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Facility Location Selection Using Preference Programming

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***Abstract*—**This paper presents preference programming technique based multiple criteria decision making analysis for selecting a facility location for a new organization or expansion of an existing facility which is of vital importance for a decision support system and strategic planning process. The implementation of decision support systems is considered crucial to sustain competitive advantage and profitability persistence in turbulent environment. As an effective strategic management and decision making is necessary, multiple criteria decision making analysis supports the decision makers to formulate and implement the right strategy. The investment cost associated with acquiring the property and facility construction makes the facility location selection problem a long-term strategic investment decision, which rationalize the best location selection which results in higher economic benefits through increased productivity and optimal distribution network. Selecting the proper facility location from a given set of alternatives is a difficult task, as many potential qualitative and quantitative multiple conflicting criteria are to be considered. This paper solves a facility location selection problem using preference programming, which is an effective multiple criteria decision making analysis tool applied to deal with complex decision problems in the operational research environment. The ranking results of preference programming are compared with WSM, TOPSIS and VIKOR methods.

***Keywords*—**Facility Location Selection, Multiple Criteria Decision Making, Multiple Criteria Decision Making Analysis, Preference Programming, Location Selection, WSM, TOPSIS, VIKOR.

I. Introduction

Facility location selection decision is observed to be of great importance in long-term strategic planning for manufacturing organizations. Facility location selection is also referred to as location planning. The facility location problem has significant impacts on the efficiency of manufacturing organizations. An ideal facility location is that which maximizes the organizational profit with the large sectoral market share. Facility location selection refers to a choice of a region or selection of a particular site under various selection criteria such as climatic conditions, availability of raw material, transport costs, access to market, availability of infrastructural facilities, availability of skilled and non-skilled labor, cost of labor, environment, and government influences, etc. The high costs associated with property acquisition and plant construction make facility location selection a long-term strategic investment decision.The location selection decision may be required for a variety of reasons, including a change in production capacity, adding, or deleting product lines, a change in distribution cost, or a change in customer demand.

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When choosing a manufacturing location, decision makers must avoid costly decision mistakes. Location selection decision errors may result in disastrous consequences for the organization due to insufficient qualified workforce, lack of raw materials, inadequate transportation, increased operating costs and even political and social interventions.

Therefore, the decision maker must select a location for a facility that will not only perform well but be flexible enough to accommodate necessary probable future changes. When choosing a plant location for a particular industrial application, several important qualitative and quantitative criteria are usually considered, such as availability of resources for production, investment cost, proximity to other facilities.

The success or failure of a production organization largely depends on the consideration of these decision criteria as they directly affect the performance of the organization. Selection of a suitable location involves evaluating multiple feasible alternatives. It is also observed that the location selection procedure involves several objectives, and it is often necessary to make compromise among the possible conflicting criteria. For these reasons, multiple criteria decision making analysis (MCDMA) method is found to be an effective approach in solving location selection problems. MCDMA approaches provide a systematic procedure to help decision makers to choose the most desirable and satisfactory alternative under uncertain situation.

For decision enrichment evaluation, the preference programming is employed to obtain the best selection from a finite set of alternative facility locations. While applying the similarity MCDMA method to solve a facility location problem, it is observed that this method proves its feasibility and potentiality to solve such type of complex decision making problems with multiple conflicting criteria and alternatives.

Different mathematical techniques are already applied to solve facility location problems. However, most of these techniques use complex mathematical formulations while ignoring qualitative information about decision criteria values. From the literature survey it is observed that MCDMA methodology has been widely used to determine the optimal location for the service facility or plant. A number of facility location problems were considered using MCDMA methods to evaluate both multiple decision criteria and limited number of alternatives [1-3].

A fuzzy TOPSIS model under group decisions for solving the facility location selection problem, where the ratings of various alternative locations under different subjective attributes and the importance weights of all attributes were assessed in linguistic values represented by fuzzy numbers.The ranking method of the mean of the integral values was applied to help derive the ideal and negative-ideal fuzzy solutions to complete the proposed fuzzy TOPSIS model [3].

An AHP (analytical hierarchy process) decision model for facility location selection from the perspective of organizations considering relocating a new facility or relocating existing facilities was presented. The AHP model provides a framework to assist managers in analyzing various location factors, evaluating location alternatives, and making final location choices. Alternatives were then evaluated and compared under both quantitative and qualitative factors to enable managers to incorporate their management experience and judgment into the resolution process [4].

A facility location selection analysis model considering both Analytic Hierarchy Process (AHP) and VIKOR method was proposed to evaluate five alternatives along with ten decision criteria [5]. Facility location problem for a plastic goods manufacturing organization was considered using AHP and TOPSIS Methods [6]. The plant location selection problem was solved with three decision making methods, Delphi, AHP and improved VIKOR which were hybridized in order to make the best use of information available based on the decision makers or experts [7].

A store location selection problem was handled with both tangible and intangible criteria using Analytic Network Process (ANP) methodology [8]. The location selection problem to position the logistics center was discussed with Alternative centers which were evaluated according to certain criteria using the axiomatic design method [9]. A decision support model for bank branch location selection was considered with five decision criteria using fuzzy AHP and TOPSIS methods for the ranking of the alternatives [10].

