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An Integrated AHP–VIKOR Methodology for Facility Layout Design

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ABSTRACT

A facility layout design (FLD) problem can be generally introduced as assignment of facilities (departments) to a site such that a set of criteria are satisfied or some objectives are minimized (maximized). Hence, it can be considered as a multi-criteria problem due to the presence of qualitative criteria such as maintenance or flexibility and quantitative criteria such as the total cost of handling material. The VIKOR method was developed to solve multiple criteria decision making problems with conflicting and non-commensurable (different units) criteria, assuming that compromising is acceptable for conflict resolution, the decision maker wants a solution that is the closest to the ideal, and the alternatives are evaluated according to all established criteria. This paper proposes a hierarchical analytic hierarchy process (AHP) and VIKOR approach to solve the FLD problem. A computer-aided layout-planning tool is adopted to generate the facility layout problems, as well as their quantitative data. The qualitative performance measures are weighted by AHP. VIKOR is then used to solve the FLD problem. Finally, the proposed integrated procedure is applied to three real-time examples.

Keywords: Facility Layout Design, Analytic Hierarchy Process, VIKOR Method

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1. INTRODUCTION

In response to increasing inflexible and various customer demands and in order to improve the competitive advantage, manufacturing and industrial organizations have to adopt decisions to achieve cost reduction, increased productivity, continual quality improvement, increased customer service and on-time delivery performance (Rao, 2012).

Selection of the optimal facility layout design (FLD) alternative for an organization is one among the most important strategic issues to fulfill all the above-mentioned objectives. Organizations always face difficulties in selecting optimal FLD alternative because it is based on conflicting and non-commensurable (different units) criteria.

The layout decision is usually based on both quantitative and qualitative performance ratings related to the desired closeness or closeness relationships among the facilities. The ‘closeness’ is an unintelligible notion that captures issues, such as the material flow and the ease of employee supervision (Karray *et al*., 2000). Clearly, the evaluation of critical criteria, especially qualitative criteria for a layout design is often a challenging and complex task (Lin and Sharp, 1999).

The 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 selected criteria for design alternatives. This will permit the selected design criteria to be better incorporated and evaluated. In addition, the direct evaluation of a design alternative in lieu of imperfect 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 multiple attribute decision making (MADM) methods. The problem seeks to evaluate a large number of layout design alternatives generated by an efficient layout design algorithm. The evaluation of a large number of design alternatives based on both quantitative and qualitative design criteria will thereby reduce the risk of missing a high-quality solution (Yang and Hung, 2007).

Most multi-criteria methods must define the weights of the criteria to characterize their relative importance (Opricovic and Tzeng, 2004). In multi-criteria analysis, no solution will likely satisfy all criteria simultaneously. Different multiple criteria decision making (MCDM) methods often create different outcomes to select or rank a set of decision alternatives (Yeh, 2002). Voogd (1983) showed that, at least 40% of time, each technique produces a different result from any other technique. Thus, the concept of compromise solution is critical in MCDM. A compromise solution for a problem with non-commensurable and conflicting criteria can help experts and decision-makers identify an acceptable response (Opricovic, 1998). This paper applied the VIKOR method, which was developed for multi-criteria optimization for complex systems, to find a compromise priority ranking of alternatives according to the selected criteria. The objective of this paper is to determine the priority ranking of FLDs. The rest of this paper is structured as follows. The pertinent literature is reviewed in Section 2. In Section 3, an overview and background of the VIKOR method is presented. In Section 4, an overview of the concepts of the AHP approach is given. Section 5 will focus on the proposed model. Then three real time examples are illustrated in Section 6. In the final section, some conclusions are drawn for the study.

2. LITERATURE REVIEW

The layout design problem is one of the most popular subjects of current publications, conferences and research. It is one of the best-researched fields to achieve its goal of productivity and profitability. Due to the significance of the problem in manufacturing and industrial organizations, it has been an active research scope for many decades (Meller and Gau, 1996). Many researchers in the past have solved the facility layout problems (FLPs) of various kinds. Various MADM methods; the near-optimal methods, namely heuristics and metaheuristics; suitable computer packages and expert systems have been developed to solve the layout selection problems and graphically generate the best layout.

Armour and Buffa (1963) proposed a heuristic algorithm and simulation approach to relative allocation of facilities. Lee and Moore (1967) used CORELAP (computerized relationship layout planning). Rosenblatt (1979) suggested using a graphical solution for solving the FLP. 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. Askin (1986) formulated an MIP mathematical model for integrated production system planning. His economic decision model integrates product selection, capacity planning, process planning, and facility layout. Grobelny (1987) presented one possibly ‘fuzzy’ approach to FLPs. Abdou and Dutta (1990) presented an integrated approach to facilities layout design using expert system. Cambron and Evans (1991) used different computer-aided layout design methods to generate a set of design alternatives that are then evaluated by AHP against a set of design criteria. Raoot and Rakshit (1991) proposed a construction-type layout design heuristic based on the 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 FLP. This model allowed solving the FLP for more than two factors handling qualitative and quantitative factors simultaneously by combining into one factor known as composite factor, and the layout resulted from the heuristic is then used in pair wise exchange routine for further improvement. Houshyar and White (1993) presented an exact optimal solution for facility layout by deciding that which pairs of locations should be adjacent. Shang (1993) presented an integrated approach for solving multi-criteria FLP. 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 the traveling salesman problem and then extended their approach to solve the FLP, 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 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 the shortest path along aisles and corridors. Maniezzo (1998) proposed an interesting ant algorithm to solve QAP, which is 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. Chwif *et al*. (1998) proposed a solution approach based on simulated annealing in the continual plane to the FLD. It addresses some practical aspects, including the facilities with different areas, shapes and orientations, any polygonal format for the border, fixed facilities, and pick-up and drop-off points. Dweiri (1999) presented a distinct methodology to develop a crisp activity relationship chart using fuzzy set theory and pair-wise comparisons of the analytic hierarchy process (AHP). Yaman and Balibek (1999) presented a decision making methodology for solving FLPs. Chan and Sha (1999) presented a new multi-objective heuristic algorithm for resolving the FLP. It incorporates qualitative and quantitative objectives and resolves the problem of inconsistent scales and different measurement units. Chung (1999) developed neuro-based expert system 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. Chau and Anson (2002) developed a knowledge-based system for construction site level facilities layout. Lee and Lee (2002) presented a shape-based block layout (SBL) approach for solving FLP with unequal-areas and fixed-shapes. The SBL approach employs a 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. Dunker *et al*. (2005) presented an algorithm combining dynamic programming and genetic search for solving the dynamic FLPs. 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 FLP. The objective function of the proposed model is the minimization of total layout cost combining material flow factor cost, shape ratio factor, and area utilization factor. 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. Aiello *et al*. (2006) proposed a genetic search algorithm and ELECTRE method to prioritize the FLPs in which the Pareto-optimal solutions are determined by employing a multi-objective constrained genetic algorithm. Ertay *et al*. (2006) proposed a combined AHP-DEA approach to decide the best FLD. The AHP is used to obtain the relative importance of the alternative layout designs. Yang and Hung (2007) used TOPSIS and fuzzy TOPSIS for selection of plant layout design. Chakraborty and Banik (2007) applied an AHP based approach for optimal FLD. Kuo, Yang, and Huang (2008) used grey relational analysis in solving MADM problems with a case study of FLD alternative. Ulutas and Islier (2009) proposed a clone selection algorithm for the selection of the dynamic facility layout. McKendall and Hakobyan (2010) proposed a boundary search (construction) technique for dynamic FLP 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 a preference selection index method to the FLD selection problem and made the comparison with the results of previous researchers. Ku *et al*. (2011) solved the unequal area FLP 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. Gonzalez-Cruz and Gomez-Senent Martinez (2011) used an entropy-based algorithm to solve the FLD problem. The algorithm is 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 is selected as the optimal solution. Mohamadghasemi and Hadi-Vencheh (2012) applied an integrated synthetic value of fuzzy judgments and nonlinear programming methodology for ranking the facility layout patterns. Hadi-Vencheh and Mohamadghasemi (2013) used an integrated AHP-NLP methodology to solve the FLD problem.

