IMPACT: International Journal of Research in Engineering & Technology
ISSN(P): 2347–4599; ISSN(E): 2321–8843
Vol. 10, Issue 7, Jul 2022, 13–20

MARGINAL ANALYSIS FOR GROUP TOPSIS WITH ANAPPLICATION TO FACILITIES LAYOUT DESIGN SELECTION

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Received: 15 Jul 2022 **Accepted:** 18 Jul 2022 **Published:** 25 Jul 2022

ABSTRACT

There is a requirement of very high capital outlay but moderate risk in setting up a Flexible Manufacturing System (FMS). The same is true while organizing production using CNC, DNC and CIM. In today's manufacturing world of JIT, economic justification techniques are insufficient by themselves since they cannot cope with the benefits such as flexibility, improved quality, reliability and maintaining delivery schedules. Hence, a robust decision making procedure for evaluating Facilities Layout (FL) alternatives requires the consideration of both economic and strategic issues. An extension of TOPSIS (Technique for Order Performance by Similarity to Ideal Solution), a Multi-Attribute Decision Making (MADM) technique, to a group decision environment is investigated here in this article. TOPSIS in conjunction with marginal analysis is a practical and useful technique for ranking and selection of a number of externally determined alternatives through distance measures. To get a broad view of the techniques used, we provide a few options for the operations, such as normalization, distance measures and mean operators, at each of the corresponding steps of TOPSIS.

The proposed model is indeed a unified process and it will be readily applicable to many real-world decision making situations without increasing the computational burden. The results have demonstrated the model to be both robust and efficient.

KEYWORDS: *Facilities Layout Selection, TOPSIS, Multi-Attribute Decision Making, Group Decision, Distance Measure, Normalization*

1. INTRODUCTION

The layout design of facilities problem is a spatial problem. It is the problem of arranging departments with the objective of optimal utilization of resources. Hence, traditionally, many FL models and techniques based on Distance-based approach (DBA) and Adjacency-based approach have been developed. These problems have also been modeled as LIP (Linear Integer Programming) and MIP (Mixed Integer Programming) problems using Discrete and Continuous representation. Also, CRAFT (Armour& Buffa 1963), ALDEP (Seehof & Evans 1967), CORELAP (Lee & Moore 1992), SPIRAL (Goetschalckx 1992) and MULTIPLE (Bozer 1994) and many Graph Theoretic approaches have done intricate discussions on FL problems.

Modern manufacturing firms need to focus on increasing the quality, degree of responsiveness to customers' demands, level of customization and while lowering costs to compete in the global competition. In today's competitive marketplace the slogan is 'produce quality, have flexibility and remain lean or perish'.

Marginal Analysis or incremental analysis is an important tool for evaluating alternatives in engineering economy. It can be defined as the examination of the differences between two alternatives from the aspect of benefits and costs. By emphasizing alternatives, in an ascending order of costs, experts decide whether or not differential costs are justified by differential benefits. This ratio is very valuable to make a correct judgment. Though, MCDM/MADM techniques rank the alternatives and aid in the selection of the best one, it has two prominent limitations. One concerning the ranking of the alternatives and another concerns the choice of alternatives. For this reason, incremental analysis becomes indispensable to solve such a problem in a robust fashion [1,2].

2. PRIOR ART

Facility Layout deals with the selection of most appropriate and effective arrangements of departments in the open continual plane to allow greater working efficiency (Apple, 1977, Deb et al. 2001a). In the last two decades, a number of researchers have addressed the selection and justification of advanced manufacturing technologies. Falkner and Benhajla 1990, Proctor and Canada 1992 and Son 1992 presented comprehensive bibliographies on justification of advanced and alternate manufacturing technologies that prove to be valuable resources for the industry.

The MADM algorithm presented in this paper is based on the concept of proximity to ideal solution. The source of this method can traced to TOPSIS developed by Hwang & Yoon, 1981) and later improved by the same researchers in 1995. The premise of this concept is that the current MADM technique selects the alternative with shortest distance from the ideal alternative and it obviously has the farthest distance from the anti-ideal alternative. The uniqueness of TOPSIS is that it considers distances from both the ideal and anti-ideal solutions simultaneously.