Decision making problem for facility location selection was handled to solve two real time facility location selection problems using preference ranking organization method for enrichment evaluation (PROMETHEE II) method which was observed to an effective multiple criteria decision making analysis tool often applied to deal with complex problems in the manufacturing environment [11].

Facility location selection problem was solved using complete and partial ranking MCDM methods. MCDM methods TOPSIS, SAW, GRA and MOORA were used to determine the best location. Then, an outranking MCDM approach (ELECTRE-I) was applied to find an appropriate plant location. The applied complete ranking MCDM methods were considered as the criteria and the evaluated values were taken as the performance of the decision matrix of the ELECTRE-I method [12].

An integrated decision making methodology for plant location selection was designed with three decision-making techniques, Delphi, analytic hierarchical process (AHP), and preference ranking organization method for enrichment evaluations (PROMETHEE) in order to make the best use of information available, either implicitly or explicitly [13].

A location selection problem for a military airport was considered using multiple criteria decision making methods. Nine main criteria and thirty-three sub-criteria were identified by considering not only requirements for a military airport such as climate, geography, infrastructure, security, and transportation but also its environmental and social effects. The criteria weights were determined using AHP. Ranking and selection processes of four alternatives are carried out using PROMETHEE and VIKOR methods. Then, the results of PROMETHEE and VIKOR methods were compared with the results of COPRAS, MAIRCA and MABAC methods. All methods suggest the same alternative as the best and produce the same results on the rankings of the location alternatives [14].

From the presented literature survey, it was observed that in most of the facility location selection papers, the past researchers mainly emphasized on the application of various MCDM techniques like AHP, TOPSIS, VIKOR and PROMETHEE. However, in the case of many criteria and alternatives, it may turn into intricacy for the decision makers to obtain a clear view of the problem and to evaluate the results due to the involvement of different preferential parameters like preference functions, veto threshold, pairwise comparison which may be very difficult to define in real time scenarios. In this paper, a modest effort was thus used to slender this research gap while exploring the suitability of similarity function approach for identifying the best facility location in a real time manufacturing environment.

Although the facility location selection problems were already solved using different MCDMA techniques, this paper makes a novel attempt to implement another appropriate MCDMA approach, i.e., preference programming MCDMA method to tackle this complex location selection decision making problem.

Consequently, the purpose of this paper is to develop and elaborate a multiple criteria methodology for decision support that allows different goals and criteria of conflicting nature to be considered; and considers the selectability of preferences depending on the multiple criteria evaluation methodology.

The complexity of multicriteria decision making is, since those multiple criteria are often conflicting with each other, and so a solution that optimizes every criterion simultaneously, or an ideal solution, is generally unfeasible. In this situation making a multiple criteria decision implies giving an answer which without being optimal is still satisfactory. Considering facility location selection as an objective matter, the standard deviation determines the objective criteria weights and preference programming relates the preference with its criterion function. The mathematical background behind preference programming is deeply analyzed.

This reminder of the paper is organized as follows: In section 2, the mathematical explanation of the preference programming with MCDMA is presented. The WSM, TOPSIS and VIKOR methods are presented for comparing the preference orders. In section 3, the experimental setting is outlined, and its results are analyzed. The location selection problem is solved through the preference programming technique with comparative results from WSM, TOPSIS and VIKOR methods. Section 4 concludes the paper with a summary of the key findings and suggestions for future research.

II. Methodology

In this section, multiple criteria decision making analyis methods, preference programming, and compromise programming techniques of WSM, TOPSIS and VIKOR are introduced to solve the mathematical decision problem for facility location selection.

A. Preference Programming

The preference programming is proposed to analyze the MCDMA evaluation problem. The preference programming method is a multiple criteria decision making approach designed to handle quantitative as well as qualitative criteria with discrete alternatives. In this method, pairwise comparison of the alternatives is performed to compute a preference function for each criterion. The preference programming achieves a synthesis indirectly and only requires evaluations to be performed of each alternative on each criterion. Based on this preference function, a preference index for alternative a_i over a_l is determined. This preference index is the measure to support the hypothesis that alternative a_i is preferred to a_l.

The preference programming methodology has significant advantages over the other MCDMA approaches such as multiple attribute utility theory (MAUT), VIKOR, WSM, WPM, TOPSIS, and AHP. The preference programming avoids trade-offs between scores on criteria, which is likely to happen in the MAUT methodology [24-32]. The preference programming method can classify the alternatives which are difficult to be compared because of a trade-off relation of evaluation standards as noncomparable alternatives. It is quite different from AHP in that there is no need to perform a pairwise comparison again when comparative alternatives are added or deleted. The preference programming is better suited to perform extensive sensitivity analyses. The preference programming provides the possibility for constructing a criteria hierarchy decision tree, through specific guidelines to determine the objective weights.

The preference function is a special type of MCDM tool that provides an outranking preference ordering of the decision options. The preference programming as an MCDMA method is developed to provide the full ranking of the decision alternatives. The preference programming structure differs from the Preference Ranking Organization Method for Enrichment Evaluation [15-18], with its preference function and ascending ranking order. The preference programming determines objective criteria weights using the standard deviation procedure from the normalized decision matrix. Considering multiple criteria as *n* functions, the ideal goal of a multicriteria decision making problem can be represented as

$$\textit{Maximize} \quad f(x) : x \in \mathbb{R} \tag{1}$$

with

$$f(x) = [\, f_1(x), f_2(x), ..., f_n(x)]^T \tag{2}$$

The area of multiple criteria decision making analysis is in fact related with optimization, and its complexity is based on the existence of multiple criteria that are often conflicting with each other. Then, the optimization for multiple criteria simultaneously, or ideal solutions, are generally unfeasible.

