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Weighted Euclidean distance based approach as a multiple attribute decision making method for plant or facility layout design selection

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ABSTRACT

In response to increasing inflexible customer demands and to improve the competitive advantage, industrial organizations have to adopt strategies to achieve cost reduction, continual quality improvement, increased customer service and on-time delivery performance. Selection of the most suitable plant or facility layout design for an organization is one among the most important strategic issues to fulfill all these above-mentioned objectives. Nowadays, many industrial organizations have come to realize the importance of proper selection of the plant or facility layout design to survive in the global competitive market. Selecting the proper layout design from a given set of candidate alternatives is a difficult task, as many potential qualitative and quantitative criteria need to be considered. This paper proposes a Euclidean distance based approach (WEDBA) as a multiple attribute decision making method to deal with the complex plant or facility layout design problems of the industrial environment. Three examples are included to illustrate the approach.

1. Introduction

Over the past few years, rapid technological advancements have triggered the need for an equally fast response from the industries. Layout design invariably has a significant impact on the performance of a manufacturing or service industry system, and consequently has been an active research area for several decades. The layout decision is usually based on both quantitative and qualitative performance ratings pertaining to the desired closeness or closeness relationships among the facilities. The 'closeness' is a vague notion that captures issues such as the material flow and the ease of employee supervision. Clearly, the evaluation of critical criteria for a layout design is often a challenging and complex task. Plant layout design selection problem focuses on the evaluation of alternative layout designs by considering both qualitative and quantitative design criteria. It simultaneously evaluates all the desired criteria for design alternatives. This will permit the desired design criteria to be better incorporated and evaluated. In addition, the direct evaluation of a design alternative in lieu of incomplete design, e.g., an improvement type layout design algorithm, will increase the level of confidence in searching for a quality solution by solving a layout design problem using MADM methods. The problem seeks to evaluate a large number of layout design alternatives

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generated by an efficient layout design algorithm. The evaluation of a large number of design alternatives will thereby reduce the risk of missing a high-quality solution.

The plant or facility layout design problem is one of the most complex and commonly occurring problems in many industries. A plant or facility is an entity that facilitates the execution of any job. Plant or facility layout is the arrangement of process elements needed for the production of goods or delivery of services. The process elements can be the machines, work centers, all departments, storage areas, etc. A good placement of facilities contributes to the overall efficiency of operations (Taghavi & Murat, 2011). Plant layout design selection problem focuses on the evaluation of alternative layout designs by considering both qualitative and quantitative design attributes. It simultaneously evaluates all the desired criteria for design alternatives. This will permit the desired design attributes to be better incorporated and evaluated.

Many researchers in the past have solved the plant layout /facility layout problems of various kinds, but still there is a great scope of improvement for these types of problems in the manufacturing industries. Rosenblatt (1979) suggested using a graphical solution for solving the facility layout problem. Dutta and Sahu (1982) solved the layout design problem by considering two conflicting criteria, cost and closeness rating into a single objective function and proposed a pair wise exchange routine for selecting new layouts. Raoot and Rakshit (1991) proposed a construction-type layout design heuristic based on fuzzy set theory. A linguistic variable was used to model various qualitative design criteria, and then to determine the closeness relationship among departments. The resulting closeness relationship matrix was used to construct a layout design.

Harmonosky and Tothero (1992) proposed a heuristic based mathematical model for multi-objective facility layout problem. This model allowed solving the facility layout problem for more than two factors handling qualitative and quantitative factors simultaneously by combining into one factor known as composite factor and then the layout resulted from the heuristic is then used in pair wise exchange routine for further improvement. Tretheway and Foote (1994) developed a fast heuristic for the facilities layout problem including aisle location. In their approach, the location of aisles is considered during the layout development procedure.

Badiru and Arif (1996) proposed a fuzzy linguistic expert system in solving a layout design problem. It incorporated an existing layout algorithm, BLOCPLAN, to efficiently create design alternatives. Dorigo et al. (1996) applied the ACO algorithm for solving traveling salesman problem (TSP) and then extended their approach to solve the facility layout problem, which is a quadratic assignment problem (QAP). Taillard and Gambardella (1997) proposed a fast ant algorithm namely FANT for QAP. Gambardella and Dorigo (1997) proposed an ant algorithm called HAS-QAP to solve QAP. They reported that the HAS-QAP and genetic hybrid (GH) algorithms are among the best methods for solving QAP. Benson and Foote (1997) proposed a constructive procedure to optimally layout a facility including aisles and door locations based on aisle flow distance matrix. They developed a methodology based on shortest path along aisles and corridors.

Maniezzo (1998) proposed an interesting ant algorithm to solve QAP, which was referred to as ANTS method. Imam and Mir (1998) presented an analytical technique to optimize the layout of building-block of unequal areas in a continuous plane. A construction-cum-improvement type algorithm was introduced in which the optimum position of each block is determined by piecewise one-dimensional search on the boundary formed by the cluster of previously placed block. Chan and Sha (1999) presented a new multi-objective heuristic algorithm for resolving the facility layout problem. It incorporates qualitative and quantitative objectives and resolves the problem of inconsistent scales and different measurement units. Chung (1999) developed neuro-based expert system (NBES) for facility layout construction in a manufacturing system.

Karray et al. (2000) proposed an integrated methodology using the fuzzy set theory and genetic algorithms to investigate the layout of temporary facilities in relation to the planned buildings in a construction site. It identified the closeness relationship values between each pair of facilities in a construction site using fuzzy linguistic representation. Mir and Imam (2001) proposed a hybrid optimization approach for the layout design of unequal area facilities. They used simulated annealing to optimize a randomly generated initial placement on an "external plane" considering the unequal-area facilities enclosed in magnified envelop block in the direction of steepest descent.

Lee and Lee (2002) presented shape based block layout (SBL) approach for solving facility layout problem with unequal-areas and fixed-shaped. The SBL approach employs hybrid genetic algorithm to find good solution. The objective function of SBL approach minimizes total material handling cost and maximizes space utilization. Deb and Bhattacharyya (2003) presented a multifactor fuzzy inference system for the placement of facilities (departments). It considers both qualitative and quantitative factors that influence the layout structure. A two-tier fuzzy inference system was proposed to compare the proposed layout methodology with that of a conventional selection routine with respect to personnel flow cost, dead space and the minimum required area of the layout. Yang and Kuo (2003) proposed a hierarchical AHP/DEA (data envelopment analysis) method to solve the plant layout design selection problem.

