Selection of Appropriate Maintenance Strategy for Oil and Gas Equipment Using Analytical Hierarchy Process (AHP)

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Abstract

The maintenance strategy is becoming increasingly critical with the increasing competition in the oil and gas industrial environment due to hundreds pieces of equipment, which operate continuously under rigorous operational conditions resulting from over pressures and fluctuated temperatures. Many pieces of equipment usually subject to an inspection and maintenance during normal operation of a plant. However, others pieces cannot be inspected and maintained during normal operation of plant unless plant facilities are totally subjected to shutdown to avoid huge production losses in the company. Therefore, the study proposed in this work was to select appropriate maintenance strategies that could be divided into four alternative: Preventive Maintenance (PM), Corrective Maintenance (CM), Predictive Maintenance (PdM) and Turnaround Maintenance (TAM) to arrange inspection and maintenance scheduling for all pieces of equipment in the oil and gas plant based on four criteria: safety, production, cost and availability associated with goal of Analytical Hierarchy Process (AHP) approach. The result is to decrease in the cost of maintenance and production losses and maximize availability and efficiency of oil and gas plant facilities.

Keywords
Maintenance strategy, Oil and gas Equipment, Analytical hierarchy process.

1. Introduction

Maintenance is considered the most crucial event in today's oil and gas industrial environment. It is a broad term that comprises a set of activities that aim to improve equipment or component. It is an activity that must be performed under normal and complicated situations. Its basic objective is to restore rapidly the equipment to its operational conditions using available resources such as manpower, spare parts and tools in order to contribute at the improving maintenance activities, reducing frequency of failures and increasing skills (Dhillon, 2006). During and up till industrial revolution the cultural within the maintenance function was focus on breakdown maintenance.

Maintenance is an effort required to keep plants to continue in their productivity capacity (Lawrence, 2012). Maintenance is an attempt to keep whole equipment and restore faulty equipment to a satisfactorily operational condition (Elwerfalli et al., 2018). Duffuaa and Ben Daya (2004) also explain that "the combination of activities by which equipment or a system is kept in, or restored to, a state in which it can perform its designed functions". (ibid.) describe maintenance as a set of needed functions to restore the equipment to normal situation. Dhillon (2006) states that it is a set of proper actions to keep or recovery an equipment to a given function. According to British Standards Institution (2010), maintenance is defined as a set of activities of technical and administrative that contributes in retaining or restoring of an equipment functionality to required operational condition.

2. Maintenance Strategy

Maintenance strategy for any a processing plant should be adapted to facilities / equipment status (Hokoma and Amaigl, 2018). Maintenance strategy can be widely classified into four types according to the way which deal with PM, CM, PdM, and TAM.

2.1 Preventive Maintenance (PM)

PM usually accounts for a major part of the maintenance function because of its relative cost which gives it acceptance between production sectors and industrial organizations. PM is a premature activity which replace component or equipment before the defect occurred to avoid unscheduled failures. Any component or equipment can be replaced or repaired based on the predetermined period to apply PM, or failure to apply PdM or CM. In the predetermined period, the component should be replaced even if item is still active. This period can be identified according to a scheduled time for each item. PM includes a set of activities that contributes in reducing the number of failures and avoid the occurrence of CM. This enhance system performance and meet minimum costs (Mobley et al., 2008). According to British Standards Institution (2010), PM can be defined as "maintenance carried out at predetermined intervals or according to failure replacement and intended to reduce the probability of failure or the degradation of the functioning of an item". Therefore, the key goals of execution of PM are to improve reliability of a system in the long term (Li et al., 2006) by minimising frequent equipment failure, reducing total inspection and maintenance costs and decreasing downtime of equipment to avoid production losses and prolong equipment life (Swanson, 2001).

2.2 Corrective Maintenance (CM)

CM is a set of remedial actions taken after occurred failure to return an equipment to normal condition because of unexpected failures that occurred during normal operation process of a plant. CM is considered a planned maintenance according to the time required for shutdown due to deferred activities (running-to-failure). CM is also considered an unplanned maintenance from immediate maintenance perspective. In addition, it can be easily performed. This type of maintenance is called reactive maintenance because the system is operated until it fails. British Standards Institution (2010), stated that "maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function".

2.3 Predictive Maintenance (PdM)

PdM is a Condition-Based Maintenance (CBM) approach in which it detects degradation onset of equipment and corrects prior to occurrence of the failure in an equipment (Swanson, 2001). It is done by diagnostic tools to obtain all details associated with causes of equipment degradation and to analyse vibration, wear, noises and oil sampling. PdM recognised failure symptom ahead of occurrence and with minimal losses of residual equipment life. It has become especially desirable in oil and gas sector (Sharma et al., 2005). It uses an advanced form to carry out routine inspection during the operational process such as vibration analysis equipment. Therefore, PdM is executed when it is compulsory, while PM is accomplished at predetermined intervals. The main goal of PdM is to minimise the probability of breakdown and reduce the total cost related to inspection and repair by decreasing unnecessary maintenance activity Gupta and Lawsirirat (2006), hence, improve productivity and overall effectiveness of plants (Mobley, 2002). Despite the popularity of PdM, it may not always be the best method to implement maintenance, however, it is highly considered based on cost effectiveness.