In this case, the concept of optimality is reduced to the idea of finding a solution that, without being an optimal one, provides a satisfactory solution. Satisfactory refers to the fact that it is not possible to find a strictly better solution for the multiple criteria decision making problem.

The multiple criteria decision making analysis is one of the most studied cases in terms of both theoretical and practical dimensions in the decision making area, and there is still much to be done in the area towards the goal of finding optimal solutions, if they exist, or at least near-optimal solutions for this kind of decision problem.

The procedural steps as involved in the preference programming are enlisted as below:

Step 1: Determine the decision matrix with the multiple criteria $g_j = (g_1, g_2, ..., g_n)$, $j = 1, ..., n$, and the set of possible alternatives $a_i = (a_1, a_2, ..., a_m)$, $i = 1, ..., m$.

Step 2: Normalize the decision matrix, $Y = (x_{ij})_{mxn}$.

If the evaluation attribute g_j is a benefit criteria, then

$$y_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{3}$$

If the evaluation attribute g_j is a cost criteria, then

$$y_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{4}$$

where x_{ij} are the evaluation indices and $i = 1, ..., m$, number of alternatives, and number of criteria, $j = 1, ..., n$.

$$y_i^{max} = \max_j \left\{ y_{1j}, y_{2j}, ..., y_{ij} \right\},\; y_i^{min} = \min_j \left\{ y_{1j}, y_{2j}, ..., y_{ij} \right\}$$

Upon normalizing criteria of the decision matrix, all elements y_{ij} are reduced to interval values [0, 1], so all criteria have the same commensurate metrics.

Step 3: Determine the weight ω_j of the criteria.

In the preference programming method, both preference function and criteria weights (objective or subjective) are required to rank concurrent alternatives. In preference programming method, the determination of objective criteria weights $\omega_j = (\omega_1, \omega_2, ..., \omega_n)$ is based on the contrast intensity and the conflicting character of the evaluation criteria. For decision criterion $g_j = (g_1, g_2, ..., g_n)$ in the normalized decision matrix, the standard deviation σ_j is calculated, and σ_j represents the measure of deviation of values of alternatives for the given criterion of average value.

To calculate the standard deviation, if $x_i = (x_1, x_2, ..., x_n)$ for $i = 1, ..., n$ a finite data set is given, then

$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n-1} \quad (5)$$

$$\mu = \frac{1}{n} \sum_{i=1}^{n} x_i \quad (6)$$

where μ corresponds to the mean of the data. It is recommended to determine criteria weights ω_j based on values of standard vector deviation σ_j.

$$\omega_j = \frac{\sigma_j}{\sum_{k=1}^{m} \sigma_k} \quad (7)$$

$$\begin{cases} \omega_j > 0 \\ \sum_{l=1}^{n} \omega_j = 1 \\ j = 1, 2, ..., n \end{cases}$$

where ω_j is the relative importance (objective weight) of *j*th criterion. The higher the weight, the more important the criterion. The selection of the criteria weights (objective or subjective) is a space of freedom. The preference programming is not allocating an intrinsic absolute utility to each alternative, neither globally, nor on each criterion. The preference structure of the preference programming is based on pairwise comparisons. In this case the deviation between the evaluations of two alternatives on a particular criterion is considered. The larger the deviation, the larger the preference.There is no objection to consider that these preferences are real numbers varying between 0 and 1.

Step 4: Determine the deviation by pairwise comparison.

The preference programming procedure is based on pairwise comparisons. 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 pairwise.

$$d_j(a_i, a_l) = g_j(a_i) - g_j(a_l) \quad (8)$$

where $d_j(a_i, a_l)$ denotes the difference between the evaluations of a_i and a_l on each criterion.

Step 5: Define the preference function.

A preference function needs to be defined $\left(P_j\left(a_i, a_l\right)\right)$ that translates the deviation between the evaluations of two alternatives (a_i and a_l) on a particular criterion (g_i) into a preference function. Given the normalized distance between two vector sets a_i and a_l, $d_j(a_i, a_l)$, a preference function between a_i and a_l is defined as

$$P_j(a_i, a_l) = 1 - d_j(a_i, a_l) = 1 - \left[g_j(a_i) - g_j(a_l)\right] \quad (9)$$

Step 6: Determine the multiple criteria preference index.

A multiple criteria pairwise preference index is then computed as a weighted average of the preference function. Calculate the aggregated preference function considering the criteria weights. Aggregated preference function:

$$\pi_i(a_i, a_l) = \sum_{j=1}^{k} P_i(a_i, a_l)\omega_j \quad (10)$$

where ω_j is the relative importance (objective weight) of *j*th criterion g_i .

Step 7: Determine the positive and negative preference flows.

