An MADM approach for Selection of a Facilities Layout

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Abstract

In this paper, ELECTRE (Elemination et Choice Translating Reality) or Concordance Analysis is used for selecting a proper layout to suit a particular type of production system. The decision making becomes more complicated due to contradicting and conflicting nature of factors influencing Facilities Layout (FL) design. Various considerations need to be taken into account in this regard. The complexity is compounded when these considerations are conflicting by nature and they have units that cannot be compared on a same common scale (incommensurable units). Also, a FL problem cannot be claimed to have a best and a unique solution. But an improper selection of FL may eventually result in affecting firm's productivity, quality of production and profitability. Hence, to effectively select a FL for a specified type of production, several factors will have to be considered simultaneously. The goal of the decision process is to evaluate alternative FLs based on the activities and their contribution to overall organizational goals. Hence in this paper the Multiple Attribute Decision Making (MADM) methodology ELECTRE is adopted to make an effective selection of a FL to suit the production process under study.
Keywords: MCDM Methodology, MADM, ELECTRE, CIM, FL Selection

I. Introduction

During the last three decades, manufacturing companies have seen an increased interest in the implementation of manufacturing philosophies such as Total Quality Management(TQM), Just-In-Time(JIT), Lean and Cellular Manufacturing, Manufacturing Resource Planning(MRP), Computer Aided Design(CAD)/Computer Aided Manufacturing(CAM)/Computer Aided Process Planning(CAPP). Modern industry demands products of superior quality, quantity on time at reduced cost. Hence an effort to coordinate different branches of manufacturing industry is need of the hour. Such an effort must be very flexible as well. With the enhanced but right use of computers in all the spheres of human activity including manufacturing, Flexible Manufacturing Systems (FMS) and Computer Integrated Manufacturing (CIM) are getting a stronger foot hold in the industry today. CIM includes Business related activities (Forecasting, Customer feedback, etc.,), CAD, CAM and FMS in it. The emergence of the new areas such as cognitive science is definitely aimed at solving various industry related problems. Perhaps, the best evolution in the field of manufacturing in the 20th century is CIM. It brings about a total coordination between all the wings of manufacturing.

Thus, CNC/ DNC systems have become prominent tools in production process even in the developing countries. Advanced materials and advanced processes are being handled to precision with ease. As a result manufacturing costs have come down. This has eventually kindled competition as well. Industry circles are abuzz with phrases like '6-sigma manufacturing', 'Zero Defects' etc.

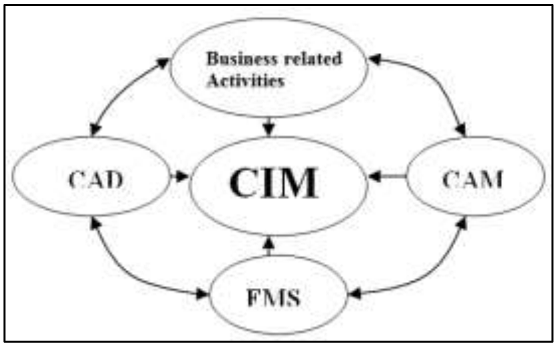

Fig. 1: Components of CIM

II. PRIOR ART ON CHOICE OF FL

The selection of a proper FL for a manufacturing system is of tremendous importance for its effective utilization. This fact has been emphasized by Sule 1994 and Tompkins et.al. 1996. A poor layout can lead to accumulation of work-in-process inventory, overloading of material handling systems, inefficient setups and longer queues (Chiang and Chiang, 1998). But a FL problem cannot be claimed to have a best and a unique solution. Various attributes based on Area, Production, Material Handling and Cost involved influence the practical selection of a FL Traditionally FL approaches have been categorized on the basis of whether the approach is Quantitative such as CRAFT (Armour and Buffa 1963) or Qualitative such as SLP (Muther 1973). The aforementioned approaches are usually used separately for solving FL problems.

Given this scenario there is a pressing need to further cut down manufacturing costs, so that profit margins can be maintained without compromising on quality and reliability. There is an urgent task to quickly and precisely design and select a proper kind of FL to rapidly advance in the field of competition. Manufacturing of goods has to pass through 3 major areas of decision making viz., design, process planning and production. FL design and selection is question directly related to profitability of a manufacturing organization. Parameters such as area, type of production, quantity & quality to be produced, material handling system used etc., govern the selection process of a FL. One of the core areas where cost reduction can be effectively done is that of arena of Facilties Layout (FL) selection. Various conflicting and contradicting factors that govern the design of a FL are to be handled efficiently. A good layout is claimed to save from 20% to 50% in investment costs.(Tomkins et.al 1996).

