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Selection of optimum maintenance strategies based on a fuzzy analytic hierarchy process

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C H R O N I C L E

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This paper presents an empirical investigation to rank different factors influencing on maintenance strategies on Iranian oil terminals' company. The study determines four main factors, production quality, reliability, cost and safety. Using fuzzy analytical process, the study determines various factors associated with each main factor and ranks them by performing pair-wise comparisons. The results indicate that reliability ranks first (0.255), followed by production quality (0.252), cost (0.25) and safety (0.244). In terms of reliability, the best utilization of resources is number one priority followed by increase access to maintenance tools, reduction in production interruption are among the most important issues. In terms of production quality, reduction in system failure as well as reworks is the most important factors followed by customer satisfaction and defects. In terms of cost items, ease of access to accessories and consulting are important factors followed by necessary software, hardware and training programs. Finally, in terms of safety factors, external, internal and employee services are the most important issues, which are needed to be considered.

1. Introduction

The analytic hierarchy process (AHP) is a structured method for analyzing complicated decisions, based on mathematics as well as psychology. Saaty (1980) is believed to be the first who introduced AHP technique and it has been extensively studied and refined for years. It has specific application in group decision making, and it is applied around the world in a wide variety of decision situations, in fields such as engineering and more specifically maintenance engineering. Rather than giving a "correct" decision, the AHP assists decision makers detect one that best fits their objective and their understanding of the problem. It also provides a good rational framework for structuring a decision problem, for quantifying its elements, for relating those elements to overall objectives, and for assessing alternative solutions. Users of the AHP initially decompose their decision problems into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed, independently. All elements of the hierarchy can be associated with any characteristic of the decision problem, which are either tangible or intangible, carefully measured or roughly estimated, well or poorly understood.

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Wang et al. (2007) presented a method to evaluate various maintenance strategies including corrective maintenance, time-based preventive maintenance, condition-based maintenance, and predictive maintenance. An efficient maintenance strategy mix is essential for increasing availability and reliability levels of production facilities. The selection of maintenance strategies is a kind of multiple criteria decision-making (MCDM) problem and to deal with the uncertain judgment of decision makers, a fuzzy AHP method was used as an evaluation technique, where uncertain and imprecise judgments of decision makers could be translated into fuzzy numbers.

Wang et al. (2007) reported that the predictive maintenance strategy is the most suitable for boilers. Cheung et al. (2005) proposed a technique to facilitate the allocation of labor resources, which was a complex and fuzzy problem in nature existing in the aircraft maintenance services industry. They reported that in the allocation of labor resources, the personnel plans needed to consider the aviation authority regulations and safety laws, qualification of the employees and customers' requirements, as well as other intangible variables.

Al-Najjar and Alsyouf (2003) evaluated the most popular maintenance approaches, i.e. strategies, policies, or philosophies, based on the implementation of a fuzzy multiple criteria decision making (MCDM) evaluation methodology. They demonstrated with two instances on how the methodology could identify the most informative approach. Using the fuzzy MCDM, it could be possible to choose in advance, the most efficient maintenance approach. Mon et al. (1994) developed a fuzzy technique for measuring the relative performance of maintenance engineering techniques and using the proposed fuzzy AHP ranked various methodologies.

Arunraj and Maiti (2010) presented a technique of maintenance selection based on risk of equipment failure and cost of maintenance using AHP and goal programming (GP) for maintenance policy selection in a case study of a benzene extraction unit of a chemical plant. The results indicated that considering risk as a criterion, condition based maintenance (CBM) was a suggested policy over time-based maintenance (TBM) as CBM had better risk reduction capability than TBM.

Arunraj and Maiti (2007) the risk analysis and risk-based maintenance methodologies were classified into appropriate classes. The factors influencing the quality of risk analysis were also detected. The applications, input data and output data were investigated to find some insight about their functioning and efficiency. The review indicated that there was no unique way to perform risk analysis and risk-based maintenance. Al-Najjar (2007) investigated on the lack of maintenance and not maintenance which costs significantly by presenting a model to determine the effect of vibration-based maintenance on company's business.

Bertolini and Bevilacqua (2006) presented a ‘Lexicographic’ GP (LGP) technique to determine the best strategies for the maintenance of critical centrifugal pumps in an oil refinery. For each pump failure mode, the model helped determine the maintenance policy burden based on inspection or repair and in terms of the manpower involved. Eti et al. (2006) presented a method for the development of preventive maintenance (PM) based on the modern approaches of FMEA, root-cause analysis, and fault-tree analysis. They explained that implementing PM could lead to a cost reduction in maintenance and less overall energy expenditure.

