SELECTION OF FACILITY LAYOUT DESIGN USING PROMETHEE AND VIKOR

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Abstract: A manufacturing plant or service center generally is an integrated system comprising of physical arrangement of different facilities within a spatial environment such as, equipment, machines, materials, human accommodation. So a plant may be viewed as a large number of finite geometric areas arranged on the floor space of the building. The problem of arranging these areas in an effective manner is the facility layout problem. The importance of facility layout is the efficient arrangement operation of an enterprise due to their effect in achieving an efficient product flow. In the present work, alternative multiple criteria decision making methodologies are used for selection of facility layout design selection problems. Here the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) and VIKOR (the Serbian name is 'Vlse Kriterijumska Optimizacija Kompromisno Resenje'); the two multi-criteria decision analysis (MCDA) method based ranking procedures are presented and is compared with the results of the available MCDA based ones. This study proposes an approach of deriving the rank value, in order to get optimal configuration, from the average of more than one set of rank results obtained through the deployment of MCDA methodologies.

Keywords: Selection of facility layout design; Multi-criteria decision making (MCDM); Preference ranking organization method for enrichment evaluation (PROMETHEE); VIKOR method.

I. INTRODUCTION

Facility layout planning and design plays a very important role in manufacturing units and also in service outfits. The distance between facilities such as equipment, machines, workstations, assembly shops, maintenance sections, or service centers determines the travel path for material movement or handling. The flow path length comprising of pick up and drop back points of the above facilities, together with human accommodation, ergonomic and environmental considerations has a direct consequences on the travel time, and costs thereof. This in-plant logistics impacts lead time and manufacturing or servicing costs significantly. Layout design can influence quality of manufactured products or service delivery as checking or testing locations needs to be incorporated in the integrated system in most befitting manner besides the fact that in certain situations material damages are obviated by reducing its handling requirement.

A good layout design ensures congestion-free, fast movement with ease and accessibility in the workplace while producing at economical cost. The disposition of facilities in a spatial zone can be arranged in a number of ways resulting in alternative layout configurations. Several such alternatives can be generated taking into consideration of the various criteria, such as, adjacency, flexibility, accessibility etc., involved in a given problem situation or setting. These alternatives are actually created by generating layout configuration using various tools including the conventional ones and engineering software, namely, CORELAP, CRAFT, COFAD, PLANET, ALDEP, or commercial software like Spiral and LayOPT, etc.

Importance of layout design was felt much earlier and works in the aforementioned field were carried out by the pioneers (Immer, 1953; Reed, 1961 and 1967; Moore, 1962; Apple, 1963; and Nadler, 1967). From the nineteen sixties, computerized techniques for design or improvement of a layout had been proposed. CRAFT, CORELAP, ALDEP, and PLANET are among the classical computer aided techniques. The Systematic Layout Planning (SLP) method of Muther (1973) considered as a milestone proposition and was used by researchers and practitioners. Since then, there has been an intensification of research that led to the development of several models for optimized solution, using operational research tools. Also, techniques such as Graph theory, Expert systems(Abdou and Dutta ,1990), simulated annealing (Harmonosky and Tothero,1992), Tabu search (Arostegui, *et al*,2006), Fuzzy set theory (Raoot and Rakshit ,1993), and Genetic algorithms (Xiaodan, *et al*,2007) have been deployed to develop facilities layout design.

Various types of facility layout design and planning are adopted by the industry depending on its product variety or the nature of service the enterprise is providing,. The problem of selection of the facility layout from the set of alternatives, which satisfy different criteria, is considered as a multiple criteria decision analysis (MCDA) problem. MCDA provides an effective framework for comparisons of layout designs based on the evaluation of multiple conflicting criteria. Distinct methodology to develop a crisp activity relationship chart using fuzzy set theory and pair-wise comparisons of the analytic hierarchy process (AHP) were proposed in layout design selection (Dweiri, 1999). Layout design selection procedures based on AHP and data envelopment analysis or DEA (Yang and Kuo ,2003), Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) and fuzzy TOPSIS (Yang and Hung ,2007, Grey Relational Analysis(Kuo, Yang, and Huang, 2008), AHP based approach (Chakraborty and Banik ,2007), are also being used by researchers in solving multiple attribute decision making problems and arrive at the optimal facility layout design.