A number of studies have been conducted in the recent past. But of late researchers are questioning the appropriateness of selecting single criterion to solve FL problem because quantitative and qualitative approaches each have advantages and disadvantages (Houshyar 1991). Thus, the new field of Multi-Criteria Decision Making (MCDM) approach has gained wide acceptance that considers both objective reality and subjective ratings and also considers mutual effects of various conflicting and even contradicting factors. In such cases of conflicting demands and varying choices, the FL designer usually assigns relative priorities to the concerned parameters/factors and tries to arrive at a good and if not a best solution. Such is the significance of MCDM methodology. The MCDM methodology is broadly classified into two categories- Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM) on the basis of nature of criteria, constraints, usage etc.

III. MADM CONCEPT

MADM should have a set of quantifiable objectives; it also possesses a set of well-defined constraints and has a process to obtain some tradeoff information between the stated and unstated objectives. The methodology – ELECTRE(Elimination et Choice Translating Reality) or Concordance Analysis- is an MADM process. A MADM problem is expressed in matrix form.

Consider a MADM problem with 'm' criteria and 'n' alternatives. Let $C_1, C_2, \ldots C_m$ and $A_1, A_2, \ldots A_n$ denote criteria and alternatives respectively. The standard feature of MADM methodology is the *decision table* as shown in Fig. 1. The score a_{ij} describes the effect of the Criteria C_i on the performance of an alternative A_j. For the sake of simplicity we assume that a higher score value means a better performance since any goal of minimisation can be easily transformed into a goal of maximisation. Weights $w_1, w_2, \ldots w_m$ are assigned to each criteria depending upon their importance in decision making and values $x_1, x_2, \ldots x_n$ are associated with the alternatives in the decision matrix are used in Multi-attribute Utility Theory (MAUT) methods and are the final ranking values of the alternatives (Keeney and Raifa 1976). Further development of the methodology can be seen in Triantaphyllou.E 2000 and Figueira et al. 2004 for state-of-art surveys and further references.

		x_1	.	.	x_n
		A_1	.	.	A_n
w_1	C_1	a_{11}	.	.	a_{m1}
.	.	.	.	.	.
.	.	.	.	.	.
w_m	C_m	a_{m1}	.	.	a_{mn}

Fig. 2: The Decision Matrix

IV. ELECTRE METHODOLOGY

Another method of MADM methodology is Outranking method proposed by Roy, 1968. ELECTRE method was originally introduced by Benayoun et.al. Since then Roy, Nijkamp, Van Delft et.al have developed this model to the present state. This method uses the concept of "Outranking Relationship". The outranking relationship of A_k to A_l shows that even though two alternatives 'k' and 'l' do not dominate each other mathematically, the decision maker accepts the risk of regarding A_k as almost surely better than A_l. Through the successive assessments of the outranking relationships of the other alternatives the dominated alternatives defined by the outranking relationship can be eliminated. But the construction of this partial order is not an unambiguous task for the decision maker. ELECTRE sets the criteria for the mechanical assessment of the outranking relationships.

This method also consists of pair wise comparison of alternatives based on the degree to which evaluations of the alternatives and the preference weights confirm or contradict the pair wise relationship between alternatives. It examines both the degree to which the preference weights are in agreements with pair wise dominance relationships and the degree to which weighted evaluations differ from each other. These stages are based on a "Concordance and Discordance" set, hence this method is also called Concordance Analysis.

This method is considered as one of the best methods for a solution to a multi-criteria situation because of its simple logic, full utilization of information contained in the decision matrix and refined computational procedure (Hwang and Yoon, 1982).

V. PROCEDURAL STEPS

- Step 1: List the set of FL alternatives ($FL_1 - FL_4$)
- Step 2: Identification of Selection Criteria (Attributes) – (X_1-X_6)
- Step 3: Develop Decision Matrix 'M' of alternatives and attributes [(4 X 6) matrix in the present case] .
- Step 4: Determine preference weights 'W' by developing pair wise comparison matrix 'P' of attributes based on relative importance of each of the attributes on 9-point scale [(6 X 6) matrix in the present case].
- Step 5: Calculate the Normalized Decision Matrix 'R' to transform various attribute scales into comparable scales.

$$R = \begin{bmatrix} r_{11} & \dots & \dots & r_{1j}. \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ r_{i1} & \dots & \dots & r_{ij} \end{bmatrix} \quad where \quad r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}}$$

- Step 6: Develop Weighted Normalized Decision Matrix 'V'.

V=RW$_i$ where Wi= preference weights' matrix = [w_1, w_2,……,w_j]

- Step 7: Determination of Concordance matrix 'C_x' and Discordance matrix 'D_x'.

Firstly, Concordance Set 'C' and Discordance Set 'D' are to be ascertained.