2.4 Turnaround Maintenance (TAM)

TAM is a philosophy (Lenahan, 2011), and to carry out a total shutdown of plant facilities for a certain time, TAM differs from one company to another due to several factors: economic aspect, geographical conditions, operational conditions and markets. Sahoo (2013) also indicated that the philosophy of TAM is a scheduled shutdown of the plant to minimise downtime and maximize efficiency of the plant. For instance, some industries have used the terminology shutdown or outage rather than turnaround in the planned shutdown. Levitt (2004) stated, "A shutdown is a melting pot in accelerated time, which means that people will be operating at or near their limits".

TAM is one of the biggest maintenance activities in processing plants in terms of manpower, materials, time and cost with the aim for restoring pieces of equipment to zero operation due to considerably decreasing in their reliability and with the lowest possible costs of the plant during a certain time period.

Despite sophisticated maintenance strategies being implemented in oil and gas industries, TAM cannot be avoided altogether. Kumar and Maiti (2012) agreed that PM, PdM and CM can be effective in many complex processes, but some cases of deterioration required an entire shutdown to carry out TAM event, which relied on many factors such as operational and environmental conditions. Therefore, PM, CM and PdM are not able to overcome all failures, which justifies the widespread adoption of TAM in real application of maintenance. The paper is presented to arrange inspection and maintenance strategy (PM, CM, PdM and TAM) for all pieces of equipment in the oil and gas plant using the AHP approach with four criteria:

- *Safety* (S); this factor refers to serious consequences on personnel, equipment and environment.
- *Production* (P); this factor refers to production losses due to unplanned shutdown.
- *Cost* (C); this factor refers to Cost of operation and maintenance and cost of equipment damage.
- *Availability* (A); this factor refers to the time a plant is in an operating condition.

3. The Analytic Hierarchy Process (AHP) Approach

The AHP approach appears to be the best tool used widely as a multi-criteria decision-making tool since the initial development by Thomas Saaty in 1971. In this research work, and due to multiple failures for critical equipment pieces that lead to an unplanned shutdown during operation periods of oil and gas plant and risk, or require PM, CM, PdM or maintenance every cycle of TAM.

Chan et al. (2006) clarified that AHP can deal with tangible and intangible factors to be evaluated. (ibid.) also proposed priorities of criteria which are combined to establish alternative decisions. The AHP helps decision makers in the identification of the best option to be suitable for the goal and understanding of a problem. AHP enables decision-makers to derive scale-priorities or weights rather than arbitrarily determining values.

In recent years, AHP approach gained momentum in the field of maintenance strategy. Saaty (2008) summarized the AHP decision-making methodology using the following implementation procedures:

- Identify and describe the problem.
- Construct the hierarchy to be goal on top, followed by broad objectives (criteria), and finally, the set of alternatives on the lowest Level (PM, CM, PdM, and TAM) as shown in Figure 1.
- Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements.
- Synthesize these judgments to yield a set of overall weights for the hierarchy for each element to obtain the overall priority.
- Determine to a final decision based on the results of the weighted values.

The problem that should be solved in this work is to select the appropriate maintenance strategy that should be taken into account in for each equipment is located in the oil and gas plants. These pieces of equipment can be classified into:

- Heat exchangers;
- Process piping,
- Pressure vessels;

- Air coolers;
- Processing columns;
- Furnaces;
- Safety & control valves;
- Pumps and Compressors; and
- Gas and steam turbines.

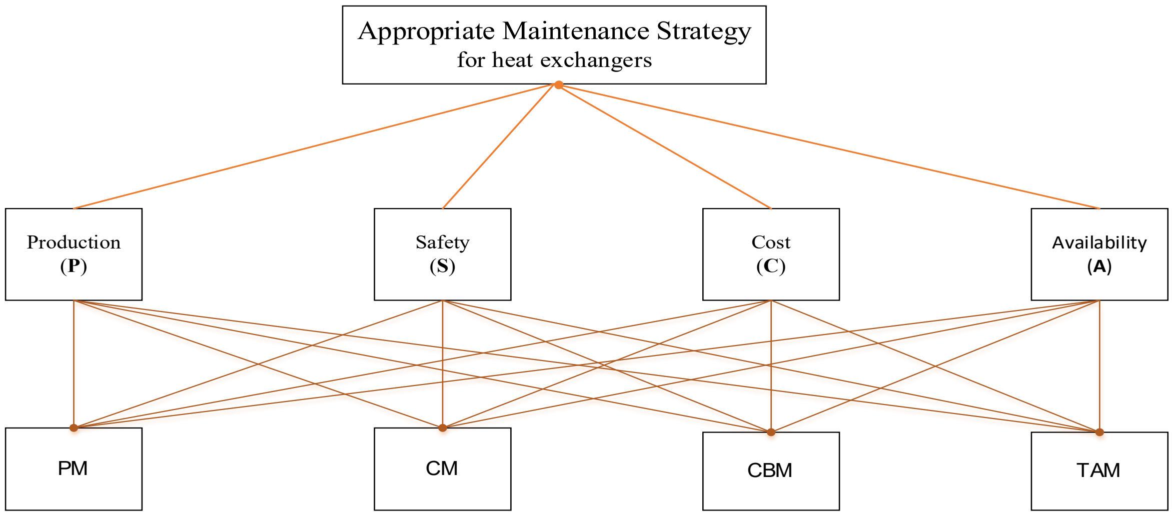

Figure 1. Decision hierarchy for selecting appreciate maintenance of heat exchangers

