SELECTION OF MAINTENANCE STRATEGY FOR MATERIAL HANDLING EQUIPMENT (MECHANICAL CRANE) BY FUZZY MULTI-CRITERIA DECISION-MAKING METHOD

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ABSTRACT

In this paper a fuzzy techniques based on Multi-Criteria Decision-Making (MCDM) methodology for selecting the optimal maintenance strategy for material handling equipment (Mechanical Crane). In the present work the evaluations of most priority of maintenance strategies (such as predictive maintenance, corrective maintenance, preventive maintenance, routine maintenance and breakdown maintenance) by ranking (based on maintenance cost loss) for material handling equipment (mechanical crane). It is very difficult to quantity the qualitative factors in the linguistics terms which can be translated into mathematical measures by using fuzzy sets & system theory. The study problem to develop a fuzzy multi-criteria decision-making techniques to rank the suitable maintenance strategy. The objective of this paper is to propose fuzzy frame work based on fuzzy number theory to solve optimal maintenance strategy which includes decision criteria analysis, weight assessment & decision mode development, the approach can aid formulating a cost-effective maintenance strategy for a material handling equipment. In this paper a specific example of selection of maintenance strategies in this company with the application of the proposed fuzzy Multi-Criteria Decision-Making method is given, showing that the breakdown maintenance strategy is the most suitable for material handling equipment (mechanical crane)

***Keywords**: Fuzzy Multi-Criteria Decision-Making, Maintenance strategy, Fuzzy sets & System, Rank, Linguistic variables and Trapezoidal Fuzzy Number.*

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1. INTRODUCTION

Maintenance costs constitute a major part of total operating costs of all manufacturing and production plants. The selection of inefficient maintenance strategy has consequences on direct maintenance costs in an organization. Selection of maintenance strategy is a complex and difficult decision making problem. A maintenance program needs to define different maintenance strategy for different material handling equipments. In present work maintenance of mechanical crane in Punj Lioyd gwalior is studied. For mechanical crane five maintenance strategy policies are considering as Predictive maintenance (M_1), Corrective maintenance (M_2), Preventive maintenance (M_3), Routine maintenance (M_4), and Breakdown maintenance (M_5). The methodology proposed in this paper for selecting the most optimal maintenance strategy involves ranking of material handling equipments, fuzzy Multi-Criteria Decision-Making method, ranking & evaluation of maintenance strategies for material handling equipments. 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 maintenance strategy using multi-criteria evaluation. The process of selection of suitable maintenance strategy for material handling equipment on the basis of quantitative & qualitative factors requires following sources. In this paper we focus five points: selection of trapezoidal fuzzy numbers & their membership's functions, defining the scale of preference, average the trapezoidal fuzzy numbers as given by the experts in terms linguistics variables, determination of fuzzy weights and overall ranking of strategy.

Maintenance strategies: maintenance strategies used in this paper are given below

(a) Corrective maintenance:- corrective maintenance is defined as maintenance carried out to restore (including adjustment and repairs on item) machinery which have ceased to meet an acceptable condition.

(b) Preventive maintenance: - preventive maintenance system refers to those critical systems which have to reduce the likelihood of failures to the absolute minimum.

(c) predictive maintenance: - predictive maintenance can be defined as "methods of surveillance used to indicate as to how well the machine is, while performing its intended tasks".

(d) Routine maintenance: - routine maintenance can be defined as a "procedure followed regularly" or "as a cyclic operation recurring periodically".

(e) Breakdown maintenance: - it is performed after the occurrence of an advanced considered failure for which advanced provision has been made in the form of repair method, spares, materials, labour and equipment.

2. LITERATURE REVIEW

In the literature, Maintenance can be classified into two main types: corrective and preventive corrective maintenance is the maintenance that occurs after system failure and it means all actions resulting from failure; preventive maintenance in the maintenance that is performed before system failure in order to retain equipment in specified condition by providing systematic inspections, detection and preventive of incipient failure. Selection of most efficient maintenance strategy is an important problem that an organization is dealing with. A proper maintenance strategy, applied to equipment will save money for the organization. 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 (Zadeh 1973). 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.Sing et.al.(2005) propose a fuzzy decision frame work for alternatives selection. Chan F.T.S.., Lau, H.C.W., lp, R.W.L., Chan, H.K., Kong, S., (2005) a case study of implementation of total productive maintenance. Mansour Momeni, Mohammad Reza Fathi, Mohammad karimi Zarchi and Sirous Azizollahi (2011) a case study of the selection of maintenance strategies in Electrofan Company is studied. Arun Nagar (2011) a case study of development of Fuzzy multi criteria decision making method foe selection of optimum maintenance alternative of Transformer of Crompton Greaves limited. Yawei (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 method are used. The methodology is adopted in this study is of D. Sing and R. L. K. Tiong (2005). In the present study, the strategy & criteria are changed to fit in the model with minor modification in the selection of suitable maintenance strategy for the material handling equipment in the Punj Lioyd plant gwalior (India).