II. METHODOLOGIES DEPLOYED IN PROPOSED LAYOUT DESIGN SELECTION PROCEDURE:

2.1 A. PROMETHEE Method

Preference function based outranking method is a special type of MCDA approach that can provide a ranking ordering of the decision alternatives. The preference ranking organization method for enrichment evaluation (PROMETHEE) was developed by Brans and Vincke in 1985. The PROMETHEE I method can provide the partial ordering of the decision alternatives, but the PROMETHEE II method can derive the full ranking of the alternatives. In this paper, the PROMETHEE II method is employed to obtain the full ranking of the facility layout designs selection to be used for a given application.

The procedural steps as involved in the PROMETHEE II method are enlisted as below (Brans, J.P. and Vincke, P.H., 1985):

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

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

(1)

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

For non-beneficial attributes, equation (1) can be rewritten as follows:

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

(2)

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

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

There are mainly six types of generalized preference functions as proposed by Brans, J.P., Vincke, P.H. and Mareschal, B., 1986. But these preference functions require the definition of some preferential parameters, such as the preference and indifference thresholds. However, in real time applications, it may be difficult for the decision makers to specify which specific form of preference function is suitable for each criterion and also to determine the parameters involved (Brans, J.P. and Vincke, P.H., 1985). To avoid this problem, the following simplified preference function (Pohekar, S.d, Ramachandran, 2004) is adopted here:

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

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

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

Aggregated preference function,

$$\pi(i, i') = \left[\sum_{j=1}^{m} w_j \times P_j(i, i')\right] \Big/ \sum_{j=1}^{m} w_j$$

(5)

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

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

Leaving (or positive) flow for i^{th} alternative, $\varphi^+(i) =$

$$\frac{1}{n-1} \sum_{i'=1}^{n} \pi(i, i') \qquad (i \ne i')$$

(6)

Entering (or negative) flow for i^{th} alternative, $\varphi^-(i) =$

$$\frac{1}{n-1} \sum_{i'=1}^{n} \pi(i', i) \qquad (i \ne i')$$

(7)

Where n is the number of alternatives.

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

Step 6: Calculate the net outranking flow for each alternative.

$$\varphi(i) = \varphi^+(i) - \varphi^-(i) \quad (8)$$

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

The PROMETHEE method is an interactive multi-criteria decision analysis (MCDA) approach designed to handle quantitative as well as qualitative attributes with discrete alternatives. In this method, pair-wise comparison of the alternatives is performed to compute a preference function for each criterion. Based on this preference function, a preference index for alternative i over i' is determined. This preference index is the measure to support the hypothesis that alternative i is preferred to i'. The PROMETHEE method has significant advantages over the other MCDA approaches, e.g. analytic hierarchy process (AHP) and multi-attribute utility theory (MAUT). Difficult to be compared the alternatives can be classifying by using PROMETHEE method because of a trade-off relation of evaluation standards as non-comparable alternatives.

2.2 VIKOR method

The VIKOR (the Serbian name is 'Vlse Kriterijumska Optimizacija Kompromisno Resenje' which means multi-criteria optimization (MCO) and compromise solution) method was mainly established by Zeleny, 2002 and later advocated by Opricovic and Tzeng, 2007. This method is developed to solve MCDA problems with conflicting and non commensurable (attributes with different units) criteria, assuming that compromise can be acceptable for conflict resolution, when the decision maker wants a solution that is the closest to the ideal solution and the alternatives can be evaluated according to all the established criteria. It focuses on ranking and selecting the best alternative from a set of alternatives with conflicting criteria, and on proposing compromise solution (one or more). The compromise solution is a feasible solution, which is the closest to the ideal solution and farthest from the negative- ideal solution, and a compromise means an agreement established by mutual concessions made between the alternatives. The following multiple attribute merit for compromise ranking is developed from the Lp-metric used in the compromise programming method (Rao RV, 2008).

The weight is calculated by entropy method. The summation of all the weights calculated is 1.

Steps to be followed:

First of all select the criteria according to the alternatives (DMUs).

Calculate the minimum and maximum of each criterion.

Calculate the weight of each criteria and go for calculating the E_i,F_i and P_i values according to standard formula.

For each alternative (DMUs) there are six numbers of criteria so for each alternative different E_i are obtained by following equation :(for beneficial criteria)

$$Ei = L_{ij} = \sum_{j=1}^{M} Wj\left[\left(M_{ij}\right)max - \left(M_{ij}\right)\right] / \left[\left(M_{ij}\right)max - \left(M_{ij}\right)min\right] \quad (9)$$

Then the maximum and minimum of E_i are to be noted. It must be noted that for beneficial and for non-beneficial the procedure is same but formula is different.