Deb and Bhattacharyya (2005) applied a fuzzy decision support system for manufacturing facilities layout planning. Wang et al. (2005) presented a genetic algorithm to solve the unequal area facility layout problem. The objective function of proposed model was the minimization of total layout cost (TLC) combining material flow factor cost (MFFC), shape ratio factor (SRF) and area utilization factor (AUF). A rule based approach of expert system was proposed by them to create space filling curve. Castillo and Westerlund (2005) proposed a mixed integer linear programming model for the block layout design problem with unequal areas that satisfies the area requirements with a given accuracy. Yang and Hung (2007) used TOPSIS and fuzzy TOPSIS for selection of plant layout design. Chakraborty and Banik (2007) applied analytic hierarchy process (AHP) based approach for optimal facility layout design. Kuo et al. (2008) used GRA method to the facility layout design selection problem. Ulutas and Islier (2009) proposed a clone selection algorithm for the selection of the dynamic facility layout. McKendall and Hakobyana (2010) proposed a boundary search (construction) technique for dynamic facility layout problem (DFLP) with unequal area departments, which places departments along the boundaries of already placed departments and applied a tabu search heuristic for improving the solution.

Maniya and Bhatt (2011) applied preference selection index method to the facility layout design selection problem and made the comparison with the results of previous researchers. However, the method proposed by them uses only the objective weights of the attributes and does not consider the preferences of the decision maker. In most of the real decision making problems, the decision maker's expertise and judgment should be taken into account and subjective weighting may be preferable. Furthermore, the authors did not consider the logic that the comparison of two MADM methods for a decision making problem becomes meaningful only when the same weights of attributes are used by both the methods. Furthermore, the method does not have enough mathematically validity and no separate steps were suggested for conversion of a qualitative attribute into a quantitative one.

Ku et al. (2011) solved the unequal area facility layout problem using the simulated annealing based parallel genetic algorithm. Taghavi and Murat (2011) developed a heuristic approach "a perturbation algorithm based on assignment decisions" for solving the integrated layout design and product flow assignment problems. Cruz and Martinez (2011) used an entropy-based algorithm to solve the facility layout design problem. The algorithm was used for the generation of the layout of workstations or departments in the industrial plant and to evaluate each possible arrangement by an entropy function, and then the layout with the lowest entropy value was selected as the optimal solution.

The plant or facility layout design selection decisions are complex, as decision making is more challenging today. There is a need for simple, systematic, and logical methods or mathematical tools to guide decision makers in considering a number of selection attributes and their interrelations. The applications of several multiple attribute decision making (MADM) methods in solving the deterministic decision making problems in the industrial environment have been reported in the literature (Rao, 2007). However, these methods have their own merits and demerits. The aim of the present paper is to propose a novel MADM method, Weighted Euclidean Distance Based Approach (WEDBA), to deal with the decision making situations of the industrial environment considering both qualitative and quantitative attributes. A ranked value judgment on a fuzzy conversion scale for the qualitative attributes is introduced. The proposed method helps the decision maker arrive at a decision based on either the objective weights of importance of the attributes or his/her subjective preferences or considering both the objective weights and the subjective preferences. The objective weights are used when decision maker is not very clear about the relative importance of attributes; subjective weights are considered when the decision maker is very sure about the relative importance of attribute. Integrated weights are proposed to incorporate both subjective and objective weights. In this paper, three examples of plant layout design selection are considered to show the effectiveness and applicability of the WEDBA method to the plant layout design selection problems of manufacturing environment. The next section describes the proposed WEDBA.

2. Weighted Euclidean distance based approach (WEDBA)

The Euclidean distance is an established concept in the field of Mathematics (Dattorro, 2008; Gower, 1982). The weighted Euclidean distance based approach (WEDBA) is based on the weighted distance of alternatives from the most and the least favorable situation, respectively. In this method, the most favorable situation is represented by the ideal point (i.e. optimum point) and the least favorable situation is represented by the anti-ideal point (i.e. non-optimum point). For practical purposes, the ideal and anti-ideal points are defined as the best and the worst values, which exist within the range of values of attributes, respectively. The ideal point, then, is simply the alternative that has all the best values of attributes and the anti-ideal point is simply the alternative that has all the worst values of attributes. It may happen that a certain alternative has the best values for all attributes or the worst values for all attributes. Therefore, in this work, the ideal and anti-ideal points are also considered as feasible solution and they are used as reference in which other alternatives are quantitatively compared. The relative numerical difference resulting from comparison represents the effectiveness of alternatives known as the index score of the alternatives. The smaller index score, the closer the alternative resembles the optimal state, and vice versa. Hence, here, the decision problem is to find a feasible solution, which is as close as possible to the ideal point. In this method, three types of attribute weights are considered: 1- objective weights, 2- subjective weights and 3- integrated weights. The step-wise procedure of the WEDBA method is given as follows (Rao & Singh, 2011).

Step 1: Decision matrix

Decision matrix is the collection of attribute data for each alternative. Establishing the decision matrix involves identifying attributes or criteria and measuring their performance of attributes for various alternatives. For an MADM problem, with m alternatives and n attributes, the i^{th} alternative can be expressed as $Y_i = (y_{i1}, y_{i2}, \ldots., y_{ij}, \ldots., y_{in})$ in decision matrix form, where y_{ij} is the performance value (or measure of performance) of attribute j ($j = 1,2,3,\ldots.,n$) for alternative i ($i = 1,2,3,\ldots.,m$). The general form of decision matrix D is given as follows:

$$D = \begin{bmatrix} y_{11} & \cdots & y_{1j} & \cdots & y_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ y_{i1} & \cdots & y_{ij} & \cdots & y_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ y_{m1} & \cdots & y_{mj} & \cdots & y_{mn} \end{bmatrix} \tag{1}$$

The attributes may be objective or subjective or combined. The subjective attributes are represented in linguistic terms and these are required to be converted into corresponding crisp scores. A ranked value judgment on a fuzzy conversion scale is proposed in this paper by using fuzzy set theory. This approach is based on the works of Chen and Hwang (1992) and Rao (2007). The presented numerical approximation system systematically converts linguistic terms to their corresponding fuzzy numbers. A seven point scale is proposed in this paper for better understanding and representation of the qualitative attribute. Table 1 represents the selection attribute on a qualitative scale using fuzzy logic, corresponding to the fuzzy conversion scale shown in Fig. 1 and helps the users in assigning the values.

