A Facility Layout Selection Model using MACBETH Method

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Abstract

Facility layout selection is a multi-criteria decision-making (MCDM) problem which primarily involves in evaluating multiple candidate layouts, designed according to a set of common criteria for choosing the best one. Designing multiple facility layouts is an easy task, thank to availability of different facility layout design software. However, the decision of selecting the best layout becomes complex due to the involvement of several conflicting evaluation criteria. Thus, the decision makers often face the problem of selecting the best one from the available facility layout alternatives. In this paper, the application of Measuring Attractiveness by a Categorical Based Evaluation TecHnique (MACBETH) approach is demonstrated while solving two real time facility layout selection problems. Even though MACBETH approach is recognized as an efficient MCDM tool for qualitative performance measures, it is also capable to deal with quantitative performance measures, as demonstrated in this paper. For the first example, having qualitative and quantitative data, the results obtained from MACBETH method exactly corroborate with those derived by the past researchers. In the second example, MACBETH method is applied to find out the best facility layout for a newly fangled case.

Keywords
Facility layout selection, decision-making, MACBETH, ranking

1. Introduction
Facility layout is defined as the most effective physical arrangement of the manufacturing facilities (machines, processing equipment, service departments etc.) of a plant and its various parts in order to achieve the best co-ordination and efficiency in the usage of manpower, machines and materials resulting in the fastest and smoothest production activities. Necessity of designing a facility layout arises not only at the time of erection of a new plant but also during the production process, due to various reasons, like introduction of new method, improvement in manufacturing procedure, change in product and its design etc. A good facility layout should require minimum material handling, provide safe working place leading to minimum accidents and hazards to the personnel, provide sufficient place for maintenance as well as improve overall productivity. A good placement of facilities can contribute to overall efficiency of operations and reduce almost 50% of the total operating expenses (Drira et al., 2007). A good number of layout design alternatives can be planned by the designers considering multiple arrangements of the manufacturing facilities, leading to dissimilar advantages and disadvantages over each other. Greed for consistent improvement in productivity leads to the development of more efficient manufacturing facilities and processes, which subsequently takes into account additional evaluation criteria, to be considered for selecting the best facility layout. Therefore, the decision for proper selection of a facility layout now becomes more complicated due to the involvement of several conflicting criteria.

Choosing the best facility layout for a given manufacturing organization from a finite set of feasible alternatives is an example of multi-criteria decision-making (MCDM) problem. It is observed that the facility layout selection decision is based on evaluation of performance of the alternatives expressed in qualitative as well as quantitative measures. The past researches in facility layout selection domain have shown that the qualitative performance measures of the alternatives need to be first converted into quantitative scores before applying any decision-making method. Yang and Kuo (2003) applied analytic hierarchy process (AHP), while Rao and Singh (2012) adopted fuzzy set theory to convert the qualitative performance measures into corresponding quantitative scores. Conversion of the performance measures from qualitative to quantitative scores increases the complexity of the facility layout selection problems. Therefore, a strong mathematical model, capable to deal with both qualitative and quantitative performance measures, is required to solve the facility layout design problems. Measuring Attractiveness by a Categorical Based Evaluation TecHnique (MACBETH) is such an MCDM approach having advantage of taking into account the decision makers' subjective judgments about different alternatives with respect to several evaluation criteria and translate those attributes into relevant quantitative scores. This ability of MACBETH method confirms its applicability for solving facility layout selection problems.

2. Literature Review

The past researchers have applied different mathematical approaches for solving the facility layout selection problems. Lin et al. (2004) developed a facility layout ranking and selection model, based on linear assignment method for single as well as group decision makers. Enea et al. (2005) implemented genetic algorithm, employing the concepts of evolutionary hybrid algorithms for facility layout selection. Ertay et al. (2006) proposed a combined data envelopment analysis (DEA) and AHP method-based approach for facility layout design selection and ranking of the alternatives. The design alternatives and performance measures on qualitative criteria were generated using a computer-aided layout planning tool (VisFactory), whereas, the performance measures on quantitative criteria were developed using AHP method. Further, ranking of the alternatives was obtained using DEA method. Kuo et al. (2008) adopted grey relational analysis (GRA) for solving facility layout selection problems. Athawale and Chakraborty (2010) applied PROMETHEE II (preference ranking organization method for enrichment evaluation) method for facility layout selection. Chatterjee et al. (2010) proposed ELECTRE II (ELimination and Et Choice Translating REality) method for ranking and selecting the best facility layout for a manufacturing environment. Maniya and Bhatt (2011) presented a methodology, based on preference selection index (PSI) method, for facility layout selection and also performed a subjective cost benefit analysis to study the benefits to cost to the organization. Yang et al. (2012) applied an MCDM approach where rough set theory was integrated with AHP to obtain the values of criteria weights. Further, the ranking of the alternative facility layout designs was obtained using TOPSIS (technique for order preference by similarity to ideal solution) method. Yang and Deuse (2012) integrated AHP with PROMETHEE II method for ranking and selecting the best facility layout. Rao and Singh (2012) applied a weighted Euclidean distance-based approach to deal with the plant layout design selection problems. A ranked value judgment on a fuzzy conversion scale was suggested to represent the qualitative performance scores. Mohamadghasemi and Hadi-Vencheh (2012) presented an integrated approach for incorporating qualitative judgments of criteria in facility layout design problem as well as ranking of the alternatives. The synthetic value of fuzzy judgment approach was applied to determine the performance measures related to qualitative criteria, while non-linear programming (NLP) was employed to derive the final ranking of the alternatives. Hadi-Vencheh and Mohamadghasemi (2012) presented an integrated AHP-NLP approach for facility layout design selection. Alternative facility layout designs, generated using 'Spiral' software, were selected using NLP, while AHP method was adopted for obtaining the criteria weight values.