Although a good amount of research works has already been carried out over the past years on facility layout evaluation and selection, there is still active research scope to implement other simple and logical mathematical tools to solve such type of challenging and complex decision-making problems involving multiple conflicting criteria and alternatives. In this paper, an effort is made to find the applicability and potentiality of a highly potential MADM method, i.e., the VIKOR method while selecting the best facility layout for a given industrial application. Three real-time facility layout selection problems are cited and solved using the VIKOR method.

3. THE VIKOR METHOD

Opricovic (1998) and Opricovic and Tzeng (2002) developed VIKOR, the Serbian name: VlseKriterijumska Optimizacija I Kompromisno Resenje, means multi-criteria optimization and compromise solution (Chu *et al*., 2007). The VIKOR method was developed for multi-criteria optimization of challenging and complex systems (Opricovic and Tzeng, 2004). This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting and non-commensurable criteria, which can help the experts and decision makers to achieve a final decision. Here, the compromise solution $F^c = (f_1^c, \cdots, f_m^c)$ is a feasible solution, which is the closest to the ideal F^*, and a compromise means an agreement established by mutual concessions, as is illustrated in Figure 1 by $\Delta f_1 = f_1^* - f_1^c$ and $\Delta f_2 = f_2^* - f_2^c$ (Opricovic and Tzeng, 2007). It introduces the multi-criteria ranking index based on the particular measure of "closeness" to the "ideal" solution (Opricovic, 1998). According to Opricovic and Tzeng (2004), the multi-criteria measure for compromise ranking is developed from the $L_p - metric$ used as an aggregating function in a compromise programming method (Yu, 1973). The various m alternatives are denoted as $A_1, A_2, \cdots, A_m$ for alternative A_i, the rating of the *j*th aspect is denoted by f_{ij}, i.e., f_{ij} is the value of *j*th criterion function for the alternative A_i; n is the number of criteria. Development of the VIKOR method started with the following form of $L_p - metric$:

$$L_{p,i} = \left\{ \sum_{j=1}^{n} \left[w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-) \right]^p \right\}^{1/p}, \quad (1)$$
$$1 \le p \le \infty; \; i = 1, 2, \cdots, m.$$

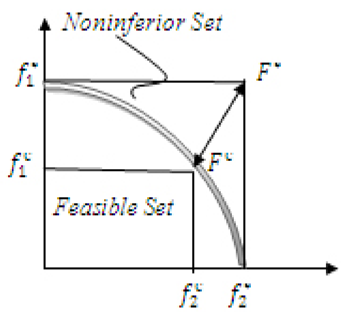

Figure 1. Ideal and compromise solution.

Within the VIKOR method $L_{1,i}$ (as R_i in Eq. (8)) and $L_{\infty,i}$ (as R_i in Eq. (9)) are used to formulate ranking measure. $L_{1,i}$ is interpreted as 'concordance' and can provide decision makers with information about the maximum 'group utility' or 'majority'. Similarly, $L_{\infty,i}$ is interpreted as 'discordance' and provides decision makers with information about the minimum individual regret of the 'opponent.'

According to Opricovic and Tzeng (2004) the method VIKOR is an effective tool in multi-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 computational procedure of the VIKOR method is quite simple, and it offers a systematic and logical approach to arrive at the best decision. The obtained compromise solution can 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. The VIKOR results depend on the ideal solution, which stands only for the given set of alternatives. Inclusion (or exclusion) of an alternative can affect the VIKOR ranking of the new set of alternatives. In this method, the ranking score of each alternative is derived from an aggregation of all the considered criteria, the weights of the criteria and a balance between total and individual satisfaction. As the VIKOR method employs linear normalization procedure, the normalized values are not dependent on the evaluation units of the selection criteria. According to above-discussed items, three real-time examples are cited in order to demonstrate and evaluate the effective and efficient performance of the VIKOR method.

4. THE AHP METHODOLOGY

The AHP, the most popular MADM techniques, developed by Saaty (1980), addresses how to determine relative importance of a set of activities in a multi-attribute decision problem. The AHP is adopted, especially for the qualitative performance data, because intangible qualitative criteria are not stateable as quantitative data. Also, the decision-maker acceptability and confidence in the analysis provided by the AHP methodology is high when it is compared with other MADM methods (Zzkarian and Kusiak, 1999). The other advantages of the AHP include: providing a systematic methodology for subjective decision, applying in sensitivity analysis, presenting a great deal of information about the evaluation criteria's implicit weights, and providing clearer understanding and participation among the members of the decision-making group and hence a commitment to the chosen alternative (Shang, 1993).

The main problem with AHP is the need for very boring calculations, which can be made much easier using personal computer software. An example of such software is the Expert Choice software package, which can greatly facilitate the use of AHP in the workplace (Partovi and Hopton, 1994; Turban, 1990). The AHP method is based on three principles: first, structure of the model; second, comparative judgment of the alternatives and the criteria; and finally, synthesis of the priorities. In the first step, a complex decision problem is structured as a hierarchy. AHP initially breaks down a complex multi-attribute decision-making problem into a hierarchy of interrelated decision criteria, decision alternatives. With the AHP, the objectives, criteria and alternatives are arranged in a hierarchical structure similar to a family tree. The hierarchy consists of the overall objective (the best alternative) at the top level, attributes and subattributes, if any, at the middle level and the different alternatives at the lowest level (Albayrak and Erensal, 2004). The second step is the comparison of the alternatives and the criteria. Once the problem has been decomposed and the hierarchy is constructed, the prioritization procedure starts in order to determine the relative importance of the criteria within each level. The pairwise judgment starts from the second level and finishes in the lowest level, alternatives. In each level, the criteria are compared pairwise according to their levels of influence and based on the specified criteria in the higher level (Albayrak and Erensal, 2004). In this paper, the basic Purpose of using the AHP is to obtain the weights indicating the relative importance of the FLPs (as alternatives) under each criterion. At the lowest level, the decision-maker will be asked to determine a comparison matrix by comparing pairs of the FLPs against the criteria. Analytic aspect of rating method enables decision-makers to evaluate a large number of alternatives easily. Since in this paper, the performance measures of the qualitative criteria are generated by the AHP, thus a hierarchy structure for FLD problem is proposed, as shown in Figure 2 (Hadi-Vencheh and Mohamadghasemi, 2013). In the following hierarchical structure, for example, the weights in the lowest level are determined by the pairwise comparison matrix based on the designer's ideas. In other words, numerical values in this matrix include the designer's evaluations as compared to the importance of a FLP against the other FLPs with respect to each qualitative criterion which are selected using 1–9 scales proposed by Saaty (1980) in Table 1.