This preference index is based on the positive $\varphi^+(a_i)$ and $\varphi^-(a_i)$ negative preference flows for each alternative, which measures how an alternative (a_i) is outranking or outranked by the other alternatives. The difference between these preference flows is represented as the net preference flow $\varphi(a_i)$ which is a value function whereby a lower value reflects a higher attractiveness of alternative (a_i).

the positive preference flow:

$$\varphi^+(a_i) = \frac{1}{n-1} \sum_{l=1}^{n} \pi(a_i, b_l) \quad (11)$$

the negative preference flow:

$$\varphi^-(a_i) = \frac{1}{n-1} \sum_{l=1}^{n} \pi(a_l, a_i) \quad (12)$$

where n is the number of alternatives. The leaving flow $\varphi^+(a_i)$ expresses how much an alternative dominates the other alternatives, while the entering flow $\varphi^-(a)$ denotes how much an alternative is dominated by the other alternatives.

Step 7: Calculate the net preference flow values and rank alternatives in ascending order.

The preference programming consists of the complete ranking. When the preference programming is considered, all the alternatives are comparable. The preference programming rankings are based on the preference flows. The net preference is the balance between the positive and the negative outranking flows. The lower the net flow, the better the alternative. Given the positive ranking and the negative ranking of (a_i) the net flow is equal to

$$\varphi(a_i) = \varphi^+(a_i) - \varphi^-(a_i) = \frac{1}{n-1}\sum_{l=1}^{n}\pi(a_i,a_l) - \pi(a_l,a_i) \quad (13)$$

$$\begin{cases} -1 \le \varphi(a_i) \le 1 \\ \sum_{l=1}^{n}\varphi(a_i) = 0 \end{cases} \quad (14)$$

where $\varphi(a_i)$ is the balance between the positive and the negative outranking flows. The lower the net flow, the better the alternative.

When $\varphi(a_i) > 0$ is more outranking all the alternatives on all the criteria, when $\varphi(a_i) < 0$ it is more outranked. Determine the ranking of all the considered alternatives depending on the values of $\varphi(a_i)$. The lower value of $\varphi(a_i)$, the better is the alternative. Thus, the best alternative is the one having the lowest $\varphi(a_i)$ value. The preference index provides a complete ranking of the alternatives from the best to the worst one, which is based on the net preference flow values.

Each preference flow induces a ranking on the set of actions. Obviously, the best actions should have a low $\varphi^-(a_i)$ value (close to 0) and a high $\varphi^+(a_i)$ value (close to 1), and thus a low negative $\varphi^-(a_i)$ value.

B. Compromise Programming

In this section, multiple criteria decision making analyis methods, WSM, TOPSIS and VIKOR, are introduced to solve compromise decision problems.

a. WSM (Weighted Sum Method)

WSM method, is developed to solve compromise decision problems with conflicting and non commensurable in criteria for multiple criteria decision making analysis [20]. In the weighted sum method, the objective functions are summed up with varying weights and this sum is optimized. The algorithm for weighted sum method is presented as follows:

Step 1: Determine the decision matrix with the multiple criteria $g_j = (g_1, g_2, ..., g_n)$, $j = 1,...,n$, and the set of possible alternatives $a_i = (a_1, a_2, ..., a_m)$, $i = 1,...,m$.

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Step 2: Normalize the decision matrix, $Y = (x_{ij})_{mxn}$.

If the evaluation attribute g_j is a benefit criteria, then

$$y_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad (15)$$

If the evaluation attribute g_j is a cost criteria, then

$$y_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \quad (16)$$

where x_{ij} are the evaluation indices and $i = 1,...,m$, number of alternatives, and number of criteria, $j = 1,...,n$.

$$y_i^{max} = \max_j \{y_{1j}, y_{2j}, ..., y_{ij}\},\ y_i^{min} = \min_j \{y_{1j}, y_{2j}, ..., y_{ij}\}$$

Upon normalizing criteria of the decision matrix, all elements y_{ij} are reduced to interval values [0, 1], so all criteria have the same commensurate metrics.

Step 3: Determine the weight ω_j of the criteria.

The determination of objective criteria weights $\omega_j = (\omega_1, \omega_2, ..., \omega_n)$ is based on the contrast intensity and the conflicting character of the evaluation criteria. For decision criterion $g_j = (g_1, g_2, ..., g_n)$ in the normalized decision matrix, the standard deviation σ_j is calculated, and σ_j represents the measure of deviation of values of alternatives for the given criterion of average value.

To calculate the standard deviation, if $x_i = (x_1, x_2, ..., x_n)$ for $i = 1,...,n$ a finite data set is given, then

$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1} \quad (17)$$

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (18)$$

where μ corresponds to the mean of the data. It is recommended to determine criteria weights ω_j based on values of standard vector deviation σ_j.

$$\omega_j = \frac{\sigma_j}{\sum_{k=1}^{m}\sigma_k}, \quad (19)$$

$$\begin{cases} \omega_j > 0 \\ \sum_{l=1}^{n} \omega_j = 1 \\ j = 1, 2, ..., n \end{cases}$$

where ω_j is the relative importance (objective weight) of *j*th criterion. The higher the weight, the more important the criterion. The selection of the criteria weights (objective or subjective) is a space of freedom.

Step 4: Construct weighted normalized decision matrix.

Compute the weighted normalized values z_i and $\prod_i$:

$$z_i(x) = y_j(x)\omega_j \tag{20}$$

$$\prod_i(x) = \sum_{j=i}^{n} y_j(x)\omega_j = \sum_{j=i}^{n} z_j(x) \tag{21}$$

$$\begin{cases} \omega_j > 0 \\ \sum_{l=1}^{n} \omega_j = 1 \\ j = 1, 2, ..., n \end{cases}$$

where ω_j is the weight of *j*th criterion.