Consequently, the AHP approach can achieve weights and scores by structuring a hierarchy and deriving ratio-scale measures through pairwise relative comparisons. The pairwise comparison process can be performed as words, or numbers. This approach is based on relative rather than absolute judgments that identify by experts. Table 1 shows the classical AHP protocol weighting criteria assigned that starts with 1 as an equal importance to 9 that refers to the most important criteria.

Table 1 pairwise comparison in AHP

Numerical / Definition	Explanation
(1) Equal importance	Two elements have equal importance.
(3) Moderate importance	Experience and judgment slightly favour one element.
(5) Strong importance	Experience and judgment strongly favour one element.
(7) Very strong importance	Dominance of one element is strongly proved in practice.
(9) Extreme importance	The highest order dominance of one element over another.

Intensities of 2, 4, 6, and 8 are interval values between two adjacent choices

Criteria comparison matrix can be determined by a series of pairwise comparisons of maintenance strategies based on four criteria P, S. C, and A.

Table 2 Criteria comparison of four-point scale matrix for heat exchangers

No	TAM	PM	PdM	CM
TAM	1	3	5	9
PM	1/3	1	3	7
PdM	1/5	1/3	1	5
CM	1/9	1/7	1/5	1
Sum columns	1.645	4.476	9.200	22

Ranking is assigned for each alternative based on four criteria as shown in Table 3. Thus, TAM is an important strategy for heat exchangers maintenance with comparing to other maintenance strategies due to cumulated layers of fouling into tubes. These layers cannot be completely removed unless plant facilities are totally shutdown of plant to conduct TAM event. This event usually execute in the long-term. This means that PM, CM| and PdM may not be appropriate to avoid consequences of failures in the heat exchangers.

Table 3 Criteria weights of four-point scale for heat exchangers

No	TAM	PM	PdM	CM	Weight (x_i)	Ranking
TAM	0.6080	0.6702	0.5434	0.4091	0.5576	1
PM	0.2026	0.2234	0.3261	0.3182	0.2676	2
PdM	0.1216	0.0744	0.1087	0.2272	0.1331	3
CM	0.0675	0.0319	0.0217	0.0455	0.0417	4
Sum	1	1	1	1	1	

It can be seen that the AHP approach plays an important role in presenting a tool to decision making to identify appropriate maintenance strategy for each equipment in the oil and gas plant. Consistency Index (CI) necessary to obtain the AHP method that calculates by

$$\mathbf{CI}= \frac{\lambda \max - n}{n-1} = 0.0856 \qquad (1)$$

λ_{max} is the highest eigenvalue in the matrix (Saaty and Vargas, 2012).

The last factor is Consistency Ratio (CR) that determines based on Saaty's empirical suggestion that a CR ≤ 10% is acceptable.

$$CR = \frac{CI}{RI} = 0.096 \qquad (2)$$

RI is the Random Consistency Index, which is normally known according to (n = 4) value as showed in Table 4 (Saaty and Vargas, 2012).

Table 4 Random Index based on # of criteria

n	1	2	3	4	5	6
RI	0	0	0.52	**0.89**	1.11	1.25

Having the CR value ≤ 0.1% means that TAM is the most appreciate maintenance strategy of heat exchangers based on the highest weight, which reaches up to 55.75% compared to other strategies of maintenance.

4. Conclusions

In this work, appropriate maintenance strategy of heat exchanger is identified according to Safety, Production, Cost and availability criteria resulting from AHP approach application. Four maintenance policies are considered; PM, CM, PdM and TAM. This work shows that TAM is the most appropriate maintenance strategy for heat exchanger used in the oil and gas industries.

In the future, AHP approach can be used for other equipment in the same sectors. Therefore, AHP approach is a tool to help management in the decision making. This work can also be added a fuzzy logic and risk-based inspection models in the selection of appropriate maintenance strategy for other pieces of equipment of oil and gas plants.

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Biography

Mr. A. Elwerfalli received his BSc degree in QC from the University of Garyounis - Libya, MSc degree in QA from the University of Teesside, United Kingdom in 2003. He earned a PhD in the Automotive Research Centre at University of Bradford. He worked as a head of engineers in Maintenance Engineering Division (MED) at Sirte Oil Company, Libya, since 1997. He has worked as a lecturer at College of Mechanical Engineering Technology at Libya since 2007. His research interests include optimization of maintenance scheduling for processing plants, TQM, QC, QA, reliability, risk.