For each pair of alternatives 'k' and 'l' (k,l=1,2,…..,m and k≠l), the set of decision criteria $J = \{j \mid j = 1,2,..., n\}$ is divided into two distinct subsets. The Concordance Set C_{kl} of A_k and A_l is composed of all criteria for which A_k is preferred to A_l. In other words, $C_{kl} = \{j \mid x_{kj} \geq x_{lj}\} = Concordance\ Index$.

The complementary subset to the above set is Discordance Set, D_{kl}.

$$D_{kl} = \{j \mid x_{kj} < x_{lj}\} = J - C_{kl}$$

- Step 8: For the Normalized Weight Set $C_{kl} = \sum w_j$

The Concordance Index C_{kl} reflects the relative importance of A_k with respect to A_l and $0 \leq C_{kl} \leq 1$. A higher value of C_{kl} indicates A_k is preferred over A_l. The successive values of the indices C_{kl} (k,l=1,2,….,m and k ≠ l) form the Concordance Matrix 'C_x' with (m X m).

$$C_x = \begin{bmatrix} - & C_{12} & \dots\dots & C_{1m} \\ C_{21} & - & \dots\dots & C_{2m} \\ \dots\dots & \dots\dots & - & \dots \\ C_{m1} & \dots\dots & C_{mm-1} & - \end{bmatrix}$$

Note: C_x is generally not a symmetric matrix.

Calculation of Discordance Matrix: The C_{kl} reflects the relative dominance of a certain alternative over a competing alternative on the basis of the relative weight attached to the successive decision criteria. So far no attention has been paid to the degree to which the evaluation of a certain A_k are worse than the evaluation of competing A_l. Therefore, a second index called the discordance index has to be defined:

$$d_{kl} = \frac{\max_{j \in D_{kl}} \left| V_{kj} - V_{lj} \right|}{\max_{j \in J} \left| V_{kJ} - V_{lj} \right|} \quad and \quad 0 \leq d_{kl} \leq 1$$

A higher value d_{kl} implies that, for the discordance criteria, A_k is less favourable than A_l and a lower value implies A_k is favourable to A_l.

The discordance indices form Discordance matrix D_x (mXm) and generally it is an asymmetric matrix.

$$D_x = \begin{bmatrix} - & d_{12} & \dots\dots & d_{1m} \\ d_{21} & - & \dots\dots & d_{2m} \\ \dots\dots & \dots\dots & - & \dots\dots \\ d_{m1} & \dots\dots & d_{mm-1} & - \end{bmatrix}$$

– Step 9: Determine Concordance Dominance Matrix by finding out $\bar{C} = \frac{\sum\sum C_{kl}}{n}$ where n= no. of elements in the concordance matrix.

– Step 10: Determine Discordance Dominance Matrix by finding out $\bar{D} = \frac{\sum\sum d_{kl}}{n}$ where n= no. of elements in the discordance matrix.

– Step 11: Determine Aggregate Dominance Matrix.

– Step 12: Eliminate less favourable alternatives and select most favourable one.

VI. CASE STUDY

In a leading manufacturing firm for the production of automobile parts a suitable FL has to be chosen from amongst 4 alternative FLs. They are represented as FL_1, FL_2, FL_3 and FL_4. Six attributes are considered for each alternative FL. The attributes identified as X_1, X_2, X_3, X_4, X_5 and X_6 are as follows:

X_1: Cost of Designing the layout: (5.6 to 9.8) * 1000 USD
X_2: Required Floor Area: (630 – 850 m^2)
X_3: Work-In-Process: (59-81 units)
X_4: Manufacturing Lead time reduction: (19-32 mins.)
X_5: Annual return on Investment: (3.5 to 8.9) * 1000 USD
X_6: Number of machines handled: (3 – 5).

One set of specific jobs was considered for the case study under the four alternative layouts. For good estimation ideal processes are assumed. The decision matrix ‘D’ and pair wise comparison matrix ‘A’ are shown below in Tables 1 and 2 respectively:

Table – 1
Decision Matrix involving

FLs	X_1	X_2	X_3	X_4	X_5	X_6
FL_1	9.4	630	59	20	8.9	4
FL_2	5.6	740	74	32	3.5	5
FL_3	7.8	690	68	28	4.9	3
FL_4	8.3	850	81	19	5.4	4

A. *Four Alternative Layouts & Six Attributes*

Table – 2
Pair wise comparison matrix of six attributes

	X_1	X_2	X_3	X_4	X_5	X_6
X_1	1	2/3	3/7	7/4	¾	7
X_2	3/2	1	1/2	3	2	7/2
X_3	7/3	2	1	2/3	6/5	5
X_4	4/7	1/3	3/2	1	9	¼
X_5	4/3	½	5/6	1/9	1	1/5
X_6	1/7	2/7	1/5	4	5	1