Step 5: Rank the alternatives, sorting by the values of $\prod_i$ in decreasing order.

b. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)

TOPSIS method, is developed to solve compromise decision problems with conflicting and non commensurable in criteria for multiple criteria decision making analysis.The best alternative should have shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [21].

The algorithm of the TOPSIS method is presented as follows:

Step 1: Determine the decision matrix with the multiple criteria $g_j = (g_1, g_2, ..., g_n)$, $j = 1, ..., n$, and the set of possible alternatives $a_i = (a_1, a_2, ..., a_m)$, $i = 1, ..., m$.

Step 2: Normalize the decision matrix, $Y = (x_{ij})_{mxn}$.

If the evaluation attribute g_j is a benefit criteria, then

$$y_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{22}$$

If the evaluation attribute g_j is a cost criteria, then

$$y_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{23}$$

where x_{ij} are the evaluation indices and $i = 1, ..., m$, number of alternatives, and number of criteria, $j = 1, ..., n$.

$$y_i^{max} = \max_j \{y_{1j}, y_{2j}, ..., y_{ij}\},\ y_i^{min} = \min_j \{y_{1j}, y_{2j}, ..., y_{ij}\}$$

Upon normalizing criteria of the decision matrix, all elements y_{ij} are reduced to interval values [0, 1], so all criteria have the same commensurate metrics.

Step 3: Determine the weight ω_j of the criteria.

The determination of objective criteria weights $\omega_j = (\omega_1, \omega_2, ..., \omega_n)$ is based on the contrast intensity and the conflicting character of the evaluation criteria. For decision criterion $g_j = (g_1, g_2, ..., g_n)$ in the normalized decision matrix, the standard deviation σ_j is calculated, and σ_j represents the measure of deviation of values of alternatives for the given criterion of average value.

To calculate the standard deviation, if $x_i = (x_1, x_2, ..., x_n)$ for $i = 1, ..., n$ a finite data set is given, then

$$\sigma^2 = \frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n-1} \tag{24}$$

$$\mu = \frac{1}{n} \sum_{i=1}^{n} x_i \tag{25}$$

where μ corresponds to the mean of the data. It is recommended to determine criteria weights ω_j based on values of standard vector deviation σ_j.

$$\omega_j = \frac{\sigma_j}{\sum_{k=1}^{m} \sigma_k}, \tag{26}$$

$$\begin{cases} \omega_j > 0 \\ \sum_{l=1}^{n} \omega_j = 1 \\ j = 1, 2, ..., n \end{cases}$$

where ω_j is the relative importance (objective weight) of *j*th criterion. The higher the weight, the more important the criterion. The selection of the criteria weights (objective or subjective) is a space of freedom.

Step 4: Construct weighted normalized decision matrix.

Compute the weighted normalized value u_i :

$$u_{ij}(x) = y_{ij}(x)\omega_j \tag{27}$$

$$\begin{cases} \omega_j > 0 \\ \sum_{l=1}^{n} \omega_j = 1 \\ j = 1,2,...,n \\ i = 1,2,...,m \end{cases}$$

where ω_j is the weight of *j*th criterion.

Step 4: Determine the positive ideal solution A_i^+ and the negative ideal solution A_i^-, respectively:

$$A_i^+ = \{u_1, u_2, ..., u_n\} = \left\{(\max_i u_{ij} \mid j \in \Omega_b), (\min_i u_{ij} \mid j \in \Omega_c)\right\} \tag{28}$$

$$A_i^- = \{u_1^-, u_2^-, ..., u_n^-\} = \left\{(\min_i u_{ij} \mid j \in \Omega_b), (\max_i u_{ij} \mid j \in \Omega_c)\right\} \tag{29}$$

where Ω_b and Ω_c are the sets of benefit and cost attributes, respectively.

$$\begin{cases} A_j^+ = \omega_j \\ A_j^- = 0 \\ j = 1,2,...,n \\ i = 1,2,...,m \end{cases} \tag{30}$$

Step 5. Calculate the separation measures, using the *n* dimensional Euclidean distance. Compute the distances d_i^+ and d_i^- for every alternative A_i between the positive ideal solution u_j^+, and the negative ideal solution u_j^-, respectively. The separation of each alternative from the ideal solution is given as

$$d_i^+ = \left[\left(u_{ij} - u_j^+\right)^2\right]^{1/2} \tag{31}$$

$$d_i^- = \left[\left(u_{ij} - u_j^-\right)^2\right]^{1/2} \tag{32}$$

Step 6. Calculate relative closeness to the ideal solution. The relative closeness of alternative A_i with respect to A_i^+ is defined as

$$C_i = \frac{d_i^-}{d_i^+ + d_i^-},\ 1 \le C_i \le 1,\ i = 1,2,...,m \tag{33}$$

Step 7. Rank the preference order.