Table 1

Conversion of linguistic terms into crisp scores (seven point scale)

Linguistic term	Fuzzy number	Membership function μ(x)	μ_R (M$_i$)	μ_L (M$_i$)	μ_T (M$_i$)
None	M1 (0, 0, 0)	$\mu_{M_1}(x) = 1, \ \ x = 0$	0	1	0
Very low/very poor	M2 (0, 0.1, 0.2)	$\mu_{M_2}(x) = \begin{cases} (x-0)/(0.1), & 0 \le x \le 0.1 \\ (0.2-x)/(0.1), & 0.1 \le x \le 0.2 \end{cases}$	0.1818	0.9091	0.1364
Low/poor	M3 (0.1, 0.3, 0.5)	$\mu_{M_3}(x) = \begin{cases} (x-0.1)/(0.2), & 0.1 \le x \le 0.3 \\ (0.5-x)/(0.2), & 0.3 \le x \le 0.5 \end{cases}$	0.4167	0.75	0.3333
Medium	M4 (0.3, 0.5, 0.7)	$\mu_{M_4}(x) = \begin{cases} (x-0.3)/(0.2), & 0.3 \le x \le 0.5 \\ (0.7-x)/(0.2), & 0.5 \le x \le 0.7 \end{cases}$	0.5833	0.5833	0.5
High/good	M5 (0.5, 0.7, 0.9)	$\mu_{M_5}(x) = \begin{cases} (x-0.5)/(0.2), & 0.5 \le x \le 0.7 \\ (0.9-x)/(0.2), & 0.7 \le x \le 0.9 \end{cases}$	0.75	0.4167	0.6667
Very high/very good	M6 (0.8, 0.9, 1)	$\mu_{M_6}(x) = \begin{cases} (x-0.8)/(0.1), & 0.8 \le x \le 0.9 \\ (1-x)/(0.1), & 0.9 \le x \le 1 \end{cases}$	0.9091	0.1818	0.8636
Excellent	M7 (1, 1, 1)	$\mu_{M_7}(x) = 1, \ \ x = 1$	1	0	1

μ_R (M$_i$): Right score; μ_L (M$_i$): Left score; μ_T (M$_i$): Total score

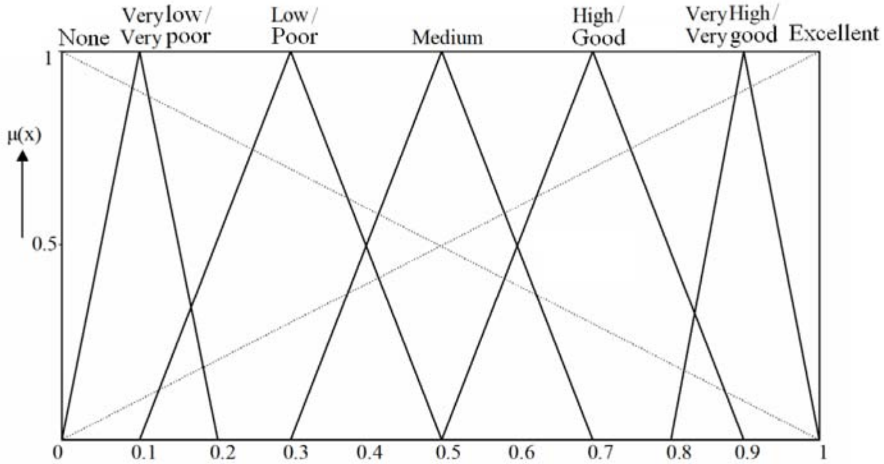

Fig. 1. Linguistic terms to fuzzy numbers conversion

Once a qualitative attribute is represented on a scale then the alternatives can be compared with each other on this attribute in the same manner as that for quantitative attributes. One may refer to Rao (2007) and Rao and Parnichkun (2009) for more details about how this scale is prepared.

Step 2: Standardization

Standardized of attribute data is used to ease the decision making process. The values of standardized attribute data are sometimes called as standard scores. The important property of standard score is that it has a mean of zero and a variance of 1 (i.e. standard deviation equals to 1), which accounts for the name standardized. The standardized decision matrix *D'* is given as follows:

$$D' = \begin{bmatrix} Z_{11} & \dots & Z_{1j} & \dots & Z_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ Z_{i1} & \dots & Z_{ij} & \dots & Z_{in} \\ \dots & \dots & \dots & \dots & \dots \\ Z_{m1} & \dots & Z_{mj} & \dots & Z_{mn} \end{bmatrix} \tag{2}$$

where,

$$Z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j} \tag{3}$$

$$x_{ij} = \frac{y_{ij}}{\max_j (y_{ij})} \quad \text{; if } j^{th} \text{ attribute is beneficial} \tag{4}$$

$$x_{ij} = \frac{\min_j (y_{ij})}{y_{ij}} \quad \text{; if } j^{th} \text{ attribute is non-beneficial} \tag{5}$$

$$\mu_j = \frac{1}{m}\sum_{i=1}^{m} x_{ij} \tag{6}$$

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}(x_{ij} - \mu_j)^2}{m}} \tag{7}$$

Z_{ij} is the standardized value of x_{ij}, μ_j is the expected value or mean value of j^{th} attribute and σ_j is the standard deviation of the attribute *j*. The uses of standardized decision matrix for the calculation of distances from ideal and anti-ideal point are somewhat simpler and easy to understand.

Step 3: Ideal and anti-ideal points

The ideal points are the set of attribute values ideally (most) desired. The anti-ideal points are the set of attribute values ideally not desired at all or least desirable. The ideal points, denoted by 'a^*' and anti-ideal points, denoted by 'b^*' are found from standardized decision matrix.

$$a^* = \{a_j^*\} \text{ and } b^* = \{b_j^*\} \text{ where } j = \{1, 2, \dots n\} \tag{8}$$

Step 4: Attribute weights

The weights of relative importance of attributes may be decided by the decision maker for the considered application either based on the attribute data for various alternatives given in the decision matrix (i.e. objective weights) or based on his/her subjective preferences on the attributes or based on a combination of objective weights and subjective preferences, called integrated weights.

i. Objective weights of importance of the attributes

In the proposed method, the entropy method is suggested for the calculation of objective weights (Rao, 2007). Entropy is a measure of uncertainty in the information formulated using probability theory. It is based in information theory, which assigns a small weight to an attribute if it has similar attribute values across alternatives, because such attribute does not help in differentiating alternatives. "If all available alternatives score about equally with respect to a given attribute, then such an attribute will be judged unimportant by most decision makers" (Zeliny, 1982). Now, the steps for objective weight determination of attributes using entropy method are as follows.

