FUZZY ANALYTICAL HIERARCHY PROCESS FOR FACILITY LAYOUT UNDER MANUFACTURING ENVIRONMENT

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Abstract Facility layout problem is an unstructured decision problem. One of the real difficulties in developing and using models for layout design is the natural vagueness associated with the inputs to the models and the problem of inconsistencies of the designers. Arbitrary numerical ratings are assigned to influencing factors without considering their relative importance for relationship chart. In this paper, multiple criteria decision-making methods are used with the support of fuzzy system to find the selection order of machines for placement in open continual plane considering zero base area allocation. Saaty's analytical hierarchy process is utilized to find the relative weights of each factors for all the moves associated with facility layout design to overcome the problem of inconsistencies. A heuristic algorithm is suggested which searches several candidate points, machine configurations, orientations and pickup/drop-off locations in order to minimize the flow cost. The suggested procedure is coded in Turbo C language and implemented in a personal computer. The experimental results with test problem are illustrated with encouraging results.

Keywords: Fuzzy decision, Analytical hierarchy process, Selection order, Facility layout.

INTRODUCTION

The most significant objective of any manufacturing system has been the maximum utilization of facilities available to achieve desired goal of productivity and profitability. Facility layout deals with the selection of most appropriate and effective arrangements of machines to allow greater efficiency. Owing to the complex and unstructured nature of facility layout, many researchers have proposed various approaches, which have not been very successful to deal with the complexities associated with the problem. Layout approaches start with the collection of data about the product to be produced. The data may be quantitative such as from-to-charts, qualitative as the relationship chart or a combination of both. Regardless of the type of data, there is an element of vagueness or fuzziness in it. Traditional layout method treats these data as exact and cannot satisfy the desirability of plant managers in handling the real problems. In Raoot and Rakshit's model (1993) the authors define the membership values of the linguistic variables by using statistics and relative preference. The model considered and assumed four independent equally weighted linguistic variables affecting the layout process. The location of department from each other, 'distance' is the dependent decision factor based on the independent input variables. Fuzzy decision-making is applied for developing relationship charts for the purpose of facility layout design [Dewri, 1999]. Most of the models and algorithms available in the literature are meant for general facility layout without considering the inconsistencies of the designer, actual dimensions of machine block and pickup/drop off locations. Analytical hierarchy process (Saaty 1980) is a decision aiding tool for dealing with complex, unstructured and multiple attribute decisions. Under heavy manufacturing environment machines are with large dimensions of length and width. Each machine with specific dimension may be considered as cell or facility. The placement of facilities under such open field configuration is very complicated (Deb et all 2001). The placement of facilities in the open continual plane starts with calculating the facility selection order. Therefore, the present research work aims to determine the facility selection order using fuzzy set theory and analytical hierarchy process. A distinct heuristic construction algorithm (Deb et all 2001) is used to generate a manufacturing facility layout under continual planner approach by minimizing the flow cost and dead space. In section 2 fuzzy sets and system are briefly explained, the section 3 illustrates the basic procedure of analytical hierarchy process (AHP), the section 4 deals with the fuzzy decision making system, in section 5 procedure and formulation of the facility layout problem (FLP) is discussed, section 6 illustrates the fuzzy multiple-criteria facility layout simulation of the proposed methodology and the last section 7 gives the concluding part of the present research paper.

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FUZZY SETS AND SYSTEM

A fuzzy set can be thought of a class of concepts/objects in which no well-defined boundary exists that belong to the class and those which do not belong. The system has inputs $u_i \in U_i$ where i=1,2…n and output $y_i \in Y_i$ where i=1,2…m. The inputs and outputs are 'crisp'. The fuzzificaton block converts the crisp inputs to fuzzy set, Formally, if X={x} is a set of objects, then the fuzzy set A on X is defined by its membership function $f_A(x)$ which assigns to each element x ε X a real number in the interval [0, 1] which represents the grade of membership of x in A or the degree to which x belongs to A. Thus A can be written as: $A=\{(f_A(x)/x)|x \in X\};X\rightarrow[0,1]$.