3. FUZZY SETS AND THEORY AS AN EXPERT SYSTEM:-

Fuzzy sets and linguistic variables can be used to quantify the meaning of natural language, which can then be manipulated. By a trapezoidal uncertain set we mean the uncertain set fully determined by the quadruplet (a, b, c, d) of crisp numbers with a < b < c < d, whose membership function is

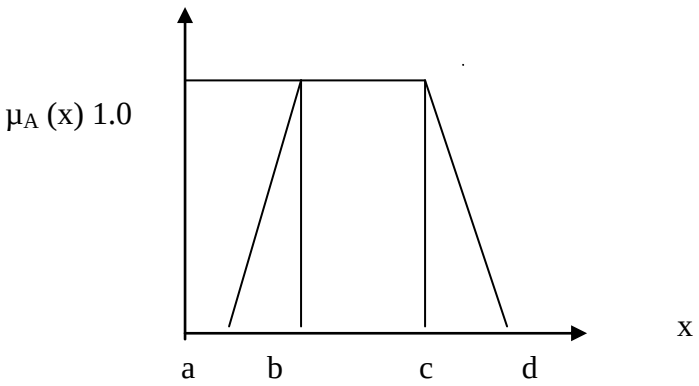

Fig-1 Trapezoidal membership function

$$\mu_A(x) = \begin{cases} \frac{(x-a)}{(b-a)} & a \le x \le b \\ 1 & b \le x \le c \\ \frac{(x-d)}{(c-d)} & c \le x \le d \\ 0 & otherwise \end{cases}$$

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 operation [+, -, x, ÷] of trapezoidal fuzzy number can be expressed as (Kaufmann & gupta 1991).

$$A + B = (a_1, b_1, c_1, d_1) + (a_2, b_2, c_2, d_2)$$
$$= (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2)$$
$$A - B = (a_1, b_1, c_1, d_1) - (a_2, b_2, c_2, d_2)$$
$$= (a_1 - a_2, b_1 - b_2, c_1 - c_2, d_1 - d_2)$$
$$A \times B = (a_1, b_1, c_1, d_1) \times (a_2, b_2, c_2, d_2)$$
$$= (a_1 \times a_2, b_1 \times b_2, c_1 \times c_2, d_1 \times d_2)$$
$$A \div B = (a_1, b_1, c_1, d_1) \div (a_2, b_2, c_2, d_2)$$
$$= (a_1 \div a_2, b_1 \div b_2, c_1 \div c_2, d_1 \div d_2)$$

Building Linguistic variable set: A linguistic variable is a variable whose values are linguistic terms. Linguistic terms have been found intuitively easy to use in expressing the subjectiveness and/or imprecision qualitative of a decision maker's assessments. 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 strategy 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 2.

Table 1: Fuzzy numbers and corresponding linguistic variables

Linguistic variables	Fuzzy numbers
Very high (VH)	(0.8, 0.9, 1.0, 1.0)
High (H)	(0.6, 0.7, 0.8, 0.9)
Moderate high (MH)	(0.5, 0.6, 0.7, 0.8)
Moderate (M)	(0.4, 0.5, 0.5, 0.6)
Moderate low (ML)	(0.2, 0.3, 0.4, 0.5)
Low (L)	(0.1, 0.2, 0.3, 0.4)
Very low (VL)	(0.0, 0.0, 0.1, 0.2)