3. MACBETH Approach

MACBETH is a multi-criteria decision analysis approach which is motivated by multi-attribute value theory. The main idea of MACBETH method is to build an interval scale from the preference information. The decision makers are asked to provide judgments on the difference of attractiveness between two stimuli at a time from a set of semantic scale having seven categories, i.e. extreme, very strong, strong, moderate, weak, very weak and no, arranged in descending order of their importance (Bana e Costa et al., 2002). The performance measures are usually qualitative judgments which are further quantified proportionately on a 0-100 scale. The criteria weights can be determined applying MACBETH method based on pair-wise comparison questioning mode (Bana e Costa et al., 2012). It helps the decision makers to rank the alternatives based on aggregated measurement of relative weighted attractiveness of performance of alternatives with respect to several decision criteria. The MACBETH method is supported by M-MACBETH software (http://www.m-macbeth.com/en/downloads.html), developed with the intention to ease out the overall procedure.

In the first step, a set of decision criteria is defined and input in the software in the form of a value tree. For all the criteria, the performance levels are decided, with identification of two reference levels (good and neutral) for each criterion. In order to solve the inter-criteria commensurability problem, it is sufficient to determine, for all interval scales, two common reference levels, i.e. good (upper reference level) and neutral (lower reference level) with the corresponding performance values of 100 and 0 respectively. Further, to quantify the qualitative performance levels or convert quantitative performance levels into proportionate MACBETH scale, the performance levels are arranged in a matrix form from left to right according to their importance and the desired MACBETH judgment (range of judgments) is identified representing the difference of attractiveness. Consistent judgments lead to generation of the converted MACBETH scale. However, the M-MACBETH software can identify inconsistencies, if any and suggest necessary actions to remove them. Further, the alternatives and their performances are entered into the model. The same procedure of preference function is used in MACBETH approach to obtain the criteria weights. Finally, the alternatives are ranked based on an overall score, derived from the preference judgments of the decision makers using an additive aggregation function.

In order to obtain quantified MACBETH scores of qualitative performance levels, the following procedure is adopted (Fakhfakh et al., 2011).

Let k be a criterion having L_i (i = 1,2,…,n) performance levels for which the cardinal MACBETH score is to be generated. The performance levels for that criterion are arranged in a matrix form according to descending order of their importance from left to right and top to bottom, as shown in Table 1. To understand the procedure, an example with four performance levels, i.e. L_1, L_2, L_3, and L_4 is considered here such that L_2 is the 'good' level, while L_4 is the 'neutral' level. Let the arrangement of preference levels according to their reducing importance is L_2-L_3-L_1-L_4. Therefore, if $v(L_1)$, $v(L_2)$, $v(L_3)$ and $v(L_4)$ are the quantified MACBETH scores for levels L_1, L_2, L_3 and L_4 respectively, then $v(L_2) = 100$, $v(L_4) = 0$ and $v(L_2) > v(L_3) > v(L_1) > v(L_4)$. Further, the strengths of performance of the levels over each other are compared. Here, it can be noted that for n reference levels, maximum $n(n - 1)/2$ number of comparisons are possible, but $(n - 1)$ number of comparisons, as presented parallel to the diagonal in Table 1, are sufficient for conversion of the scale. Comparison of strengths of performance can be done using one or a range of seven semantic scales. If the decision maker does not provide any strength of performance, it is noted by positive or P in the corresponding cell of the matrix. If the decision maker prefers performance of L_1 over L_2 with a strength $h \in \{0,1,\ldots,6\}$, i.e. $L_1 \overset{h}{\succ} L_2$

Then,

$$v(L_1) - v(L_2) = h\alpha \tag{1}$$

where α is a coefficient necessary to meet the condition that $v(L_1)$ and $v(L_2) \in [0,100]$. The quantified MACBETH scores are obtained by solving the related equations for all the performance levels. Let the decision maker decides the strengths of performance, as expressed in Table 1 and when all the strengths of performance levels are provided, the matrix of judgments is ready for quantification of the data.