Linguistic variable

The experts use a linguistic description to identify the characteristics of the inputs and outputs to specify rules for the rule base of the system. The linguistic variables are generally descriptive terms such as "very high", "medium", "in between high and medium", "production link". The linguistic variable u_i takes on linguistic values that are used to describe the characteristic of the variables. The set of linguistic values for $\overline{u_i}$ are denoted by

$$\overline{A_i} = \{\overline{A_i^j} : j = 1,2,........n_i\}.$$

If $\overline{A_1}$ *and* $\overline{A_2}$ *are the set of values of linguistic variables*

$\overline{u_1} \equiv$ "*Information link*" *and* $\overline{u_2} \equiv$ "*Supervision link*"

$$\text{then } \overline{A_1} = \{\overline{A_1^1}, \overline{A_1^2}, \overline{A_1^3}\} \equiv \{High, Medium, Low\}$$

$$\text{and } \overline{A_2} = \{\overline{A_2^1}, \overline{A_2^2}, \overline{A_2^3}, \overline{A_2^4}\} \equiv \{VH, M, L, VL\}$$

Membership function

Fuzzy sets and fuzzy logic are used to heuristically quantify the meaning of linguistic variable, values and linguistic rules that are specified by the expert. The concept of fuzzy set is introduced by defining a membership function. The function $\mu(u_i)$ associated with $\overline{A_i^j}$ that maps U_i to [0, 1] is called a membership function. The membership function describe the degree to which u_i belongs to $\overline{A_i^j}$. Membership function is subjectively specified in an ad hoc (heuristic) manner from experience or intuition. In the present research paper the commonly used triangular and trapezoidal functions are used as shown in figure [ ]. Most commonly used membership functions such as triangular and trapezoidal fuzzy number can be expressed mathematically as:

- *For tringular fuzzy number* $A(c,a,b)$,

the membership function becomes

$$\mu(u_i) = \begin{cases} (\mu_1 - c)/(a-c) & c \le \mu_1 \le a \\ 1 & \mu_1 = a \\ (\mu_1 - b)/(a-b) & a \le \mu_1 \le b \\ 0 & otherwise \end{cases}$$

- *For trapezoidal fuzzy number* $A(c,a,b,d)$,

the membership function becomes :

$$\mu(u_i) = \begin{cases} (\mu_1 - c)/(a-c) & c \le \mu_1 \le a \\ 1 & a \le \mu_1 \le a \\ \mu_1 - b)/(a-b) & b \le \mu_1 \le d \\ 0 & otherwise \end{cases}$$

For example, if $\overline{u_i}$ is material flow link, U_i=[0,50] is universe of discourse and $\overline{A_i} = \{Low, mediu, high\}$ then the membership function for linguistic values may be expressed in different ways.

(1)Triangular pattern

L(0, 0, 20); M(10, 20, 30), H(20, 30, 50)

(2)Trapezoidal pattern

L(0, 0, 10, 20);M(0, 10, 20, 30);H(10, 20, 30, 40)

ANALYTICAL HEIRARCHY PROCESS

The AHP is a decision making tool for dealing with complex, ill structured and multiple attributes decision problem. It helps in evaluating multiple attribute alternatives when subjective assessments of qualitative factors are integrated with quantitative factors. L. Saaty developed it during 1970s. Since its initial development, AHP has been used in a wide variety of decision areas, including manufacturing and production systems [Dweri, 1999]. The traditional decision making approaches consider only the quantitative factors, failing to recognize the many importance qualitative factors such as environmental link, supervision link in a manufacturing system. Moreover traditional layout decision overlooks the problem of inconsistencies of designers. The AHP uses a nine-point scale defined to get intensity importance factor (a_{ij}) as: 1- equal importance, 3-moderate importance, 5-strong importance, 7-very strong importance, and 9-extreme importance. The even numbers 2, 4, 6 and 8 are for compromise, and the reciprocals show the inverse pair wise comparisons. These numbers represent the weight factors (priorities) of the reasons involved in the decision making process. The intensity importance of factor i over factor j is equal to reciprocal of intensity importance of factor j over factor i.

PROCEDURE FOR THE USE OF AHP

Since AHP involves a comparison of two factors, the matrix that contains the weight assignments must be a square matrix. Let A represents the matrix and its size as n×n. AHP uses a process known as systemization. The procedure is as follows:

Step 1. Form the importance intensity matrix A=[a_{ij}] by using Saaty's 9 point scale.

Step 2. Find geometric mean of a_{ij} for all the participants to get groups numerical assignment when factor i is compared with factor j with popular 9 point scale of Saaty.

