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# Development of Fuzzy Multi Criteria Decision Making Method for Selection of Optimum Maintenance Alternative

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***Abstract*** - An optimal maintenance strategy is a key support to production in the manufacturing industry. This paper present a fuzzy approach based on Multi-Criteria Decision-Making (MCDM) methodology for selecting the optimal maintenance alternative. In the present work the criticality of each equipment is achieved by ranking (based on production loss).It is very difficult to quantify the qualitative factors in exact numerical value. These factors can be expressed in the linguistics terms which can be translated into mathematical measures by using fuzzy sets & system theory. The study problem to develop a fuzzy decision approach to rank the suitable maintenance alternative. The objective of this paper is to propose fuzzy frame work based on fuzzy number theory to solve optimal maintenance alternative which includes decision criteria analysis, weight assessment & decision model development. The approach can aid formulating a cost-effective maintenance strategy for a manufacturing plant.

***Keywords*** - *Multiple-Criteria Decision Making, Maintenance alternative, Fuzzy Sets, Rank.*

## I. INTRODUCTION

Selection of maintenance alternative is a complex and difficult decision making problem. A maintenance program needs to define different maintenance alternative for different equipments. In present work manufacturing of transformer in Crompton greaves (C.G) is studied. took a major leap in the electrical engineering segment. The transformer technology for manufacture of 400kv transformer and aluminum wounds. Manufacturing of transformer is divided into three sections, winding, assembly, and tanking section. For each equipment namely, Air caster ($M_{1)}$ , five alternatives maintenance policies are considering as Predictive maintenance($A_1$),Breakdown maintenance ($A_2$),Routine maintenance ($A_3$), Preventive maintenance($A_4$), and Corrective maintenance($A_5$). The methodology proposed in this paper for selecting the most appropriate maintenance approach involves ranking of equipment, fuzzy multiple criteria decision making method, ranking & evaluation of maintenances alternative for equipment.At the first level of selection, it is essential to identify the most critical equipment in proportion with its criticality index. The second level of decision making concerns a fine-tuned selection of the alternative maintenance approaches using multi-attribute evaluation. The process of selection of suitable maintenance alternative for manufacturing plant on the basis of quantitative & qualitative factors requires following sources.

- Selection of fuzzy numbers & their memberships functions.
- Defining the scale of preference.
- Averaging the fuzzy numbers as given by the experts in terms linguistics variables.
- Determination of fuzzy weights.
- Overall ranking of alternative.

## II. LITERATURE REVIEW

The effective maintenance contributes to maximizing process profitability in term of reducing operating and manufacturing cost.Fuzzy set theory (Zadeh1965) provides a useful tool to deal with decision in which the phenomena are imprecise & vague, it enables us to qualify imprecision information, to reason & make decision based on vague & incomplete data (Zadeh1973).Dubois, D. and Prade,H.(1980) ,Possibility theory an approach to computerized processing of uncertainty .When a problem involves number of experts, criteria, unsound information & risk stands. (Hipel1993). Lin & Chen (2004) developed a fuzzy linguistic approach for bid decision making process. Li.et. (2005) propose a multi layer fuzzy pattern recognition method for selection of contractor D.Singh et.al.(2005) propose a fuzzy decision frame work for alternatives selection. Chan F.T.S.., Lau, H.C.W., Ip, R.W.L., chan, H.K., Kong, S., (2005) a case study of implementation of total productive maintenance. Yaveli (2007) a fuzzy frame work for selection of contractors at the stages of pre qualification where four approaches

namely, Fuzzy Number Recognition method , Fuzzy Topsis method, Fuzzy number weight centre method & Simple defuzzification methods are used. The methodology is adopted in this study is of D.Singh and Robert.L.K.Tiong(2005). In the present study, the attributes & criteria are changed to fit in the model with minor modification in the selection of suitable maintenance alternative for the equipment in the manufacturing plant.

