Effectiveness of a Facilities Layout using Multi-Criteria Decision Making Model

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Abstract— **Performance measurement is an area to which facilities have paid much attention recently. There is a wide range of choices in measuring facility performance is essential to support various decision making problems that may arise during a facilities layout life cycle. The existing models have considered only material handling cost as the performance measurement factor. Nevertheless, general, flow of material, flexibility, space utilization, materials handling, storage arrangement, shipping and receiving, building and utilities, expandability without major disruption, and service activities have a significant contribution towards the layout effectiveness. Therefore, it is necessary to have an efficient model to determine the facilities layout's effectiveness by considering a set of layout effectiveness factors. The proposed model, using a fuzzy multiple attributes decision-making method, enables the decision-maker of a manufacturing enterprise to analyze alternative layouts in different boards, based on which they can develop decision towards productivity improvement. An illustrative example has been adopted for an empirical illustration. Results showed that the proposed model is a logical, simple and convenient implementation framework.**

Index Terms— **Layout evaluation, multi-criteria decision making, assessment of alternatives, criterion weights, fuzzy logic/modeling.**

I. INTRODUCTION

A facility layout problem is one of the most classical NP-complete problems, of which the task is to assign facilities to locations in order to minimize a total cost function [1-3]. It is one of the strategic fields that determine the long run efficiency and performance of the operation. The U.S. Annual Capital Expenditure Survey for 2001 indicates that around $192.4 billion have been spent on new facilities in the manufacturing sector alone, about 8% of the gross national product (GNP) for that year [4]. The size of investment in creating new facilities each year makes this field of facilities planning important [5], in which its application is popular in the real world, which includes layout of buildings on university campuses, arrangement of departments within hospitals, total wire length in electronic circuits, as well as others. The complexity of the problem has motivated researchers to develop many procedures [6-13].

Some evaluation criteria are difficult to be measured by crisp values; they are usually neglected during the evaluation. Another difficulty is about those models that are based on crisp values. They cannot deal with decision makers' uncertainties, ambiguities, and obscurities, which cannot be handled by crisp values. In real-world problems, some of the decision data can be properly assessed while others cannot [14-16]. For those data, which cannot be precisely assessed, Zadeh's fuzzy sets [17] can be used to deal with them. The use of fuzzy set theory allows us to incorporate incomplete, unquantifiable, and non-obtainable information, and partly ignorant facts into the decision model. When decision data are exactly known, they should not be faced into a fuzzy format in the decision analysis. Implementations of fuzzy sets within the domain of decision-making have, for the most part, consisted of supplements or ''fuzzifications'' of the classical theories of decision-making. While decision-making under situations of risk and uncertainty have been modeled by probabilistic decision theories and by game theories, fuzzy decision theories try to deal with the vagueness or fuzziness inherent in subjective or imprecise determinations of goals, constraints, and preferences.

Teng and Tzeng [18] presented the fuzzy multi-objective programming using the fuzzy spatial algorithm for the problem of transportation investment project evaluation. Avineri, et al. [19] presented a methodology for the selection and ranking of transportation projects using fuzzy sets theory. Chen [20], Coldrick, et al. [21], Karsak, et al. [22], and Zhang, et al. [23] proposed different fuzzy ranking methods for evaluating and ranking manufacturing system investments. Recently, Yang et al. [24] presented a fuzzy multiple attribute decision-making model for a layout design.

In this paper, fuzzy multi-attributes with multi-experts approach for evaluating the best layout among others will be introduced; and the implementation process will be shown by an illustrative example.

II. BASIC CONCEPTS OF FUZZY NUMBERS

A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$, which consorts with each element x in X a real number in the interval [0, 1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$. Special cases of fuzzy numbers include crisp real number and intervals of real numbers. Although there are many forms of fuzzy numbers such as the triangular and trapezoidal forms are used most often for representing fuzzy numbers (For more details, see Lee and Lee-Kwang [25]). The following describes and definitions show that membership function of the triangular fuzzy number, and its operations.