The amount of decision information contained in decision matrix and associated with each attribute can be measured by the entropy value E_j as,

$$E_j = \frac{-\left(\sum_{i=1}^{m} p_{ij} \ln p_{ij}\right)}{\ln m} \qquad ; (j = 1, 2, \ldots, n) \tag{9}$$

where,

$$p_{ij} = \frac{y_{ij}}{\sum_{k=1}^{m} y_{kj}} \tag{10}$$

'y_{ij}' is the value of attribute 'j' for alternative 'i' and 'm' is the number of alternatives. The degree of divergence (d_j) of the average intrinsic information contained by each attribute can be calculated as

$$d_j = 1 - E_j \quad , \qquad (1 \le j \le n) \tag{11}$$

The more divergent the performance ratings p_{ij} (i = 1, 2, …, m) for the attribute j, the higher its corresponding d_j, and the more important the attribute j for the decision making problem under consideration (Rao, 2007). The objective weight for each attribute 'j' is thus given by

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{12}$$

ii. Subjective weights of importance of the attributes

The subjective weights determination is based on the decision maker's preferences over the attributes for the considered application. He/she may assign the weights of importance arbitrarily as per his/her preferences or may use any of the systematic methods of assigning relative importance such as analytical hierarchy process (AHP) (Saaty, 2000), points method (Edwards & Newman, 1986), digital logic method (Manshadi et al., 2007), etc.

iii. Integrated weights of importance of the attributes

Integrated weights are used when the decision maker wishes to utilize both the objective and subjective weights of the attributes. Let w_j^O and w_j^S be the objective and subjective weights respectively of j^{th} attribute, then the integrated weights are described as:

$$w_j^I = \frac{w_j^O \times w_j^S}{\sum_{k=1}^{n} w_k^O \times w_k^S} \tag{13}$$

where, w_j^I is the integrated weight of the jth attribute.

Step 5: Weighted Euclidean distance, index score and ranking

The proposed WEDBA method is based on the concept that the chosen alternative (optimum) should have the shortest distance from the ideal solution (best possible alternative) and be farthest from the anti-ideal solution (worst possible alternative). The measure ensures that the top ranked alternative is closest to the ideal solution and farthest from the anti-ideal solution. Euclidean distance is the shortest distance between two points. The overall performance index score of an alternative is determined by its Euclidean distance to ideal solution and anti-ideal solutions. This distance is interrelated with the attributes' weights and should be incorporated in the distance measurement. This is because all alternatives are compared with ideal and anti-ideal solutions, rather than directly among themselves. Hence, weighted Euclidean distances are considered in the proposed method.

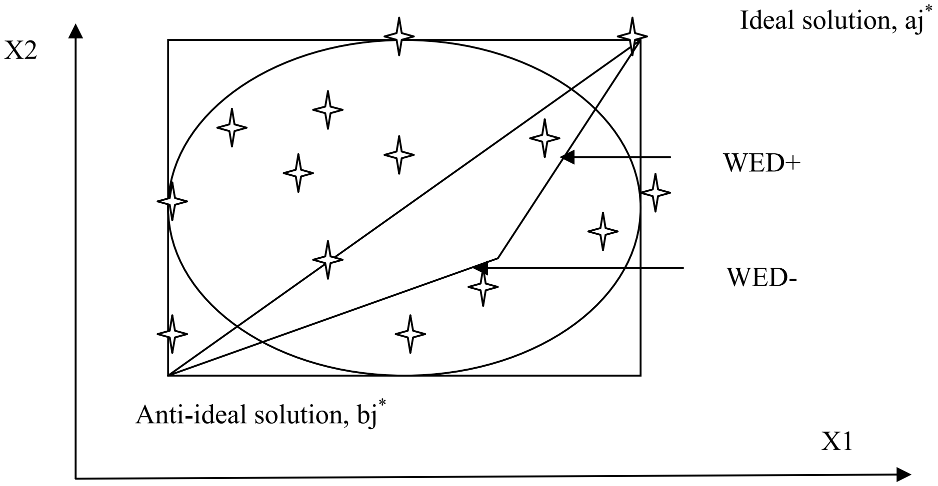

Fig. 2 Euclidean distance of an alternative to ideal and anti-ideal solutions in 2D space (case of two attributes)

Fig. 2 shows Euclidean distance of an alternative to ideal and anti-ideal solutions in 2D space in case of two attributes X1 and X2. The real domain is shown inside the rectangular box. The Euclidean distance between points *P* and *Q* in '*n*' dimensional space is the length of the line segment, PQ . In Cartesian coordinates, if $P = (p_1, p_2, ..., p_n)$ and $Q = (q_1, q_2, ..., q_n)$ are two points in Euclidean *n*-space, then the distance from P to Q is given by $d(PQ) = \sqrt{\sum_{i=1}^{n} (p_i - q_i)^2}$.

Weighted Euclidean distance (WED) between an alternative '*i*' and ideal point 'a^*' is denoted by WED_i^+ and between an alternative '*i*' and anti-ideal point 'b^*' is denoted by WED_i^- .

$$WED_i^+ = \left[\sum_{j=1}^{n} \{w_j \cdot (Z_{ij} - a_j^*)\}^2\right]^{1/2} \qquad \text{for (i = 1, 2, …, m)} \tag{14}$$

$$WED_i^- = \left[\sum_{j=1}^{n} \{ w_j \cdot (Z_{ij} - b_j^*) \}^2 \right]^{1/2} \quad \text{for } (i = 1, 2, \ldots, m) \tag{15}$$

The index score is calculated using Eq. (16).

$$Index\ Score_i = \frac{WED_i^-}{WED_i^+ + WED_i^-} \tag{16}$$

The index score represents the relative closeness of a particular alternative to the ideal solution. The higher the index scores for a particular alternative, the closer the alternative to the ideal solution. The alternative for which the value of index score is the highest is the best choice for the considered decision making problem. The higher the index score, the higher the rank of that alternative.

A final decision can be made by taking into account its practical considerations. All possible constraints likely to be experienced by the user have to be examined at this stage. These include availability, economic, management, social and political constraints, among others. However, compromise may be made in favor of an alternative with a higher value of index score. In the next section, three examples of plant layout design selection are considered and solved using WEDBA method.

3. Examples

Three examples are considered to demonstrate and validate the application of the proposed methodology of WEDBA to the plant or facility layout design selection problems of the industrial environment.