E_i can be obtained for non beneficial criteria by using following equation:

$$Ei = L_{ij} = \sum_{j=1}^{M} Wj\left[\left(M_{ij}\right) - \left(M_{ij}\right)min\right] / \left[\left(M_{ij}\right)max - \left(M_{ij}\right)min\right] \quad (10)$$

The F_i is calculated there after by the equation as follows

$$Fi = L\infty, j = MAX^{m} of \left\{\frac{Wj[(Mij)-(Mij)]}{[(Mij)max-(Mij)min]}\right\} \quad (11)$$

Here also beneficial and non-beneficial are to be considered.

The P_i is calculated by the equation as follows:

$$P_i=v((E_i-E_{i\text{-}min})/(E_{i\text{-}max}-E_{i\text{-}min}))+(1-v)((F_i-F_{i\text{-}min})/(F_{i\text{-}max}-F_{i\text{-}min})) \quad (12)$$

where $E_{i\text{-}max}$ and $E_{i\text{-}min}$ are the maximum and minimum values of E_i respectively, and $F_{i\text{-}max}$ and $F_{i\text{-}min}$ are the maximum and minimum values of Fi respectively. v is introduced as weight of the strategy of 'the majority of attributes' (or 'the maximum group utility'). The value of v lies in the range of 0–1. Normally, the value of v is taken as 0.5. The compromise can be selected with 'voting by majority' ($v > 0.5$), with 'consensus' ($v = 0.5$) or with 'veto' ($v < 0.5$).

According to the P_i values we get the rank, lowest the value of P_i highest the rank.

III. APPLICATION OF MCDA ON SECONDARY DATA

Yang & Kuo, (2003) have presented an illustrative problem for evaluation and selection of optimal facility layout design by using the AHP and data envelopment analysis (DEA) based method. Yang and Kuo(2003) have generated and considered 18 facility layout design alternatives or "Decision Making Unit", (DMU) and six facility layout design 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 quantitative measures of various criteria for the 18 facility layout design alternatives are given in Table 1.

Table 1 Quantitative measures of different criteria for the alternative layouts (Yang & Kuo, 2003).

DMU NO	Distance	Adjacency	Shape ratio	Flexibility	Accessibility	Maintenance
1	185.95	8	8.28	0.0494	0.0294	0.013
2	207.37	9	3.75	0.0494	0.0147	0.0519
3	206.38	8	7.85	0.037	0.0147	0.0519
4	189.66	8	8.28	0.037	0.0147	0.0519
5	211.46	8	7.71	0.0617	0.0147	0.039
6	264.07	5	2.07	0.0494	0.0147	0.0519
7	228	8	14	0.0247	0.0735	0.0649
8	185.59	9	6.25	0.037	0.0441	0.039
9	185.85	9	7.85	0.0741	0.0441	0.0519
10	236.15	8	7.85	0.0741	0.0588	0.0649
11	183.18	8	2	0.0864	0.1029	0.0909
12	204.18	8	13.3	0.037	0.0588	0.026
13	225.26	8	8.14	0.0247	0.0735	0.0519
14	202.82	8	8	0.0247	0.0588	0.0519
15	170.14	9	8.28	0.0864	0.1176	0.1169
16	216.38	9	7.71	0.0741	0.0735	0.0519
17	179.8	8	10.3	0.0988	0.1324	0.0909
18	185.75	10	10.16	0.0741	0.0588	0.039
MAX	264.07	10	14	0.0988	0.1324	0.1169
MIN	170.14	5	2	0.0247	0.0147	0.013
BF/NBF	NBF	BF	NBF	BF	BF	BF
WT	0.179174	0.177096	0.164646	0.163549	0.14839	0.167145

In this present work, the same data set as secondary data has been used to obtain the ranking of layout design alternatives to determine the optimal layout configuration for deploying PROMETHEE and VIKOR methodologies. While solving the problem it has been considered that Distance and Shape ratio as non beneficial as these two are to be minimized and Adjacency, Flexibility, Accessibility, Maintenance are considered as beneficial as these are to be maximized. The weight is calculated by entropy method. The summation of all the weights calculated is 1.

3.1Application of PROMETHEE Method on Secondary Data

Step 1: Using the following equation (1) and (2), Normalization of the decision matrix for the beneficial and non-beneficial attributes are done respectively.

Step 2: Now, the preference functions are calculated for all the pairs of alternatives, using Eqns. (3) and (4) respectively.

Step 3: The leaving flow and entering flow alternatives for different layouts are calculated using Eqns. (6) and (7) respectively and are given in Table 2.