Step 3. Obtain column total (S_j) by adding the weight assignments in each of the column j

$$S_j = \sum_{i=1}^{n} a_{ij} \quad \forall \; j = 1, n.$$

Step 4. Divide each element of matrix A by its column total (S_j) to get normalized pair wise comparison matrix:

$$V = [v_{ij}]$$

$$where\; v_{ij} = \frac{a_{ij}}{S_j} \quad \forall \; i = 1, n.$$

Step 5. Estimate relative priorities of each factor by computing the average of the normalized weights in each of i row. Let p_i represents the relative priority of factor i. Then,

$$p_i = \sum_{j=1}^{n} \frac{v_{ij}}{n} \quad \forall i = 1, n.$$

$$Also \sum_{i=1}^{n} p_i = 1.$$

Consistency ratio estimation

Following steps are performed to compute the consistency ratio estimation.

Step1. Multiply each of the columns of comparison matrix A by the relative priorities corresponding to that column and add to obtain an n∗1 matrix called B. Thus the new matrix can be expressed as:

$$B = \begin{pmatrix} b_1 \\ b_2 \\ - \\ - \\ b_n \end{pmatrix} = \begin{pmatrix} p_1 a_{11} + p_2 a_{12} + - - - + p_n a_{1n} \\ p_1 a_{21} + p_2 a_{22} + - - - + p_n a_{2n} \\ ------------------------- \\ ------------------------- \\ p_1 a_{n1} + p_2 a_{n2} + - - - + p_n a_{nn} \end{pmatrix}$$

Step2. Compute consistency ratio (CI) as follows

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad where\; \lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{b_i}{p_i}$$

Step3. Obtain consistency ratio as CR=CI/RI where RI is a random index which represents the consistency index of a randomly generated comparison matrix taken from standard random index table which is given by Saaty for the number of factors used in the decision-making. Any value of CR ≤ 0.1 is considered as an acceptable ratio of consistency.

FUZZY DECISION MAKING FOR LAYOUT

Traditional approaches of facility layout are maid under crisp environment, thus failed to provide an efficient layout by handling inexact parameters. This complex and imprecise involves the use of natural language (e.g. high material flow, very low supervision etc) to develop a critical and precise layout.

Variables identification

The first step to design plant layout is to identify the different variables that can influence the design. Because of the vast and ill structured of FLP it is very difficult to collect the exact numerical data. Fuzzy set theory is very suitable under such situation for handling the inexact and imprecise data, yet to work mathematically strict and vigorous way. The experts assign numerical ratings based on a designed scale and suggest a membership function for analysis. The decision may be based on single expert or multiple expert opinions.

COMMON INFLUENCING VARIABLES

Some of the most common factors (input variables) used by decision makers to develop the relationship ratings between machine blocks in manufacturing system are:

- Material flow (MF): the flow of parts, raw materials, work in process etc. it can be measured in units per unit time, Experts can use these variables some linguistic values such as high, low, medium etc.
- Information flow (IF): the communication required between different machines for controlling and coordinating and the unit can be number of communications per time unit. The experts can fuzzify this variable using linguistic variables.
- Equipment flow (EF): the number of equipments or tools required to perform jobs in machine cells, such as number of material handling equipments etc.
- Weight link (WL): it is numerical values between 0 and 1 assigned to different factors involved in the multi criteria decision making process. These values are determined by using AHP. This variable is fuzzified using a set of membership functions such as very low, high, very high etc.

- Rating link (RL): The experts assign values to each move to represent the closeness rating of interactions among different machine cells based on the input variables, such as A=6, E=5, I=4, O=3, U=2 and X=1.

FUZZY INFERENCE SYSTEM

A fuzzy inference system (FIS) consists of four main components as shown in Fig. 1. The four components of FDMS are

1) Fuzzification interface: The different input and output variables are measured and converted into natural language. Fuzzy sets are used to quantify the information in the rule base, and the inference mechanism operates on fuzzy sets; the process of converting the numeric inputs u_i ε U_i into fuzzy sets so that they can be used by the fuzzy system is called fuzzification. Let U_i^* denote the set of all possible fuzzy sets that can be defined on U_i . Given u_i εU_i, fuzzification transforms u_i to a fuzzy set defined on the universe of discourse U_i.
2) Knowledge base interface: The database that contains the experts' knowledge of the application and the control rules of the process. The experts based on their knowledge of the system decide the membership functions.
3) In decision rules module the expert's decision-making ability is simulated based on a fuzzy concept. The mapping of the inputs to the outputs for a fuzzy system is in part characterized by a set of condition→ action rules in the form of IF-THEN. In this paper multi-input single-output (MISO) is considered in the following form:
IF (MF) is (VH) and (IF) is (H) and----
THEN rating is (A)
The number of rules is represented by

$$N = \sum_{i=1}^{n} \left(\prod_{j=1}^{m} M_j \right),$$

where N is the total number of rules
n = Number of set of rules used in decision making,
m = Number of input variables used in one set of rule.,
and M_j *is the number of membership functions or labels of the linguistic values in fuzzy decision..*