3.1 Example 1

In this example, the layout design problem presented by Yang and Hung (2007) and Yang and Kuo (2003) is adopted and the problem is related to an IC packaging plant. The IC packaging plant usually adopts the process layout strategy that clusters the same tool type to form a workstation. A product traverses all the workstations in the same sequence. For the case study problem, there were ten departments (workstations) whose names and area size information were: wafer sawing (89.21 m^2), die bond (181.51 m^2), wire bond (577.38 m^2), molding (599.57 m^2), dejunk/trimming & curing (183.71 m^2), electro deflash/solder platting (500.13 m^2), marking (199.94 m^2), forming and singulation (186.40 m^2), lead scanning/inspection (110.78 m^2) and packaging (51.09 m^2).

Yang and Kuo (2003) had generated a set of potential 'good' layout alternatives by commercial software, Spirals (Goetschalckx, 1992). According to the flow distance criterion, the top 17 layout design alternatives were generated and selected for further analysis. The existing layout design was the 18th alternative choice. A preliminary study was conducted to determine the design attributes among the area experts that subsequently led to three quantitative and three qualitative design attributes. The quantitative attributes included material handling distance (in 'meters'), adjacency score and shape ratio which are the direct outputs of Spirals. The handling distance was measured by the sum of the products of flow volume and rectilinear distance between the Centroid of two departments. The adjacency score is the sum of all positive relationships between adjacent departments. There was a positive relationship between two consecutive departments along the process routing. Shape ratio was defined as the maximum of the depth-to width and width-to-depth ratio of the smallest rectangle that completely encloses the department. For a layout design problem, it is required to minimize both the shape ratio and the flow distance, while maximizing the adjacency score. There were three qualitative attributes in this case study and these were: flexibility, accessibility and maintenance. Flexibility involved two aspects: the first was the capability to perform a variety of tasks under a variety of operating conditions and the second was the flexibility of future expansion. Accessibility involves material handling and operator paths. Finally, the maintenance issue involved the required space for maintenance engineers and tool movement. The performance ratings for the 18 alternatives with respect to the six attributes are summarized in Table 2 (Yang & Hung, 2007).

Table 2
Quantitative data of the plant layout design selection attributes for various alternatives in Example 1 (Yang and Kuo, 2003; Yang and Hung, 2007, Kuo *et al.*, 2008)

Alternatives	C1	C2	C3	C4	C5	C6
1	185.9500	8.0000	8.2800	0.0119	0.0260	0.0690
2	208.3700	9.0000	3.7500	0.0595	0.0260	0.0575
3	206.3800	8.0000	7.8500	0.0714	0.0519	0.0345
4	189.6600	8.0000	8.2800	0.0714	0.0779	0.0460
5	211.4600	8.0000	7.7100	0.0714	0.0390	0.0460
6	264.0700	5.0000	2.0700	0.0357	0.0519	0.0690
7	228.0000	8.0000	14.000	0.0476	0.0390	0.0230
8	185.5900	9.0000	6.2500	0.0476	0.0130	0.0575
9	185.8500	9.0000	7.8500	0.0357	0.0260	0.0575
10	236.1500	8.0000	7.8500	0.0595	0.0779	0.0690
11	183.1800	8.0000	2.0000	0.0952	0.1169	0.0920
12	204.1800	8.0000	13.3000	0.0357	0.0390	0.0575
13	225.2600	8.0000	8.1400	0.0714	0.0390	0.0345
14	202.8200	8.0000	8.0000	0.0357	0.0779	0.0575
15	170.1400	9.0000	8.2800	0.0952	0.1169	0.0920
16	216.3800	9.0000	7.7100	0.0476	0.0519	0.0690
17	179.8000	8.0000	10.3000	0.0476	0.0779	0.0345
18	185.7500	10.0000	10.1600	0.0595	0.0519	0.0345

C1: material handling distance (in 'meters'), C2: adjacency score, C3: shape ratio, C4: flexibility, C5: accessibility and C6: maintenance.

The attributes C2 (adjacency score), C4 (flexibility), C5 (accessibility) and C6 (maintenance) are of beneficial type and the attributes C1 (material handling distance) and C3 (shape ratio) are of non-beneficial type. The attribute data (Table 2) is standardized using the Eq. (2) to Eq. (7) and the standardized decision matrix is given in Table 3. From standardized decision matrix, the ideal and anti-ideal points obtained are {1.7336, 1.8234, 2.7427, 1.8898, 2.1177, 1.9292} and {-2.2442, -3.3049, -0.7858, -2.0788, -1.4690, -1.7261}.

Table 3
Standardized data for plant layout design selection Example 1

Alternatives	C1	C2	C3	C4	C5	C6
1	0.7828	-0.2279	-0.3795	-2.0788	-1.0203	0.7107
2	-0.2741	0.7977	0.8216	0.1890	-1.0203	0.1015
3	-0.2301	-0.2279	-0.3250	0.7559	-0.1262	-1.1169
4	0.5827	-0.2279	-0.3795	0.7559	0.7713	-0.5077
5	-0.4516	-0.2279	-0.3060	0.7559	-0.5715	-0.5077
6	-2.2442	-3.3049	2.6035	-0.9449	-0.1262	0.7107
7	-1.1043	-0.2279	-0.7858	-0.3780	-0.5715	-1.7261
8	0.8027	0.7977	-0.0565	-0.3780	-1.4690	0.1015
9	0.7883	0.7977	-0.3250	-0.9449	-1.0203	0.1015
10	-1.3923	-0.2279	-0.3250	0.1890	0.7713	0.7107
11	0.9376	-0.2279	2.7427	1.8898	2.1177	1.9292
12	-0.1307	-0.2279	-0.7548	-0.9449	-0.5715	0.1015
13	202.8200	-0.2279	-0.3624	0.7559	-0.5715	-1.1169
14	-0.0683	-0.2279	-0.3447	-0.9449	0.7713	0.1015
15	1.7336	0.7977	-0.3795	1.8898	2.1177	1.9292
16	-0.6561	0.7977	-0.3060	-0.3780	-0.1262	0.7107
17	1.1328	-0.2279	-0.5745	-0.3780	0.7713	-1.1169
18	0.7938	1.8234	-0.5635	0.1890	-0.1262	-1.1169

The weights of attributes considered by Yang and Hung (2007) were the subjective weights, which are: w_{C1} = 0.20, w_{C2} = 0.20, w_{C3} = 0.15, w_{C4} = 0.10, w_{C5} = 0.20 and w_{C6} = 0.15. The objective weights are obtained by entropy method and the weights obtained are: w_{C1} = 0.0172, w_{C2} = 0.0209, w_{C3} = 0.2298, w_{C4} = 0.2088, w_{C5} = 0.3623 and w_{C6} = 0.1610. The integrated weights are obtained using the Eq. (13) which are: w_{C1} = = 0.0215, w_{C2} = 0.0262, w_{C3} = 0.2160, w_{C4} = 0.1308, w_{C5} = 0.4541 and w_{C6} = 0.1514. The weighted Euclidean distances are calculated using Eq. (14) and Eq. (15) and index score values are calculated using Eq. (16). For the objective, subjective and integrated weights, the index score values and rank of alternatives are given in Table 4.