Table 1: Strengths of performance levels for k^{th} criterion

Performance level	L_2	L_3	L_1	L_4
L_2 (Good)	No	Strong	P	P
L_3		No	Moderate	P
L_1			No	Very weak
L_4 (Neutral)				No

The quantitative measures for a seven point semantic scale are as follows extreme = 6, very strong = 5, strong = 4, moderate = 3, weak = 2, very weak = 1 and no = 0. Therefore, from the judgments provided in Table 1, the following system of equations can be extracted:

$$v(L_2) - v(L_3) = 4\alpha \tag{2}$$

$$v(L_3) - v(L_1) = 3\alpha \tag{3}$$

$$v(L_1) - v(L_4) = \alpha \tag{4}$$

On solving Eqns. (2)-(4), the obtained solutions are $\alpha = 12.5$, $v(L_1) = 12.5$ and $v(L_3) = 50$. The quantification of performance levels for all the remaining criteria as well as the corresponding criteria weights can be obtained adopting the same procedure.

Convergence of the quantitative performance levels into proportionate MACBETH scores can be performed employing the following procedure.

Even though MACBETH approach is famous for dealing with qualitative performance scores, it analyzes the quantitative performance scores too. In this approach, quantitative performance levels are also converted into proportionate MACBETH scale with two reference levels, i.e. good and neutral. In fact, conversion of qualitative or quantitative data on a 0-100 MACBETH scale can be treated as normalization of data, as it serves the same purpose of normalization, generally used in other decision-making methods. To convert quantitative performance levels into MACBETH scores, the selected quantitative performance levels are arranged in descending order of their importance from top to bottom and left to right. The desired MACBETH judgments (range of judgments) are selected showing difference of attractiveness of one performance level over the other. Consistency of judgments is checked and necessary changes are done, if required. The MACBETH scale is generated for consistent judgments by M-MACBETH software. The conversion from quantitative performance levels can be done based on the following formulas.

Let x_{ij} be the performance measure of i^{th} alternative on j^{th} criterion, (i = 1,2,…,n; j = 1,2,…,m) and $v(x_{ij})$ be the converted numerical MACBETH scale for x_{ij}. Let (x_j^-) is the lower reference level and (x_j^+) is upper reference level for j^{th} criterion. In MACBETH approach, the MACBETH numerical scale is anchored on two predefined reference levels, and assigned the scores of 0 and 100 to the lower and upper reference levels respectively. Therefore, $v(x_j^-)$ = 0 and $v(x_j^+)$ = 100. The MACBETH score for any intermediate performance measure x_{ij} can be obtained as follows:
For beneficial criteria

$$v(x_{ij}) = v(x_j^-) + \frac{(x_{ij} - x_j^-)}{(x_j^+ - x_j^-)}[v(x_j^+) - v(x_j^-)] \quad (5)$$

For non-beneficial criteria

$$v(x_{ij}) = v(x_j^-) + \frac{(x_j^- - x_{ij})}{(x_j^- - x_j^+)}[v(x_j^+) - v(x_j^-)] \quad (6)$$

Further, the converted MACBETH scores for all the performance measures are multiplied by the respective criteria weights and are added together to find out the overall attractiveness scores for the alternatives. The final overall score is obtained using the following additive value model.

$$V(X_i) = \sum_{j=1}^{m} w_j (v_j) \quad (7)$$

with

$$\sum_{j=1}^{m} w_j = 1, w_j \succ 0 \text{ and } \begin{cases} v_j(x_j^+) = 100 \\ v_j(x_j^-) = 0 \end{cases} \quad (8)$$

Finally, the alternatives are ranked based on $V(X_i)$ values in descending order of preference.

4. Illustrative Examples

In order to demonstrate the capability and appropriateness of MACBETH approach for solving facility layout selection problems, the following two examples are illustrated.

4.1 Example 1

Rao and Singh (2012) presented a facility layout design selection problem for a chemical packaging industry. From four alternative layouts, the best one was chosen based on five decisive criteria, e.g. interaction with existing facility distance (IEFD) (in m), area available for each assembly group (AAG) (in m^2), material quantity flow (MQF) (in kg/hr), accessibility for firefighting (AFF) (in %) and comfort of crew (COC). The performances of the alternatives with respect to first four criteria were expressed in quantitative measures, while for the last criterion (COC), qualitative measures were employed. Rao and Singh (2012) deployed a seven point fuzzy scale to convert the qualitative performance scores of the alternatives into corresponding crisp values. However, keeping in view the ability of MACBETH method to quantify qualitative performance scores on its own, the original qualitative measures are used here. Table 2 shows the decision matrix for this problem. The 'IEFD' criterion is of non-beneficial type (preferring lower value), whereas, the remaining attributes are of beneficial type (preferring higher values).

