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Published version

MOHAMED, Abdel and SAAD, Sameh (2016). Fuzzy analytical hierarchy process for the selection of maintenance policies within petroleum industry. In: GOH, Yee Mey and CASE, Keith, (eds.) Advances in Manufacturing Technology XXX : Proceedings of the 14th International Conference on Manufacturing Research, incorporating the 31st National Conference on Manufacturing Research, September 6-8, 2016 Loughborough University, UK. Advances in transdisciplinary engineering (3). Amsterdam, IOS Press, 529-534.

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The final publication is available at IOS Press through
http://dx.doi.org/10.3233/978-1-61499-668-2-529

Fuzzy Analytic Hierarchy Process for the Selection of Maintenance Policies within Petroleum Industry

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Abstract. The selection of the maintenance policies is considered to be a complex matter at the strategic level and a trade-off between the criteria that should be considered is required to achieve the optimum maintenance selection. The purpose of this study is to develop a Fuzzy-Analytic Hierarchy Process multi criteria decision making model for the selection of maintenance policies within the petroleum industry. The model enables practitioners to decompose the structure of the hierarchy which assists in identifying the main criteria, sub-criteria and alternatives that impact on the selection of maintenance activities. The proposed AHP model is validated and in addition a comparison between classic and fuzzy analytic hierarchy process is conducted in terms of different derivation methods. Moreover, a sensitivity analysis is performed to validate the response of each derivation method at different inconsistency ratio which proved that the proposed model can be considered as the most accurate presentation of the criteria, sub-criteria and alternatives that should be used to decide upon the strategic maintenance policies within petroleum industry.

Keywords. Optimum Maintenance Selection, Fuzzy Analytic Hierarchy Process, Maintenance Management and Petroleum Industry.

1. Introduction

In the petroleum industry, varieties of machines align along the production line from upstream to downstream. Therefore, different levels of reliability and availability of equipment is required. Moreover, the likelihood and consequences of risk vary from machine to another, which showcases the importance of analysing and questioning the selection of maintenance policy to enhance the overall system's productivity.

The selection of the most appropriate maintenance policy leads to the arrival at the optimisation of the entire operation of maintenance. Plants which are equipped with various machines and have different reliability requirements, safety levels and failure effect require a comprehensive methodology on the strategic level to assist in selecting the appropriate maintenance policy. Analytic hierarchy process (AHP) is considered as one of the most used methods of multi-criteria decision-making (MCDM) with the capability to decompose any problem to arrive at the selection of the most appropriate alternatives [1]. [2] outlined that inappropriate or insufficient selection of maintenance policies, exorbitant maintenance costs and increasing failure frequency.

In this work, we deal with the selection of maintenance policies within the petroleum industry and a hierarchy structure is created to identify the criteria and possible alternatives. Classical derivation methods (mean normalised value MNV, normalised geometric mean NGM and eigenvector method EVM) and fuzzy AHP are applied to study the different outcomes of the applied methods.

2. The Hierarchy Structure for the Selection of Maintenance Policies

In order to arrive at the selection of the most appropriate maintenance policy within the oil and gas industry, identification of the criteria that impact the decision is vital of which the alternatives "Time-Based Maintenance (TBM), Condition-Based Maintenance (CBM) and Corrective Maintenance (CM) are selected. Maintenance policy selection is a hierarchy structure which includes the main target, criteria, sub-criteria and alternatives (figure 1).