Let $A_{ij}(i,\ j=1,\cdots,m)$ be the comparison of *i*th FLP against *j*th FLP generated by the commercial software. By constructing the pairwise comparison matrix for comparing m FLPs regarding to each the qualitative criterion C, C = 1, ⋯, n, we have:

$$A=\left(A_{ij}\right)_{m\times m}=\begin{bmatrix} A_{11} & \cdots & A_{1m} \\ \vdots & \cdots & \vdots \\ A_{m1} & \cdots & A_{mm} \end{bmatrix},\ i,\ j=1,\cdots,m, \quad (2)$$

Where $A_{ij}=1/A_{ji}$ for $i,\ j=1,\cdots,m$. If in this matrix for $i,\ j,\ k=1,\cdots,m,\ A_{ij}=A_{ik}\times A_{kj}$ hold true, then A is said

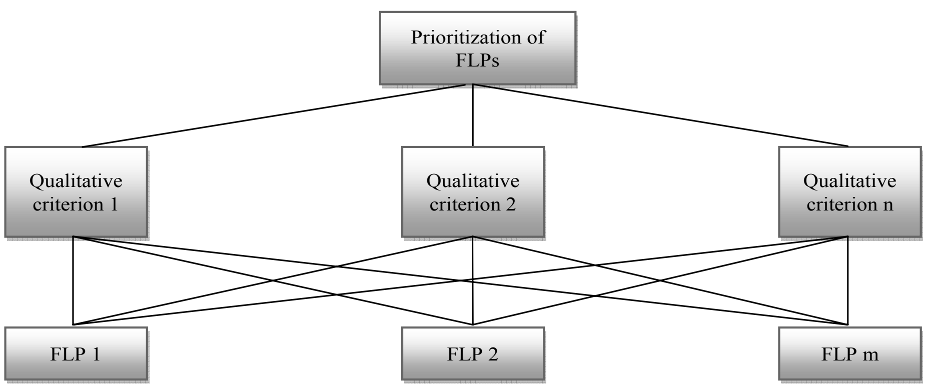

Figure 2. A hierarchical structure of analytic hierarchy process for facility layout design. FLP: facility layout problem.

Table 1. The 1–9 scales proposed by Saaty (1980) for pairwise comparisons in the analytic hierarchy process

Importance intensity	Definition
1	Equal importance
3	Moderate importance of one pattern as compared to another
5	Strong importance of one pattern as compared to another
7	Very strong importance of one pattern as compared to another
9	Extreme importance of one pattern as compared to another
2, 4, 6, and 8	Intermediate values
Reciprocals	Reciprocals for inverse comparison

to be perfectly consistent.

$$AW = \lambda_{max} W \tag{3}$$

Where λ_{max} is the largest eigenvalue of matrix A. If the pairwise comparisons are completely consistent, the matrix A has rank 1 and $\lambda_{max} = n$. It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pairwise comparison judgments. The consistency is defined by the relation between the entries of: $A_{ik} \times A_{kj} = A_{ij}$. The consistency index CI is:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{4}$$

The final consistency ratio (CR), usage of which let someone to conclude whether the evaluations are the sufficiently consistent, is calculated as the ratio of the CI and the random index (RI), as indicated.

$$CR = \frac{CI}{RI} \tag{5}$$

Where RI is a random inconsistency index whose value are determined according to the size of matrix A. The interested readers can refer to Saaty (1980) for more detailed for determining the RI. If $CR \le 0.1$, then A is said to has acceptable consistent limit; otherwise, the pairwise comparisons should be revised.

5. FLD SELECTION METHODOLOGY

This section describes the proposed methodology for the selection of optimal FLD alternative. The main steps of FLD selection methodology are described below in details. The steps 1 to 3 of the algorithm are taken from Maniya and Bhatt (2011) and the steps 4 to 8 are compromise ranking algorithm of the VIKOR method.

- Step-1: *Define the problem.* Define the application or production condition or manufacturing industries for which FLD is required.
- Step-2: *Generate FLD alternatives.* After defining the application, decision makers should be required to generate a large number of FLD alternatives using various traditional methods or commercial software, such as Spiral, VisFactory, and etc., or using computerized techniques, such as CRAFT, COFAD, CORELAP, CLASS, PLANET, ALDEP, SHAPE, MULTIPLE, etc.
- Step-3: *Decide the FLD criteria.* Now, identify and decide the possible significant FLD selection attributes or criteria, such as material handling distance, adjacency score, shape ratio, cost, flexibility, maintenance, accessibility, quality, hand-carry utility, etc. Also, evaluate the all potential FLD selection criteria with respect to every FLD alternatives. Therefore, in this step, the AHP usage is to obtain the weights indicating the relative importance of the FLPs (as alternatives) under each criterion and the performance measures of the qualitative criteria.
- Step-4: Determine the maximum f_j^* and the minimum f_j^- values of all criterion functions $j = 1, 2, \cdots, n.$ if the jth function represents a benefit then:

$$f_j^* = \max_i f_{ij}; \tag{6}$$

$$f_j^- = \max_i f_{ij}; \tag{7}$$

- Step-5: Compute the values S_i and R_i; $i = 1, 2, \cdots, m$ by these relations:

$$S_i = \sum_{j=1}^{n} w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-), \tag{8}$$

$$R_i = \max_j \, w_j (f_j^* - f_{ij}) / (f_j^* - f_j^-). \tag{9}$$

where w_j are the weights of criteria, expressing their relative importance.

- Step-6: Compute the values Q_i; $i = 1, 2, \cdots, m,$ by the following relation:

$$Q_i = \frac{v(S_i - S^*)}{S^- - S^*} + \frac{(1-v)(R_i - R^*)}{R^- - R^*} \tag{10}$$

where

$$S^* = \min_i S_i, \quad S^- = \max_i S_i$$
$$R^* = \min_i R_i, \quad R^- = \max_i R_i$$

v is introduced as weight of the strategy of "the majority of criteria" (or "the maximum group utility"), here suppose that $v = 0.5$.

- Step-7: Rank the alternatives, sorting by the values S, R and Q in increasing order.
- Step-8: 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:

$$Q(A'') - Q(A') \ge DQ, \tag{11}$$

where A'' is the alternative with second position in the ranking list by Q; $DQ = 1/(m-1)$ 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: 1) alternatives A' and A'' if only condition C2 is not satisfied, or 2) alternatives $A', A'', \cdots, A^{(M)}$ 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."

6. FLD SELECTION EXAMPLES

Now, three real-time examples are considered and examined to demonstrate and validate the FLD selection methodology based on an integrated AHP-VIKOR method.