But the traditional TOPSIS approach uses Euclidean norm to normalize the original attribute values and the distance to calculate each alternatives' distances from the ideal and anti-ideal solutions. The ideal solution is the one having best attribute values and anti-ideal is one that has worst attribute values attainable. The relative proximity (similarity) of each alternative to the ideal solution is calculated based on the distances from both the ideal and anti- ideal solutions at the same time. The preference of alternatives is determined by making the calculated proximity measures in the descending order. Kim et.al. 1997, Agarwal et.al. 1997 have used TOPSIS for various applications such as robot selection, selection of optimum grippers. Normalization in TOPSIS is carried out to make all the attributes unit-free components so as to make them comparable.

There exists a post selection operation called Sensitivity Analysis, which attempts to guarantee the evaluation results to be robust. This investigates the change in the optimal solution resulting from a perturbation in a variety of parameters or trade-off rates, even on the weights of criteria or the uncertainty on performance measures [3]. Nevertheless, the aim of the analysis provides additional information about the range of parameters of alternatives so that the experts can be cautious in making decisions [1].

3. PROCEDURAL STEPS

Step 1: Construct the Decision Matrix

Depict all the objective and subjective criteria. Ascertain all the alternative FLs (FL_1, FL_2, FL_3,…….FL_i), the team of experts (E_1, E_2, E_3,……..E_k) and number of criteria (X_1, X_2, X_3,……..X_n)

$$D^K = \begin{array}{c} \\ FL_1 \\ FL_2 \\ FL_3 \\ \vdots \\ FL_m \end{array} \begin{array}{c} \begin{array}{cccc} X_1 & X_2 & X_3 \;\dots\dots & X_n \end{array} \\ \begin{bmatrix} x_{11}^k & x_{12}^k & & x_{1n}^k \\ x_{21}^k & x_{22}^k & \cdots\cdots & x_{2n}^k \\ x_{31}^k & x_{32}^k & & x_{3n}^k \\ \vdots & \vdots & \ddots & \vdots \\ x_{m1}^k & x_{m2}^k & \cdots\cdots & x_{mn}^k \end{bmatrix} \end{array} \tag{1}$$

where FL_i denotes i^{th} alternative, i=1,2,….,m, X_j denotes j^{th} criteria, j=1,2,…..,n and K denotes number of Decision Makers. Thus x_{ij}^k denotes element 'x' of the i^{th} alternative of the j^{th} criteria according to k^{th} decision maker. There should be 'K' decision matrices for the K members of the group. To avoid confusion in the incremental analysis, we must separate all the elements of the decision matrix D^k into two categories of benefit and cost criteria. That is, it must be such that, p benefit and q cost criteria will follow $p + q = n$.

Step 2: Normalize the decision matrix D^K to get the matrix N^K. The elements of the matrix will be $n_{ij}^k = \frac{x_{ij}^k}{\sqrt{\sum_{j=1}^n \left(x_{ij}^k\right)^2}}$, where i=1, …,m; j=1,….,n.

Step 3: The weights are calculated by each expert using **Entropy Method** [4]. The weights are assigned to the benefit criteria only of each decision maker.

Step 4: Normalise the weights to obtain normalised weight matrix W^K of the decision matrix. The elements of W^K are obtained using $w_{ij}^{nk} = \frac{w_{ij}^k}{\sum_{j=1}^n w_{ij}^k}$ with i=1, …, m; j=1,….,n.

Step 5: Construct the modified normalized weighted decision matrix M^K, with each element of M^K is obtained using $m_{ij}^k = w_{ij}^{nk} \times n_{ij}^k$

Step 6: Find out Ideal and Anti-Ideal solutions for all the benefit criteria for each expert. For the k^{th} expert, k=1,….,K, the ideal and anti-ideal solutions are given by (refer TOPSIS [4])

$$M^{K+} = \{m_i^{K+}, \dots \quad \dots\dots.., \quad \dots m_n^{K+}\} = \{\max m_{ij}^{K+} | j \in J | i = 1, \dots, m\} \text{ and}$$

$$M^{K-} = \{m_i^{K-}, \dots \quad \dots\dots.., \quad \dots m_n^{K-}\} = \{\min m_{ij}^{K+} | j \in J | i = 1, \dots, m\}$$

Step 7: Calculate the separation measures from both the ideal and anti-ideal solutions, $(SM)_{Bi}^{+}$ and $(SM)_{Bi}^{-}$ respectively, for the benefit criteria of the group of experts. The subscript 'B' indicates benefit criteria. This step has two sub-steps – 1) to calculate distances for individual experts and then 2) for the group.