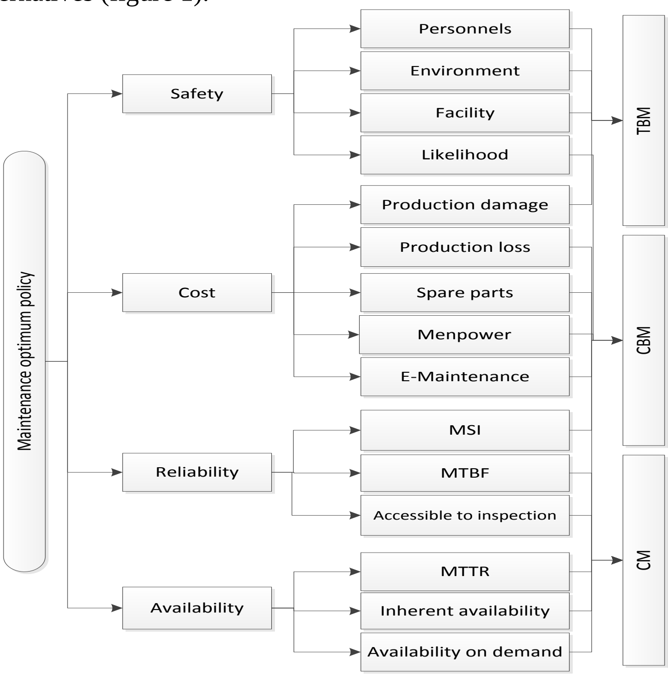

Figure 1. The Hierarchy Structure for the Maintenance Optimum Policy

Four main criteria have been identified (availability, reliability, cost and safety) and each of these criteria have sub-criteria, which impact on the main criterion. Availability is defined as a measure of the percentage of time that the equipment is in an operable state. Three sub-criteria are identified to impact on availability which are:- Mean Time To Repair (MTTR) includes the time to diagnose the problem, the time to get the technicians and material required on-site and hand it over to the operation department. Inherent availability considers the importance and criticality of equipment's availability to the system. The equipment is considered to be inherent to the system when, for instance, has no stand-by equipment. Availability on demand considers the possibility of having whether a spare system that can take over in case of maintenance/failure or that the process can function without the equipment availability.

Reliability is a criterion that has to be considered while selecting the type of maintenance policy. In the oil and gas industry, there are machines which require more level of reliability to increase the overall system reliability [3]. Three sub-criteria have been identified to influence on reliability. Maintenance Significant Items (MSI) is a sub- criterion that considers the importance of equipment to the reliability of the system [4]. Accessible to inspection indicates the accessibility of equipment and its parts that need to be inspected and mean time between failure (MTBF). The main criterion (cost) deals with the costs incurred to keep equipment and its parts in a good condition. Five major costs have been identified that contribute to the cost as main criterion which are:- production damage, production loss, spare parts , manpower and E-maintenance.

Safety level within the petroleum industry is considerably high, due to the nature of the industry and the possibility of risk and its catastrophic consequences [5]. Hence, this criterion is considered to shape the selection of maintenance policy. Within the hierarchy structure, four sub- criteria are considered to influence (Cost) which are:- likelihood of failure and its consequences on three main areas (facility, personnel and environment). Three possible alternative maintenance policies are considered as possible maintenance solutions which are: - Corrective maintenance (CM), Time Based Maintenance (TBM) and Condition Based Maintenance (CBM).

3. Analytic Hierarchy Process Derivation methods

The data was collected and fifty participants from academic and industrial background took part to complete the questionnaire. Table (1) shows the scale which was used to score the pairwise comparison [6].

Table 1. Scale of relative importance

Intensity of importance	Definition
1	Equal importance
3	Weak importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments

Table (2) demonstrates the pairwise comparison for the main-criteria matrix and similar matrixes were created to compare between criteria with respect to upper level.

Table 2. Comparison matrix of main criteria

main-criteria	Cost	Availability	Reliability		Safety
Cost	1	1/7	1/5		1/3
Availability	7	1	1		3
Reliability	5	1	1		5
Safety	3	1/3	1/5		1
			Inconsistency	0.04	

3.1. Application of derivation methods

In this work, the inconsistency of each matrix was measured by using Expert Choice software. Different derivation methods (mean normalised values (MNV), normalised geometric Mean (NGM) and eigenvector mean (EVM)) were used to derive the priorities within the comparison matrixes to compare the outcomes. Due to limitation in space, we will show only the scoring of global maintenance preference for each method.