6.1 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 company. Yang and Kuo (2003) have generated and considered 18 FLD alternatives and six FLD selection attributes or criteria using computer-aided layout planning which affect the facility layout selection decision making process, i.e., distance, adjacency, shape ratio, flexibility, accessibility, and maintenance. The interested reader can refer to Yang and Kuo (2003) and Yang and Hung (2007) for more details as compared to name and area of departments, the FLPs generated by commercial software Spiral and the definitions of criteria. The data of FLD selection attributes of Example-1 are shown in Table 2. The following procedural steps are carried out.

- Step-I: The objective of the Example-1 is to select the optimal FLD alternative for the given industrial application. In the present Example-1, 18 FLD alternatives and 6 FLD selection attributes or criteria are considered which are same as of Yang and Hung (2007). These all FLD alternatives are evaluated with every FLD selection attributes and its performance measures which are same as of Yang and Hung (2007). These all FLD alternatives are evaluated with every FLD selection attributes and its performance measures are shown in Table 2. This table represents the step-1 to step-3 of proposed FLD selection methodology.
- Step-II: The best and the worst values of all criterion ratings are determined as follows:

$$f_1^* = 170.14,\ f_2^* = 10,\ f_3^* = 2,\ f_4^* = 0.0952,\ f_5^* = 0.1169,$$
$$f_6^* = 0.092,\ f_1^- = 264.07,\ f_2^- = 5,\ f_3^- = 14,\ f_4^- = 0.0119,$$
$$f_5^- = 0.013,\ f_6^- = 0.023,$$

Table 2. Quantitative data of the plant layout design selection attributes for various alternatives in Example-1

No.	C1	C2	C3	C4	C5	C6
A1	185.95	8	8.28	0.0119	0.0260	0.0690
A2	207.37	9	3.75	0.0595	0.0260	0.0575
A3	206.38	8	7.85	0.0714	0.0519	0.0345
A4	189.66	8	8.28	0.0714	0.0779	0.0460
A5	211.46	8	7.71	0.0714	0.0390	0.0460
A6	264.07	5	2.07	0.0357	0.0519	0.0690
A7	228.00	8	14.00	0.0476	0.0390	0.0230
A8	185.59	9	6.25	0.0476	0.0130	0.0575
A9	185.85	9	7.85	0.0357	0.0260	0.0575
A10	236.15	8	7.85	0.0595	0.0779	0.0690
A11	183.18	8	2.00	0.0952	0.1169	0.0920
A12	204.18	8	13.30	0.0357	0.0390	0.0575
A13	225.26	8	8.14	0.0714	0.0390	0.0345
A14	202.82	8	8.00	0.0357	0.0779	0.0575
A15	170.14	9	8.28	0.0952	0.1169	0.0920
A16	216.38	9	7.71	0.0476	0.0519	0.0690
A17	179.80	8	10.30	0.0476	0.0779	0.0345
A18	185.75	10	10.16	0.0595	0.0519	0.0345
Weight	0.2	0.2	0.15	0.1	0.2	0.15

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

Table 3. The values of *S*, *R*, and *Q* for all alternatives

Layout alternatives	*S*	*R*	*Q*
1	0.5171	0.1750	0.7367
2	0.4340	0.1750	0.6677
3	0.5090	0.1251	0.5248
4	0.4037	0.1000	0.3341
5	0.5179	0.1500	0.6344
6	0.6474	0.2000	0.9478
7	0.7103	0.1500	0.7942
8	0.4582	0.2000	0.7908
9	0.4680	0.1750	0.6959
10	0.4616	0.1406	0.5490
11	0.1078	0.0800	0.0062
12	0.5901	0.1500	0.6943
13	0.5776	0.1500	0.6840
14	0.4461	0.0800	0.2869
15	0.1185	0.0785	0.0089
16	0.4421	0.1251	0.4693
17	0.4615	0.1250	0.4849
18	0.4282	0.1251	0.4578

- Step-III and step-IV: The values of *S*, *R*, and *Q* are calculated for all alternatives as Table 3.
- Step-V: The ranking of the alternatives by *R*, and Q in decreasing order is shown in Table 4.
- Step-VI: As we see in Table 4, the alternative 11 is the best ranked by *Q* and also the condition C2 are satisfied but the condition C1 $(Q_{A_{15}} - Q_{A_{11}}) \geq \frac{1}{m-1} = (0.0089 - 0.0062) \geq \frac{1}{18-1}$ are not satisfied.

The results indicate the set of compromise solutions.

6.1.1 Result comparison and discussion

In this section, results of the proposed methodology based on VIKOR method is compared with published results of various methods to validate the FLD selection methodology. To compare the results, all the FLD alternatives are ranked by the values *S*, *R*, and *Q* in increasing order. A result comparison of the proposed methodology and published results of the TOPSIS, fuzzy TOPSIS and DEA methods is shown in Table 4. As we see in Table 4, the alternative A11 is the best ranked by Q and also the condition C2 are satisfied but the condition C1 $(Q_{A_{15}} - Q_{A_{11}}) \geq \frac{1}{m-1} = (0.0089 - 0.0062) \geq \frac{1}{18-1}$ are not satisfied. Condition C1 is not satisfied, there must be a compromise solution consisting of first M alternative for which the inequality $Q(A^{(M)})\_Q(A') < DQ$ must be attained. In this example $M = 2$. Thus, the desired result was achieved on the first calculated, then results of our methodology indicate the set of compromise solutions including {A11, A15} as good alternatives.

According to Maniya and Bhatt (2011), the cost benefit analysis (CBA) is an analytical tool that can be used to evaluate the benefits and costs of selected alternatives. Generally, the cost analysis is based on the comparison of a base case and selected alternative. 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 (benefit to company), C5 (benefit to company), and C6 (benefit to company),

Table 4. Ranking the facility layout problems by our model and compared with the TOPSIS, fuzzy TOPSIS, and DEA model

Ranking layout alternatives	By *S*	By *R*	By *Q*	TOPSIS	fuzzy TOPSIS	DEA
1	A11	A15	A11	A11	A11	A11
2	A15	A11	A15	A15	A15	A15
3	A4	A14	A14	A10	A18	A18
4	A18	A4	A4	A4	A4	A2
5	A2	A17	A18	A14	A17	A16
6	A16	A3	A16	A6	A8	A6
7	A14	A16	A17	A17	A10	A8
8	A8	A18	A3	A16	A14	A9
9	A17	A10	A10	A2	A2	A17
10	A10	A5	A5	A3	A16	A1
11	A9	A7	A2	A18	A9	A4
12	A3	A12	A13	A5	A5	A10
13	A1	A10	A12	A8	A1	A14
14	A5	A13	A9	A13	A3	A5
15	A13	A1	A1	A9	A12	A3
16	A12	A9	A8	A1	A6	A13
17	A6	A6	A7	A12	A7	A12
18	A7	A8	A6	A7	A13	A7

15 is better with respect to two attributes—i.e., C1 (reduce the cost to company) and C2 (benefit to company)—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 (reduce the cost to company) with a large difference and also alternative layout design 11 has the minimum value of Q. This shows that alternative 11 can be preferred over alternative 15. 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, respectively.

