AHP and Sensitivity Analysis to Study Cost-Dependency of Decision Variables in Facilities Layout Selection

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***Abstract:* - Selection of a proper Facilities Layout (FL) to accommodate a particular type of manufacturing environment is a Herculean task. Multi-Criteria Decision Making (MCDM) approaches provide comprehensive solutions to FL selection problems, so that an efficient and cost effective FL can be selected from amongst many. These tools also provide a mechanism that can handle complementary, conflicting and even contradictory factors. Analytical Hierarchy Process (AHP) is one such tool. Here, Decisions Matrix and Pair wise Comparison (PWCP) matrices are formed on the basis of objective and subjective evaluation of a given scenario and corresponding Priority Vector (PV) values are calculated. These PV values are calculated through iterative process and are accepted if the concerned matrices yield Consistency Ratios (CR) below a specific limit. Then Composite Priority (CP) values are found out and used as Subjective Factor Measure (SFM)s in determining Facility Layout Measure (FLM)s. The algorithm is coded in 'C' language. The program is general and can be used to handle varieties of 'selection from amongst many' kind of problems. In the next step, a Sensitivity Analysis is taken up, to estimate the model's performance when subjected to minor changes where CP values are used as SFMs in determining FLMs.**

***Keywords:* Facilities Layout, AHP, CR, FLM, Sensitivity Analysis.**

I. INTRODUCTION

Modern industry has challenges to meet on many fronts. Product Design, Production, Marketing and Customer Care are the vital fields. Since the advent of Computer Integrated Manufacturing (CIM) system as a means of production automation of manufacturing technologies, the manufacturing scene has undergone a dramatic change. The production capacity has increased manifolds. Nearly all modern production setups make an all pervasive use of computers to design the products, plan the production, control the operations and perform various business related functions needed in a manufacturing firm. Computer Aided Design/ Computer Aided Manufacturing (CAD/CAM) is used today almost synonymously with CIM.

Over the past two decades manufacturing has become more complex due to global competition, great varieties and rapid advances in technology. The development of Flexible Manufacturing Systems (FMS) is of interest from both the economic and technological points of view. An FMS is a series of computer controlled NC machine tools that can randomly process a group of parts, having an integrated material handling system and central computer control to dynamically balance resource utilization, so that the system can adopt automatically to changes in parts production, mixes and levels of output. The problem of FMS operation is divided in common parlance into many interconnected sub-problems, each of which can be solved independently. Flexible Layout Design is the need of the hour to effectively save investment up to the tune of 20%. Hence in the present context an attempt is made at selection of a proper FL in the rapidly changing industrial environment.

Early researchers in this field have mostly concentrated on development of a general model for FL selection, relying completely on a single criterion. But the adoption of Multi-Criteria Decision Making (MCDM) methodology has revolutionized the way FL selection process is being looked at. The importance of selection of a proper FL 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. 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 is gaining wide acceptance that considers both objective reality and subjective ratings and also considers 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 and factors and tries to arrive at a good and not a best solution. Such is the significance of MCDM methodology.

FL decisions involve designing the arrangement of elements in manufacturing systems. Among the most critical decisions in this area are regarding the arrangement of departments, production units, manufacturing cells, centres, storage areas etc. Also as pointed out be Apple(1977), it is crucial to incorporate Material Handling decisions in the layout design. Tomkins et al.(1996) estimate that between 20% to 50% of the operating expenses in manufacturing can be attributed to Facilities Planning and Material Handling. Thus cost saving in this area can contribute to the overall efficiency of the production system.

II. PROBLEM DEFINITION

Multi-Criteria Decision Making Process

MCDM has several kinds of inputs. However, there are some common characteristics of such problems. That includes:

- Multiple objectives / attributes: Each problem will have conflicting and co-operating objectives / attributes. They must be precisely defined.
- Incommensurable units: Each objective / attribute has a different unit of measurement.
- Design / Selection: The aim of MCDM is to finally select an alternative which fits best with the criteria requirements. A criterion is in fact a measure of effectiveness. These emerge as forms of attributes or objectives in the actual formulation of the problem.

Table 1: The Nine-point scale of pair wise comparison

Intensity of relative importance	Definition
1	Equally important
3	Moderately preferred
5	Essentially preferred
7	Very strongly preferred
9	Extremely preferred
2, 4, 6, 8	Intermediate importance between two adjacent judgments

A MCDM problem involves at least two conflicting criteria and at least two alternative solutions to a problem. There are several methods to adopt MCDM processes. One such method is AHP that has been adopted in the present case.