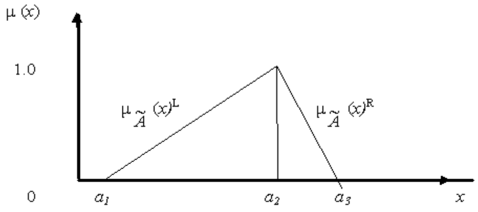

Figure 1. The membership function $\mu_{\tilde{A}}$

Definition 2.1. A triangular fuzzy number can define as a triplet (a_1, a_2, a_3), as shown in Fig.1. Its membership function is defined as:

$$\mu_{\tilde{A}} = \begin{cases} 0, & x < a_1 \\ (x - a_1)/(a_2 - a_1) & a_1 \le x \le a_2, \\ (a_3 - x)/(a_3 - a_2) & a_2 \le x \le a_3, \\ 0, & x > a_3 \end{cases} \quad \text{....(1)}$$

Let $\tilde{A}$ and $\tilde{B}$ be two fuzzy numbers parameterized by the triplet (a_1, a_2, a_3) and (b_1, b_2, b_3), respectively. Thus, the operations of triangular fuzzy numbers are expressed as:

$$\tilde{A} \oplus \tilde{B} = (a_1, a_2, a_3) \oplus (b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_3, a_3 + b_3),$$
$$\tilde{A} \ominus \tilde{B} = (a_1, a_2, a_3) \ominus (b_1, b_2, b_3) = (a_1 - b_3, a2 - b_2, a3 - b_1), \quad \text{.......(2)}$$
$$\tilde{A} \otimes \tilde{B} = (a_1, a_2, a_3) \otimes (b_1, b_2, b_3) = (a_1 \times b_1, a_2 \times b_2, a_3 \times b_3),$$
$$\tilde{A} \oslash \tilde{B} = (a_1, a_2, a_3) \oslash (b_1, b_2, b_3) = (a_1 / b_3, a_2 / b_2, a_3 / b_1).$$

Definition 2.2. A linguistic variable is a variable whose values are expressed in linguistic terms. For illustration, weight is a linguistic variable whose values are very low, low, medium, high, very high, etc. Triangular Fuzzy numbers can represent these linguistic values.

Definition 2.3. For a fuzzy set $\tilde{A}$ defined on X and for any number α ∈ [0, 1]; the α-cut, $\tilde{A}^{\alpha}$, and the strong α-cut, $\tilde{A}^{\alpha+}$, are defined as:

$$\tilde{A}^{\alpha} = \{x \mid \mu_{\tilde{A}}(x) \ge \alpha\},$$
$$\tilde{A}^{\alpha+} = \{x \mid \mu_{\tilde{A}}(x) > \alpha\}. \quad \text{.......................... (3)}$$

That is, the α-cut (or the strong α -cut) of a fuzzy set $\tilde{A}$ is the crisp set $\tilde{A}^{\alpha}$ (or the crisp set $\tilde{A}^{\alpha+}$) that contains all the elements of the universal set X whose membership grades in $\tilde{A}$ are greater than or equal to (or only greater than) the specified value of α.

A level threshold (0<α<1) of the fuzzy set is defined to show the decision-makers' confidence to their opinions. The definition of the triangular fuzzy number with the interval confidence at level α can be determined as follows:

$$M_{\alpha} = [(a_2 - a_1)\,\alpha + a_1, (a_2 - a_3)\,\alpha + a_3] \;\forall\; \alpha \in [0, 1] \text{........ (4)}$$

III. ALGORITHM AND METHODOLOGY TO EVALUATE LAYOUTS

In the following, a methodology to deal with layout evaluating problems is developed. The concept evaluating can be described as a problem of ranking *m* Layouts (L_i; i = 1, 2, .., *m*) by the decision maker. He/she wishes to select the layouts which best satisfy the criteria from amongst *m* layouts, with the help of information about the layouts for each of *k* Criteria (C_j; j = 1, 2,…., n) and also the relative importance of each criterion (W_j; j = 1, 2. …, n).

