**Multi-Criteria Decision Analysis in Selection of Facility Layout Design**

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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) the multi-criteria decision analysis (MCDA) method based on ranking procedure is presented and it 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); PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation).

**1 Introduction**

Facility layout planning and design plays an 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 direct consequences on the travel time, and costs thereof. This in-plant logistics have impacts on lead time and manufacturing, or servicing, costs significantly. Layout design can influence quality of manufactured products or service delivery as checking or testing locations need 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; 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, 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 system (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 algorithm (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 et al., 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.

**2 Methodology Deployed in Proposed Layout Design Selection Procedure Based on PROMETHEE**

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 design selection to be used for a given application.

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

Step 1: To normalize the decision matrix using the following equation:

 (1)

Where, Xij is the performance measure of ith alternative with respect to jth criterion.

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

 (2)

Step 2: To calculate the evaluative differences of ith alternative with respect to other alternatives. This step involves the calculation of differences in criteria values between different alternatives pair-wise.

Step 3: To calculate the preference function, 

There are mainly six types of generalized preference functions as proposed by Brans, J.P., Vincke, P.H. and Mareschal, B. in 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 and Vincke, 1985). To avoid this problem, the following simplified preference function (Pohekar and Ramachandran, 2004) is adopted here:

 (3)

 (4)

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

Aggregated preference function,  (5)

Where wj is the relative importance (weight) of jth criterion.

Step 5: To determine the leaving and entering outranking flows as follows:

Leaving (or positive) flow for ith alternative, φ+(i) =  (6)

Entering (or negative) flow for ith alternative, φ-(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: To calculate the net outranking flow for each alternative.

 (8)

Step 7: To determine the rankings of all the considered alternatives depending on the values of the higher is the value of the better is the alternative. Thus, the best alternative is the one having the highest  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  is determined. This preference index is the measure to support the hypothesis that alternative i is preferred to. 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 alternatives can be classified by using PROMETHEE method because of a trade-off relation of evaluation standards as non-comparable alternatives.

**3 Application of MCDA on Secondary Data**

Yang and 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.

Distance can be defined as the path to be followed by materials from facility to facility during transformation process. Adjacency can be achieved by maximizing the closeness and compactness between various departments in the facility layout.  Shape ratio is the ratio of longer dimension to its shorter dimension. It may be applied to two characteristic dimensions of a three-dimensional shape. It plays a very important role in facility layout for proper use of cubic space of the floor. Flexibility means either capability to perform variety of operation under a variety of operating conditions or future expansion. Flexibility refers to the ease with which parameters and components of the facility layout can be modified in dynamic scenarios or in performing some sort of scenario analysis. Accessibility can be viewed as the ‘ability to access’ and benefit from some system or entity. Maintenance involves space allotted for maintenance personnel and maintenance equipments for smooth and trouble free operation.

In the 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 methodology. 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.

**4 Application of PROMETHEE Method on Secondary Data**

Step 1: Using Equations (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 Equations (3) and (4) respectively.

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

**Table 1** Quantitative measures of different criteria for the alternative layouts (Yang and 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 |

**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 Equation (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 with its ranking. 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 |

**5. Comparative Analysis of Results on Ranking**

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

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

Yang and 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 the 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.

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 the authors take the average of all proposed and existing methodologies which demonstrate over the same problem. Comparative study of the proposed and existing methodologies shows that the (A11) alternative having the minimum rank is the best optimal facility layout design alternative.

**Table 6** Comparative study of different methodologies

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Alternative | Proposed methodology PROMETHEE II | DEA  Yang and Kuo (2003) | TOPSIS  Yang and Hung (2007) | Fuzzy TOPSIS  Yang and Hung (2007) | GRA  Kuo et al. (2008) |
| A1  A2  A3  A4  A5  A6  A7  A8  A9  A10  A11  A12  A13  A14  A15  A16  A17  A18 | 14  9  8  11  6  1  3  15  13  2  17  7  4  10  18  5  16  12 | 10  4  15  11  14  6  18  7  8  12  1  17  16  13  1  5  9  1 | 16  9  10  4  12  6  18  13  15  3  1  17  14  5  2  8  7  11 | 13  9  14  4  12  16  17  6  11  7  1  15  18  8  2  10  5  3 | 10  8  15  11  13  16  17  7  5  9  3  18  14  12  1  6  2  4 |

**6. Conclusion**

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

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