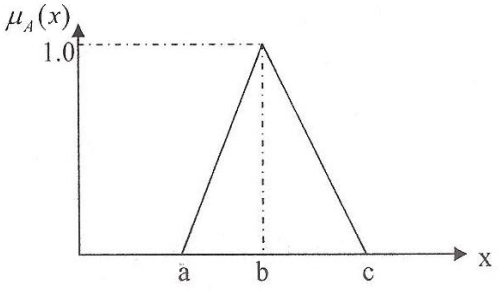
## III. FUZZY SETS AND THEORY AS AN EXPERT SYSTEM

Membership's function of an element represents a degree to which the elements belong to a set. Ai be a fuzzy number such that ∀Ai ε R (set of real number) and considered in the form of

$$Ai = (a, b, c, d);$$

$$i = 1 \ldots.m$$

Where a<b<c<d is the scale of preference to be used by the experts & M is the fuzzy numbers to be used the analysis .The memberships function for triangular and trapezoidal fuzzy number is shown

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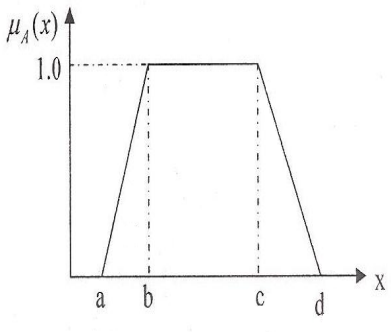


Fig-1 Traingular membership function

Fig-2 Trapezoidal membership function

$$\mu_A(x) = \begin{cases} \dfrac{(x-a)}{(b-a)} & a \le x \le b \\ \dfrac{(c-x)}{(c-a)} & b \le x \le c \\ 0 & \text{Otherwise} \end{cases} \qquad \mu_A(x) = \begin{cases} \dfrac{(x-a)}{(b-a)} & a \le x \le b \\ 1 & b \le x \le c \\ \dfrac{(x-d)}{(c-d)} & c \le x \le d \\ 0 & \text{Otherwise} \end{cases}$$

Operations on fuzzy numbers: Let A & B be the two fuzzy numbers parameterized by A= ($a_1$, $b_1$, $c_1$, $d_1$& B= ($a_2$, $b_2$, $c_2$, $d_2$) respectively. Then the operations [+,-, ×, ÷] of trapezoidal fuzzy number can be expressed as (Kaufmann & gupta1991).

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Building Linguistic variables set: It is difficult for decision maker to give an exact numerical value to express his opinion & the decision maker feel comfortable to describe in it fuzzy terms of "high" "low" or "very high" etc.These fuzzy terms can be expressed in trapezoidal fuzzy numbers. For the selection of maintenance alternatives trapezoidal fuzzy numbers are taken. The fuzzy numbers associated with the corresponding the linguistic variables are shown in Table 1. & same is graphically represented in Figure 3

Table 1: Fuzzy numbers and corresponding linguistic variables

| Linguistic variable | Fuzzy number |
|---|---|
| Very high (VH) | (0.8,0.9,1,1) |
| High | (0.6,0.7,0.8,0.9) |
| Moderate high | (0.5,0.6,0.7,0.8) |
| Moderate | (0.4,0.5,0.5,0.6) |
| Moderate low | (0.2,0.3,0.4,0.5) |
| Low | (0.1,0.2,0.3,0.4) |
| Very low | (0.0,0.0,0.1,0.2) |

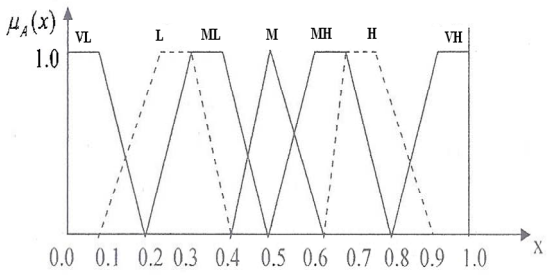


Fig. 3: Graphical representation of fuzzy numbers for linguistic variables

Determination of fuzzy weight for decision criteria**:** Following are the steps:

Step1: The linguistic variables assigned by the experts for each criteria are translated into fuzzy numbers and the same is represented in the matrix (fuzzy decision matrix).