Table 2: Decision matrix for facility layout selection problem 1

Alternative	IEFD	AAG	MQF	AFF	COC
L_1	102	3000	200	94	Very low
L_2	84	1800	140	82	High
L_3	123	2200	230	56	Average
L_4	224	2500	180	98	Low

Rao and Singh (2012) solved this problem using a weighted Euclidean distance-based approach and using AHP method, determined the criteria weights as $w_{IEFD} = 0.1159$, $w_{AAG} = 0.2065$, $w_{MQF} = 0.2429$, $w_{AFF} = 0.3395$, $w_{COC} = 0.0952$. The same set of criteria weights and performance of the alternatives are considered here for selecting the best facility layout design, so that the obtained results can be compared with those as observed by Rao and Singh (2012). This facility layout selection problem is now solved using the free downloaded version of M-MACBTH software. Initially, all the five evaluation criteria are entered into the M-MACBTH software to develop the corresponding value tree, as shown in Fig. 1. In this value tree, the 'Benefit criteria' node contains all the beneficial attributes, while the 'Cost criteria' node consists of the single non-beneficial attribute.

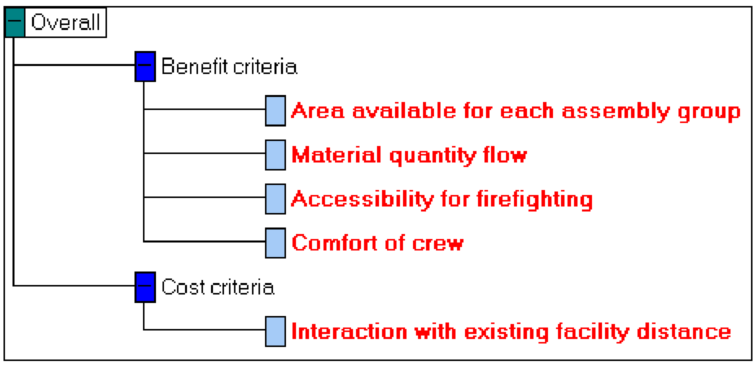


Figure 1: MACBETH value tree for facility layout selection problem 1

The performances of alternatives are then input in the respective criteria's properties window. For 'IEFD', 'AAG', 'MQF' and 'AFF' criteria, performances of the alternatives are expressed in quantitative measures. Therefore, two reference levels, i.e. upper and lower are chosen for these four criteria. In case of beneficial criteria, the upper reference level is the highest performance criteria value, whereas, for non-beneficial criteria, it is the lowest performance criteria value. The lower reference level is selected 10% below the lowest performance value in case of beneficial criteria and for non-beneficial criteria, it is chosen 10% above the highest performance value. The performance of qualitative criterion 'COC' is expressed using a seven point scale, i.e. excellent (Ex), very high (VH), high (H), average (A), low (L), very low (VL) and none (N). These scales are entered as performance levels with 'Ex' identified as upper reference level while 'N' set as lower reference level. Figure 2 shows the reference levels for all the criteria as involved in this problem.

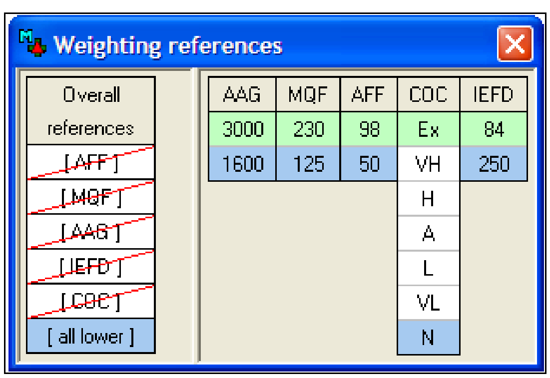
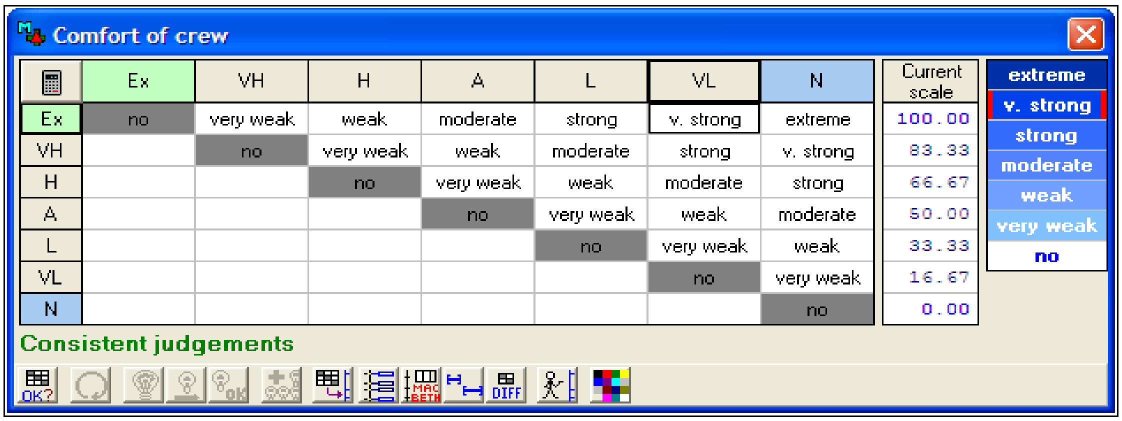