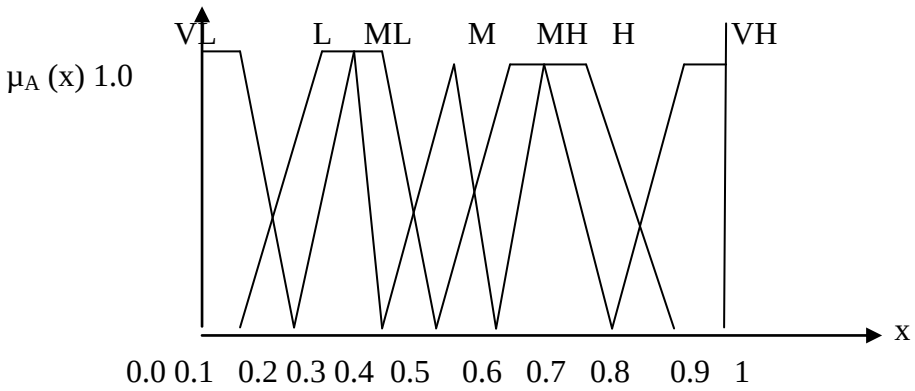

Fig. 2: Graphical representation of fuzzy numbers for linguistic variables

Determination of fuzzy weight for decision criteria:

Following are the steps:

Step 1: 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).

Step 2: Let A^j_{ik} be the fuzzy number assigned to a strategy A_i by the experts (E_k) for decision criteria, C_j the average of fuzzy number is given as:

$$A_{ij} = 1/p \times (a_{i1} + a_{i2} + \ldots\ldots\ldots\ldots + a_{ik}); K = 1, 2\ldots p \qquad aq^n \ldots\ldots\ldots 1$$

The average fuzzy score matrix for each criteria is obtained.

Step 3: 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

$$e = \frac{(a+b+c+d)}{4} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{eq}^{n} \ldots\ldots\ldots\ldots..2$$

Step 4: The normalized weight for each criteria (C_j) is obtained as normalized weight for each criterion is obtained by diving the defuzzified scores of each criterion by the total of all the criteria.

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

(a) Maintenance strategies 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).

(b) The average fuzzy score matrix for each maintenance strategy are obtained.

(c) The crisp score (defuzzfied value) for each maintenance strategy is 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 strategy, n is the number criteria.

(d) Total aggregated score for maintenance strategy against each criteria is obtained as

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

(e) On the basis of total score obtained maintenance strategy against decision criteria overall scores are obtained, using simple average method, which provide final ranking of maintenance strategy for each critical material handling equipment.

4. CASE STUDY

The propose methodology allows the experts to rank the suitable maintenance strategy in the Punj Lioyd limited gwalior (India). In the mechanical engineering segment, the acquisition of Mechanical crane is the 20 tone lifting capacity. The effect of maintenance strategy that depends on Predictive maintenance, Corrective maintenance, Preventive maintenance, Routine maintenance, and Breakdown maintenance. It is preferable to choose the best maintenance strategy 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, E_4, E_5) were consulted to get the linguistic variables in terms of importance of each criteria used to rank the five maintenance strategies (M_1, M_2, M_3, M_4, M_5). For each equipment & eight decision criteria as listed below:

1. Purchasing cost (C_1) 2. Maintenance labour cost (C_2) 3. Operating cost (C_3) 4. Maintenance time (C_4) 5. Reliability (C_5) 6. Operational flexibility (C_6) 7. Productivity (C_7) 8. Risks (safety) (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	MH	H	MH
C_2	H	MH	H	MH	MH
C_3	H	M	MH	MH	MH
C_4	H	H	MH	MH	MH
C_5	MH	H	MH	H	H
C_6	MH	M	H	MH	MH
C_7	M	MH	M	MH	M
C_8	VH	H	VH	H	VH

Determination of weights (W_j) for criteria: Now these linguistic variables are converted into fuzzy numbers. The fuzzy decision matrix is as

X_{ij} =

$$\begin{bmatrix} (0.8,0.9,1.0,1.0) & (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) & (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) \\ (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) & (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) \\ (0.6,0.7,0.8,0.9) & (0.4,0.5,0.5,0.6) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) \\ (0.6,0.7,0.8,0.9) & (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) \\ (0.5,0.6,0.7,0.8) & (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) & (0.6,0.7,0.8,0.9) & (0.6,0.7,0.8,0.9) \\ (0.5,0.6,0.7,0.8) & (0.4,0.5,0.5,0.6) & (0.6,0.7,0.8,0.9) & (0.5,0.6,0.7,0.8) & (0.5,0.6,0.7,0.8) \\ (0.4,0.5,0.5,0.6) & (0.5,0.6,0.7,0.8) & (0.4,0.5,0.5,0.6) & (0.5,0.6,0.7,0.8) & (0.4,0.5,0.5,0.6) \\ (0.8,0.9,1.0,1.0) & (0.6,0.7,0.8,0.9) & (0.8,0.9,1.0,1.0) & (0.6,0.7,0.8,0.9) & (0.8,0.9,1.0,1.0) \end{bmatrix}$$