Step 7a: Individual separation measures are calculated using

$(SM)^{+} = \{\sum_{j=1}^{n} \left| m_{ij}^{k} - m_{j}^{k+} \right|^{p}\}^{\frac{1}{p}}$ for alternative FL$_1$, i=1,2,…, m and

$(SM)^{-} = \{\sum_{j=1}^{n} \left| m_{ij}^{k} - m_{j}^{k-} \right|^{p}\}^{\frac{1}{p}}$ for alternative FL$_1$, i=1,2,…, m.

But, for most common cases the value of p=2.

Step 7b: Calculate the separation measures of the group. The group separation measures of each alternative are combined through an operation that can have many choices viz., geometric mean, arithmetic mean, harmonic mean or their modifications.

Step 8: The Relative Closeness Rating CR_i^* to the ideal solution for the group and for the benefit criteria is calculated. The alternatives are ranked in the descending order. This can be expressed $CR_i^* = \frac{SM_i^-}{SM_i^+ + SM_i^-}$, where i=1,2,…., m.

Step 8a: The group separation measures with K experts are calculated using

$$SM_{Gi}^{+} = (\prod_{k=1}^{K} SM^{K+})^{\frac{1}{K}} \text{and} SM_{Gi}^{-} = (\prod_{k=1}^{K} SM^{K-})^{\frac{1}{K}}$$

Step 8b: The group relative closeness to ideal solution for the benefit criteria of the group is calculated using $CR_{Gi}^* = \frac{SM_{Gi}^-}{SM_{Gi}^+ + SM_{Gi}^-}$, i=1,2,….m. Here, 0≤ CR_{Gi}^* ≤1 and larger is the value of CR_{Gi}^*, better is the performance of the alternative.

Step 9: Construct the Cost Indicator value for Cost Criteria$(CC_i)$by directly considering the normalized MH cost valuesas shown on Table 12. This is calculated using $CC_i = \frac{y_i}{\sqrt{\sum_{i=1}^{n}(y_i)^2}}$, i=1,..m, and y = MH cost factor.

Step 10: Conduct Incremental Analysis: Rearrange all the alternatives by their benefit and cost indices in the ascending order. The incremental analysis is carried out on pair-wise basis of the cost information. It has the following step:

Step 10a: The differences in the benefits ΔCR_i^* and that of costs ΔCC_i^K are calculated. They are listed with the smallest index and the next smallest one. If the ratio of the differences of benefit and cost, $\Delta CR_i^*/\Delta CC_i^K$ is greater than 1, then the latter one is kept; otherwise, the former one is reserved [2]. The alternative left is manipulated with the alternative with the next smallest cost index of the order until the alternative with the largest cost index is compared.

4. A CASE STUDY

A modern manufacturing company, that manufactures high value, high precision components that go in the assembly of critical parts is considered for the study here. 5 experts were to select one best suited layout from amongst 4 alternatives considering 8 influential criteria. There were 5 objective criteria and 3 subjective criteria under consideration of which 7 benefit criteria and 1 cost criteria. The Decision Matrix ‘D^k’, k=1,2,….,K by each decision maker and with the objective values are depicted as below

Table 1: Objective Performance Capability Criteria of the FLs

FL Options	Area needed (m^2)	Machines handled	WIP(units)	Bottle Necks	MH Costs ($)
FL_1	640	10	59.6	4	95,000
FL_2	940	12	74.9	3	55,000
FL_3	680	09	68.8	5	45,000
FL_4	820	08	81.5	2	40,000