Step2: Let $A^j_{ik}$ be the fuzzy number assigned to an alternative $A_i$ by the experts ($E_k$) for decision criteria, $C_j$ the average of fuzzy number is given as:

$$A_{ij} = \frac{1}{p} \oplus \left(a^j{}_{i1} \oplus a^j{}_{i2} + \ldots + a^j{}_{ik}\right); \quad K = 1, 2, \ldots\ldots\ldots, P. \text{ eq……1}$$

The average fuzzy score matrix for each criteria is obtained.

Step3: The crisp score (defuzzified values) for each criteria is obtained defuzzification of fuzzy number is an operation that produces a non fuzzy crisp value. Defuzzified is given by the following equations (Kaufman & Gupta 1991).

Trapezoidal fuzzy number

$$e = \frac{(a+b+c+d)}{4} \qquad \text{……..eq2}$$

Triangular fuzzy number

$$e = \frac{(a+2b+c)}{4} \qquad \text{…..……..eq3}$$

Step4: The normalized weight for each criterion ($C_j$) is obtained as normalized weight for each criterion is obtained by dividing the deffuzzified scores of each criterion by the total of all the criteria.

Rating of suitable maintenance alternative: In similar way as procedure adopted for the calculation of weight criteria, the rating of suitable maintenance alternative is derived as

- Maintenance alternatives suitable on each of the criteria are to be rated in the linguistic variables by the experts which is converted into fuzzy number & the same is represented in the matrix form (fuzzy decision matrix).
- The average fuzzy score matrix for each maintenance alternative are obtained.
- The crisp score (defuzzfied value) for each maintenance alternative are obtained & same is represented in the matrix form as $X_{ij}$ where i= 1, 2,… m & J = 1, 2, n

  Where m is the number of maintenance alternative, n is the number criteria.
- Total aggregated score for maintenance alternative against each criteria is obtained as

  TS = [Xij] [Wj]
- On the basis of total score obtained maintenance alternative against decision criteria overall scores are obtained, using simple average method, which provide final ranking of maintenance alternative for each critical equipment.

## IV. CASE STUDY

The propose methodology allows the experts to rank the suitable maintenance alternative in the Crompton greaves limited Gwalior (India). In the electrical engineering segment, the acquisition of transformer technology from weinsting house electrical corporation U.S.A for manufacture of 400kv transformer. The effect of maintenance activities that depends on Predictive maintenance, Break down maintenance, Routine maintenance, Corrective maintenance and Preventive maintenance. It is preferable to choose the best maintenance alternative on the basis of different decision criteria.

The advantage of fuzzy set theory facilities the assessment to be made on the basis of linguistic, quantitative and qualitative manner, for simplicity five experts ($E_1$,$E_2$,$E_3$, E4,$E_5$) were consulted to get the linguistic variables in terms of importance of each criteria used to rank the five maintenance alternatives ($A_1$,$A_2$,$A_3$,$A_4$,$A_5$) For each equipments & eight decision criteria as listed below:

1. Purchasing cost($C_1$)
2. Establishment cost (machine –floor requirements, etc.)($C_2$)
3. Operating cost ($C_3$)

4. Reliability ($C_4$)
5. Operational flexibility($C_5$)
6. Productivity($C_6$)
7. Risks (safety)($C_7$)
8. Supplier's environmental behaviors($C_8$)

**Table 2. Linguistic variable assigned by the experts decision criteria**

| Criteria | Experts | | | | |
|---|---|---|---|---|---|
| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ |
| $C_1$ | VH | H | VH | H | MH |
| $C_2$ | H | VH | MH | M | VH |
| $C_3$ | VH | VH | MH | M | VH |
| $C_4$ | VH | MH | MH | VH | H |
| $C_5$ | VH | H | VH | H | VH |
| $C_6$ | VH | MH | M | H | H |
| $C_7$ | H | MH | M | H | VH |
| $C_8$ | MH | ML | VH | VH | VH |