Rank alternatives according to the irrelative closeness to the ideal solution.The bigger the C_i, the better the alternative A_i. The best alternative is the one with the biggest relative closeness to the ideal solution. The best (optimal) alternative is decided according to the preference rank order of C_i. Therefore, the best alternative is the one that has the shortest distance to the ideal solution. Therefore, any alternative which has the shortest distance from the ideal solution is also guaranteed to have the longest distance from the negative-ideal solution.

c. VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje)

VIKOR method, is developed to solve compromise decision problems with conflicting and non commensurable in criteria for multiple criteria decision making analysis by comparing the measure of closeness to the ideal solution [22, 23]. The algorithm of the VIKOR method is presented as follows:

Step 1: Determine the decision matrix with the multiple criteria $g_j = (g_1, g_2, ..., g_n)$, $j = 1,...,n$, and the set of possible alternatives $a_i = (a_1, a_2, ..., a_m)$, $i = 1,...,m$.

.

Step 2: Normalize the decision matrix, $Y = (x_{ij})_{mxn}$.

If the evaluation attribute g_j is a benefit criteria, then

$$y_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{34}$$

If the evaluation attribute g_j is a cost criteria, then

$$y_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{35}$$

where x_{ij} are the evaluation indices and $i = 1,...,m$, number of alternatives, and number of criteria, $j = 1,...,n$.

$$y_i^{max} = \max_j \left\{y_{1j}, y_{2j}, ..., y_{ij}\right\},\ y_i^{min} = \min_j \left\{y_{1j}, y_{2j}, ..., y_{ij}\right\}$$

Upon normalizing criteria of the decision matrix, all elements y_{ij} are reduced to interval values [0, 1], so all criteria have the same commensurate metrics.

Step 3: Determine the weight ω_j of the criteria

The determination of objective criteria weights $\omega_j = (\omega_1, \omega_2, ..., \omega_n)$ is based on the contrast intensity and the conflicting character of the evaluation criteria. For decision criterion $g_j = (g_1, g_2, ..., g_n)$ in the normalized decision matrix, the standard deviation σ_j is calculated, and σ_j represents the measure of deviation of values of alternatives for the given criterion of average value.

To calculate the standard deviation, if $x_i = (x_1, x_2, ..., x_n)$ for $i = 1, ..., n$ a finite data set is given, then

$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n-1} \quad (36)$$

$$\mu = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (37)$$

where μ corresponds to the mean of the data. It is recommended to determine criteria weights ω_j based on values of standard vector deviation σ_j.

$$\omega_j = \frac{\sigma_j}{\sum_{k=1}^{m}\sigma_k}, \quad (38)$$

$$\begin{cases} \omega_j > 0 \\ \sum_{l=1}^{n}\omega_j = 1 \\ j = 1, 2, ..., n \end{cases}$$

where ω_j is the relative importance (objective weight) of *j*th criterion. The higher the weight, the more important the criterion. The selection of the criteria weights (objective or subjective) is a space of freedom.

Step 4: Construct weighted normalized decision matrix.

Compute the weighted normalized values u_i, S_i and R_i:

$$u_{ij}(x) = y_{ij}(x)\omega_j \quad (39)$$

$$S_i = \sum_{j=i}^{n} y_{ij}\omega_j = \sum_{j=i}^{n} u_{ij}(x)$$

$$R_i^+ = \max_j |\, y_{ij}\omega_j \,|$$

$$\begin{cases} \omega_j > 0 \\ \sum_{l=1}^{n}\omega_j = 1 \\ j = 1, 2, ..., n \\ i = 1, 2, ..., m \end{cases}$$

where ω_j is the weight of *j*th criterion.

Step 5：Compute the value Q_i, by the relation.

$$Q_i = \begin{cases} \left(\frac{R_i - R^+}{R^- - R^+}\right) & if \;\; S^+ = S^- \\ \left(\frac{S_i - S^+}{S^- - S^+}\right) & if \;\; R^+ = R^- \\ \left(\frac{S_i - S^+}{S^- - S^+}\right)v + \left(\frac{R_i - R^+}{R^- - R^+}\right)(1-v) & otherwise \end{cases} \quad (40)$$

where

$S^+ = \min_i S_i$, $S^- = \max_i S_i$

$R^+ = \min_i R_i$, $R^- = \max_i R_i$

and *v* is introduced as weight of the strategy of ‘‘the majority of criteria’’ (or ‘‘the maximum group utility’’), here *v* =0.5.

Rank the alternatives, sorting by the values S, R and Q in decreasing order. The results are three ranking lists.

Propose as a compromise solution the alternative (a'), which is ranked the best by the measure Q (Minimum) if the following two conditions are satisfied:

C1. ‘Acceptable advantage’:

$$Q(a'') - Q(a') \geq DQ$$

where (a'') is the alternative with second position in the ranking list by *Q*; $DQ = 1/(m-1)$; *m* is the number of alternatives.

C2. ‘Acceptable stability in decision making’:

Alternative (a') must also be the best ranked by S or/and R. This compromise solution is stable within a decision making process, which could be ‘‘voting by majority rule” (when v > 0.5 is needed), or ‘‘by consensus” $v \approx 0,5$, or ‘‘with veto” (v < 0.5). Here, *v* is the weight of the decision making strategy ‘‘the majority of criteria” (or ‘‘the maximum group utility”).

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

Alternatives (a') and (a'') if only condition C2 is not satisfied, or Alternatives a', a'', ..., $a^{(M)}$ if condition C1 is not satisfied; $a^{(M)}$ is determined by the relation $Q(a^{(M)}) - Q(a') < DQ$ for maximum *M* (the positions of these alternatives are ‘‘in closeness”).