4) Defuzzification interface: To convert all the related rules for any move in the layout a defuzzification method is used. The fuzzy outputs are converted into crisp (nonfuzzy) values by center of area (COA) method, center of maximum method (COM) and mean of maximum method (MOM). In this research paper the most commonly used method COA is used. The FIS developed for the present problem consists of two stages as shown in figure 1. The first stage takes into account the consistency of the designers by considering the weights of each variable as input of the inference

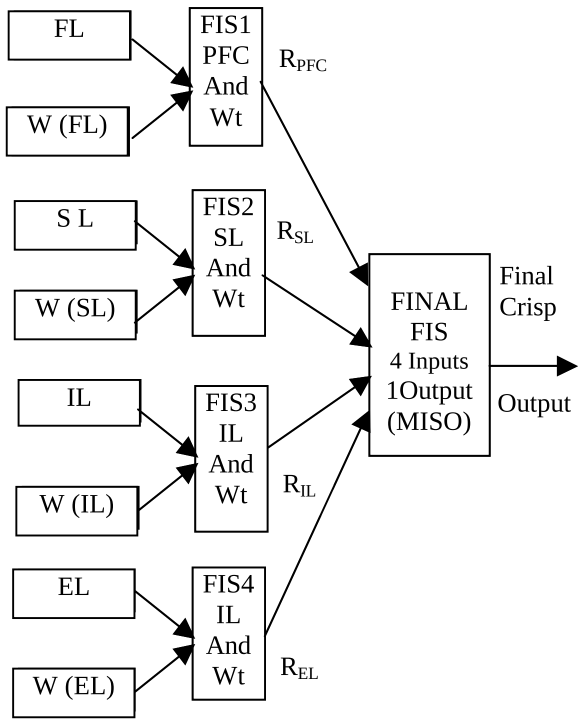

Fig. 1 Two-stage Fuzzy Inference System for Multi-criteria facility selection routine.

engine. The output of the first inference system is used as the inputs of the second stage FIS to get the final output rating.

PROCEDURE AND FORMULATION

The layout problem becomes much complex under a manufacturing system. It seeks the best arrangements of machine cells or block based on inter facility interaction. The primary objective of manufacturing facility layout design is to achieve minimum transportation cost. The procedure and formulation for the proposed facility layout design can be performed in two steps

Facility selection order

The layout is developed on the basis of a selection order of machines. The machine, which is having the highest interactions with the other machines, is placed first at the center of the continual plane or open field. The approach searches several candidate points on the blocks already placed for different configurations and orientations of the incoming machines in order to minimize the flow cost, dead space and minimum area required for layout. The selection order for placing the machines in the open field layout depends on objective links as well as subjective links. These links may be quantitative and qualitative or combination of both. It is necessary to define the universe of discourse and define the membership functions and the linguistic values of these variables. In this research the values of the variables are randomly chosen within a scale [0, 10]. The triangular membership functions are commonly chosen for important factors and trapezoidal membership functions are chosen for comparatively less important variables. The following steps are adopted to determine the selection order:

1) Identify the input variables influencing the layout and assign values as per designed scale for all moves.
2) Find the relative priorities of each factor/criteria using Saaty's analytical hierarchy process as discussed in section 3.
3) Find the minimum values of the input variables' membership values using minimum operator.
4) Design the linguistic rules for fuzzy decision – making.
5) Find the outputs of first stage fuzzy inference system by using four sets of linguistic rules, i.e. weight versus flow, supervision, environment and information link.
6) Apply the second stage fuzzy inference system (FIS) with the outputs of the first stage FIS to get the final fuzzy rating of each move.
7) Aggregate ratings to get the final rating if multiple experts are taking part in FDMS.
8) Form a final rating matrix $R_{n*n} = [\ r_{ij}\ ] \quad \forall \quad i,j = 1,2,\ldots\ldots n$ and $r_{ij} = 0$ for $i = j$.
9) Calculate the total fuzzy rating of the ith machine with the other machines and find the maximum value (F_k) to select the first facility as machine K.