The average fuzzy scores, defuzzified values & normalized weight of criteria are obtained & given in the Table3

Table3: Normalized weight of criterion

Criteria	Average fuzzy scores				Defuzzified value	Normalized weight
C_1	0.600	0.700	0.800	0.880	0.745	0.250
C_2	0.540	0.640	0.740	0.840	0.690	0.232
C_3	0.500	0.600	0.680	0.780	0.640	0.215
C_4	0.540	0.640	0.740	0.840	0.690	0.232
C_5	0.560	0.660	0.760	0.860	0.710	0.238
C_6	0.500	0.600	0.680	0.780	0.640	0.215
C_7	0.440	0.540	0.580	0.680	0.560	0.188
C_8	0.720	0.820	0.920	0.960	0.855	0.287

Rating of maintenance strategy 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 table 4 as defined in the table 1. These linguistic variables are

converted into fuzzy numbers. The average fuzzy score & defuzzified value are given in the Table4.

Table 4: Linguistic variables for maintenance strategies for Mechanical crane.

Criteria	Experts					
	Maintenance Strategies	E_1	E_2	E_3	E_4	E_5
C_1	M_1	H	VH	MH	H	MH
	M_2	MH	H	MH	MH	H
	M_3	H	MH	VH	MH	H
	M_4	H	H	VH	H	MH
	M_5	VH	H	VH	VH	H
C_2	M_1	M	M	MH	MH	M
	M_2	MH	MH	M	MH	H
	M_3	MH	MH	H	M	H
	M_4	MH	H	MH	MH	MH
	M_5	H	H	MH	H	H
C_3	M_1	M	MH	MH	M	H
	M_2	H	MH	H	H	MH
	M_3	MH	H	MH	MH	H
	M_4	MH	M	MH	MH	H
	M_5	H	H	MH	H	H
C_4	M_1	M	M	M	MH	MH
	M_2	MH	MH	MH	H	MH
	M_3	H	MH	MH	MH	H
	M_4	M	MH	MH	M	M
	M_5	VH	VH	H	VH	VH
C_5	M_1	M	M	MH	M	M
	M_2	H	MH	H	MH	H
	M_3	MH	MH	M	MH	M
	M_4	H	MH	H	MH	H
	M_5	VH	H	MH	H	VH
C_6	M_1	M	MH	MH	M	M
	M_2	H	H	H	MH	H
	M_3	M	MH	M	MH	H
	M_4	H	H	MH	MH	H
	M_5	H	VH	H	H	VH
C_7	M_1	MH	H	MH	MH	M
	M_2	H	H	MH	MH	H
	M_3	H	MH	M	H	MH
	M_4	MH	M	MH	MH	H
	M_5	MH	VH	VH	MH	H
C_8	M_1	VH	MH	H	H	MH
	M_2	MH	MH	H	MH	VH
	M_3	MH	VH	MH	VH	H
	M_4	VH	VH	H	H	MH
	M_5	VH	H	VH	VH	H

Table 5: Average fuzzy score & defuzzified scores

Criteria	Maintenance Strategies	Average fuzzy scores				Defuzzified scores
C_1	M_1	0.600	0.700	0.800	0.880	0.745
	M_2	0.540	0.640	0.740	0.840	0.690
	M_3	0.600	0.700	0.800	0.880	0.745
	M_4	0.620	0.720	0.820	0.900	0.765
	M_5	0.720	0.820	0.920	0.960	0.855
C_2	M_1	0.440	0.540	0.580	0.680	0.560
	M_2	0.500	0.600	0.680	0.780	0.640
	M_3	0.520	0.620	0.700	0.800	0.660
	M_4	0.520	0.620	0.720	0.820	0.670
	M_5	0.580	0.680	0.780	0.880	0.730
C_3	M_1	0.480	0.580	0.640	0.740	0.610
	M_2	0.560	0.660	0.760	0.860	0.710
	M_3	0.540	0.640	0.740	0.840	0.690
	M_4	0.500	0.600	0.680	0.780	0.640
	M_5	0.580	0.680	0.780	0.880	0.730
C_4	M_1	0.440	0.540	0.580	0.680	0.560
	M_2	0.520	0.620	0.720	0.820	0.670
	M_3	0.540	0.640	0.740	0.840	0.690
	M_4	0.440	0.540	0.580	0.680	0.560
	M_5	0.760	0.860	0.960	0.980	0.890
C_5	M_1	0.420	0.520	0.540	0.640	0.530
	M_2	0.560	0.660	0.760	0.860	0.710
	M_3	0.460	0.560	0.620	0.720	0.590
	M_4	0.560	0.660	0.760	0.860	0.710
	M_5	0.660	0.760	0.860	0.920	0.800
C_6	M_1	0.440	0.540	0.580	0.680	0.560
	M_2	0.580	0.680	0.780	0.880	0.730
	M_3	0.480	0.580	0.640	0.740	0.610
	M_4	0.560	0.660	0.760	0.860	0.710
	M_5	0.680	0.780	0.880	0.940	0.820
C_7	M_1	0.500	0.600	0.680	0.780	0.640
	M_2	0.560	0.660	0.760	0.860	0.710
	M_3	0.520	0.620	0.700	0.800	0.660
	M_4	0.500	0.600	0.680	0.780	0.640
	M_5	0.640	0.740	0.840	0.900	0.780
C_8	M_1	0.600	0.700	0.800	0.880	0.745
	M_2	0.580	0.680	0.780	0.860	0.725
	M_3	0.640	0.740	0.840	0.900	0.780
	M_4	0.660	0.760	0.860	0.920	0.800
	M_5	0.720	0.820	0.920	0.960	0.855