Table 4
Index scores and ranks of alternatives example 1

Alternatives	Objective weights		Objective weights		Objective weights	
	Index score	Rank	Index score	Rank	Index score	Rank
1	0.2176	18	0.4845	11	0.2095	16
2	0.3474	12	0.5330	8	0.2764	13
3	0.3934	8	0.4621	13	0.3585	9
4	0.5121	4	0.5539	4	0.5265	4
5	0.3575	10	0.4474	15	0.2924	11
6	0.4984	5	0.3281	18	0.4815	7
7	0.2477	15	0.3712	17	0.2308	15
8	0.2438	16	0.5326	9	0.1862	18
9	0.2262	17	0.5385	6	0.1990	17
10	0.5190	3	0.4842	12	0.5430	3
11	0.9761	1	0.7643	1	0.9719	1
12	0.2610	14	0.4482	14	0.2571	14
13	0.3431	13	0.4074	16	0.2793	12
14	0.4541	6	0.5188	10	0.5131	5
15	0.6976	2	0.7472	2	0.7277	2
16	0.3811	9	0.5350	7	0.3762	8
17	0.4417	7	0.5426	5	0.4909	6
18	0.3553	11	0.5949	3	0.3429	10

For the same subjective weights, the rankings obtained by using WEDBA method is: 11 – 15 – 18 – 4 – 17 – 9 – 16 – 2 – 8 – 14 – 1 – 10 – 3 – 12 – 5 – 13 – 7 – 6. The rankings proposed by Yang and Kuo (2003) using DEA was: (11 – 15 – 18) – 2 – 16 – 6 – 8 – 9 – 14 – 1 – 4 – 10 – 14 – 5 – 3 – 13 – 12 – 7, the rankings proposed by Yang and Hung (2007) using TOPSIS and fuzzy TOPSIS method were: 11 – 15 – 10 – 4 – 14 – 6 – 17 – 16 – 2 – 3 – 18 – 5 – 8 – 13 – 9 – 1 – 12 – 7 and 11 – 15 – 18 – 4 – 17 – 8 – 10 – 14 – 2 – 16 – 9 – 5 – 1 –3 – 12 – 6 – 7 – 13 respectively and the rankings proposed by Kuo *et al.* (2008) using GRA was: 15 – 17 – 11 – 18 – 9 – 16 – 8 – 2 – 10 – 1 – 4 – 14 – 5 – 13 – 3 – 6 – 7 – 12.

The proposed WEDBA method is suggesting plant layout designs 11 and 15 as the first and the second choices respectively. Yang and Kuo (2003) had also suggested the same using the DEA method. Yang and Hung (2007) had also proposed the layout designs 11 and 15 as the best two choices using TOPSIS and fuzzy TOPSIS methods. But, Kuo *et al.* (2008) proposed layout design 15 as the best and 17 as the second best. On comparing the data for alternatives 11 and 15, it is observed that both the alternatives perform equally with respect to three attributes (i.e. C4, C5 and C6), 15 is better with respect to two attributes (i.e. C1 and C2) but the difference in the values of these attributes for the alternatives 11 and 15 is less. The alternative 11 is better than the alternative 15 with respect to the attribute C3 with a large difference and this shows that alternative 11 can be preferred over alternative 15.

3.2 Example 2

This example is of facility layout design (FLD) selection problem taken from the work of Ertay *et al.* (2006). They had used the integrated procedure of analytical hierarchy process (AHP) and data envelopment analysis (DEA) for solving this FLD selection problem to the real data set of a case study, which consists 19 FLDs for the plastic profile production system to the company "Sert Plastic Profile Industry Co.". A computer aided layout planning tool, VisFactory, was adopted by Ertay *et al.* (2006) to facilitate the layout design process as well as to collect quantitative data. A software package, which operates under the AutoCAD environment and is effective and user-friendly, was adopted to constitute the layout alternative generation process as well as to collect the quantitative performance data such as adjacency scores, shape ratios, material handling cost and material handling vehicle utilizations. The data set of 19 facility layout alternatives including the current layout is given in Table 5.

Table 5
Decision matrix for example 2 (Ertay *et al.,* 2006)

Alternatives	C	AS	SR	F	Q	FCU
1	20309.56	6405.00	0.4697	0.0113	0.0410	30.89
2	20411.22	5393.00	0.4380	0.0337	0.0484	31.34
3	20280.28	5294.00	0.4392	0.0308	0.0653	30.26
4	20053.20	4450.00	0.3776	0.0245	0.0638	28.03
5	19998.75	4370.00	0.3526	0.0856	0.0484	25.43
6	20193.68	4393.00	0.3674	0.0717	0.0361	29.11
7	19779.73	2862.00	0.2854	0.0245	0.0846	25.29
8	19831.00	5473	0.4398	0.0113	0.0125	24.8
9	19608.43	5161	0.2868	0.0674	0.0724	24.45
10	20038.1	6078	0.6624	0.0856	0.0653	26.45
11	20330.68	4516	0.3437	0.0856	0.0638	29.46
12	20155.09	3702	0.3526	0.0856	0.0846	28.07
13	19641.86	5726	0.269	0.0337	0.0361	24.58
14	20575.67	4639	0.3441	0.0856	0.0638	32.2
15	20687.5	5646	0.4326	0.0337	0.0452	33.21
16	20779.75	5507	0.3312	0.0856	0.0653	33.6
17	19853.38	3912	0.2847	0.0245	0.0638	31.29
18	19853.38	5974	0.4398	0.0337	0.0179	25.12
19	20355.00	17402	0.4421	0.0856	0.0217	30.02

C: Cost ($); AS: Adjacency score; SR: Shape ratio; F: Flexibility; Q: Quality; HCU: Hand-carry utility