2. The proposed study

In this section, we present details of the implementation of fuzzy analytical hierarchy process to rank important factors influencing maintenance strategies in Iranian oil terminals’ company. Fig. 1 shows details of various components influencing maintenance programs.

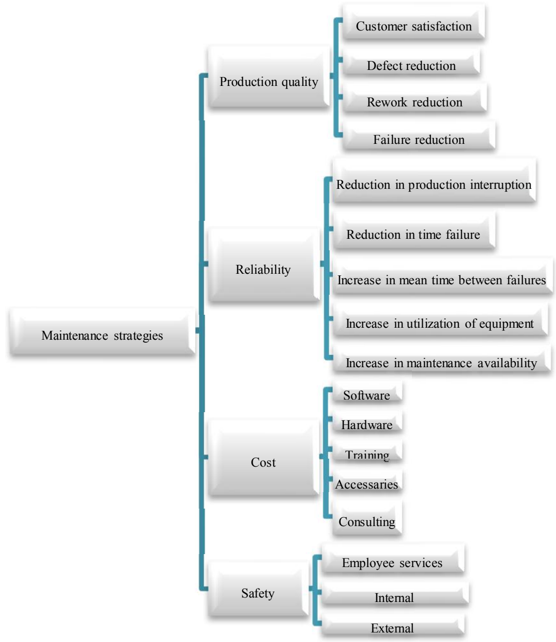

Fig. 1. The structure of the proposed study

In this study, we use fuzzy AHP introduced by Chang (1996) and applies triangular numbers shown in Fig 2 as follows,

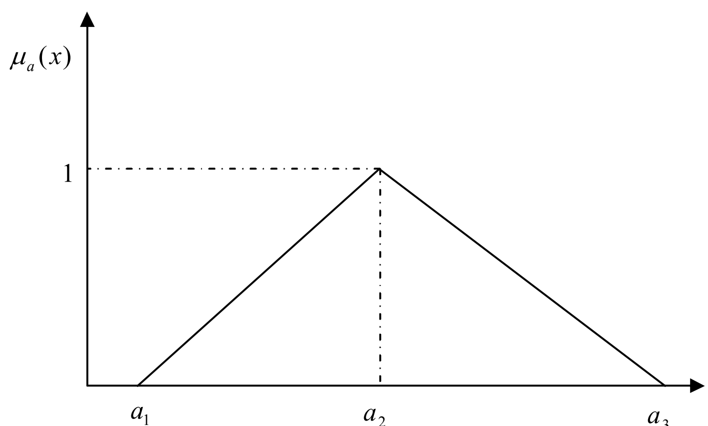

Fig. 2. Triangular number

In addition, Table 1 demonstrates the summary of arithmetic operations used for the proposed study of this paper.

Table 1
Basic equations of the two triangular fuzzy numbers (Zimmermann, 1992)

Operational law	Equations
Addition	$(a+b)=(a_1+b_1, a_2+b_2, a_3+b_3)$
Subtraction	$(a-b)=(a_1-b_1, a_2-b_2, a_3-b_3)$
Multiplication	$(a\times b)=(a_1\times b_1, a_2\times b_2, a_3\times b_3)$, $k(a)=(ka_1, ka_2, ka_3)$
Division	$(a\div b)=(a_1\div b_1, a_2\div b_2, a_3\div b_3)$
Inverse	$(a_1, a_2, a_3)^{-1}=(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1})$

AHP approach uses the following steps to detect relative importance degree of criteria:

Step 1 - Arrange the pair wise comparison matrix A by utilizing the ratio scale given in Table 2.