$F_i = \sum (r_{ij} + r_{ji}) \quad \forall \quad i , j = 1,2,\ldots\ n.$

$F_k = \max \{ Fi \} \quad \forall \quad i = 1,2,\ldots\ldots\ n.$

10) Find next machine that has maximum fuzzy rating with the facility already selected and repeat the process.

Placement procedure

Another important criteria for developing layout under heavy processing environment is to minimize the area required for layout. One of the inherent characteristics of layout design under open field generation (continual plane) is the development of dead space. Because of NP hardness nature of problem the optimal solution is not possible under such situation. Hence, a heuristic approach is adapted to develop the layout (Deb et al 2001).

SIMULATION

A problem is designed to demonstrate the applicability of the proposed procedure. The methodology seeks the determination of machine selection order for their placements in the open continual plane based on multiple inter facility interactions. In the present work four relationships are generated. They are material flow link (FL), supervision link (SL), environmental link (EL) and information link (IL). The factors can be quantitative as well as qualitative or combination of both. The simulation of the fuzzy multiple criteria decision-making system for the layout process starts by generating the sequential order in which the machine blocks to be placed. The selection order of placement plays a prominent role while generating a layout under manufacturing environment considering zero area allocation. The generation of layout under continual planner approach is very complicated as no particular pattern is available for machine block placement. The experimentation of the multiple criteria fuzzy decision-making system for the layout process consists of four distinct simulation parts: (1) Determination of weight for each criteria for all the moves by applying AHP, (2) Developing the fuzzy selection order using two-stage fuzzy inference system, (3) Developing heuristic procedure for placement of machine blocks in the open field, (4) Comparative analysis of the layout developed with the proposed procedure and other existing methodologies. The algorithm was coded in turbo C language and the problem was run on IBM Pentium III, 550 MH machine. The material flow values and machine specifications used in the computer simulation are taken from 6 machines (Deb et all 2001). The different link values associated with 30 moves are chosen within the designed scale [0, 10] and the intensity importance values of factors assigned by the decision-maker in line with Saaty's nine-point scale. The relative weights of each factor for all the moves are determined. The rule base for the second stage of FIS contains 625 rules having five levels {VL, L, M, H, VH} for each output factor of first stage FIS. Four set of FIS diagram for first stage is considered to overcome the inconsistencies of the designers. The values of intensity importance factors, relative weights and crisp outputs of individual FIS are show in table 1. The final rating matrix obtained by using 625 rules in the second stage FIS is shown in table 2. The layout developed by using fuzzy-AHP selection orders is shown in figure 2 and the values of flow cost, dead space and minimum required area of layout is obtained.

CONCLUSION AND DISCUSSION

The distinct methodology presented in this paper is very effective in handling the imprecise variables associated with an unstructured problem like facility layout. The analytical hierarchy process utilized in the solution process easily eliminates the inconsistencies of the designers. The methodology can easily be applied to improve other existing facility layout algorithms where REL-chart and FLOW-chart are based on imprecise data.

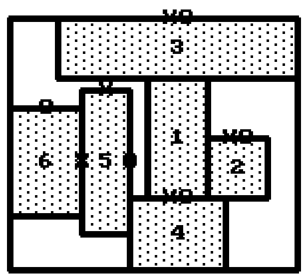

Fig. 2. Layout based on Fuzzy-AHP.

Table 1. Values of relative weights, intensity factors and crisp ratings of two stage FIS