Analytical Hierarchy Process (AHP)

AHP is a powerful tool in formulating and handling complex, multi-person and multi-period problems hierarchically. This process is used in a large number of applications including Engineering Design, Economic Planning, Energy Policy, Project Selection, Budget Allocation (Saaty, 1980) etc. It can provide useful insight into the trade-offs embedded in a decision making problem. The three fundamental steps of AHP are:

i) defining a multi-criteria problem hierarchically
ii) assigning relative priorities to the various elements using PWCP techniques
iii) integrating these priorities to converge at an overall evaluation of decision alternatives.

For assigning weights to the alternatives as well as criteria for constructing the decision matrix and PWCP matrices, the concept of relative importance is used to arrive at the decision maker's preferences. The intensity scale of importance (Table 1) introduced by Saaty[5] has been used here.

The DM and PWCP matrices used in AHP are all square matrices. The consistency of the judgment values assigned to the decision alternatives and criteria are checked using eigen vectors. Based on these checks, the decision maker revises and modifies the preference values, if required.

Generating a Model

A model, based on the Multi-Attribute Preference Theory was developed. In this model the Objective Factor Cost (OFC)s and Objective Factor Measure (OFM)s, Facilities Layout Measure (FLM)s, Subjective Factor Measure (SFM)s, Critical Factor Measure (CFM)s and Objective Factor Decision Weight ($\propto$) are interrelated.

The relationships are given by the equations

$$FLM_i = CFM_i\left[\left(\alpha\, OFM_i\right)+\left(1-\alpha\right)SFM_i\right] \quad (1)$$

where i = 1, 2, 3, . . . n are the number of alternatives and $0 \le \propto \le 1$ and

$$OFM_i = \left[OFC_i \sum\left(\frac{1}{OFC_i}\right)\right]^{-1} \quad (2)$$

While selecting a proper FL, the equations (1) and (2) consider all aspects. This approach is indeed a holistic and multidimensional one. Usually the value of '$\propto$' is taken as **0.67**. The basis for this value of $\propto$ is the result of brain storming session where experts from design, manufacturing, operations and maintenance departments were present. Whereas OFM values are objectives and tangible, SFM values are subjective and intangible. The CFM values vary as the location changes and it can be either 0 or 1. CFM is a product of individual critical factor index for each value of 'i' with respect to critical factor 'j'. In the present case since the location does not affect the selection of FL, the CFM value is taken as 1.

Cost Component (in $ X 0.1mn)	Alternative FLs				
	FL_1	FL_2	FL_3	FL_4	FL_5
Designing	0.39	0.45	0.55	0.24	0.85
Installation	2.35	3.65	2.68	1.88	4.54

Maintenance	1.89	1.65	1.73	1.98	2.02
Improvement	2.05	1.89	2.23	1.65	2.46
Material Handling	2.89	2.49	3.49	3.56	1.86
Unit Space	0.02	0.04	0.035	0.024	0.016
Total Cost	9.59	10.17	10.715	9.334	11.746
OFMi	0.2135	0.2014	0.1911	0.2194	0.1743

Table 2. Cost Factor Components

FL Selection Problem

Five criteria viz. **Floor Area, Production rate, Material being processed, Cost of attributes, Type of Labour** have been considered and coded as **AT_1, AT_2, AT_3, AT_4** and **AT_5** respectively. Five different layouts are considered and are coded as **FL_1, FL_2, FL_3, FL_4** and **FL_5**. It is presumed that the performance of these five alternative layouts with respect to each attribute is known. Now AHP is used to arrive at a decision based on the methodology shown below.

III. THE PROPOSED METHODOLOGY

The proposed methodology integrates the present model with AHP and also uses Sensitivity Analysis to assess the effect of cost on the selection of FL. The methodology is applied to calculate the PV weights for different attributes by Eigen Vector Method for each PWCP matrix. Next, composite weights are found out by AHP method. The different cost attributes related to the selection of FL are shown in table 2. Five types of cost component for FLs are considered. These actually are the OFCs of FLs.