The alternative evaluation attributes are cost, adjacency score, shape ratio; flexibility, quality and hand-carry utility. Attribute cost is related to the material handling cost involved in transporting material from one department to another. The adjacency scores are calculated based on penalty scores indicating inappropriate layouts which are obtained by entering the closeness relationship values between the departments to the FactoryPLAN module (Ertay *et al.,* 2006). Shape ratio is the factor based on the shape of the departments, higher value of shape ratio is required for the layout. The flexibility involves two sub-criteria. The first is ''volume flexibility'' based on ones of future expansion. The second is ''variety flexibility'' related to the capability to perform a variety of products under the different operating conditions. Quality involves also two sub-criteria based on ''product'' and ''production''. Production quality is influenced by the locations according to each other of the departments. To constitute the alternative layout designs with the VisFactory software package, both FactoryFLOW and FactoryPLAN modules are considered for entering the data related to the departments, products, and flows (Ertay *et al.,* 2006). The required data about parameters for these modules are gathered from the historical data in company records. And the opinions and experiences of the managers are used to constitute the relationship scores between departments according to fuzzy set theory.

The attributes cost and adjacency score are non-beneficial attributes and the attributes shape ratio, flexibility, quality and hand-carry utility are beneficial attributes. The attribute data (Table 5) is standardized using the equations (2) to (7) which is given in Table 6.

Table 6

Standardized data for plant layout design selection problem in Example 2

Alternatives	C	AS	SR	F	Q	HCU
1	-0.5157	-0.8025	0.9179	-1.4292	-0.5682	0.7595
2	-0.8183	-0.2810	0.5648	-0.6546	-0.2067	0.9095
3	-0.4279	-0.2193	0.5781	-0.7549	0.6189	0.5496
4	0.2610	0.4185	-0.1081	-0.9727	0.5456	-0.1934
5	0.4286	0.4917	-0.3865	1.1400	-0.2067	-1.0598
6	-0.1670	0.4704	-0.2217	0.6593	-0.8076	0.1664
7	1.1118	2.6381	-1.1351	-0.9727	1.5617	-1.1064
8	0.9505	-0.3292	0.5848	-1.4292	-1.9605	-1.2697
9	1.6567	-0.1326	-1.1195	0.5107	0.9657	-1.3863
10	0.3074	-0.6530	3.0644	1.1400	0.6189	-0.7199
11	-0.5788	0.3600	-0.4857	1.1400	0.5456	0.283
12	-0.0500	1.2268	-0.3865	1.1400	1.5617	-0.1801
13	1.5496	-0.4730	-1.3178	-0.6546	-0.8076	-1.3430
14	-1.3014	0.2555	-0.4812	1.1400	0.5456	1.1960
15	-1.6256	-0.4289	0.5046	-0.6546	-0.363	1.5325
16	-1.8904	-0.3493	-0.6249	1.1400	0.6189	1.6625
17	0.8803	0.9687	-1.1429	-0.9727	0.5456	0.8928
18	0.8803	-0.6020	0.5848	-0.6546	-1.6967	-1.163
19	-0.6513	-2.5589	0.6104	1.1400	-1.5110	0.4696

The ideal and anti-ideal points obtained are {1.6567, 2.6381, 3.0644, 1.1400, 1.5617, 1.6625} and {-1.8904, -2.5589, -1.3178, -1.4292, -1.9605, -1.3863}.

$$\begin{array}{c|cccccc|} \text{Attributes} & C & AS & SR & F & Q & HCU \\ C & 1 & 2 & 2 & 1 & 1 & 2 \\ AS & 1/2 & 1 & 1 & 1/3 & 1/3 & 1/2 \\ SR & 1/2 & 1 & 1 & 1/3 & 1/3 & 1/2 \\ F & 1 & 3 & 3 & 1 & 1 & 2 \\ Q & 1 & 3 & 3 & 1 & 1 & 2 \\ HCQ & 1/2 & 2 & 2 & 1/2 & 1/2 & 1 \end{array}$$

The subjective weights of the attributes are obtained using AHP method for the prepared relative importance of attributes and the weights obtained are: w_C = 0.2129, w_{AS} = 0.0828, w_{SR} = 0.0828, w_F = 0.2437, w_Q = 0.2437 and w_{HCQ} = 0.1341. The judgments on deciding the relative importance of attributes are highly consistent with consistency ratio as 0.0087. The objective weights are obtained by entropy method and the weights obtained are: w_C = 0.0004, w_{AS} = 0.2533, w_{SR} = 0.0674, w_F = 0.4349, w_Q = 0.2293 and w_{HCQ} = 0.0147. The integrated weights are obtained using the Eq. (13) which are: w_C = 0.0004, w_{AS} = 0.1102, w_{SR} = 0.0293, w_F = 0.5564, w_Q = 0.2934 and w_{HCQ} = 0.0104. The weighted Euclidean distances are calculated using Eq. (14) and Eq. (15) and index score values are calculated using Eq. (16). For the objective, subjective and integrated weights, the index score values and rank of alternatives are given in Table 7.

Table 7
Index scores and ranks of alternatives example 2

	Objective weights		Objective weights		Objective weights	
Alternatives	Rank	Index score	Rank	Index score	Rank	Index score
1	0.2742	18	0.3677	18	0.2215	18
2	0.4051	14	0.4269	14	0.3801	14
3	0.4424	12	0.5132	11	0.4377	11
4	0.464	11	0.5221	10	0.4051	13
5	0.6638	4	0.5714	7	0.7286	7
6	0.595	9	0.4884	12	0.6144	8
7	0.618	6	0.6127	4	0.5055	10
8	0.2683	19	0.3545	19	0.123	19
9	0.6029	8	0.6514	3	0.7328	6
10	0.6164	7	0.6596	2	0.7818	5
11	0.6863	2	0.5947	5	0.8025	2
12	0.7972	1	0.6888	1	0.9067	1
13	0.3486	16	0.4671	13	0.3185	16
14	0.6771	3	0.5611	8	0.7995	3
15	0.3834	15	0.3856	17	0.3625	15
16	0.6264	5	0.5303	9	0.7868	4
17	0.5012	10	0.5734	6	0.4137	12
18	0.3105	17	0.3866	16	0.2557	17
19	0.4292	13	0.4218	15	0.573	9