Determination of weights ($W_j$) for criteria:

Now these linguistic variables are converted into fuzzy numbers. The fuzzy decision matrix is as

$$X_{C_2} = \begin{bmatrix} (0.8,0.9,1.1) & (0.6,0.7,0.8,0.9) & (0.8,0.9,1.1) & (0.6,0.7,0.8,0.9,) & (0.5,0.6,0.7,0.8) \\ (0.6,0.7,0.8,0.9) & (0.8,0.9,1.1) & (0.5,0.6,0.7,0.8) & (0.4,0.5,0.5,0.6) & (0.8,0.9,1.1) \\ (0.8,0.9,1.1) & (0.8,0.9,1.1) & (0.5,0.6,0.7,0.8) & (0.4,0.5,0.5,0.6) & (0.8,0.9,1.1) \\ (0.8,0.9,1.1) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) & (0.8,0.9,1.1) & (0.6,0.7,0.8,0.9) \\ (0.8,0.9,1.1,) & (0.6,0.7,0.8,0.9) & (0.8,0.9,1.1) & (0.6,0.7,0.8,0.9) & (0.8,0.9,1.1) \\ (0.8,0.9,1.1) & (0.5,0.6,0.7,0.8) & (0.4,0.5,0.5,0.6) & (0.6,0.7,0.8,0.9) & (0.6,0.7,0.8,0.9) \\ (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) & (0.4,0.5,0.5,0.6) & (0.6,0.7,0.8,0.9) & (0.8,0.9,1.1) \\ (0.5,0.6,0.7,0.8) & (0.2,0.3,0.4,0.5) & (0.8,0.9,1.1) & (0.8,0.9,1.1) & (0.8,0.9,1.1) \end{bmatrix}$$

The average fuzzy scores, defuzzified values & normalized weights of criteria are obtained & given in the Table.3

**Table3. Normalized weights of criterion**

| Criteria | Average fuzzy scores | | | | Defuzzified value | Normalized weight |
|---|---|---|---|---|---|---|
| $C_1$ | .660 | .760 | .860 | .920 | .800 | .250 |
| $C_2$ | .620 | .720 | .800 | .860 | .750 | .234 |
| $C_3$ | .660 | .760 | .840 | .880 | .785 | .245 |
| $C_4$ | .640 | .740 | .840 | .900 | .780 | .243 |
| $C_5$ | .720 | .820 | .920 | .960 | .855 | .267 |
| $C_6$ | .580 | .680 | .760 | .660 | .670 | .209 |
| $C_7$ | .580 | .680 | .760 | .840 | .715 | .223 |
| $C_8$ | .620 | .720 | .820 | .860 | .755 | .235 |

Rating of maintenance alternative on the criterion ($X_{ij}$): Suitability of maintenance strategies against each criteria are to be rated & linguistic variables are assigned by the experts to the maintenance strategies table4 as defined in the table1. These linguistic variables are converted into fuzzy numbers. The average fuzzy score & defuzzified values are given in the Table-5.