Table 2: Subjective Appraisal of Alternative FLs by Experts

FL Options	Expert 1			Expert 2			Expert 3			Expert 4			Expert 5		
	LF	LR	LIP	LF	LR	LIP	LF	LR	LIP	LF	LR	LIP	LF	LR	LIP
FL_1	2	9	6	4	9	2	6	9	5	7	9	6	9	3	3
FL_2	3	8	7	3	8	9	3	6	5	5	3	9	8	4	3
FL_3	5	7	4	5	7	4	2	3	8	8	5	9	7	5	6
FL_4	9	2	5	7	3	4	5	4	2	2	3	2	3	8	7

(LF–Layout Flexibility; LR–Layout Reliability; LIP–Layout Improvement Possibility)

Table 3: Normalized Decision Matrix of Benefit Criteria (Objective)

FL Options	Area needed (m^2)	Machines handled	W-I-P(units)	Bottle Necks
FL_1	0.4107	0.5070	0.4159	0.5443
FL_2	0.6031	0.6084	0.5226	0.4083
FL_3	0.4364	0.4563	0.4801	0.6805
FL_4	0.5262	0.4056	0.5687	0.2722

Table 4: Normalized Decision Matrix of Benefit Criteria by Experts (Subjective)

FL Options	Expert 1			Expert 2			Expert 3			Expert 4			Expert 5		
	LF	LR	LIP	LF	LR	LIP	LF	LR	LIP	LF	LR	LIP	LF	LR	LIP
FL_1	0.1833	0.6396	0.5345	0.4020	0.5669	0.1849	0.6975	0.7553	0.4603	0.5874	0.8082	0.4221	0.6317	0.2810	0.2956
FL_2	0.2750	0.5685	0.6236	0.3015	0.5039	0.8320	0.3488	0.5035	0.4603	0.4196	0.2694	0.6333	0.5615	0.3746	0.2956
FL_3	0.4583	0.4975	0.3563	0.5025	0.4409	0.3698	0.2325	0.2518	0.7364	0.6714	0.4490	0.6333	0.4913	04683	0.5912
FL_4	0.8250	0.1421	0.4454	0.7035	0.1890	0.3698	0.5813	0.3357	0.1841	0.1678	0.2694	0.1407	0.2106	0.7493	0.6900

Table 5: Weights - Experts' Rating by ENTROPY Method

Experts	Areaneeded (m^2)	Machines handled	W-I-P(units)	BottleNecks	LF	LR	LIP
1	0.0339	0.0329	0.0196	0.1443	0.4220	0.2890	0.0584
2	0.0368	0.0355	0.0212	0.1565	0.1422	0.1953	0.4123
3	0.0358	0.0346	0.0207	0.1523	0.2347	0.2446	0.2772
4	0.0302	0.0292	0.0174	0.1281	0.2417	0.2705	0.2826
5	0.0429	0.0414	0.0248	0.1825	0.2277	0.2320	0.2487

Table 6: Normalized Weights of Benefit Criteria by Experts

Experts	Area needed (m^2)	Machines Handled	W-I-P(units)	Bottle Necks	LF	LR	LIP
1	0.1887	0.1895	0.1889	0.1889	0.3327	0.2347	0.0457
2	0.2048	0.2045	0.2044	0.2048	0.1108	0.1586	0.3223
3	0.1993	0.1993	0.1996	0.1993	0.1851	0.1986	0.2167
4	0.1682	0.1682	0.1678	0.1681	0.1906	0.2197	0.2209
5	0.2389	0.2385	0.2392	0.2389	0.1795	0.1884	0.1944

(Note: The original weights are calculated by entropy method: The weights of criteria are normalized by an operation of division with their total scores by each expert. Also, the information of cost criteria is excluded here so that there are only seven criteria for which weights will have to be calculated.)

Table 7: Modified Weighted Normalized Matrix of Benefit Criteria -Expert 1

FL Options	Area Needed (m^2)	Machines Handled	W-I-P(units)	Bottle Necks	LF	LR	LIP
FL_1	0.0775	0.0961	0.0786	0.1028	0.0610	0.1501	0.0244
FL_2	0.1138	0.1152	0.0987	0.0771	0.0915	0.1334	0.0285
FL_3	0.0823	0.0865	0.0907	0.1285	0.1525	0.1168	0.0163
FL_4	0.0992	0.0769	0.1074	0.0514	0.2745	0.0334	0.0204