Step 1. Perform a decision-makers' committee of experts (DM_k; k=1, 2,…, l) and determine the layouts' alternatives (P_i; i= 1, 2, …, m) and the decision criteria (C_j; j=1, 2, …, n) to be evaluated.

Step 2. Determine the fuzzy rating and importance weight of the k-th decision maker. Hence, the aggregated fuzzy weights (W_j) of each criterion can be calculated as:

$$W_j = 1/k \otimes (W_1 + W_2 + \ldots.. + W_{jk}),\ j = 1, 2, \ldots., n. \quad \text{............(5)}$$

Step 3. Obtain the decision matrix by identifying the criteria values as crisp data, triangular fuzzy numbers or linguistic expressions for each k-th decision maker. Thus, the aggregated crisp data can be computed as:

$$X_{ij} = 1/k \sum_{k=1}^{l} x_{ijk} \quad \text{.................................. (6)}$$

However, the aggregated rating linguistic terms as well as for the aggregated rating of fuzzy numbers can be calculated as:

$$a_{ij} = \min_k \{a_{ijk}\},$$
$$b_{ij} = 1/k \sum_{k=1}^{l} b_{ijk} \quad \text{.. (7)}$$
$$c_{ij} = \max_k \{c_{ijk}\},$$

Step 4. Normalize the decision matrix so that a linear criteria scales into unit-free and comparable. The group of criteria can be divided into profit criteria (the larger the scaling, the greater the preference) and cost criteria (the smaller the scaling, the greater the preference). Thus, the normalized data can be calculated as:

For crisp ratings, the normalized values for profit-related criteria (j=1,…., n_1) as well as for cost-related criteria (j= n_1+1, …, n_2) can be expressed in (8).

$$r_{ij} = \begin{cases} x_{ij} / \sum_{i=1}^{m} x_{ij} \\ \dfrac{x_{ij}^{-1}}{\sum_{i=1}^{m} x_{ij}^{-1}} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (8)$$

For fuzzy ratings denoted by triangular fuzzy numbers as (a_{ij}, b_{ij}, c_{ij}), the normalized values for profit –related criteria (j= n_2+1, …, n_3) and cost-related criteria (j= n_3+1, …, n) can be expressed in Eq.(9).

$$r_{ij} = \begin{cases} \left(\dfrac{a_{ij}}{\sum_{i=1}^{m} c_{ij}}, \dfrac{b_{ij}}{\sum_{i=1}^{m} b_{ij}}, \dfrac{c_{ij}}{\sum a_{ij}} \right) \\ \left(\dfrac{c_{ij}^{-1}}{\sum_{i=1}^{m} a_{ij}^{-1}}, \dfrac{b_{ij}^{-1}}{\sum_{i=1}^{m} b_{ij}^{-1}}, \dfrac{a_{ij}^{-1}}{\sum_{i=1}^{m} c_{ij}^{-1}} \right) \end{cases} \quad \ldots\ldots\ldots\ (9)$$

Step 5. Compute the weighted normalized decision matrix by multiplying the aggregate weights for each criterion by normalized criterion values. This can be expressed as in (10).

$$r_i = \sum_{j=1}^{n} w_j \otimes r_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \quad (10)$$

Step 6. Determine the ordering value of each of the alternatives. Using Eq. (11) and Eq. (12), calculate the fuzzy distances of each alternative with the maximum distance ($\overset{\alpha}{D}_{\max i}$, $\overset{1}{D}_{\max i}$) and the minimum distance ($\overset{\alpha}{D}_{\min i}$, $\overset{1}{D}_{\min i}$) determine by Eq. (13) and Eq. (14). $\overset{\alpha}{D}$ and $\overset{1}{D}$ are the fuzzy distances under f(α) = α and f(α) = 1, respectively.