Figure 3 shows the pictorial representation and comparison of the rankings of the proposed method with published results of various methods to validate the FLD selection methodology. There exists an approximately high rank correlation between these two rankings of the VIKOR method and DEA method (Spearman rank correlation coefficient, r_s = 0.5934), which shows the potentiality of both these methods in solving such type of FLD selection problems. A results and discussion shows that proposed methodology suggests the same optimal facility different decision making methodologies like DEA, TOPSIS, fuzzy TOPSIS, and etc. Hence, the ranking of the alternative layouts obtained using the VIKOR method can be acceptable.

Now, Example-1 is considered to study the benefits to cost to the company. In this Example-1, alternative A18 is current layout or base case and alternative A11 is suggested as optimal choice for the existing layout by proposed method. Figure 4 shows the pictorial representation and comparison of base case, i.e., A18 and selected alternative A11 to study the benefits to cost to the company. CBA is applied to determine the feasibility of selected alternative by quantifying its costs and benefits. In addition, benefits often can be more difficult to quantify than costs. Here, only subjective comparison or subjective CBA is described due to non-availability of exact cost of each criteria. Now on comparing the alternative layout design 11 and 18, it is found that five attribute—i.e., C1 (reduce the cost to company), C3 (reduce the cost to company), C4 (benefit to company), C5 (benefit to company), and C6 (benefit to company)—are in favor of alternative layout design quantifying its costs and benefits. In addition, benefits often can be more difficult

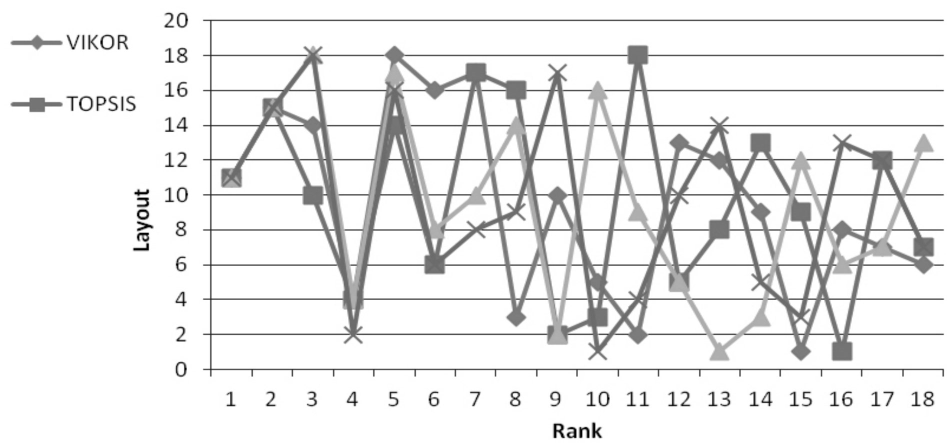

Figure 3. Comparative ranking of layout alternatives for Example-1.

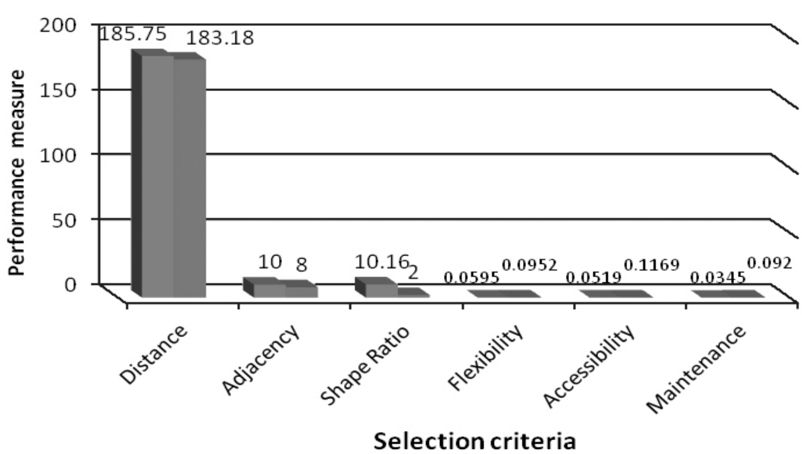

Figure 4. Subjective cost benefit analysis for the selected facility layout alternative for Example-1.

to quantify than costs. Here, only subjective comparison or subjective CBA is described due to non-availability of exact cost of each criteria. Now on comparing the alternative layout design 11 and 18, it is found that five attributes—i.e., C1 (reduce the cost to company), C3 (reduce the cost to company), C4 (benefit to company), C5 (benefit to company), and C6 (benefit to company)—are in favor of alternative layout design 11, one attribute C2 (Reduce the cost to company) is in favor of layout design 18, therefore weighted sum of selected attributes of alternative layout design 11 is equal to 0.9172 and weighted of selected attribute of alternative layout design 18 is equal to 0.0828. Hence, alternative layout design 11 should be preferred over layout design 18, which is same as obtained using integrated procedure of AHP and VIKOR. Therefore, alternative A11 is an optimal choice for the decision maker looking to subjective CBA.

6.2 Example-2

In this example, the layout design problem presented by Ertay *et al*. (2006) is adopted and the problem is related to the company "Sert Plastic Profile Industry Co., Ltd." Ertay *et al*. (2006) have generated and considered 19 FLD alternatives and six FLD selection attributes or criteria using computer aided layout planning which affect the facility layout selection decision making process, i.e., cost ($), adjacency score, shape ratio, flexibility, quality, hand-carry utility. The interested reader can refer to Ertay *et al*. (2006) for more details as compared to name and area of departments, the FLPs generated by commercial software VisFactory and the definitions of criteria. The data of FLD selection attributes of Example-2 are shown in Table 5. The following procedural steps are carried out.

- Step-I: The objective of the Example-2 is to select the optimal FLD alternative for the given industrial application. In the present Example-2, 19 FLD alternatives and 6 FLD selection attributes or criteria are considered which are same as of (Ertay *et al*., 2006). These all FLD alternatives are evaluated with every FLD selection attributes and its performance measures are shown in Table 5. This table represents the step-1 to step-3 of proposed FLD selection methodology.
- Step-II: The maximum and the minimum values of all criterion ratings are determined as follows:

$$f_1^* = 19608.43,\ f_2^* = 2862,\ f_3^* = 0.6624,\ f_4^* = 0.0852,$$
$$f_5^* = 0.0846,\ f_6^* = 33.6,\ f_1^- = 20779.75,\ f_2^- = 17402,$$
$$f_3^- = 0.269,\ f_4^- = 0.0113,\ f_5^- = 0.0125,\ f_6^- = 24.45,$$

- Step-III and step-IV: The values of S, R, and Q are calculated for all alternatives as Table 6.
- Step-V: The ranking of the alternatives by S, R, and Q in increasing order is shown in Table 7.