Table 2
The ratio scale and definition of AHP

Intensity of importance	Definition
1	Equally important
3	Moderately important
5	Strongly more important
7	Very strong important
9	Extremely more important
2,4,6,8	Intermediate more important

Saaty (1980)

Step 2 - Let $C_1, C_2, ..., C_n$ be the set of elements, where a_{ij} presents a quantified judgment on pair of elements $C_{i.}, C_{j.}$ the matrix A as follows;

$$A = \left[a_{ij}\right] = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix}$$

where, $a_{ij} = 1$ and $a_{ji} = \frac{1}{a_{ij}}, i.j = 1,2,...,n$

In matrix A, the problem is to determine a set of numerical weights $W_1, W_2, ..., W_n$ in front of n element $C_1, C_2, ..., C_n$. If A is a consistency matrix, then the relationship between weights and judgments are given by $a_{ij} = \frac{W_j}{W_i}$, for $(i, j = 1,2,3,....,n)$. The largest Eigen-value $\lambda_{\max}$ is suggested by Saaty (1980) as;

$$\lambda_{\max} = \sum_{j=1}^{n} a_{ij} \frac{W_j}{W_i} \tag{1}$$

Let A be the consistency matrix, then eigenvector X can be computed as follows,

$$(A - \lambda_{\max} I)X = 0 \tag{2}$$

So, the consistency index (C.I.) and random index (R.I.) verify the consistency ratio (C.R.). The consistency index and consistency rate are as indicated;

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \text{ , and } C.R. = \frac{C.I}{R.I} \tag{3}$$

The number 0.1 is the accepted upper limit of C.R. If the final consistency ration is higher this value, the evaluation process should be done again to improve consistency.

3. The results

In this section, we present details of our findings on ranking various factors mentioned in Fig. 1 using fuzzy AHP method. Table 3 demonstrates the summary of various factors.

Table 3
The summary of ranking factors influencing maintenance engineering

Main criteria	Sub-criterion	Weight
Production quality (0.252)	Customer satisfaction	0.0612
	Reduction of failure products	0.061
	Reduction on reworks	0.064
	Reduction on failure process	0.0658
Reliability (0.255)	Reduction on production interruption	0.0492
	Reduction on time of interruption	0.0485
	Increase on mean time between failure	0.049
	Increase on utilization of equipment	0.0548
	Increase of maintenance	0.0536
Cost (0.25)	Hardware	0.0488
	Software	0.0475
	Employee training	0.0495
	Accessories	0.0531
	Consulting	0.051
Safety (0.244)	Employee services	0.0488
	Internal environment	0.091
	External environment	0.1042

The results indicate that reliability ranks first (0.255), followed by production quality (0.252), cost (0.25) and safety (0.244). In terms of reliability, the best utilization of resources is number one priority followed by increase access to maintenance tools, reduction in production interruption are among the most important issues. In terms of production quality, reduction in system failure as well as reworks is the most important factors followed by customer satisfaction and defects. In terms of cost items, ease of access to accessories and consulting are important factors followed by necessary software, hardware and training programs. Finally, in terms of safety factors, external, internal and employee services are the most important issues, which are needed to be considered. We have also considered three maintenance strategies including corrective maintenance strategy, preventive maintenance strategy as well as predictive maintenance strategies using fuzzy AHP and Fig. 3 shows details of our investigation.

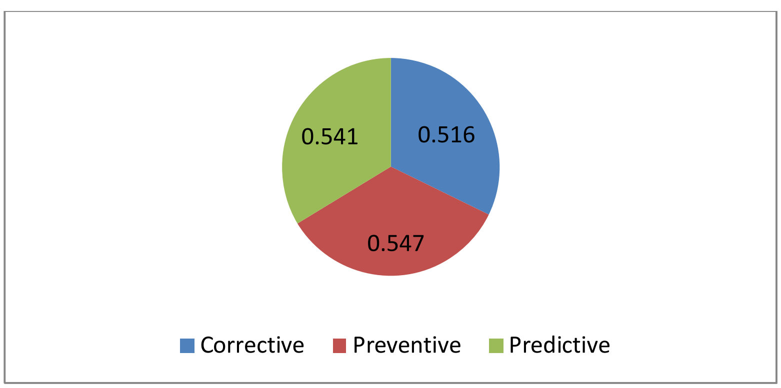

Fig. 3. The relative importance of different maintenance strategies

As we can observe from the results of Fig. 3, preventive maintenance strategy is the most important factor followed by predictive maintenance strategy and corrective maintenance strategy.

4. Conclusion

In this paper, we have presented an empirical investigation to rank different factors of optimum maintenance strategies based on a fuzzy analytic hierarchy process on Iranian oil terminals' company. The study has asked some experts to make a pairwise comparison on four major factors as well as various sub-criteria. The survey has accomplished based on fuzzy AHP and the results have indicated that reliability is number one priority followed by production quality. In addition, our survey indicated that preventive maintenance is the most important strategy for improving the performance of the firm.

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