Table 2 Leaving flows, entering flows for different facility layout

Layout	Leaving flow, φ+	Layout	Entering flow, φ-
1	0.51278829	1	3.87879373
2	2.31814636	2	2.2182363
3	2.19937118	3	1.77779639
4	0.78604391	4	3.44590356
5	2.84029797	5	1.46177453
6	11.4412484	6	1.59625214
7	6.16685109	7	0.54650655
8	0.51353142	8	4.07712301
9	0.59420761	9	3.85328131
10	6.64643363	10	0.54581395
11	0.22411473	11	4.99720518
12	2.76634359	12	1.79407393
13	4.86171059	13	0.78506215
14	1.63946764	14	2.07650864
15	0.39456424	15	6.53389526
16	3.62161848	16	1.13224999
17	0.64649607	17	4.78868667
18	1.06275894	18	3.72683082

Step 5: Using Equ. (8), the values of the net out ranking flow for alternative layout are estimated. Table 3 shows the net outranking flow values for different layouts are ranked in descending order . The best choice of layout for the given situation is layout A6.

Table 3: Net flow values for different facility layout and give the ranking

Layout	Net φ	Rank
1	-3.36601	14
2	0.09991	9
3	0.421575	8
4	-2.65986	11
5	1.378523	6
6	9.844996	1
7	5.620345	3
8	-3.56359	15
9	-3.25907	13
10	6.10062	2
11	-4.77309	17
12	0.97227	7
13	4.076648	4
14	-0.43704	10
15	-6.13933	18
16	2.489368	5
17	-4.14219	16
18	-2.66407	12

3.2Application of VIKOR Method on Secondary Data

Step-I: The objective of the Example is to select the optimal facility layout design alternative for the given industrial application. In the present Example, 18 facility layout design alternatives and 6 facility layout design selection attributes or criteria are considered which are same as of Yang and Kuo (2003).

Step-II: Calculation of the minimum and maximum of each criterion has done.

Step-III: The weight is calculated by entropy method. Weight of the each criterion is accordingly 0.179174, 0.177096, 0.164646, 0.163549, 0.14839, and 0.167145.

Then go for calculating the F_i values according to standard formula.

Table-4 Calculation of the F_i values

DMU NO	Fi 1	Fi 2	Fi 3	Fi 4	Fi 5	Fi 6	MAX(Fi)	MIN(Fi)
1	0.030158	0.106258	0.086165	0.109033	0.129857	0.167145	0.167145	0.030158
2	0.071017	0.141677	0.024011	0.109033	0.14839	0.104566	0.14839	0.024011
3	0.069129	0.106258	0.080265	0.136401	0.1484	0.104566	0.14839	0.069129
4	0.037235	0.106258	0.086165	0.136401	0.14839	0.104566	0.14839	0.037235
5	0.078819	0.106258	0.078344	0.081885	0.14839	0.125319	0.14839	0.078344
6	0.179174	0	0.00096	0.109033	0.14839	0.104566	0.179174	0
7	0.11037	0.106258	0.164646	0.163549	0.074258	0.083653	0.164646	0.074258
8	0.029471	0.141677	0.058312	0.136401	0.111324	0.125319	0.141677	0.029471
9	0.029967	0.141677	0.080265	0.054516	0.111324	0.104566	0.141677	0.029967
10	0.125916	0.106258	0.080265	0.054516	0.092791	0.083653	0.125916	0.054516
11	0.024874	0.106258	0	0.027369	0.037192	0.041826	0.106258	0
12	0.064932	0.106258	0.155042	0.136401	0.092791	0.146232	0.155042	0.064932
13	0.105143	0.106258	0.084244	0.163549	0.074258	0.104566	0.163549	0.074258
14	0.062338	0.106258	0.082323	0.163549	0.092791	0.104566	0.163549	0.062338
15	0	0.141677	0.086165	0.027369	0.018659	0	0.141677	0
16	0.088204	0.141677	0.078344	0.054516	0.074258	0.104566	0.141677	0.054516
17	0.018427	0.106258	0.11388	0	0	0.041826	0.11388	0
18	0.029776	0.177096	0.111959	0.054516	0.092791	0.125319	0.177096	0.029776

Step-IV: Then E_i and P_i is calculated by using the standard formula.