$$D^2(\tilde{X}, M) = (b-M)^2 + 1/3\,(b-M)\,[(c+a)-2b] + 1/18\,[(c-b)^2 + (b-a)^2] - 1/18[(c-b)(b-a)] \quad f(\alpha) \approx \alpha \quad \ldots\ (11)$$

$$D^2(\tilde{X}, M) = (b-M)^2 + 1/2\,(b-M)\,[(c+a)-2b] + 1/9\,[(c-b)^2 + (b-a)^2] - 1/9[(c-b)(b-a)] \quad f(\alpha) \approx 1 \quad \ldots\ldots\ (12)$$

where M is either Max. or Min. and f(α) is a weighted function: f(α) ≈ α indicating more weights given to intervals at higher α level, and f(α) ≈ 1 representing equal weights for intervals at different levels of α.

The Max. and Min. are determined as follows:

$$\text{Max. (M)} \geq \sup \left[\bigcup_{i=1}^{m} s\left(\tilde{P}_i\right) \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots.. \quad (13)$$

$$\text{Min. (M)} \leq \inf \left[\bigcup_{i=1}^{m} s\left(\tilde{P}_i\right) \right] \quad \ldots\ldots\ldots\ldots \quad (14)$$

Where $s\left(\tilde{P}_i\right)$ is the support of fuzzy numbers $\left(\tilde{P}_i\right)$, *i* =1, 2,.., m.

Step 7. Rank the alternatives with respect to their fuzzy distances. If $D_{max.p} > D_{max.q}$ and $D_{min\ p} < D_{min\ q}$; then, $r_p < r_q$, p ≠ q, p = 1, 2, …, m; q = 1, 2, ….., m; and L_q is ranked earlier than L_p. If only one of two conditions is persuaded, a fuzzy number might be outranked the others depending upon context of the problem. Zhang, et al. [26] has provided an example to show how different decision makers make decision under this condition.

IV. ILLUSTRATED EXAMPLE

A high technology company desires to select a suitable proposed mutually exclusive facility layout to improve their performance. After preliminary screening, five layouts, L_1, L_2, L_3, L_4, and L_5, remain for further evaluation. A committee of three decision-makers DM_1, DM_2, and DM_3 has been established to choose the most suitable layout. Four criteria are mainly considered:

1) Net Present Value (millions of S.R.) (C_1),
2) Response to Competition (C_2),
3) Product and Volume Flexibility (C_3), and
4) Work-In-Process (WIP) (C_4).

The assessment of the layout alternatives versus the four criteria are given using crisp values in Net Present Values, Response to Competition in linguistic ratings as well as Product and Volume Flexibility (Extremely Poor, Very Poor, Poor, Medium Poor, Fair, Medium Good, Good, Very Good, and Extremely Good), while the WIP is stated via triangular fuzzy numbers. Table 1 shows the data set used to assess

Table 1. Data used to assess the ranking of layout alternatives.

Criteria \ Layouts	L_1	L_2	L_3	L_4	L_5	Weight
Net Present Value (millions SR.)						
DM_1	3.9	5.0	6.7	3.8	6.0	H
DM_2	3.1	5.3	6.3	3.4	5.9	VH
DM_3	3.3	5.6	7.0	3.5	6.7	MH
Response to Competition						
DM_1	G	P	F	MP	EG	MH

DM_2	F	F	VG	F	MG	H
DM_3	VG	VP	G	MP	G	H
Product and Volume Flexibility						
DM_1	G	G	F	VG	F	EH
DM_2	F	G	F	VG	F	H
DM_3	VG	VG	MG	EG	G	VH
Work-In-Process (WIP)						
DM_1	(410,430,450)	(290,320,340)	(570,590,640)	(310,370,400)	(600,630,660)	L
DM_2	(520,550,590)	(370,440,460)	(520,550,590)	(350,370,410)	(520,570,610)	ML
DM_3	(400,430, 470)	(320,370,390)	(550,580,600)	(330,360,400)	(570,590,620)	M

the ranking of the layout alternatives. In the data set, EP, VP, P, MP, F, MG, G, VG, EG denote "Extremely Poor", "Very Poor", "Poor", "Medium Poor", "Fair", "Medium Good", "Good", "Very Good", Extremely Good", respectively. The membership functions of the linguistic variables are demonstrated in Fig.2.