From Table 2, priority vector values, also called preference weights w_j is obtained.

$$[w_j]^T = [0.069 \quad 0.420 \quad 0.490 \quad 0.017 \quad 0.003 \quad 0.0043]$$

The Normalised decision matrix is developed as under:

$$R = \begin{array}{c} \\ FL_1 \\ FL_2 \\ FL_3 \\ FL_4 \end{array} \begin{array}{cccccc} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 \\ \end{array}$$
$$\begin{bmatrix} 0.015 & 1.008 & 0.094 & 0.032 & 0.014 & 0.006 \\ 0.0073 & 0.962 & 0.226 & 0.042 & 0.0056 & 0.007 \\ 0.011 & 0.970 & 0.095 & 0.039 & 0.007 & 0.004 \\ 0.010 & 1.020 & 0.097 & 0.023 & 0.006 & 0.005 \end{bmatrix}$$

The weighted normalised decision matrix ‘V’ is

$$V = \begin{bmatrix} 0.00104 & 0.423 & 0.046 & 0.0005 & 4.2\times10^{-6} & 2.5\times10^{-5} \\ 0.0005 & 0.404 & 0.111 & 0.0007 & 1.5\times10^{-6} & 3.01\times10^{-5} \\ 0.0008 & 0.407 & 0.047 & 0.00066 & 2.1\times10^{-6} & 1.72\times10^{-5} \\ 0.0007 & 0.428 & 0.048 & 0.00039 & 1.8\times10^{-6} & 2.15\times10^{-5} \end{bmatrix}$$

$$C_x = \begin{bmatrix} - & 0.4203 & 0.4246 & 0.0216 \\ 0.5803 & - & 0.5803 & 0.5803 \\ 0.5760 & 0.4203 & - & 0.0173 \\ 0.9790 & 0.4203 & 0.9833 & - \end{bmatrix}$$

Concordance matrix ‘C_x’

$$F_x = \begin{bmatrix} - & 0 & 0 & 0 \\ 1 & - & 1 & 1 \\ 1 & 0 & - & 0 \\ 1 & 0 & 1 & - \end{bmatrix}$$

Concordance Dominance matrix

$$D_x = \begin{bmatrix} - & 1.0 & 0.0625 & 0.4 \\ 0.292 & - & 0.0469 & 0.3809 \\ 1.0 & 1.0 & - & 1.0 \\ 0.22 & 1.0 & 0.0129 & - \end{bmatrix}$$

Discordance matrix ‘D_x’

$$D_x = \begin{bmatrix} - & 1.0 & 0.0625 & 0.4 \\ 0.292 & - & 0.0469 & 0.3809 \\ 1.0 & 1.0 & - & 1.0 \\ 0.22 & 1.0 & 0.0129 & - \end{bmatrix}$$

Discordance matrix ‘D_x’
Therefore, the Aggregate Dominance matrix will be

$$E_x = \begin{bmatrix} - & 0 & 0 & 0 \\ 1 & - & 1 & 1 \\ 0 & 0 & - & 0 \\ 1 & 0 & 1 & - \end{bmatrix}$$

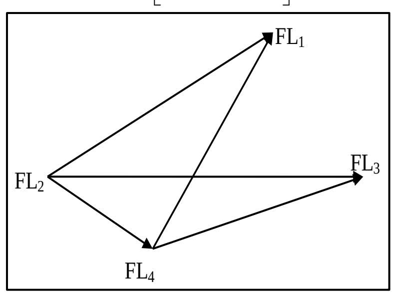

Fig. 3: Elimination of less favourable alternatives.

VII. Results and Discussion

From the above arrow diagram the unfavourable alternatives are eliminated and the most favourable one was found out to be FL2 and hence can be choosen as the appropriate FL for the present production system. The concordance analysis examines both the degree to which the preference weights are in agreement with pair wise dominance relationships and the degree to which the weighted evaluations differ from each other. The selected FL is the best among all the alternatives because it incurs least cost on designing. This layout takes a middle position as far as required floor area and WIP are concerned and handles maximum number of machines. This ELECTRE methodology can further be developed to perform more accurate elimination of less favourable alternatives. This can be done by acquiring subjective data from the decision maker.

VIII. Conclusion

While a number of alternative FLs are possible for a particular type of manufacturing process, it is important to find a more suitable one though it can never be claimed that the selected layout is the best and unique solution. This is due to the fact that various varieties factors govern the selection process (For eg. Objective & Subjective factors, conflicting & complementary factors etc) and also the factors have incommensurable units. Hence concordance analysis emerges as one of the favourable analytical tool.

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