (CM), closeness to raw material (CR), land transportation (LT), air transportation (AT), cost of labor (CLR) (in rupees/worker), availability of labor (AL), community education (E) and business climate (BC). Among these criteria, only CLR is a non-beneficial attribute and the remaining are the beneficial attributes.

Table 1: Information for facility location alternatives [1]

Location	CM	CR	LT	AT	CLR	AL	E	BC
P1	H	VH	H	AA	250	H	AA	VH
P2	VH	H	H	VH	265	AA	H	VH
P3	A	H	VH	AA	255	AA	VH	H

At first, the information for various facility location alternatives with respect to different criteria, as shown in Table 1, are converted to crisp scores using the 11-point scale, as given in Table 2. The transformed objective data, as given in Table 3, are then normalized using Eqn. (1) or (2) and are given in Table 4. Rao [1] determined the criteria weights for the considered criteria as w_{CM} = 0.1267, w_{CR} = 0.1267, w_{LT} = 0.0883, w_{AT} = 0.0517, w_{CLR} = 0.0929, w_{AL} = 0.0706, w_{E} = 0.1668 and w_{BC} = 0.2764 using AHP method and the same criteria weights are used here for PROMETHEE II method-based analysis.

Table 2: 11-point fuzzy scale

Linguistic term	Crisp score
Exceptionally low	0.045
Extremely low	0.135
Very low	0.255
Low	0.335
Below average	0.410
Average	0.500
Above average	0.590
High	0.665
Very high	0.745
Extremely high	0.865
Exceptionally high	0.955

Table 3: Objective data for facility location selection problem

Location	CM	CR	LT	AT	CLR	AL	E	BC
P1	0.665	0.745	0.665	0.590	250.000	0.665	0.590	0.745
P2	0.745	0.665	0.665	0.745	265.000	0.590	0.665	0.745
P3	0.500	0.665	0.745	0.590	255.000	0.590	0.745	0.665

Table 4: Normalized decision matrix

Location	CM	CR	LT	AT	CLR	AL	E	BC
P1	0.6735	1	0	0	1	1	0	1
P2	1	0	0	1	0	0	0.4839	1
P3	0	0	1	0	0.6667	0	1	0

Now, the preference functions are calculated for all the pairs of alternatives, using Eqns. (3) and (4), and are given in Table 5. Table 6 exhibits the aggregated preference function values for all the paired alternatives, as calculated using Eqn. (5). The leaving and the entering flows for different location alternatives are now computed using Eqns. (6) and (7) respectively, and are shown in Table 7.

Table 5: Preference functions for all the pairs of alternatives

Location pair	CM	CR	LT	AT	CLR	AL	E	BC
(P1,P2)	0	1	0	0	1	1	0	0
(P1,P3)	0.6735	1	0	0	0.3333	1	0	1
(P2,P1)	0.3265	0	0	1	0	0	0.4839	0
(P2,P3)	1	0	0	1	0	0	0	1
(P3,P1)	0	0	1	0	0	0	1	0
(P3,P2)	0	0	1	0	0.6667	0	0.5161	0

Table 6: Aggregated preference function

Location	P1	P2	P3
P1	-	0.2902	0.59
P2	0.1739	-	0.4548

P3	0.2551	0.2363	-

Table 7: Leaving and entering flows for different locations

Location	Leaving flow	Entering flow
P1	0.4401	0.2144
P2	0.3643	0.1182
P3	0.2457	0.5224

Table 8: Net outranking flow values for different location alternatives

Location	Net outranking flow	Rank
P1	0.2257	2
P2	0.2461	1
P3	-0.2767	3

The net outranking flow values for different alternative locations and their relative rankings are given in Table 8. Now, the alternative locations are arranged in descending order according to their net outranking flow values. The best choice of location for the given industrial application is location 2, which exactly matches with the observations as derived by Rao [1] while solving this problem using graph theory and matrix approach. This proves the applicability and potentiality of the PROMETHEE II method for solving complex decision-making problems in the manufacturing domain.

5. Conclusions

Location selection decision has long-term implications because changing the locations of the existing facilities may be quite expensive. 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 problem of facility location selection is a strategic issue and has significant impact on the performance of the manufacturing organizations. The present study explores the use of PROMETHEE II method in solving a location selection problem and the results obtained can be valuable to the decision maker in framing the location selection strategies. It is also observed that this MCDM approach is a viable tool in solving the location selection decision problems. It allows the decision maker to rank the candidate alternatives more efficiently and easily. The cited real time industrial example demonstrates the computational process of the PROMETHEE II method and the same can also be applied to other strategic decision-making problems.

6. References

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