Figure 2: Reference levels for layout selection problem 1

In order to quantify the qualitative performance levels, used to express the performance of alternatives with respect to 'COC' criterion, seven semantic scales, provided by MACBETH method, are used to represent the attractiveness of a specific level over the other. After selecting the preferences of attractiveness, consistency of judgments is checked. Consistent judgments lead to quantification of the performance levels. Figure 3 shows the comparison of attractiveness between the preference levels as well as the converted MACBETH scale for 'COC' criterion.

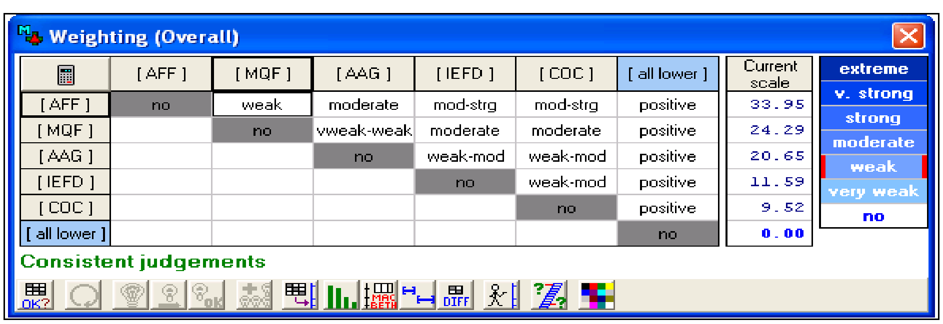
The converted MACBETH scale for performance levels of 'COC' criterion is obtained by solving a system of equations based on Eqn. (1), as shown below.
$v(\text{Ex}) - v(\text{VH}) = \alpha$, $v(\text{VH}) - v(\text{H}) = \alpha$, $v(\text{H}) - v(\text{A}) = \alpha$, $v(\text{A}) - v(\text{L}) = \alpha$, $v(\text{L}) - v(\text{VL}) = \alpha$ and $v(\text{VL}) - v(\text{N}) = \alpha$. After solving the above system of equations, the results are obtained as $\alpha = 16.67$, $v(\text{Ex}) = 100$, $v(\text{VH}) = 83.33$, $v(\text{H}) = 66.67$, $v(\text{A}) = 50$, $v(\text{L}) = 33.33$, $v(\text{VL}) = 16.67$ and $v(\text{N}) = 0$.



	Ex	VH	H	A	L	VL	N	Current scale
Ex	no	very weak	weak	moderate	strong	v. strong	extreme	100.00
VH		no	very weak	weak	moderate	strong	v. strong	83.33
H			no	very weak	weak	moderate	strong	66.67
A				no	very weak	weak	moderate	50.00
L					no	very weak	weak	33.33
VL						no	very weak	16.67
N							no	0.00

Figure 3: Comparison of attractiveness between reference levels for 'COC' criterion

Now, four alternatives (L_1, L_2, L_3 and L_4) as well as performances of these alternatives with respect to five considered criteria are entered into M-MACBETH software. For criteria weights, those values as determined by Rao and Singh (2012) are used here. In fact, MACBETH method can compute criteria weights on its own by pair-wise comparison procedure. Initially, all the criteria are arranged according to their decreasing importance, i.e. 'AFF'-'MQF'-'AAG'-'IEFD'-'COC', from left to right and top to bottom in a matrix. The judgments of preference of each criterion over the remaining criteria are selected using a seven point semantic scale. Consistency checking is performed for the judgments. After considering the suggestions for eliminating inconsistencies (if any), the judgments are made consistent and subsequently, the criteria weights are computed. As the M-MACBETH software provides scope for adjusting the criteria weights within a range based on judgments, the weights are adjusted to those as used by Rao and Singh (2012). Figure 4 shows the overall weighing judgments for this example.