Table 5. Quantitative data of the plant layout design selection attributes for various alternatives in Example-2

No.	C1	C2	C3	C4	C5	C6
A1	20309.56	6405	0.4679	0.0113	0.0410	30.89
A2	20411.22	5393	0.4308	0.0337	0.0484	31.34
A3	20280.28	5294	0.4392	0.0308	0.0653	30.26
A4	20053.20	4450	0.3776	0.0245	0.0638	28.03
A5	19998.75	4370	0.3526	0.0856	0.0484	25.43
A6	20193.68	4393	0.3674	0.0717	0.0361	29.11
A7	19779.73	2862	0.2854	0.0245	0.0846	25.29
A8	19831.00	5473	0.4398	0.0113	0.0125	24.80
A9	19608.43	5161	0.2868	0.0674	0.0724	24.45
A10	20038.10	6078	0.6624	0.0856	0.0653	26.45
A11	20330.68	4516	0.3437	0.0856	0.0638	29.46
A12	20155.09	3702	0.3526	0.0856	0.0846	28.07
A13	19641.86	5726	0.2690	0.0337	0.0361	24.58
A14	20575.67	4639	0.3441	0.0856	0.0638	32.20
A15	20687.50	5646	0.4326	0.0337	0.0452	33.21
A16	20779.75	5507	0.3312	0.0856	0.0653	33.60
A17	19853.38	3912	0.2847	0.0245	0.0638	31.29
A18	19853.38	5974	0.4398	0.0337	0.0179	25.12
A19	20355.00	17402	0.4421	0.0856	0.0217	30.02
Weight	0.2129	0.0828	0.0828	0.2437	0.2437	0.1341

C1: cost ($), C2: adjacency score, C3: shape ratio, C4: flexibility, C5: quality, C6: hand-carry utility.

Table 6. The values of S, R, and Q for all alternatives

Layout alternatives	S	R	Q
1	0.6190	0.2437	0.8939
2	0.5333	0.1702	0.5476
3	0.4769	0.1797	0.5203
4	0.5022	0.2004	0.6189
5	0.3868	0.1224	0.2254
6	0.4525	0.1639	0.4395
7	0.4327	0.2004	0.5447
8	0.7185	0.2437	1.0000
9	0.3272	0.1341	0.2023
10	0.2664	0.1048	0.0359
11	0.3388	0.1313	0.2049
12	0.2504	0.0994	0.0000
13	0.5715	0.1702	0.5885
14	0.3437	0.1758	0.3645
15	0.5695	0.1961	0.6760
16	0.3629	0.2129	0.5135
17	0.4346	0.2004	0.5467
18	0.6291	0.2254	0.8412
19	0.5299	0.2126	0.6908

- Step-VI: As we see in Table 7, the alternative A12 is the best ranked by Q and also the condition C2 are satisfied but the condition C1 $(Q_{A_{10}} - Q_{A_{12}}) \geq \frac{1}{m-1} = (0.0359 - 0.0000) \geq \frac{1}{19-1}$ are not satisfied. The results indicate the set of compromise solutions.

6.2.1 Result comparison and discussion

In this section, results of the proposed methodology based on VIKOR method is compared with published results to validate the FLD selection methodology. To compare the results, all the FLD alternatives are ranked by the values S, R, and Q in increasing order. A result comparison of the proposed methodology and published results of DEA method is shown in Table 7. As we see in Table 7, the alternative A12 is the best ranked by Q and also the condition C2 are satisfied but the condition C1 $(Q_{A_{10}} - Q_{A_{12}}) \geq \frac{1}{m-1} = (0.0359 - 0.0000) \geq \frac{1}{19-1}$ are not satisfied.

Condition C1 is not satisfied, there must be a compromise solution consisting of first M alternative for which the inequality $Q(A^{(M)})\_Q(A') < DQ$ must be attained. In this example M = 2. Thus, the desired result was achieved on the first calculated, then results of our methodology indicate the set of compromise solutions including {A12, A10} as good alternatives. On comparing the data by using CBA for alternatives 12 and 10, it is observed that both the alternatives perform equally with respect to attribute C4 (benefit to company), 12 is better with respect to three attributes—i.e., C2 (reduce the cost to company), C5 (benefit to company), and C6 (benefit to company)—and 10 is better with respect to two attributes—i.e., C1 (reduce the cost to company)

Table 7. Ranking the facility layout problems by our model and compared with the DEA model

Ranking layout alternatives	By S	By R	By Q	DEA*
1	A12	A12	A12	A16
2	A10	A10	A10	A15
3	A9	A5	A9	A14
4	A11	A11	A11	A2
5	A14	A9	A5	A1
6	A16	A6	A14	A3
7	A5	A2	A6	A17
8	A7	A13	A16	A11
9	A17	A14	A3	A6
10	A6	A3	A7	A4
11	A3	A15	A17	A12
12	A4	A4	A2	A10
13	A19	A7	A13	A19
14	A2	A17	A4	A5
15	A15	A19	A15	A7
16	A13	A16	A19	A18
17	A1	A18	A18	A8
18	A18	A1	A1	A13
19	A8	A8	A8	A9

* Ertay *et al*., 2006.

and C3 (benefit to company), therefore weighted sum of selected attributes of alternative layout design 12 is equal to 0.4606 and weighted sum of selected attribute of alternative layout design 10 is equal to 0.2957 and also alternative layout design 12 has the minimum value of Q. This shows that alternative 12 can be preferred over alternative 10. Ertay *et al*. (2006) had proposed the layout design 16 as the best choice using integrated procedure of AHP and DEA. Now on comparing the alternative layout design 12 and 16 by using CBA, it is found that four attribute—i.e., C1 (reduce the cost to company), C2 (reduce the cost to company), C3 (benefit to company), and C5 (benefit to company)—are in favor of alternative layout design 12, one attribute C6 is in favor of layout design 16 and one attribute C4 is equally good for both the alternatives, therefore weighted sum of selected attributes of alternative layout design 12 is equal to 0.6222 and weighted of selected attribute of alternative layout design 16 is equal to 0.2437. Hence, alternative layout design 12 should be preferred over layout design 16, which is same as obtained using integrated procedure of AHP and VIKOR.

Figure 5 shows the pictorial representation and comparison of the rankings of the proposed method with published results of DEA method to validate the FLD selection methodology. There exists a low rank correlation between these two rankings of the VIKOR method and DEA method (Spearman rank correlation coefficient, $r_s = 0.2246$), which shows the different potentiality of both these methods in solving such type of FLD selection problems. According to above-discussed results, this shows that our proposed method of comparing the DEA method is giving better results for FLD selection problem.

Now, Example-2 is considered to study the benefits to cost to the company. In this Example-2, alternative A19 is current layout or base case and alternative A12 is suggested as optimal choice for the existing layout by proposed method. Figure 6 shows the pictorial representation and comparison of base case, i.e., A19 and selected alternative A12 to study the benefits to cost to the company. CBA is applied to determine the feasibility of selected alternative by quantifying its costs and benefits. In addition, benefits often can be more difficult to quantify than costs. Here, only subjective comparison or subjective CBA is described due to non-availability of exact cost of each criteria. Now on comparing the alternative layout design 12 and 19, it is found that three attribute—i.e., C1 (reduce the cost to company), C2 (reduce the cost to company), and C5 (benefit to company)—are in

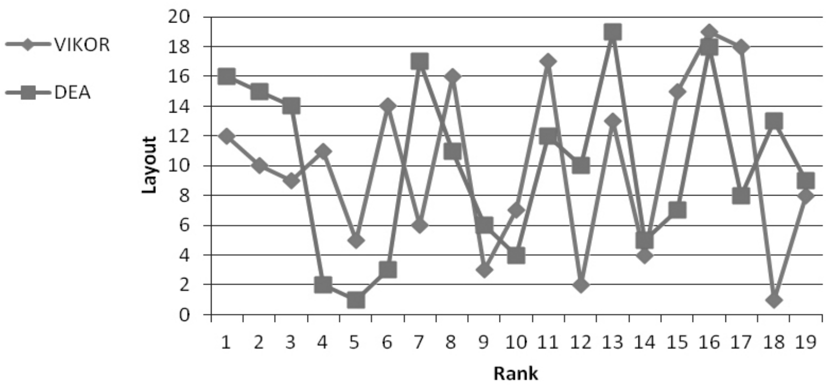

Figure 5. Comparative ranking of layout alternatives for Example-2.