Table-5 calculation of E_i and P_i

	Ei	Pi	Rank
1	0.295629664	0.218719	1
2	0.353800065	0.450719	10
3	0.34537794	0.255524	4
4	0.32	0.236293	2
5	0.386911277	0.289643	6
6	0.297229599	0.719902	18
7	0.538897132	0.598456	16
8	0.335500474	0.248217	3
9	0.460586451	0.34076	8
10	0	0.5	14
11	0.503828703	0.489799	12
12	0.429891481	0.318051	7
13	0.432355145	0.492819	13
14	0.369096381	0.273072	5
15	0.660897951	0.488959	11
16	0.553968358	0.603099	17
17	0.675821992	0.580904	15
18	0.525289881	0.38863	9

COMPARATIVE ANALYSIS OF RESULTS ON RANKING

Results obtained by using PROMETHEE II and VIKOR methodologies are compared with published results of various MCDA methods to validate the facility layout design selection methodology.

In VIKOR method all the 18 alternative configurations in possible facility layout design is compared and ranking is done according to the performance score obtained. That is, lowest the value of P_i highest the rank. The best choice of layout for the given situation is layout A1.

In PROMETHEE II, the net outranking flow values for different layouts are ranked in descending order as shown in Table 3. The best choice of layout for the given situation is layout alternative A6.

Yang & Kuo, (2003) have presented the illustrative problem for evaluation and selection of optimal facility layout design by using the AHP and data envelopment analysis (DEA) based method. DEA suggest the facility A11, A15 and A18 as optimal facility layout design alternative. Hence, it poses difficulty in deciding the best layout. Yang and Hung (2007) solved the same problem using TOPSIS and fuzzy TOPSIS. TOPSIS suggests the alternative A11 as optimal layout configuration. Kuo et al. (2008) used Grey Relational Analysis (GRA) for solving the facility layout design problems. Kuo et al. (2008) suggest alternative A15 as optimal facility layout design alternative.

The comparative analysis on ranking results is presented here, and for this the same problem as referred earlier has been considered with solutions using different MCDA methodologies.

In present work PROMETHEE II method is solving facility layout selection decision-making problem. This method can incorporate the decision maker's preferences regarding the relative importance of different criteria. The measures of the qualitative and quantitative criteria and their relative importance are used together to rank the alternative layout, providing a better evaluation of the alternatives. The PROMETHEE I method cannot provide a complete ranking of the facility layout design , whereas the PROMETHEE II method can provide the complete preorder by using a net flow.

The VIKOR method is solve the facility layout selection decision making problems with conflicting and non commensurable (attributes with different units) criteria, assuming that compromise can be acceptable for conflict resolution, when the decision maker wants a solution that is the closest to the ideal solution and the alternatives can be evaluated according to all the established criteria. It focuses on ranking and selecting the best alternative from a set of alternatives with conflicting criteria, and on proposing compromise solution (one or more).

All the MCDA methodologies can give different answers to the same problem. The most difficult problem that arises here is how one can evaluate a multi-dimensional decision analysis method (MCDA) when the proper superlative alternative is not known. For that we take the average of all proposed and existing methodologies which demonstrate over the same problem. Calculating the average value by combining all of the proposed and existing methodologies, it is seen that the alternative having the minimum average value (A11) is the best optimal facility layout design alternative.

Table 6 Comparative study of different methodology

Alternative	Proposed methodology VIKOR	Proposed methodology PROMETHEE II	DEA Yang and Kuo (2003)	TOPSIS Yang and Hung (2007)	FuzzyTOPSIS Yang and Hung (2007)	GRA Kuo et al. (2008)	Average
A1	1	14	10	16	13	10	10.67
A2	10	9	4	9	9	8	8.17
A3	4	8	15	10	14	15	11
A4	2	11	11	4	4	11	7.17
A5	6	6	14	12	12	13	10.5
A6	18	1	6	6	16	16	10.5
A7	16	3	18	18	17	17	14.83
A8	3	15	7	13	6	7	8.5
A9	8	13	8	15	11	5	10
A10	14	2	12	3	7	9	7.83
A11	12	17	1	1	1	3	5.83
A12	7	7	17	17	15	18	13.5
A13	13	4	16	14	18	14	13.17
A14	5	10	13	5	8	12	8.83
A15	11	18	1	2	2	1	5.83
A16	17	5	5	8	10	6	8.5
A17	15	16	9	7	5	2	9
A18	9	12	1	11	3	4	6.67

CONCLUSION

The proposed methodologies for selection of optimal facility layout design alternative using PROMETHEE II and VIKOR method is a relatively less cumbersome approach. The proposed methodologies based on PROMETHEE II and VIKOR are helpful in selecting an optimal facility layout alternative. In this work, it is proposed that to determine the best alternative it is required to compute the average value of the order of the rank from the available rank order obtained by using more than one methodology.

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