	[AFF]	[MQF]	[AAG]	[IEFD]	[COC]	[all lower]	Current scale
[AFF]	no	weak	moderate	mod-strg	mod-strg	positive	33.95
[MQF]		no	vweak-weak	moderate	moderate	positive	24.29
[AAG]			no	weak-mod	weak-mod	positive	20.65
[IEFD]				no	weak-mod	positive	11.59
[COC]					no	positive	9.52
[all lower]						no	0.00

Figure 4: MACBETH weighing judgments for layout selection problem 1

The overall attractiveness scores for all the four alternatives are obtained using Eqn.(8) and quantitative performance scores for the alternatives with respect to five criteria are shown in Fig. 5.

Options	Overall	AAG	MQF	AFF	COC	IEFD
L1	81.04	100.00	71.43	91.67	16.67	89.16
L2	46.99	14.29	14.29	66.67	66.67	100.00
L3	51.01	42.86	100.00	12.50	50.00	76.51
L4	64.94	64.29	52.38	100.00	33.33	15.66
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00
[all lower]	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.2065	0.2429	0.3395	0.0952	0.1159

Figure 5: MACBETH table of scores for layout selection problem 1

Based on the overall attractiveness scores obtained using MACBETH method, the ranking of alternative facility layout designs is obtained as L_1-L_4-L_3-L_2 which shows that L_1 is the best choice. Rao and Singh (2012) also obtained the same ranking for the facility layout alternatives using a weighted Euclidean distance-based approach.

Sensitivity analysis is performed by consistently varying a specific criterion weight and subsequently adjusting the difference equally over the remaining criteria in such a way that $\Sigma w_j = 1$. The results of sensitivity analysis for the most important criterion 'AFF' (having maximum weight) is displayed in Fig. 6. It is observed that L_1 is the best chosen layout for weight up to 0.775, thereafter, L_4 becomes the first choice. In case of 'MQF' criterion, L_1 remains as the first choice up to a weight of 0.631, then L_3 replaces L_1 as the best alternative. Variation in weight for 'AAG' criterion shows no change in ranking of the first alternative. L_1 is the best choice up to a weight of 0.786 for 'IEFD' criterion, and then it is replaced by L_2. Ranking of the alternatives is observed to be quite sensitive for 'COC' criterion with respect to its changing weights. In this case, L_1 remains as the best alternative for a weight up to 0.462. Varying the weight beyond 0.542 shows that ranking of the alternatives is totally reversed.