	FL_1	**FL_2**	**FL_3**	**FL_4**	**FL_5**
FL_1	1	1/3	1/5	3	5
FL_2	3	1	1/7	7	9
FL_3	5	7	1	5	7
FL_4	1/3	1/7	1/5	1	1/3
FL_5	1/5	1/9	1/7	3	1

Table 4. Pair wise Comparison Matrix for Criterion AT_1

	FL_1	**FL_2**	**FL_3**	**FL_4**	**FL_5**
FL_1	1	1/3	8	1/7	5
FL_2	3	1	9	1/5	6
FL_3	1/8	1/9	1	1/3	8
FL_4	7	5	3	1	9
FL_5	1/5	1/6	1/8	1/9	1

Table 5. Pair wise Comparison Matrix for Criterion AT_2

	FL_1	**FL_2**	**FL_3**	**FL_4**	**FL_5**
FL_1	1	9	1/3	1/8	1/5
FL_2	1/9	1	1/5	1/6	1/3
FL_3	3	5	1	1/3	1/7
FL_4	8	6	3	1	1/9
FL_5	5	3	7	9	1

Table 6. Pair wise Comparison Matrix for Criterion AT_3

	FL_1	**FL_2**	**FL_3**	**FL_4**	**FL_5**
FL_1	1	6	5	4	3
FL_2	1/6	1	1/6	1/5	9
FL_3	1/5	6	1	1/7	1/8
FL_4	1/4	5	7	1	1/5
FL_5	1/3	9	8	5	1

Table 7. Pair wise Comparison Matrix for Criterion AT_4

	FL_1	**FL_2**	**FL_3**	**FL_4**	**FL_5**
FL_1	1	5	3	7	1/9
FL_2	1/5	1	1/9	1/7	1/7
FL_3	1/3	9	1	1/6	1/5
FL_4	1/7	7	6	1	1/3
FL_5	9	7	5	3	1

Table 8. Pair wise Comparison Matrix for Criterion AT_5

Algorithm of the proposed methodology

Step 1: List of set of alternatives (FL_1 – FL_5)

Step 2: Identification of Criteria (AT_1 – AT_5)

Step 3: Determination of OFM values for each of alternative layouts

Step 4: Assigning weights to each of the criteria based on relative importance of its contribution according to the 9-point scale. This is the Decision Matrix(DM).

Step 5: For each criterion, creation of Pair Wise Comparison Matrix (PWCP) matrices.

Step 6: Determination of PVs and multiplication of the sum of each column with corresponding PV values. Calculation of the sum of these products, i.e. the Principal

Eigen value λ_{max}.

Step 7 : Calculation of Consistency Index (CI) for each of the matrices, using

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \quad (3)$$

where 'n' is the order of each matrix.

Step 8 :Determination of Random Consistency Index (RI) for each of the matrices using

$$RI = \frac{[1.98(n-2)]}{n} \quad (4)$$

Step 9 : Determination of CR for each of the matrices, using

$$CR = CI / RI \qquad (5)$$

if CR < 0.1 then the method of selection is accepted. Else all the steps are redone until CR becomes less than 0.1 (equations (3) – (5) ref. Saaty, 1994)

Step 10 : Calculation of the composite values SFM for each of the alternatives. This is done for each alternative by multiplying its PV values for a particular criterion with corresponding PV value of that criterion and adding the products.

Step 11 : Determination of FLM for each alternative using

$$FLM_i = \left[\left(\alpha\, OFM_i\right) + \left(1-\alpha\right) SFM_i\right] \qquad (6)$$

here $CFM_i = 1$.

Step 12 : Ranking of the alternatives according to the descending order of their FLM values.

Step 13 : Selection of the best alternative - i.e. the highest value of FLM.

IV. RESULTS FOUND FROM THE PRESENT METHODOLOGY

The algorithm is coded as a 'C' program that operates under MS-DOS. Tables 3 – 8 show matrices for selection criteria and available alternatives. Figure 1 to 6 show the PV values obtained for each of those matrices. Finally, Table 9 shows CP values and in Figure 7 gives a graphical presentation. The layout FL_5 has the highest CP value.

V. SENSITIVITY ANALYSIS

Importance of the present study

Sensitivity analysis is used to determine how "sensitive" a model is to changes in the value of the parameters of the model and to changes in the structure of the model. In this paper, we focus on parameter sensitivity. Parameter sensitivity is usually performed as a series of tests in which the modeler sets different parameter values to see how a change in the parameter causes a change in the dynamic behavior of the stocks. By showing how the model behavior responds to changes in parameter values, sensitivity analysis is a useful tool in model building as well as in model evaluation. Sensitivity analysis helps to build confidence in the model by studying the uncertainties that are often associated with parameters in models.