Moves	Relative weights				Relative intensity factors						FIS1 crisp values				FIS2
M_i	W_{iF}	W_{iS}	W_{iE}	W_{iI}	a_{iFS}	a_{iFE}	a_{iFI}	a_{iSE}	a_{iSI}	a_{iEI}	R_{iF}	R_{iS}	R_{iE}	R_{iI}	R_{iFinal}
1-2	0.43	0.16	0.30	0.09	2.00	3.00	3.00	0.33	2.00	4.00	3.2	1.9	4.0	3.0	2.25
2-1	0.10	0.27	0.16	0.45	0.50	0.33	0.33	3.00	0.50	0.25	1.6	4.0	1.0	2.6	2.92
1-3	0.33	0.07	0.38	0.20	4.00	1.00	2.00	0.25	0.20	3.00	2.6	1.0	4.4	1.9	1.85
3-1	0.48	0.06	0.24	0.19	5.00	2.00	4.00	0.33	0.17	2.00	3.6	1.0	3.0	1.9	1.99
1-4	0.48	0.20	0.25	0.06	2.00	4.00	6.00	0.25	5.00	2.00	3.6	3.0	3.0	1.9	2.58
4-1	0.41	0.07	0.27	0.23	5.00	1.00	3.00	0.33	0.25	1.00	3.0	1.9	3.0	2.4	2.38
1-5	0.22	0.41	0.23	0.12	2.00	0.25	1.00	6.00	4.00	1.00	2.3	4.5	1.9	1.0	2.50
5-1	0.46	0.07	0.25	0.20	7.00	1.00	4.00	0.50	0.25	1.00	3.4	1.0	1.9	1.9	2.44
1-6	0.29	0.19	0.27	0.22	6.00	1.00	0.33	2.00	1.00	4.00	1.9	1.9	1.9	2.4	2.69
6-1	0.38	0.19	0.28	0.14	5.00	0.50	3.00	1.00	2.00	1.00	3.4	2.8	1.9	1.9	2.45
2-3	0.31	0.24	0.28	0.15	3.00	0.50	2.00	1.00	3.00	1.00	2.7	1.9	1.9	1.9	2.25
3-2	0.27	0.25	0.08	0.37	7.00	1.00	0.25	2.00	3.00	0.17	1.9	1.9	1.9	3.6	2.09
2-4	0.37	0.07	0.19	0.35	5.00	2.00	1.00	0.33	0.25	0.50	2.8	1.9	3.8	1.9	2.25
4-2	0.37	0.17	0.27	0.17	4.00	1.00	2.00	0.50	2.00	1.00	3.4	2.9	3.0	1.8	2.34
2-5	0.43	0.12	0.14	0.29	4.00	2.00	2.00	1.00	0.50	0.33	3.2	1.2	2.2	1.4	2.17
5-2	0.39	0.15	0.28	0.16	8.00	1.00	2.00	0.25	3.00	1.00	2.9	1.4	1.9	1.0	1.88
2-6	0.31	0.20	0.28	0.19	3.00	2.00	1.00	0.17	4.00	1.00	2.5	1.9	3.0	1.9	2.25
6-2	0.37	0.18	0.28	0.14	2.00	1.00	4.00	0.50	2.00	1.00	2.8	2.8	1.9	1.9	2.25
3-4	0.46	0.13	0.24	0.15	9.00	1.00	3.00	0.50	2.00	1.00	3.4	2.5	1.9	1.0	2.13
4-3	0.48	0.13	0.21	0.16	4.00	2.00	3.00	0.50	1.00	1.00	3.8	2.2	3.0	1.8	2.25
3-5	0.27	0.16	0.21	0.34	3.00	1.00	1.00	2.00	0.17	1.00	2.3	2.4	1.9	2.6	2.65
5-3	0.48	0.14	0.11	0.26	5.00	3.00	2.00	1.00	1.00	0.25	3.8	2.2	2.1	2.3	2.80
3-6	0.32	0.21	0.19	0.27	6.00	1.00	0.50	2.00	1.00	1.00	2.7	3.0	1.9	1.3	1.93
6-3	0.25	0.20	0.25	0.28	4.00	1.00	0.17	2.00	1.00	3.00	3.0	1.9	3.0	2.4	2.28
4-5	0.30	0.12	0.33	0.23	3.00	1.00	1.00	0.50	0.50	2.00	2.6	2.1	3.1	1.9	2.25
5-4	0.39	0.17	0.20	0.22	7.00	1.00	2.00	3.00	0.25	1.00	2.8	3.1	4.0	2.4	2.40
4-6	0.25	0.07	0.28	0.39	4.00	1.00	0.50	0.33	0.17	1.00	2.3	1.9	3.0	2.9	2.44
6-4	0.37	0.18	0.21	0.22	2.00	1.00	3.00	1.00	1.00	0.50	2.8	3.5	4.0	2.1	2.39
5-6	0.33	0.11	0.31	0.24	8.00	1.00	0.50	0.33	1.00	2.00	2.8	1.0	2.1	1.8	2.33
6-5	0.23	0.13	0.33	0.29	3.00	1.00	0.25	0.33	1.00	2.00	3.4	2.4	3.2	1.4	2.30

Table 2. Final fuzzy rating matrix

M1	000	2.25	1.85	2.58	2.50	2.69
M2	2.92	000	2.25	2.25	2.17	2.25
M3	1.99	3.09	000	2.13	2.65	1.93
M4	2.34	2.34	2.25	000	2.25	2.44
M5	2.44	1.88	2.80	2.40	000	2.33
M6	2.45	2.25	2.28	2.39	2.20	000

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