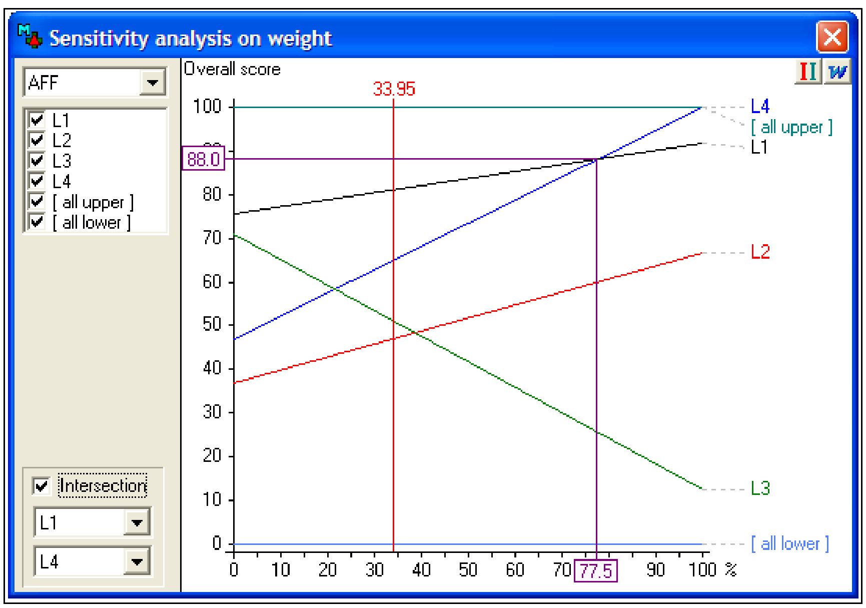


Figure 6: Sensitivity analysis with respect to 'AFF' criterion

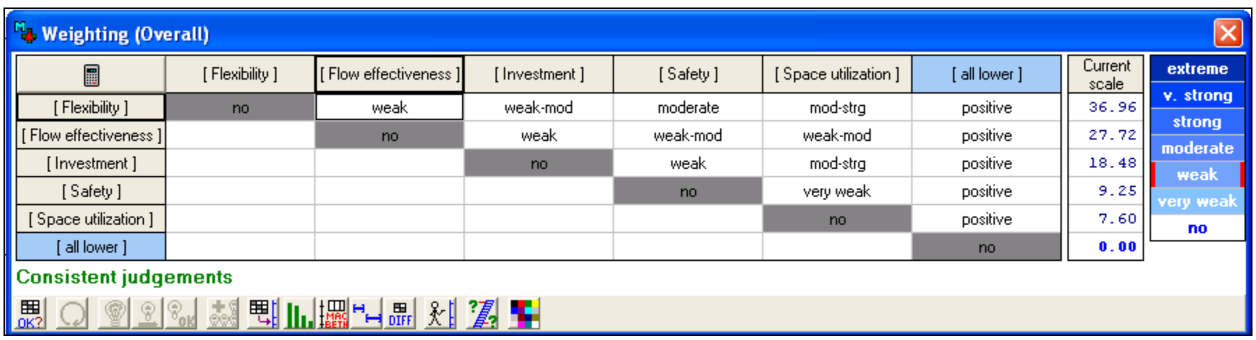
4.2 Example 2

Here, another example with qualitative measures for performance of the alternatives is considered for ranking and selection of the best facility layout design. The performance of five alternative facility layouts is compared with respect to five evaluation criteria, i.e. flexibility (F), flow effectiveness (FE), space utilization (SU), safety (S) and investment (I). Among these criteria, 'investment' is the only non-beneficial criterion, while the remaining four criteria are beneficial in nature. The performance of the alternatives is expressed using a scale of seven qualitative levels. For beneficial criteria, these performance levels are arranged in descending order of their attractiveness as very good (VG), good (G), medium good (MG), fair (F), medium poor (MP), poor (P) and very poor (VP). For non-beneficial criteria, this preference order is just reversed. Table 3 shows the decision matrix for the considered problem.

Table 3: Decision matrix for facility layout selection problem 2

Alternative	Flexibility	Flow effectiveness	Space utilization	Safety	Investment
FL1	F	G	VG	P	G
FL2	G	MG	G	P	P
FL3	VG	MG	MG	VP	G
FL4	F	MG	MP	P	F
FL5	MP	F	G	F	MG

In order to derive the ranking of the alternative facility layouts, the considered criteria, layout alternatives, seven scale performance levels and performance of the alternatives with respect to five criteria (shown in Table 3) are entered into M-MACBETH software. In order to convert the performance levels for all criteria into proportionate quantitative MACBETH scores, they are pair-wise compared with the help of a seven point semantic scale, satisfying the consistency requirements. Further, for obtaining the criteria weights, all the criteria are arranged in descending order of their importance from left to right and top to bottom in the weighing matrix, as shown in Fig. 7. A pair-wise comparison of the criteria using the seven point semantic scale leads to determination of criteria weights as $w_F = 0.3696$, $w_{FE} = 0.2772$, $w_I = 0.1848$, $w_S = 0.0925$ and $w_{SU} = 0.0760$.


Weighting (Overall)

	[Flexibility]	[Flow effectiveness]	[Investment]	[Safety]	[Space utilization]	[all lower]	Current scale
[Flexibility]	no	weak	weak-mod	moderate	mod-strg	positive	36.96
[Flow effectiveness]		no	weak	weak-mod	weak-mod	positive	27.72
[Investment]			no	weak	mod-strg	positive	18.48
[Safety]				no	very weak	positive	9.25
[Space utilization]					no	positive	7.60
[all lower]						no	0.00

Figure 7: Weighing judgments for layout selection problem 2

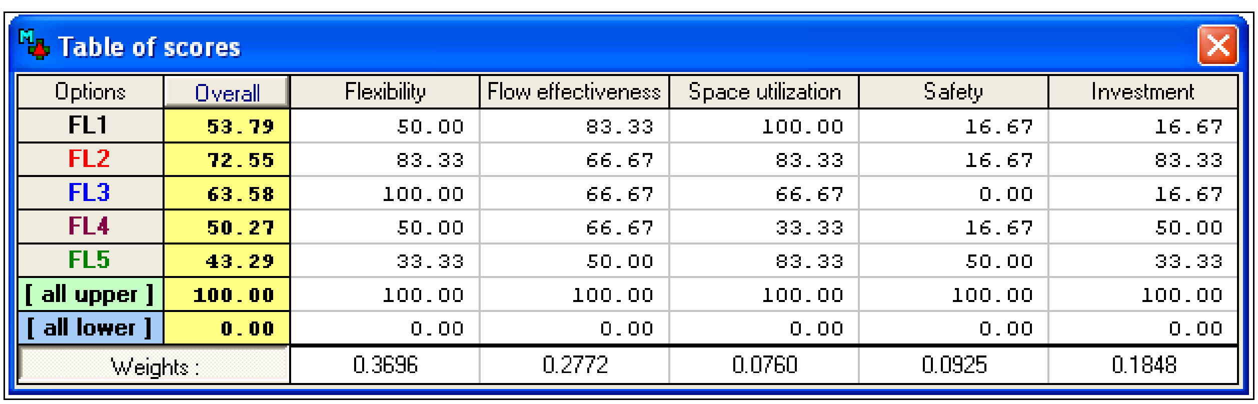


Table of scores

Options	Overall	Flexibility	Flow effectiveness	Space utilization	Safety	Investment
FL1	53.79	50.00	83.33	100.00	16.67	16.67
FL2	72.55	83.33	66.67	83.33	16.67	83.33
FL3	63.58	100.00	66.67	66.67	0.00	16.67
FL4	50.27	50.00	66.67	33.33	16.67	50.00
FL5	43.29	33.33	50.00	83.33	50.00	33.33
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00
[all lower]	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.3696	0.2772	0.0760	0.0925	0.1848