3.1.1. Mean Normalised Value (MNV)

To apply this method, three steps were taken. The first step, calculate the sum of each column and this step is applied for all matrixes. The second step, normalize the columns by dividing each column's values by its sum; the final step, calculate the mean value for each row which is the weight of the criterion.

Equation (1) demonstrates the steps of calculating the global alternatives weight. Each weight of local alternatives with respect to sub-criteria is multiplied by the weight the sub-criteria and the weight of main criteria which results into small alternatives weights which are then summed up.

$$Global\ alternative\ weight\ G_{AW} = \sum W_{MC} \times W_{SC} \times A_{WSC} \quad (1)$$

Where:- W_{MC} Weight of main criteria, W_{SC} Weight of sub criteria and A_{WSC} Alternative's weight of sub criteria.

The steps were applied and the global weight of the maintenance alternatives were obtained as TBM is mostly prefered (47%), followed by CBM 43.9 % and lastly CM (8.9%)

3.1.2. Normalised Geomatric Mean NGM

The normalised geometric mean is an alternative measure of the priorities and is formed by taking the root of the product matrix of row elements divided by the column sum of row geometric means. Equation (2) is applied to calculate the geometric mean for each row p.

$$\sqrt{a.b.c \dots\dots n} \quad (2)$$

Where a, b, c and n are the comparison values for each rows

The second step is to summarize the results of each row and finally, normalizing the results to obtain the priorities. Applying the NGM method, the global alternative priority with respect to main goal was calculated (TBM 47.045%, CBM 44.167%, and CM 8.857%).

3.1.3. Eigenvector Method (EVM)

This is the original Saaty's approach to derive the priorities from the AHP method. In this work, Expert Choice Software is used which follows the EVM process to generate the weights, priorities and alternatives for the criteria. The problem was modeled on the software and with facilitated interface the data was entered and the global alternatives priority were computed (The priority of the maintenance policies goes first to TBM with 47.2% followed by CBM with 44% and CM with 8.8%.). Expert Choice allows the possibility of conducting the sensitivity analysis to estimate the responsiveness to any change in preference between criteria.

3.2. Fuzzy AHP

The steps of the fuzzy AHP are described in details in the published work [7]. The membership function triangular fuzzy number (TFN) is applied which computes eigenvectors until the composite final vector is obtained. The final vector of weights (global weight) shows the relative importance of each alternative towards the main goal [8]. Different scales are proposed for the conversion scale. Table (3) demonstrates the conversion scale which was applied to convert the rigid numbers to fussy membership before computing them [9].

Table 3. Triangular fuzzy conversion scale

Linguistic scale	Importance	Fuzzy scale	Importance	Reciprocal Fuzzy Scale
Equally important	1	(1/2,1,3/2)	1/1	(1/2,1,3/2)
Weakly more important	3	(1,3/2,2)	1/3	(1/2,2/3.1/1)
strongly more important	5	(3/2,2,5/2)	1/5	(2/5,1/2,2/3)
very strongly more important	7	(2,5/2,3)	1/7	(1/3,2/5,1/2)
absolutely more important	9	(5/2,3,7/2)	1/9	(2/7,1/3,2/5)

The steps of applying the converting scale on the matrixes were taken and computing all of the matrixes to arrive at the global priority of the maintenance alternatives (TBM 40%, CBM comes second with 2% difference from TBM (38%) and the least preferred alternative (CM) comes last with 22%).

3.3. Correspondence of Pairwise Matrix Evaluation Methods to Zero Inconsistency of Main Criteria Matrix

In this section, the sensitivity analysis is performed for all the applied derivation methods (MNV, NGM, EVM and TFN) by the selection of one matrix and equally adjusting the preferences to investigate the impact of this adjustment on the prioritization of alternatives cross the four derivations methods. The matrix of main criteria was adjusted by the use of Expert Choices function to arrive at 0.0 inconsistency where originally the inconsistency was 0.04.