Table.5: Linguistic variables for maintenance alternatives for Aircaster

| Criteria | Experts | | | | | |
|---|---|---|---|---|---|---|
| | Maintenance Alternative | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ |
| $C_1$ | $A_1$ | VH | H | H | VH | MH |
| | $A_2$ | MH | VH | VH | MH | M |
| | $A_3$ | VH | H | MH | H | VH |
| | $A_4$ | H | H | MH | MH | H |
| | $A_5$ | VH | VH | H | MH | VH |
| $C_2$ | $A_1$ | H | H | VH | MH | H |
| | $A_2$ | VH | MH | H | H | VH |
| | $A_3$ | H | VH | VH | M | MH |
| | $A_4$ | MH | VH | H | H | VH |
| | $A_5$ | M | MH | H | MH | H |
| $C_3$ | $A_1$ | VH | MH | VH | VH | M |
| | $A_2$ | M | VH | H | M | M |
| | $A_3$ | VH | H | H | VH | H |
| | $A_4$ | H | MH | VH | MH | MH |
| | $A_5$ | VH | VH | H | H | H |
| $C_4$ | $A_1$ | H | VH | H | VH | MH |
| | $A_2$ | VH | H | VH | H | VH |
| | $A_3$ | M | MH | H | M | MH |
| | $A_4$ | MH | VH | H | VH | VH |
| | $A_5$ | H | VH | MH | H | VH |
| $C_5$ | $A_1$ | VH | H | MH | H | VH |
| | $A_2$ | M | VH | H | MH | H |
| | $A_3$ | VH | H | MH | VH | H |
| | $A_4$ | VH | MH | MH | MH | H |
| | $A_5$ | H | VH | H | VH | H |
| $C_6$ | $A_1$ | VH | VH | H | VH | H |
| | $A_2$ | H | MH | H | MH | VH |
| | $A_3$ | H | MH | H | MH | M |
| | $A_4$ | VH | H | VH | MH | MH |
| | $A_5$ | VH | MH | H | H | H |
| $C_7$ | $A_1$ | H | VH | VH | MH | H |
| | $A_2$ | VH | H | H | H | VH |
| | $A_3$ | H | MH | MH | H | H |
| | $A_4$ | M | MH | M | M | MH |
| | $A_5$ | H | VH | VH | H | VH |
| $C_8$ | $A_1$ | VH | H | H | VH | VH |
| | $A_2$ | VH | VH | H | MH | H |
| | $A_3$ | H | H | H | VH | MH |
| | $A_4$ | VH | VH | H | H | VH |
| | $A_5$ | H | MH | H | MH | VH |

**Table 5: Average fuzzy score & defuzzified scores**

| Criteria | Maintenance alternative | Average fuzzy scores | | | | Defuzzified scores |
|---|---|---|---|---|---|---|
| $C_1$ | $A_1$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_2$ | 0.600 | 0.700 | 0.780 | 0.840 | .730 |
| | $A_3$ | 0.660 | 0.620 | 0.860 | 0.920 | .765 |
| | $A_4$ | 0.560 | 0.660 | 0.760 | 0.860 | .710 |
| | $A_5$ | 0.700 | 0.800 | 0.900 | 0.940 | .835 |
| $C_2$ | $A_1$ | 0.620 | 0.720 | 0.820 | 0.900 | .765 |
| | $A_2$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_3$ | 0.620 | 0.720 | 0.800 | 0.660 | .700 |
| | $A_4$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_5$ | 0.520 | 0.620 | 0.700 | 0.800 | .660 |
| $C_3$ | $A_1$ | 0.660 | 0.760 | 0.840 | 0.880 | .785 |
| | $A_2$ | 0.520 | 0.620 | 0.660 | 0.740 | .635 |
| | $A_3$ | 0.680 | 0.780 | 0.880 | 0.940 | .820 |
| | $A_4$ | 0.580 | 0.680 | 0.780 | 0.860 | .725 |
| | $A_5$ | 0.660 | 0.780 | 0.880 | 0.940 | .815 |
| $C_4$ | $A_1$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_2$ | 0.720 | 0.820 | 0.920 | 0.960 | .855 |
| | $A_3$ | 0.480 | 0.580 | 0.640 | 0.740 | .610 |
| | $A_4$ | 0.700 | 0.800 | 0.900 | 0.940 | .835 |
| | $A_5$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| $C_5$ | $A_1$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_2$ | 0.580 | 0.680 | 0.760 | 0.840 | .715 |
| | $A_3$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_4$ | 0.580 | 0.680 | 0.780 | 0.860 | .725 |
| | $A_5$ | 0.680 | 0.780 | 0.880 | 0.940 | .820 |
| $C_6$ | $A_1$ | 0.720 | 0.820 | 0.920 | 0.960 | .855 |
| | $A_2$ | 0.600 | 0.700 | 0.800 | 0.880 | .745 |
| | $A_3$ | 0.520 | 0.620 | 0.700 | 0.800 | .660 |
| | $A_4$ | 0.680 | 0.780 | 0.880 | 0.940 | .820 |
| | $A_5$ | 0.620 | 0.720 | 0.820 | 0.900 | .765 |
| $C_7$ | $A_1$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_2$ | 0.680 | 0.780 | 0.880 | 0.940 | .820 |
| | $A_3$ | 0.560 | 0.660 | 0.760 | 0.860 | .710 |
| | $A_4$ | 0.440 | 0.540 | 0.580 | 0.680 | .560 |
| | $A_5$ | 0.720 | 0.820 | 0.920 | 0.960 | .855 |
| $C_8$ | $A_1$ | 0.720 | 0.820 | 0.920 | 0.960 | .855 |
| | $A_2$ | 0.660 | 0.760 | 0.860 | 0.920 | .800 |
| | $A_3$ | 0.620 | 0.720 | 0.820 | 0.900 | .765 |
| | $A_4$ | 0.720 | 0.820 | 0.920 | 0.960 | .855 |
| | $A_5$ | 0.600 | 0.700 | 0.800 | 0.880 | .745 |