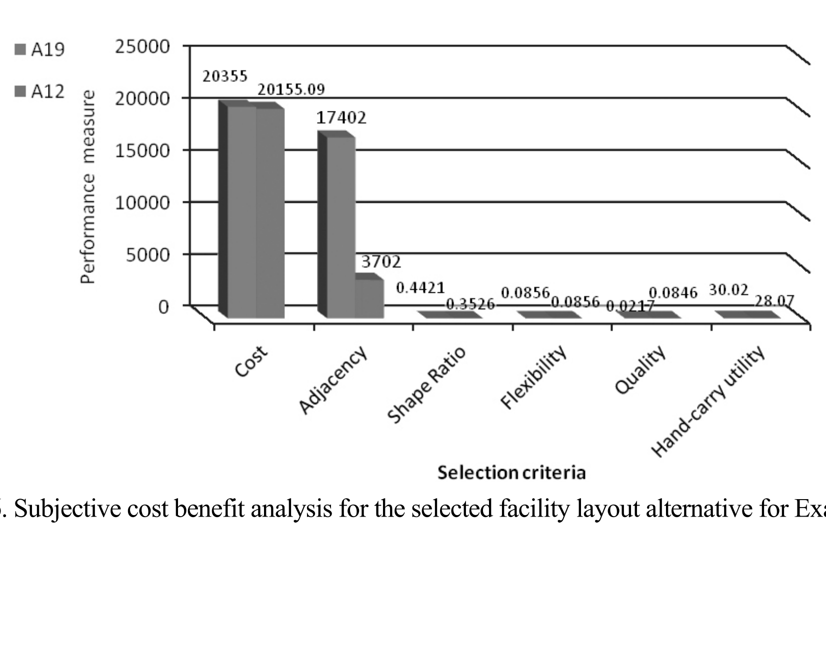

Figure 6. Subjective cost benefit analysis for the selected facility layout alternative for Example-2.

favor of alternative layout design 12, two attribute C3 (benefit to company) and C6 (benefit to company) is in favor of layout design 19 and one attribute C4 is equally good for both the alternatives, therefore weighted sum of selected attributes of alternative layout design 12 is equal to 0.5394 and weighted sum of selected attributes of alternative layout design 19 is equal to 0.2169. Hence, alternative layout design 12 should be preferred over layout design 19, which is same as obtained using integrated procedure of AHP and VIKOR. Hence, alternative A12 is an optimal choice for the decision maker looking to subjective CBA. Therefore, it should be conclude that the proposed method will be a potential tool for selection of optimal facility layout alternative and it can be applied directly for decision making when it is difficult to perform the CBA.

The proposed method does not generate the facility layout alternatives but the proposed method is helpful to select an optimal facility layout alternative from a large number of alternatives generated using various traditional methods or commercial software, such as Spiral, VisFactory, and etc., or using computerized techniques, such as CRAFT, COFAD, CORELAP, CLASS, PLANET, ALDEP, SHAPE, MULTIPLE, etc., for a given application and it can be used for any types of manufacturing industry but all alternatives generated which are involved in the selection process must be for the same application.

6.3 Example-3

Chakraborty and Banik (2007) have presented an illustrative problem for evaluation and selection of optimal FLD alternative using AHP method for a give industrial application. In this problem, Chakraborty and Banik (2007) have considered 10 FLD alternatives and 6 FLD selection attributes or criteria which affect the facility layout selection decision making process, i.e., material flow, information flow, equipment flow, maintenance, flexibility, and adjacency. The interested reader can refer to Chakraborty and Banik (2007) for more details as compared to name and area of departments, the FLPs generated and the definitions of criteria. The data of FLD selection attributes of Example-3 are shown in Table 8. The following procedural steps are carried out.

- Step-I: The objective of the Example-3 is to select the optimal FLD alternative for the given industrial application. In the present Example-3, 10 FLD alternatives and 6 FLD selection attributes or criteria are considered which are same as of (Chakraborty and Banik, 2007). These all FLD alternatives are evaluated with every FLD selection attributes and its performance measures are shown in Table 8. This table represents the step-1 to step-3 of proposed FLD selection methodology.
- Step-II: The maximum and the minimum values of all criterion ratings are determined as follows:

$$f_1^* = 78.16,\ f_2^* = 149.86,\ f_3^* = 117.83,\ f_4^* = 83.8,$$
$$f_5^* = 2.5,\ f_6^* = 166.64,\ f_1^- = 118.72,\ f_2^- = 267.46,$$
$$f_3^- = 141.76,\ f_4^- = 117.12,\ f_5^- = 1.11,\ f_6^- = 128.66,$$

- Step-III and step-IV: The values of S, R, and Q are calculated for all alternatives as Table 9.

Table 9. The values of *S*, *R*, and *Q* for all alternatives

Layout alternatives	*S*	*R*	*Q*
1	0.6082	0.2457	0.6160
2	0.5407	0.2506	0.5621
3	0.1695	0.0587	0.0000
4	0.2749	0.1529	0.2100
5	0.2722	0.1043	0.1461
6	0.7525	0.4524	1.0000
7	0.2584	0.1696	0.2171
8	0.3072	0.0916	0.1598
9	0.3122	0.1395	0.2250
10	0.2362	0.1011	0.1111

Table 8. Quantitative data of the plant layout design selection attributes for various alternatives in Example-3

No.	C1	C2	C3	C4	C5	C6
A1	100.34	267.46	124.05	102.15	1.6	166.64
A2	100.63	252.38	125.24	98.13	2.5	164.94
A3	82.04	171.1	117.83	84.08	1.11	142.92
A4	82.04	222.5	117.83	84.08	1.11	145.9
A5	80.08	199.44	120.08	107.35	1.11	142.66
A6	118.72	149.86	141.76	117.12	1.11	128.66
A7	78.16	230.46	121.49	83.8	1.37	144.15
A8	86.37	155.67	126.37	113.64	1.11	133.69
A9	90.67	188.39	130.67	84.08	2.5	144.54
A10	83.14	197.9	125.86	84.08	2.5	129.26
Weight	0.4524	0.2475	0.1308	0.075	0.0587	0.0356

C1: material flow, C2: information flow, C3: equipment flow, C4: maintenance, C5: flexibility, C6: adjacency.