Figure 8: MACBETH table of scores for layout selection problem 2

Finally, the weighted global scores representing the overall attractiveness of the five alternatives are computed using the additive aggregation model to rank the alternatives, as shown in Fig. 8. The ranking of alternatives, derived from the overall scores, is FL_2-FL_3-FL_1-FL_4-FL_5. Therefore, FL_2 is found to be the most attractive facility layout, whereas, FL_5 is the worst chosen alternative. It is noticed that although alternative FL_2 requires less investment, its performance with respect to four beneficial criteria is second best attractive among all the alternatives. Therefore, selection of FL_2 as the best layout is well justified. Similarly, the least attractive performance of alternative FL_5 with respect to two most important criteria justifies the last ranking of this alternative.

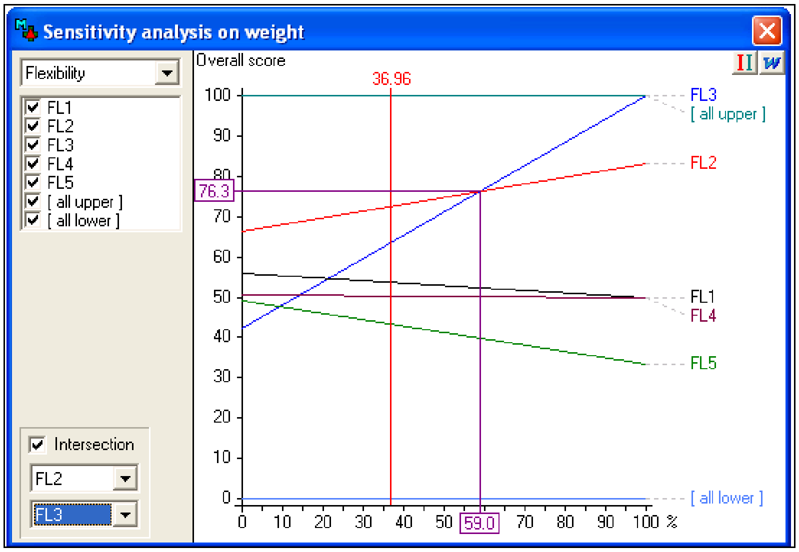


Figure 9: Sensitivity analysis with respect to 'flexibility' criterion

While performing the sensitivity analysis for this example, it is observed that for the most important criteria, i.e. 'flexibility' (having weight of 0.3696), alternative FL_2 remains as the first choice up to a weight of 0.590 and thereafter, FL_3 is replaced by FL_2 as the best alternative. For the next important criteria 'flow effectiveness', FL_2 is observed to be the best preferred layout up to a weight of 0.660, and then layout FL_1 becomes the first choice. In case of 'investment' criterion, up to a weight of 0.056, FL_3 is the first choice, whereas, FL_2 becomes the most preferred layout thereafter. For 'safety' criterion, alternative FL_2 remains as the best layout, when its weight is varied from 0 to 0.517. Changing its weight beyond 0.517 makes FL_5 as the first choice, followed by FL_2. On the other hand, in case of 'space utilization' criterion, layout FL_2 is the best choice up to a weight of 0.565, and beyond this, FL_1 replaces FL_2. Figure 9 shows the results of sensitivity analysis for this facility layout selection problem with respect to 'flexibility' criterion.

5. Conclusions

Selecting the best layout design is observed to be a complex decision-making problem due to the involvement of several conflicting evaluation criteria. The performances of the alternatives with respect to these criteria are usually expressed in qualitative as well as quantitative measures. This paper provides the application of MACBETH method and M-MACBETH software in guiding the decision makers in arriving at the best facility layout selection decision. MACBETH is a very simple approach with strong software support, does not require lengthy mathematical calculations and also has minimum computational time as compared to other decision-making methods. Although MACBETH method has wide applications for selection of the alternatives with qualitative performance measures, in this paper, it is applied to solve two illustrative examples having quantitative performance measures. The solution accuracy of the derived results proves the capability of this approach for solving problems having qualitative as well as quantitative performance measures. Further, it can also be successfully applied to other complex decision-making situations as being encountered in present day manufacturing environment.

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Biography

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