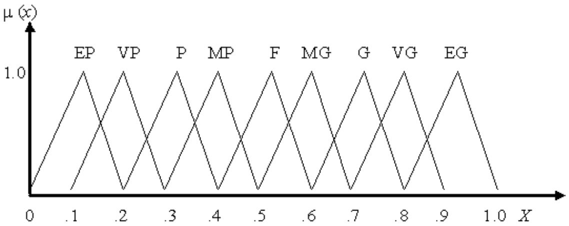

Figure 2. Membership functions for linguistic variables.

The decision makers utilize the linguistic terms to identify the importance of the decision criteria, where EL, VL, L, ML, M, MH, H, VH, and EH denote "Extremely Low", "Very Low", "Low", "Medium Low", "Medium", "Medium High", "High", "Very High", and "Extremely High" importance, respectively. The weights assigned to the criteria by the three decision makers are given in Table 1. The membership functions of the importance weights are represented in the Fig. 3.

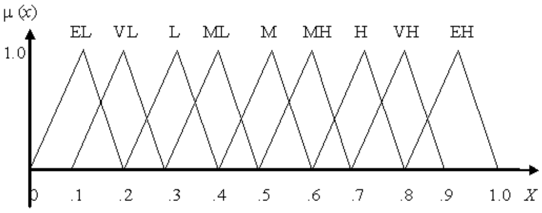

Figure 3. Membership functions for importance weights.

The aggregated fuzzy rating that are calculated by Eq. (7), and fuzzy weight of each criterion that are computed using Eq. (5) are shown in Table 2.

The criteria values for each layout are normalized using Eq. (8) and Eq. (9). These normalized fuzzy ratings are shown in Table 3.

The transformation values of fuzzy weights of the four criteria are computed for each layout using Eq. (10) as shown bellow:

$$r_1 = 0.136 \otimes (.6,.7,.8) \oplus (.172, .237, .330) \otimes (.567, .667, .767) \oplus (.149, .201, .272) \otimes (.7, .8, .9) \oplus (.130, .195, .266) \otimes (.3, .4, .5)$$

$$r_2 = 0.211 \otimes (.6,.7,.8) \oplus (.069, .117, .184) \otimes (.567, .667, .767) \oplus (.164, .219, .293) \otimes (.7, .8, .9) \oplus (.167, .243, .367) \otimes (.3, .4, .5)$$

$$r_3 = 0.265 \otimes (.6,.7,.8) \oplus (.171, .237, .330) \otimes (.567, .667, .767) \oplus (.112, .159, .223) \otimes (.7, .8, .9) \oplus (.120, .160, .205) \otimes (.3, .4, .5)$$

$$r_4 = 0.142 \otimes (.6,.7,.8) \oplus (.099, .152, .227) \otimes (.567, .667, .767) \oplus (.191, .249, .329) \otimes (.7, .8, .9) \oplus (.187, .250, .344) \otimes (.3, .4, .5)$$

$$r_5 = 0.246 \otimes (.6,.7,.8) \oplus (.189, .258, .356) \otimes (.567, .667, .767) \oplus (.123, .171, .237) \otimes (.7, .8, .9) \oplus (.116, .153, .205) \otimes (.3, .4, .5)$$

Then, the fuzzy values for each layout are obtained as shown in the following matrix:

Table 2. The aggregated fuzzy ratings and fuzzy weights.