Table 4. The main criteria matrix with 0.0 inconsistency

main-criteria	Cost	Availability	Reliability	Safety
Cost	1	1/7	1/7	1/3
Availability	7	1	1	3
Reliability	7	1	1	3
Safety	3	1/3	1/3	1
			Inconsistency	0.00

Figure (2) demonstrates the maintenance policy's priorities resulted from the four derivation methods with respect to main goal (0.0 inconsistency). The prioritization of the alternatives (maintenance policies) remains the same for all methods with TBM firstly preferred followed by CBM and CM as the least preferred maintenance policy.

The change in the preference of alternatives by the use of each derivation method following the slight adjustment to arrive at 0.0 inconsistency is attributed to the way each method is conducted mathematically. The alternative weights resulted from applying MNV remains almost the same in the case of CBM and CM. Whereas, slight change occurs in the weight of TBM which decreases by 0.5% following the change in the adjustment in the matrix. The weight of TBM, CBM and CM using NGM slightly change, while the priority of TBM increases 3.29% over CBM. The results of weights of alternatives using EVM remain the same despite the changes of the inconsistency.

The priority of the maintenance alternatives remain the same applying fuzzy AHP with slight increase in the preference of TBM and CBM (0.05% and 0.02 respectively) and slight decreasing in CM prioritization (0.06%)

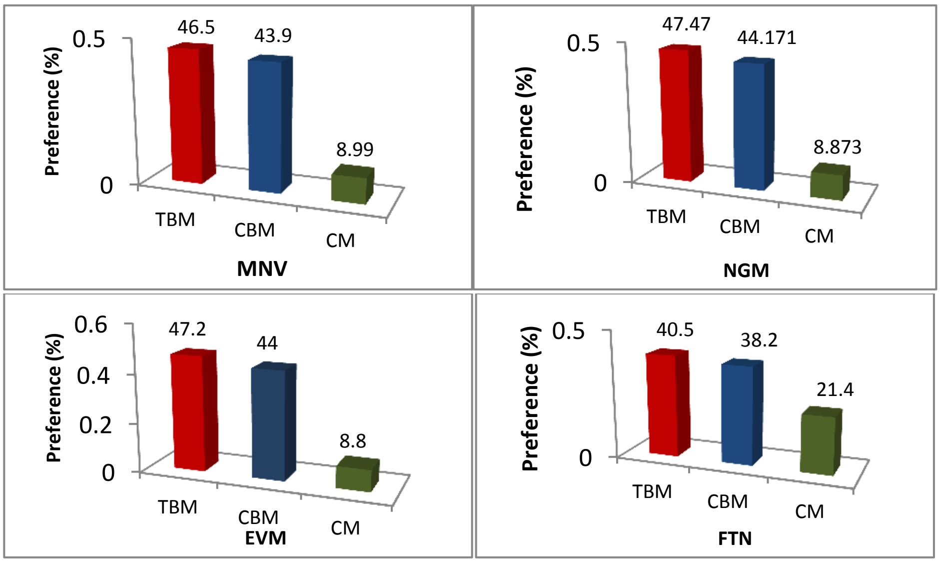

Figure 2. Alternatives Priorities with Respect to Main Goal

Conclusion

In this paper, the selection of maintenance policies for the petroleum industry was discussed and a hierarchy structure was proposed to select the most appropriate maintenance policy for equipment within the petroleum industry. AHP and fuzzy AHP with different derivations methods were applied to study respond of each method to the global selection of the alternatives. A sensitivity analysis was conducted to demonstrate the response of each method to the change in the prioritization. The results show that fuzzy AHP demonstrates more stability and accuracy for the translation of the linguistic preference as it takes into account the uncertainty of the judgments.

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