- Step-V: The ranking of the alternatives by *S*, *R*, and *Q* in increasing order is shown in Table 10.
- Step-VI: As we see in Table 10, the alternative 3 is the best ranked by *Q*. Also the condition C1 and C2 are satisfied $(Q_{A_{10}} - Q_{A_3}) \geq \frac{1}{m-1} = (0.1111 - 0.0000) \geq \frac{1}{10-1}$ and A3 is best ranked by R and S. So is alternative 3 is the best choice.

6.3.1 Result comparison and discussion

In this section, results of the proposed methodology based on VIKOR method is compared with published results to validate the FLD selection methodology. To compare the results, all the FLD alternatives are ranked by the values *S*, *R*, and *Q* in increasing order. A result comparison of the proposed methodology and published results of AHP method is shown in Table 10. As we see in Table 10, the alternative 3 is the best choice by using integrated procedure of AHP and VIKOR. Chakraborty and Banik (2007) had proposed the layout design 2 as the best choice using AHP method. Figure 7 shows the pictorial representation and comparison of alternative 3 and 2 to study the benefits to cost to the company. Now on comparing the alternative layout design 3 and 2 by using CBA, it is found that four attribute—i.e., C1 (reduce the cost to company), C2 (reduce the cost to company), C3 (reduce the cost to company), and C4 (reduce the cost to company)—are in favor of alternative layout design 3, two attribute—C5 (benefit to company) and C6 (benefit to company)—is in favor of layout design 2, therefore, weighted sum of selected attributes of alternative layout design 3 is equal to 0.9057 and weighted sum of selected attributes of alternative layout design 2 is equal to 0.0943. Hence, alternative layout design 3 should be preferred over layout design 2, which is same as obtained using integrated procedure of AHP and VIKOR.

Figure 8 shows the pictorial representation and comparison of the rankings of the proposed method with published results of AHP method to validate the FLD selection methodology. There exists a low rank correlation between these two rankings of the integrated procedure of AHP and VIKOR and AHP method (Spearman rank correlation coefficient, r_s = -0.2848), which shows the different potentiality of both these methods in solv-

Table 10. Ranking the facility layout problems by our model and compared with the analytic hierarchy process (AHP) model

Ranking layout alternatives	By *S*	By *R*	By *Q*	AHP*
1	A3	A3	A3	A2
2	A10	A8	A10	A1
3	A7	A10	A5	A6
4	A5	A5	A8	A9
5	A4	A9	A4	A10
6	A8	A4	A7	A7
7	A9	A7	A9	A4
8	A2	A1	A2	A5
9	A1	A2	A1	A8
10	A6	A6	A6	A3

* Chacraborty and Banik (2007).

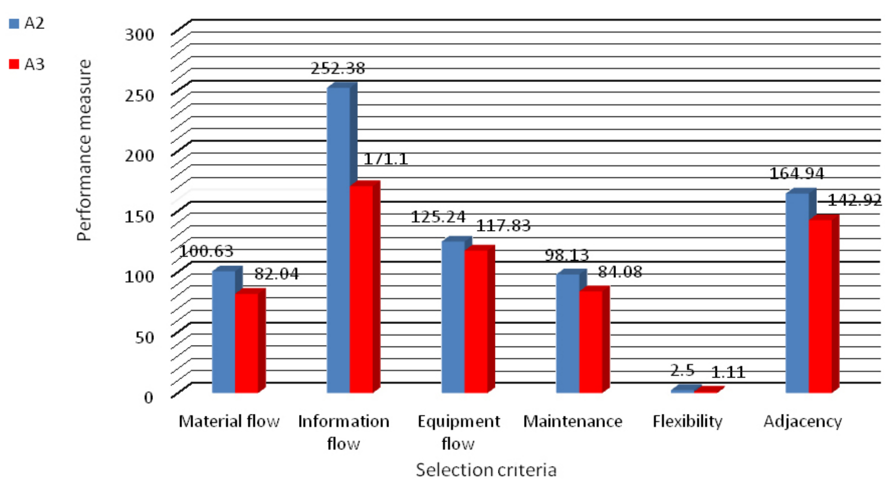

Figure 7. Subjective cost benefit analysis for the selected facility layout alternative for Example-3.

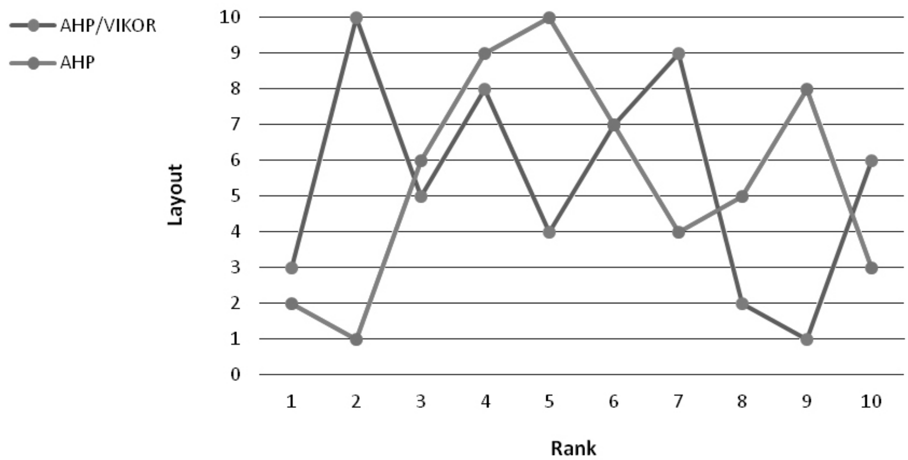

Figure 8. Comparative ranking of layout alternatives for Example-3.

ing such type of FLD selection problems. According to above-discussed results, this shows that our proposed method of comparing the AHP method is giving better results for FLD selection problem.

7. CONCLUSION

The layout design problem is a strategic issue and has significant impacts to the efficiency of a manufacturing system. The importance of an effective facility layout for smooth and streamlined functioning of an organization cannot be overlooked in the present day's highly competitive global environment. The layout decision is usually based on both quantitative and qualitative criteria.

Ignoring the significant criteria (especially, the qualitative criteria which are not easily stateable in the quantitative measures form) in design time will certainly result in increasing the costs, decreasing the productivity, and etc. Keeping this in view, two real time examples are considered and subsequently solved using the VIKOR method which demonstrates the potentiality, applicability, and adaptability of this MADM method in solving the facility layout selection problems. This method focuses on ranking and selecting from a set of alternatives, and determines compromise solutions for a problem with conflicting and non-commensurable criteria, which can help the decision makers to achieve a final decision. Since the priority-ranking alternative by VIKOR is the closest to the optimal solution, the compromise solution is with high acceptance. Also, in this paper the traditional AHP was applied for comparing the FLPs with respect to each qualitative criterion in the pairwise comparison matrix using crisp ratios (the 1–9 scales proposed by Saaty (1980)). But since in world real, evaluating and comparing criteria (particularly qualitative criteria) are stated as linguistic expressions and judgments, it is better to use the fuzzy sets theory for comparisons. The result comparisons show the good reliability of the proposed methodology for selection of optimal FLD alternative from the set of FLD alternatives. Also, it is observed that this method is very flexible, logical, efficient and convenient ranking technique in conception and application as compared to other methods. This method can also be used for any type of decision-making problem, involving any number of qualitative and quantitative criteria, and any number of alternatives.

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