Table 8: Modified weighted normalized matrix of Benefit Criteria -Expert 2

FL Options	Area Needed (m^2)	Machines Handled	W-I-P(units)	Bottle Necks	LF	LR	LIP
FL_1	0.0841	0.1037	0.0850	0.1115	0.0445	0.0899	0.0596
FL_2	0.1235	0.1245	0.1068	0.0836	0.0334	0.0799	0.2682
FL_3	0.0893	0.0934	0.0981	0.1394	0.0557	0.0699	0.1192
FL_4	0.1077	0.0830	0.1162	0.0557	0.0779	0.0299	0.1192

Table 9: Modified weighted normalized matrix of Benefit Criteria -Expert 3

FL Options	Area needed (m^2)	Machines handled	W-I-P(units)	Bottle Necks	LF	LR	LIP
FL_1	0.0819	0.1010	0.0830	0.1085	0.1291	0.1496	0.0997
FL_2	0.1202	0.1213	0.1043	0.0814	0.0646	0.0999	0.0997
FL_3	0.0870	0.0909	0.0957	0.1356	0.0430	0.0500	0.1596
FL_4	0.1049	0.0808	0.1135	0.0542	0.1075	0.0666	0.0399

Table 10: Modified weighted normalized matrix of Benefit Criteria -Expert 4

FL Options	Area needed (m^2)	Machines Handled	W-I-P(units)	Bottle Necks	LF	LR	LIP
FL_1	0.0691	0.0852	0.0698	0.1037	0.1120	0.1776	0.0932
FL_2	0.1014	0.1023	0.0877	0.0686	0.0800	0.0592	0.1399
FL_3	0.0734	0.0767	0.0806	0.1144	0.1280	0.0986	0.1399
FL_4	0.0885	0.0682	0.0954	0.0458	0.0320	0.0590	0.0311

Table 11: Modified weighted normalized matrix of Benefit Criteria -Expert 5

FL Options	Area Needed (m^2)	Machines Handled	W-I-P(units)	Bottle Necks	LF	LR	LIP
FL_1	0.0981	0.1210	0.0995	0.1300	0.1334	0.0529	0.0575
FL_2	0.1441	0.1451	0.1250	0.0975	0.1008	0.0706	0.0575
FL_3	0.1043	0.1088	0.1144	0.1626	0.0882	0.0882	0.1149
FL_4	0.1257	0.0967	0.1355	0.0650	0.0378	0.1412	0.1341

(Note: The modified weighted normalized decision matrix is obtained by multiplying normalized weight of each expert (Table - 6) with normalized decision matrix [with both objective and subjective data – Tables 3 & 4] separately.)

Ideal and Anti-Ideal Solutions of Benefit Criteria by Experts

$$M^{1+} = \{0.1138, \quad 0.1152, \quad 0.1074, \quad 0.1285, \quad 0.2745, \quad 0.1501, \quad 0.0285\}$$

$$M^{1-} = \{0.0775, \quad 0.0769, \quad 0.0786, \quad 0.0514, \quad 0.0610, \quad 0.0334, \quad 0.0163\}$$

$$M^{2+} = \{0.1235, \quad 0.1245, \quad 0.1162, \quad 0.1394, \quad 0.0779, \quad 0.0899, \quad 0.2682\}$$

$$M^{2-} = \{0.0841, \quad 0.0830, \quad 0.0850, \quad 0.0557, \quad 0.0334, \quad 0.0299, \quad 0.0596\}$$

$$M^{3+} = \{0.1202, \quad 0.1213, \quad 0.1135, \quad 0.1356, \quad 0.1291, \quad 0.1496, \quad 0.1596\}$$

$$M^{3-} = \{0.0870, \quad 0.0808, \quad 0.0830, \quad 0.0542, \quad 0.0430, \quad 0.0500, 0.0399\}$$

$$M^{4+} = \{0.1014, \quad 0.1023, \quad 0.0954, \quad 0.1144, \quad 0.1280, \quad 0.1776, \quad 0.1399\}$$

$$M^{4-} = \{0.0691, \quad 0.0682, \quad 0.0698, \quad 0.0458, \quad 0.0320, \quad 0.0590, \quad 0.0311\}$$

$$M^{5+} = \{0.1441, \quad 0.1451, \quad 0.1355, \quad 0.1626, \quad 0.1334, \quad 0.1412, \quad 0.1341\}$$

$$M^{5-} = \{0.0981, \quad 0.0967, \quad 0.0995, \quad 0.0650, \quad 0.0378, \quad 0.0529, \quad 0.0575\}$$