Sensitivity Analysis can also be used to determine the model resemblance with the process under study. It is a very popular technique in financial applications, risk analysis etc. It is also useful as it considers the consequences of using faulty scenarios and estimates the accuracy of the data.

In order to take into account the dependency of the decision variables of FLs on costs, a Sensitivity Analysis has been carried out based on the method given earlier(step11-13). The governing equation for each of the alternative FL becomes, accordingly,

$$Y_i = (OFM_i - SFM_i)X_i + SFM_i \qquad (7)$$

here Y is the Facility Layout Measure(FLMi);X the objective factor decision weight (α).

This represents the equation of a straight line. The plots for the five layouts are shown in the Fig.7. Finally, the FLM values are calculated for α=0.71 and the result presented in the Table.10.

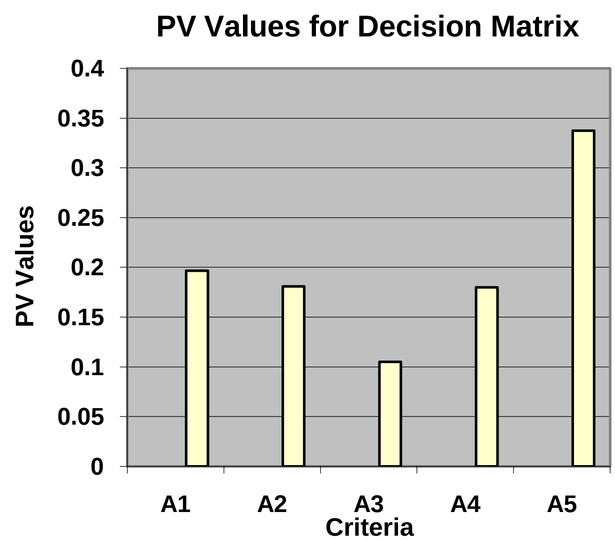


Figure 1. PV Values

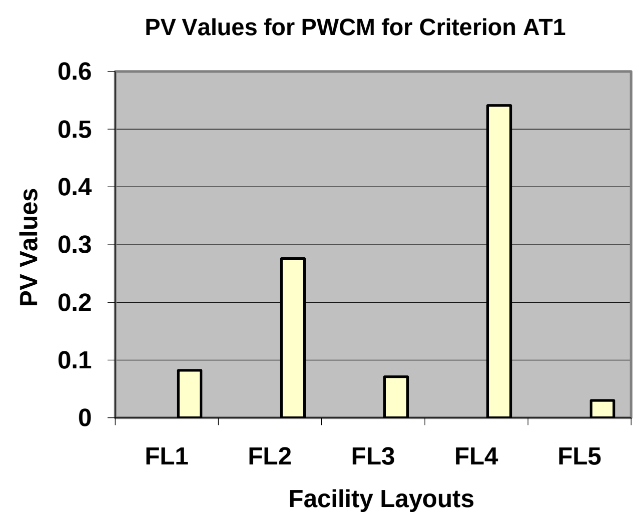


Figure 2. PV Values

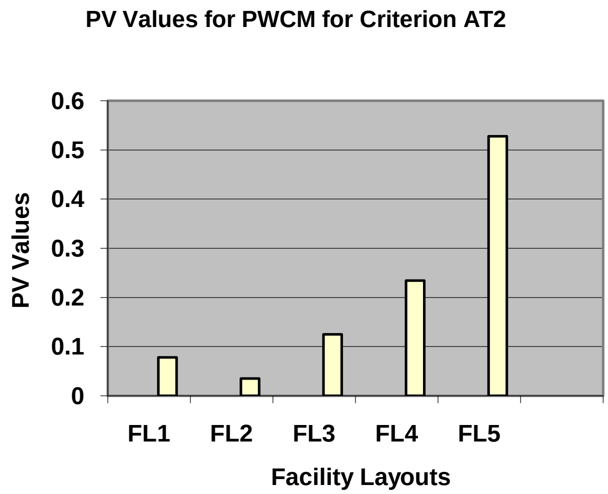


Figure 3. PV Values

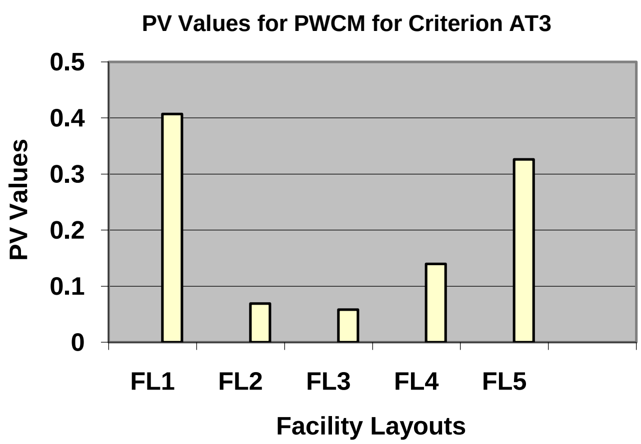


Figure 4. PV Values

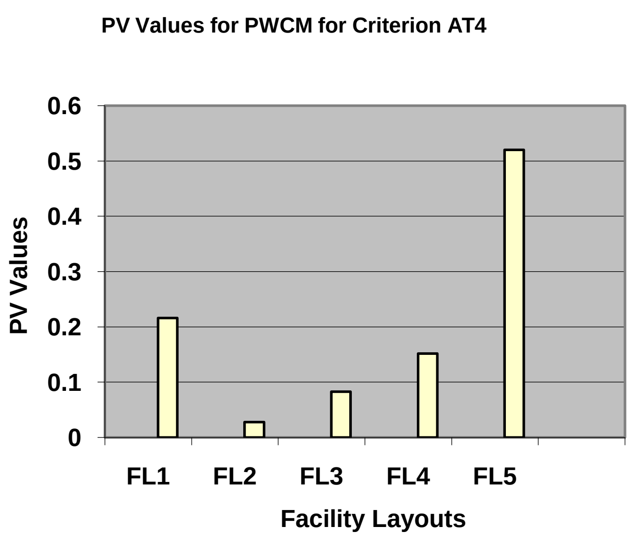


Figure 5. PV Values

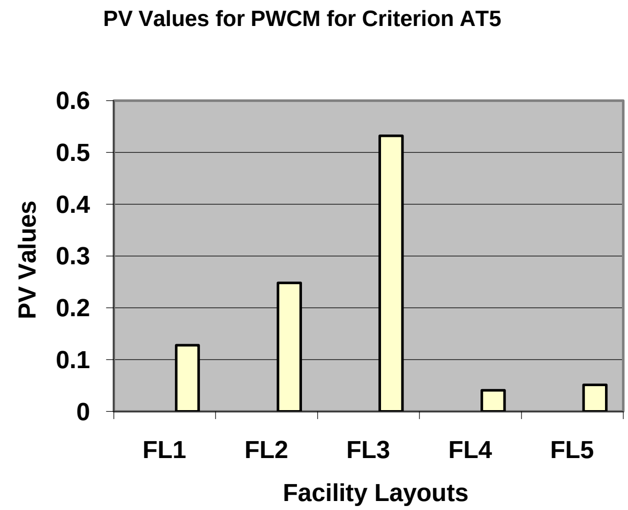
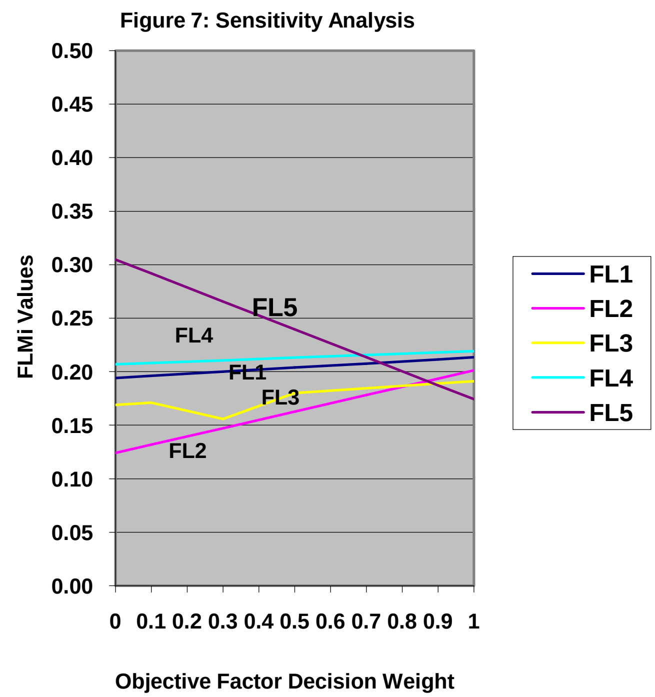


Figure 6. PV Values



VI. DISCUSSION

The number of criteria or alternatives should be reasonably small to allow for consistency in PWCP matrices. A maximum of seven criteria or alternatives can be used [5]. For more than seven criteria / alternatives, one can group the criteria with respect to a common property and add another level to incorporate groupings [5,7].