Using the simple additive weighting method , the total scores(TS) for each maintenance alternatives can be calculated as follows

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $W_j$ |
|---|---|---|---|---|---|---|
| $C_1$ | 0.800 | 0.730 | 0.765 | 0..710 | 0.835 | 0.250 |
| $C_2$ | 0.765 | 0.800 | 0.700 | 0.800 | 0.660 | 0.234 |
| $C_3$ | 0.785 | 0.635 | 0.820 | 0.725 | 0.815 | 0.245 |
| $C_4$ | 0.800 | 0.855 | 0.610 | 0.835 | 0.800 | 0.243 |
| $C_5$ | 0.800 | 0.715 | 0.800 | 0.725 | 0.820 | 0.267 |
| $C_6$ | 0.855 | 0.745 | 0.660 | 0.820 | 0.765 | 0.209 |
| $C_7$ | 0.800 | 0.820 | 0.710 | 0.560 | 0.855 | 0.223 |
| $C_8$ | 0.855 | 0.800 | 0.765 | 0.855 | 0745 | 0.235 |

$TS = [X_{ij}] [W_j]$

TS =

Total score for maintenance alternatives ($A_1$) on the criterion is obtained as (.800×.250) + (.765×.234) + (.785×.245)+ (.800×.243) + (.800×.267) + (.855×.209) + (.800×.223) + (.855×.235) = 1.973. Similarly, Total score for maintenance alternatives ($A_2$),($A_3$)($A_4$),($A_5$) for air caster($M_1$)are obtained. In the selection of maintenance strategies for any equipment for manufacturing plant, quantities & qualitative criteria, each has equal weight age hence the final score & ranking of maintenance alternative are given in the table7

Table.7: Final scores and ranking of maintenance alternative for Air caster ($M_1$)

| Maintenance alternatives | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ |
|---|---|---|---|---|---|
| Final scores | **1.973** | **1.450** | **1.393** | **1.435** | **1.293** |
| Rank | **1** | **2** | **4** | **3** | **5** |

## V. RESULT & DISCUSSION

With the fuzzy multi criteria decision approach the order ranking of maintenance alternative for Air caster $M_1$ are as $A_1 > A_2 > A_4 > A_3 > A_5$. $> A_3 > A_5$.The results shows that $A_1$, is the best maintenance alternative for $M_1$. Since fuzzy logic incorporates the linguistic variable more practically & also help in eliminating the imprecision & vagueness.

## VI. CONCLUSION

In this paper the selection of maintenance alternative for different equipment in manufacturing plant is studied. An optimal maintenance alternative can improve availability & reliability levels of plants equipments & reduce unnecessary investment in maintenance. The evaluation of maintenance alternative for each equipment is a multiple criteria decision making (MCDM)problem, considering the imprecise judgments of experts views with trapezoidal fuzzy number & the fuzzy simple average method is used for different maintenance alternative for each equipment in manufacturing plant & useful for other similar MCDM problems.

## VII. ACKNOWLEDGEMENTS

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