Table 12: Separation Measures of Benefit Criteria and Cost Criteria information

FLs	Expert 1			Expert 2			Expert 3		
	SM^{1+}	SM^{1-}	CR^*	SM^{2+}	SM^{2-}	CR^*	SM^{3+}	SM^{3-}	CR^*
FL_1	0.2133	0.1292	0.3772	0.2199	0.0858	0.2807	0.0844	0.1559	0.6488
FL_2	0.1910	0.1222	0.3902	0.0739	0.2248	0.7526	0.1151	0.1034	0.4732
FL_3	0.2392	0.1472	0.3810	0.1599	0.1128	0.4136	0.1065	0.1457	0.5777
FL_4	0.1460	0.2166	0.5974	0.1856	0.0851	0.3144	0.1737	0.0754	0.3027

(Cont'd Table 12)

FLs	Expert 4			Expert 5			(CC_i) Cost Criteria
	SM^{4+}	SM^{4-}	CR^*	SM^{5+}	SM^{5-}	CR^*	
FL_1	0.0674	0.1672	0.7127	0.1368	0.1181	0.4633	0.7588
FL_2	0.1359	0.0745	0.3541	0.1275	0.1022	0.4449	0.4393
FL_3	0.0889	0.2561	0.7423	0.0926	0.1304	0.5848	0.3594
FL_4	0.2029	0.0321	0.1366	0.1237	0.1253	0.5032	0.3195

Table 13: Group Separation Measures of Benefit Criteria by Experts

FLs	SM_{Gi}^{+}	SM_{Gi}^{-}	CR_{Gi}^{*}
FL_1	**0.1296**	**0.1278**	**0.4965**
FL_2	**0.1230**	**0.1167**	**0.4869**
FL_3	**0.1274**	**0.1519**	**0.5439**
FL_4	**0.1639**	**0.0890**	**0.3519**

Table 14: Incremental Analysis by Group Benefit and Cost Ratio

FL Options	Benefit Criteria Relative Closeness	Cost Criteria Relative Closeness	Order by Cost	Marginal Comparison of two FLs (Incremental Analysis)		
	CR_G^*	CC_i		$FL_3 - FL_4$	$FL_2 - FL_3$	$FL_2 - FL_1$
FL_1	**0.4965**	**0.7588**	**4**	**4.812>1**	**0.0799<1**	**0.03005<1**
FL_2	**0.4869**	**0.4393**	**3**			
FL_3	**0.5439**	**0.3594**	**2**			
FL_4	**0.3519**	**0.3195**	**1**			

5. DISCUSSION & CONCLUSION

Since cost is the central part of the incremental analysis, the benefit and cost study becomes a powerful tool in identifying the right choice. The study becomes more robust and realistic as it considers the subjective evaluation of different experts with equal weight. However, it is not inferred that the alternatives are mutually exclusive and independent. It is of common knowledge that alternatives are mutually exclusive in MCDM problems so that only one alternative, normally the best one is to be selected from a set of options. Notwithstanding this, the situation of alternatives being independent is popular for resource allocation problems in which more than one alternative can be chosen. The incremental benefit-cost ratio or cutoff ratio is the key for judgment in making an incremental analysis. It is still unclear to researchers as to how this alone can be a standard for discrimination. But, an appropriate logic is extended in this work.

In the Table 14, the FLs are arranged in the ascending order of cost factor $\boldsymbol{CC_i}$. First, FL_3 is compared with FL_4 and the incremental value was found out to be 4.812>1. Similarly, other two comparisons are made and ratios calculated. But the ratios are found out to be less than 1. However, in the differential ratio of Benefit to Cost considered with FL_3 over FL_4, the alternative 3 outweighs alternative 4 in terms of benefit over cost. Further, when FL_2 is compared with FL_3 and validated, it is found that alternative 2 is less favorable alternative 3. Hence FL_3 is a favorable choice.

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