For subjective weight of attribute, the ranking of facility layout design obtained using WEDBA method is: 12 – 10 – 9 – 7 – 11 – 17 – 5 – 14 – 16 – 4 – 3 – 6 – 13 – 2 – 19 – 18 – 15 – 1 – 8 and for objective and integrated weights he ranking of facility layout design obtained using WEDBA method are: 12 – 11 – 14 – 5 – 16 – 7 – 10 – 9 – 6 – 17 – 4 – 3 – 19 – 2 – 15 – 13 – 18 – 1 – 8 and 12 – 11 – 14 – 16 – 10 – 9 – 5 – 6 – 19 – 7 – 3 – 17 – 4 – 2 – 15 – 13 – 18 – 1 – 8 respectively. The WEDBA method is giving alternative layout design ‘12’ as the best alternative and ‘8’ as the worst alternative. The ranking proposed by Ertay *et al.* (2006) using integrated procedure of AHP and DEA was: 16 – 15 – 14 – 2 – 1 – 3 – 17 – 11 – 6 – 4 – 12 – 10 – 19 – 5 – 7 – 18 – 8 – 13 – 9. Now on comparing the alternative layout design 12 and 16, it is found that four attribute (i.e. ‘C’, ‘AS’, ‘SR’ and ‘Q’) are in favor of alternative layout design 12, one attribute ‘HCU’ is in favor of layout design 16 and one attribute ‘F’ is equally good for both the alternatives, therefore alternative layout design 12 should be preferred over layout design 16, which is same as obtained using WEDBA method. This shows that the proposed WEDBA method is giving better results for plant layout design selection problem.

3.3 Example 3

This problem is a case study conducted for the selection of plant layout design for a chemical packaging industry situated in the western part of India. There are four alternative plant layout designs available. The best alternative plant layout design is to be selected based on five attributes namely “interaction with existing facility distance (m), “area available for each assembly group (m^2), “material quantity flow (kg/hr)”, accessibility for firefighting (%)” and “comfort of crew”. The last attribute “comfort of crew” is expressed in subjective terms. A seven point fuzzy scale is used to convert these subjective terms into corresponding crisp scores (Table 1). The decision matrix of the problem is given in the Table 8. The crisp score for the corresponding fuzzy value is given in parenthesis. The attribute “interaction with existing facility distance” is of non-beneficial type and rest of the attributes are of beneficial type. The relative importance of attributes matrix found by decision makers is given below.

Table 8
Decision matrix of example 3

Alternatives	IEFD	AAG	MQF	AFF	COC
P1	102	3000	200	94	Very low (0.1364)
P2	84	1800	140	82	High (0.6667)
P3	123	2200	230	56	Average (0.5)
P4	224	2500	180	98	Low (0.3333)

Attributes: IEFD (interaction with existing facility distance in metres); AAG (area available for each assembly group in m^2); MQF (material quantity flow in kg/hr); AFF (accessibility for firefighting in %); COC (comfort of crew)

The subjective weights are obtained using the AHP method for the considered relative importance of attributes matrix.

$$\begin{array}{c|ccccc|} \text{Attributes} & \text{IEFD} & \text{AAG} & \text{MQF} & \text{AFF} & \text{COC} \\ \hline \text{IEFD} & 1 & 1/2 & 1/3 & 1/3 & 2 \\ \text{AAG} & 2 & 1 & 1 & 1/2 & 2 \\ \text{MQF} & 3 & 1 & 1 & 1/2 & 3 \\ \text{AFF} & 3 & 2 & 2 & 1 & 2 \\ \text{COC} & 1/2 & 1/2 & 1/3 & 1/2 & 1 \\ \hline \end{array}$$

The subjective weights of attributes obtained are w_{IEFD} = 0.1159, w_{AAG} = 0.2065, w_{MQF} = 0.2429, w_{AFF} = 0.3395, w_{COC} = 0.0952 having the consistency ratio (CR) of matrix as 0.0436. The objective weights of attributes obtained are w_{IEFD} = 0.2961, w_{AAG} = 0.0664, w_{MQF} = 0.0605, w_{AFF} = 0.082, w_{COC} = 0.495 and the integrated weights obtained are w_{IEFD} = 0.2491, w_{AAG} = 0.0995, w_{MQF} = 0.1068, w_{AFF} = 0.2022, w_{COC} = 0.3423. The problem is solved similar to previous examples. The ideal and anti-ideal point are (1.6711, 1.3951, 0.9553, 1.3280, 1.1863) and (-0.9432, -1.3302, -1.5953, -1.4634, -1.0502) respectively. The index score and rank of alternatives for the objective, subjective and integrated weights are given in Table 9.

Table 9
Index scores and ranks of alternatives of example 3

	Objective weights		Objective weights		Objective weights	
Alternatives	Rank	Index score	Rank	Index score	Rank	Index score
P1	0.3230	3	0.7512	1	0.4432	3
P2	0.8579	1	0.4189	4	0.7271	1
P3	0.6149	2	0.4319	3	0.5232	2
P4	0.3209	4	0.6344	2	0.4167	4

For the subjective, objective and integrated weights, the rank order of alternative obtained by using the proposed WEDBA are P1>P4>P3>P2, P2>P3>P1>P4 and P2>P3>P1>P4 respectively. Alternative layout design P1 is the best and P2 is the worst with respect to subjective weights and P2 is best with respect to objective and integrated weights. This is due to the objective weights obtained from the distribution of data. In this problem, as only four alternatives are there, so less data is available to get the objective attribute weights and approximate 50% objective weights is found for the attribute "COC" using entropy method, so ranking of alternatives is inclined towards the value of attribute "COC". So, when problem is having less number of alternatives, the final decision should be taken based on subjective value of attribute weights. Therefore, the best alternative layout design is P1.

4. Conclusions

Weighted Euclidean distance based multiple attribute decision making method is proposed in this paper to deal with the plant layout design selection problems of industrial environment. The proposed method helps the decision maker to arrive at a decision based on either the objective weights of importance of the attributes or his/her subjective preferences or considering both the objective weights and the subjective preferences. Entropy method is suggested for determining the objective weights of importance of the attributes and the use of AHP method or points method or digital logic method is suggested for considering the decision maker's preferences on attributes. Both the objective and subjective weights of importance of the attributes are combined to determine the integrated weights. Three examples of plant layout design selection are solved using WEDBA and the results are compared with previous researchers' results and it is found that the results obtained by using WEDBA are more logical and genuine.

The methodology proposed in this paper suggests a ranked value judgment on a fuzzy conversion scale to represent the qualitative selection attribute. The uniqueness of the proposed methodology is that it offers a general procedure that can be applicable to diverse selection problems encountered in industrial environment that incorporate vagueness and a number of selection attributes. The methodology is logical, simple and convenient to implement when compared with the other MADM methods.

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