The best alternative, ranked by Q, is the one with the minimum value of Q. The main ranking result is the compromise ranking list of alternatives, and the compromise solution with the ‘advantage rate’. VIKOR is an effective tool in multiple criteria decision making, particularly in a situation where the decision maker is not able, or does not know to express his/her preference at the beginning of system design.

The obtained compromise solution could be accepted by the decision makers because it provides a maximum ‘‘group utility” (represented by min S) of the ‘‘majority”, and a minimum of the ‘‘individual regret” (represented by min R) of the ‘‘opponent”. The compromise solutions could be the basis for negotiations, involving the decision maker’s preference by criteria weights.

Step 4：Rank the alternatives, sorting by the values of Q_i in decreasing order. The reverse ranking result is due to applying normal linear normalization technique instead of traditional VIKOR normalization method.

III. Application

In this paper, the preference programming with MCDMA method is employed to obtain the full ranking of the alternative locations for a given industrial application. The preference programming is employed for selection of the best facility location for a given industrial application. The illustrative example is considered here to demonstrate the applicability and effectiveness of the preference programming method as a robust MCDM tool.

This example considers eight facility location selection criteria and three alternative facility locations for decision analysis problem [19]. The objective and subjective information regarding different location selection criteria is 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 linguistic judgments average (L6), above average (L7), high (L8) and very high (L9), shown in Table 1, are considered equivalent to good, very good etc. with respect to different criteria. The eight selection criteria as considered in the decision problem 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 $/worker), availability of labor (AL), community education (E) and business climate (BC). Among these multiple criteria, only CLR is a non-beneficial attribute, and the remaining are the beneficial attributes.

Table 1. Information for facility location alternatives

Location	CM	CR	LT	AT	CLR	AL	E	BC
L1	L8	L9	L8	L7	3,37	L8	L7	L9
L2	L9	L8	L8	L9	3,57	L7	L8	L9
L3	L6	L8	L0	L7	3,44	L7	L9	L8

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 equations (3) and (4) and are given in Table 4. The objective criteria weights for the considered criteria are determined using the standard deviation method (5), (6) and (7) the objective criteria weights are used for the preference programming analysis.

Table 2. Conversion of linguistic terms into crisp scores (11-point linguistic scale)

Linguistic term	Symbol	Crisp score
Exceptionally low	L1	0,045
Extremely low	L2	0,135
Very low	L3	0,255
Low	L4	0,335
Below average	L5	0,410
Average	L6	0,500
Above average	L7	0,590
High	L8	0,665
Very high	L9	0,745
Extremely high	L10	0,865
Exceptionally high	L11	0,955

Table 3. Decision data for facility location selection problem

Location	CM	CR	LT	AT	CLR	AL	E	BC
L1	0,665	0,745	0,665	0,590	3,37	0,665	0,590	0,745
L2	0,745	0,665	0,665	0,745	3,57	0,590	0,665	0,745
L3	0,500	0,665	0,745	0,590	3,44	0,590	0,745	0,665

Table 4. Normalized decision matrix

Location	CM	CR	LT	AT	CLR	AL	E	BC
L1	0,67	1,00	0,00	0,00	0,00	1,00	0,00	1,00
L2	1,00	0,00	0,00	1,00	1,00	0,00	0,48	1,00
L3	0,00	0,00	1,00	0,00	0,35	0,00	1,00	0,00

After the objective criteria weights are elicited, the preference functions are calculated for all the pairs of alternatives, using equations, (8) and (9), and are given in Table 5. Table 6 exhibits the aggregated preference function values for all the paired alternatives, as calculated using equation (10). The aggregated preference function is shown in Table 7. The leaving and the entering flows for different location alternatives are now computed using equations (11) and (12) respectively and are shown in Table 8.

Table 5. Pairwise comparison of alternatives

LocationPairs	CM	CR	LT	AT	CLR	AL	E	BC
d(L1,L2)	-0,33	1,00	0,00	-1,00	-1,00	1,00	-0,48	0,00
d(L1,L3)	0,67	1,00	-1,00	0,00	-0,35	1,00	-1,00	1,00
d(L2,L1)	0,33	-1,00	0,00	1,00	1,00	-1,00	0,48	0,00
d(L2,L3)	1,00	0,00	-1,00	1,00	0,65	0,00	-0,52	1,00
d(L3,L1)	-0,67	-1,00	1,00	0,00	0,35	-1,00	1,00	-1,00
d(L3,L2)	-1,00	0,00	1,00	-1,00	-0,65	0,00	0,52	-1,00

Table 6. Preference index

LocationPairs	CM	CR	LT	AT	CLR	AL	E	BC
d(L1,L2)	0,15	0,00	0,13	0,26	0,23	0,00	0,17	0,13
d(L1,L3)	0,04	0,00	0,26	0,13	0,16	0,00	0,23	0,00
d(L2,L1)	0,08	0,26	0,13	0,00	0,00	0,26	0,06	0,13
d(L2,L3)	0,00	0,13	0,26	0,00	0,04	0,13	0,17	0,00
d(L3,L1)	0,19	0,26	0,00	0,13	0,07	0,26	0,00	0,26
d(L3,L2)	0,23	0,13	0,00	0,26	0,19	0,13	0,05	0,26

Table 7. Aggregated preference function

Location	L1	L2	L4
L1	0,00	1,08	0,81
L2	0,92	0,00	0,74
L3	1,19	1,26	0,00

Table 8. Leaving and entering flows for different locations

Location	Leaving flow	Entering flow
L1	1,89	2,11
L2	1,66	2,34
L3	2,45	1,55

Table 9. Net outranking flow values for different location alternatives

Location	Net outranking flow	Rank
L1	-0,22	2
L2	-0,68	1
L3	0,90	3

The net outranking flow values for different alternative locations and their relative rankings (13) and (14) are given in Table 9. The alternative locations are arranged in ascending order according to their net outranking flow values. The best choice of location for the given industrial application is location 2 (L2), $L2 \succ L1 \succ L3$, which exactly matches with the observations [19] while solving this problem using graph theory and matrix approach. This proves the applicability and potentiality of the preference programming method for solving complex decision making problems in the manufacturing domain.