Layouts / Criteria	L_1	L_2	L_3	L_4	L_5	Weight
Net Present Value	3.43	5.30	6.67	3.57	6.20	(.6,.7,.8)
Response to Competition	(.57,.67,.77)	(.23,.33,.43)	(.57,.67,.77)	(.33,.43,.53)	(.63,.73,.83)	(.57,.67,.77)
Product and Volume Flexibility	(.57,.67,.77)	(.63,.73,.83)	(.43,.53,.63)	(.73,.83,.93)	(.47,.57,.67)	(.7,.8,.9)
Work-In-Process (WIP)	(400,470,590)	(290,377,460)	(520,573,640)	(310,367,410)	(520,597,660)	(.3,.4,.5)

Table 3. The normalized fuzzy ratings and fuzzy weights.

Criteria \ Layouts	L_1	L_2	L_3	L_4	L_5
Net Present Value	0.136	0.211	0.265	0.142	0.246
Response to Competition	(.17,.24,.33)	(.07,.12,.18)	(.17,.24,.33)	(.10,.15,.23)	(.19,.26,.36)
Product and Volume Flexibility	(.15,.20,.27)	(.16,.22,.29)	(.11,.16,.22)	(.19,.25,.33)	(.12,.17,.24)
Work-In-Process (WIP)	(.13,.20,.27)	(.17,.24,.37)	(.12,.16,.21)	(.19,.25,.34)	(.12,.15,.21)

$$R = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \\ r_4 \\ r_5 \end{bmatrix} = \begin{cases} (.3223, .4921, .7397) \\ (.3306, .4981, .7571) \\ (.3704, .5348, .7683) \\ (.3310, .5000, .7558) \\ (.3757, .5423, .7857) \end{cases}$$

From the previous matrix, let Max. (M) = 0.7857 and Min. (M) = 0.3223, the ordering values of all layouts can be computed using Eq. (11) and Eq. (12). The results are tabulated in Table 4.

From the above calculations, the ranking order can be obtained for all alternatives. When $f(\alpha) \approx \alpha$, the ranking order was L_5, L_3, L_4, L_2, and L_1. When $f(\alpha) \approx 1$, the ranking order was also the same sequence. The decision, therefore, is to select layout #5, which is the best layout among the proposed ones.

V. CONCLUSION

Exact approaches to the facility layout problems based on crisp criteria are limited to find optimal solutions only for small sized-problems due to the computational complexity of the problem. In this paper, a multi-goals' framework was proposed to solve facility layout problems. The presented framework proved its capability to select the most appropriate improvement layout within a group of suggested alternatives even within unequal important attributed variables. Its adaptively provides the ability to modify its decision making in response to changes in the behavior of the system in real-time, therefore ensuring its performance superiority over other used models.

Decisions are made today in increasingly complex environments. In more and more cases the use of experts in various fields is necessary, considering different value systems is to be taken into account, etc. In many of such decision-making situations the theory of fuzzy decision-making can be of usage. Fuzzy numbers decision-making can overcome this difficulty. Finally, the proposed algorithm has the capability to deal with similar types of the same situations such as: ranking the best universities in the country, ranking the best videos of the year, the best players of the year, etc.

The methodology proposed in this paper suggested a judgment based on ranked value on a fuzzy conversion scale to represent the selected qualitative attribute. The uniqueness of the proposed framework is that it offers a general procedure that can be applicable to solve problems encountered in industrial environment that incorporate vagueness and uncertainties of selected attributes. The proposed framework is logical and convenient implementation when compared with the other multiple attribute decision making methods. The application of the developed model and its procedures may also be extended for the layout design of distributing and arrangement of displays and controls in automobiles and control panels.

In this paper, different levels of linguistic values for the layouts' requirements and needs are designated in the rating and weighting scales. However, linguistic values could be assigned based on the needs of both detailed evaluation and available data parameters. To simplify and generalize the proposed framework, a professional computerized tool should be developed using one of the available computer softwares. An important thing to mention is that this software will not only can solve the design layouts, it can also be used for solving general multi-criteria decision-making problems.

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