In the present work OFC is expressed in Dollars. OFM is non-dimensional, so also FLM. Higher the FLM value, better would be the selection. The value of α varies between 0 and 1. For $\alpha = 0$, FLM = SFM, i.e. selection depends only on the subjective assessment from AHP and SFM dominates over OFM. Then there is no significance considering the cost factor component. For α = 1, FLM = OFM, then FLM depends solely on objective assessment and entire cost factor component has all the significance.

VII. CONCLUSION

When viewed from the point of view of optimization process, selection of a FL is a complicated problem. Hence the present methodology lends a helping hand, firstly by quantifying apparently intangible factors in a systematic manner and then finding best available alternative depending on their cost components. It can also be applied under unstructured environment, unlike traditional approaches.

Alternative Layouts	Composite Priorities (CP)
FL_1	0.1943
FL_2	0.1242
FL_3	0.1689
FL_4	0.2070
FL_5	0.3049

$FLM_i = \left[\left(\alpha\, OFM_i \right) + \left(1 - \alpha \right) SFM_i \right]$ here $CFM_i = 1$ and $\alpha = 0.71$

Table 10: FLM values of alternative layouts

Alternative Layouts	**FLMi (for α = 0.71)**	**Rank**
FL_1	0.2079	3
FL_2	0.1790	5
FL_3	0.1842	4
FL_4	**0.2158**	**1**
FL_5	0.2122	2

REFERENCES

[1]. Tompkins, White, Bozer, Tonchoco, ‘ Facilities Planning’.

[2]. Francis, McGinnis, White, ‘Facility Layout and Location’.

[3]. Moore.J.M., ‘Plant Layout & Design’, The Macmillan Company, New York, 1962

[4]. Muther, R., ‘Systematic Layout Planning’, Industrial Education Institute, Boston, 1961

[5]. T.L.Saaty, ‘The Analytical Hierarchy Process’, McGraw Hill New York, 1980

[6]. E.S.Buffa, ‘Modern Production/Operation Management’, Wiley Eastern Limited, New Delhi, 1993.

[7]. T.L.Saaty, ‘How to make a Decision: The Analytical Hierarchy Process’, European Journal of Operations Research, Vol. 48, No.1, 1990, pp 9.26.

[8]. T.L.Saaty, J.W.France and K.R.Valentine, ‘Modelling the Graduate Business School Admissions Process’, Socio-economic Planning Sciences, Vol.25, No.2, 1999, pp 155-162.

[9]. Dr.S.Bhattacharya, B.Sarkar, R.N.Mukherjee, ‘Selection a Conveyor Belt Under Multi-Criteria Decision Making Environment’, IE (I) Journal – MC, Vol.86, October 2005, p 140-144.

[10]. Tompkins.J.A and R.Reed.Jr., ‘An Applied Model for the Facilities Design Problem’, International Journal of Production Research, Vol.14, No.5, 1976, pp 583-595.

[11]. Luotsma.F.A,Scale Sensitivity in the multiplicative AHP & SMART. Journal of Multi-Criteria DecisionAnalysis 2, 87-110, 1993 .

[12]. Fakhreddine Karray, Essam Zaneddin, Tarex Hegazy, IEEE Transactions on Fuzzy Systems, vol.8, No.4, August 2000, ‘ Tools of Soft Computing a Applied to the Problem of Facilities Layout Planning’.

[13]. S.Chittratanawat and J.S.Noble, ‘An integrated approach for Facilities layout, P/D location and MH system design’, IJPR, Vol.37, No.3, 683-706, 1999.

[14]. Gulfem Isiklar and Gulcin Buyukozkan, ‘Usin MCDM approach to evaluate mobile phone alternatives, Computer Standards Interfces, 29, 2007, 265-274.

[15]. Mikell P.Groover, ‘Automation in Engineering’, Printice Hall India.

[16]. C.LHwang, K.Yoon, ‘MADM-Methods and Applications, Springer-Verlag, Heidelberg, 1981.