Applying the proposed preference function in the preference programming algorithm, a complete ascending ordered ranking is obtained. The decision problem presented with a new preference function, is applicable to handle multiple decision making problems, and can be an efficient decision tool for the multiple criteria decision making analysis.

Table 10. The mean, standard deviation, and weight of the criteria

Criteria→	CM	CR	LT	AT	CLR	AL	E	BC
μ	0,56	0,33	0,33	0,33	0,45	0,33	0,49	0,67
σ_j	0,51	0,58	0,58	0,58	0,51	0,58	0,50	0,58
ω_j	0,12	0,13	0,13	0,13	0,12	0,13	0,11	0,13

Table 11. Weighted normalized decision matrix

Location	CM	CR	LT	AT	CLR	AL	E	BC
L1	0,08	0,13	0,00	0,00	0,00	0,13	0,00	0,13
L2	0,12	0,00	0,00	0,13	0,12	0,00	0,05	0,13
L3	0,00	0,00	0,13	0,00	0,04	0,00	0,11	0,00

Table 12. WSM, Weighted Sum Method preference ranking

Location	Preference Index $\prod_i$	Rank
L1	0,47	2
L2	0,55	1
L3	0,28	3

Table 13. TOPSIS, the positive ideal solution A_i^+ and the negative ideal solution A_i^-

Location	CM	CR	LT	AT	CLR	AL	E	BC
A^+	0,12	0,13	0,13	0,13	0,12	0,13	0,11	0,13
A^-	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Table 14. TOPSIS, the separation measures, d_i^+ and d_i^- values

Location	d_i^+	d_i^-
L1	0,53	0,47
L2	0,45	0,55
L3	0,72	0,28

Table 15. TOPSIS preference ranking

Location	Preference Index C_i	Rank
L1	0,47	2
L2	0,55	1
L3	0,28	3

Table 16. VIKOR computed S_i and R_i values

Location	S_i	R_i
L1	0,63	0,50
L2	0,50	0,50
L3	0,25	0,25

Table 17. VIKOR computed Q_i with $R^+ = R^-$ condition

Location	Q_i	Rank
L1	0,70	2
L2	1,00	1
L3	0,00	3

Table 18. Comparing the preference order of the Preference Programming, WSM, TOPSIS and VIKOR methods

Location	$\varphi(a_i)$	$\prod_i$	C_i	Q_i
L1	2	2	2	2
L2	1	1	1	1
L3	3	3	3	3

IV. Conclusion

Decision support systems need to be designed to articulate preferences. The new preference function yielded ascending ordered ranking for the three facility locations in the study. The ranking order was $L2 \succ L1 \succ L3$ under the preference programming methodology. In multiple criteria evaluations, different MCDMA methods generate different compromise and noncompromise solutions for the same ranking problem because of the varying mathematical models. The preference programming approach is an outranking method that takes advantage of robust pairwise comparison of alternatives along with the preference measure, and the methodology of the objective multiple criteria weights for decision enrichment solutions. As a robust MCDMA method, the preference programming ranks alternatives with their factual criteria values. In the preference programming method, decision maker only needs to specify the evaluation criteria of the decision problem to rank a set of alternatives.

Facility 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 period. The problem of facility location selection is a strategic decision making problem and has significant impact on the performance of the manufacturing organizations.

The present study explores the use of preference programming method in solving a facility 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 industrial example demonstrates the computational process of the preference programming method and the same can also be applied to other strategic decision making problems.

This paper presents a preference function-based approach for facility location selection problem from a set of candidate alternatives in manufacturing environment. This method is based on the quality characteristic values of the considered location alternatives for arriving at the satisfactory results. The basic concept of preference function is to convert a multiple objective problem into a single objective function with the consideration of overall selectability.

The lower value of overall selectability indicates the best alternative. One real time facility location selection example is considered to demonstrate the application competence and suitability of the proposed method. The result obtained using the preference function-based method almost substantiate with those derived by utility theory method which signify that this method is an efficient approach as compared to other well established facility location selection methods like AHP,WSM, VIKOR, PROMETHEE, TOPSIS, and ELECTRE in which most of these techniques either require very lengthy computations involving pairwise comparisons or they need some preferential parameters to be defined which may be very complicated for the decision makers in practical situations.

In this study, multiple criteria decision making analysis methods were applied to determine the facility location selection problem. Objective criteria weights were determined by performing standard deviation analysis. Utilizing these objective criteria weights, Preference Programing, WSM, TOPSIS and VIKOR methods are applied, and alternatives were listed. When comparing the results, it was seen that L2 was the most important alternative in four methods.

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