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

$$\begin{array}{c} \\ C1 \\ C2 \\ C3 \\ C4 \\ C5 \\ C6 \\ C7 \\ C8 \end{array} \begin{array}{c} \begin{array}{ccccc} M_1 & M_2 & M_3 & M_4 & M_5 \end{array} \\ \begin{bmatrix} 0.745 & 0.690 & 0.745 & 0.765 & 0.855 \\ 0.560 & 0.640 & 0.660 & 0.670 & 0.730 \\ 0.610 & 0.710 & 0.690 & 0.640 & 0.730 \\ 0.560 & 0.670 & 0.690 & 0.560 & 0.890 \\ 0.530 & 0.710 & 0.590 & 0.710 & 0.800 \\ 0.560 & 0.730 & 0.610 & 0.710 & 0.820 \\ 0.640 & 0.710 & 0.660 & 0.640 & 0.780 \\ 0.745 & 0.725 & 0.780 & 0.800 & 0.855 \end{bmatrix} \end{array} \begin{array}{c} W_j \\ \begin{bmatrix} 0.250 \\ 0.232 \\ 0.215 \\ 0.232 \\ 0.238 \\ 0.215 \\ 0.188 \\ 0.287 \end{bmatrix} \end{array}$$

TS = $[Xij][Wj]$

Total score for maintenance strategies (M_1) on the criteria is obtained as (0.745 x 0.250) + (0.560 x 0.232) + (0.610 x 0.215) + (0.560 x 0.232) + (0.530 x 0.238) + (0.560 x 0.215) + (0.640 x 0.188) + (0.745 x 0.287) = 1.158. Similarly, Total score for maintenance strategies (M_2), (M_3), (M_4) and (M_5) for mechanical crane are obtained. In the selection of maintenance strategies for mechanical crane Punj Lioyd plant, quantities & qualitative criteria, each has equal weight age hence the final score & ranking of maintenance strategy are given in the table 6

Table 6: Final scores and ranking of maintenance strategy for mechanical crane.

Maintenance Strategies	M_1	M_2	M_3	M_4	M_5
Final scores	1.158	1.297	1.267	1.286	1.505
Rank	5	2	4	3	1

5. RESULT & DISCUSSION

The use of fuzzy multi- criteria decision-making techniques the order ranking of maintenance strategy for mechanical crane is as $M_5 > M_2 > M_4 > M_3 > M_1$. The results show that M_5, is the best maintenance strategy for mechanical crane and M_1 is the poor maintenance strategy for mechanical crane. Since fuzzy logic incorporates the linguistic variable more practically & also help in eliminating the imprecision & vagueness.

6. CONCLUSION

In this paper the selection of maintenance strategy for mechanical crane in Punj Lioyd plant is studied. An optimal maintenance strategy can improve availability & reliability levels of plants mechanical crane & reduce unnecessary investment in maintenance. The evaluation of maintenance strategy for mechanical crane is a multi-criteria decision-making (MCDM) problem, considering the imprecise judgments of expert's views with trapezoidal fuzzy

number & the fuzzy simple average method is used for different maintenance strategy for mechanical crane in Punj Lioyd plant & useful for other similar MCDM problems.

7. ACKNOWLEDGEMENTS

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